Subject: Hemsby Coastal Management report

Report to: Executive Leadership Team – 9th July 2018
Environment Committee - 18th July 2018

Report by: Bill Parker Head of Coastal Partnership East

SUBJECT MATTER/RECOMMENDATIONS
o Note the progress of and support the on-going work of Coastal Partnership East with specific reference to Hemsby o Note the content of the report o Support work to undertake stakeholder feedback and consultation in relation to the study findings o To develop further potential options around adaptation o To investigate funding opportunities to further develop a full business case

Hemsby and Winterton Report

Presentation of the report by consultants Jacob and CPE

Background

During March 2018 the Hemsby and Winterton coastline has been under severe erosion pressure, specifically on w/c 26 February and more recently during the week following the weekend of 17th / 18th March. The spring tides together with strong easterly winds has led to wide spread beach loss. The wave action has cut large steps (3m+ in places) into the front of the beach from Winterton to Gorleston. The beaches were already at a low level prior to these tides due to adverse conditions in January 2018, and the recent storm events have tested the coastline again. The following photographs show the lowering beach levels which have enabled the waves to reach and erode the face of the sand dunes and the subsequent loss of 12 properties and one moved by the owner.

 

Management options

The coastline from Winterton to Caister is a complex and constantly changing and a review of coastal processes and management methods had been planned for 2018. However following the recent events the Council, working through Coastal Partnership East, has accelerated the commissioning of phase 1 of the Winterton to Great Yarmouth study to specifically look at Hemsby and Winterton and this work has been fortunately funded by the Environment Agency.

Consultants, Jacobs, have been appointed to carry out this work and report back to the community, Parish Council and Borough Council in July 2018. At an early stage of the review a public drop-in/meeting took place at the Hemsby Village Hall on the 12th April which was attended by more than 120 people from the community.

A significant amount of useful information was exchanged at this event, both by the community and groups with proposed options.

Jacobs have completed this first phase of the study and will present the findings at this briefing, subsequent committee meeting and public meeting at Hemsby.

Jacobs have been reviewing the up to date coastal monitoring data, working through the coastal processes and analysing the changes to beaches along the study area. Using this information, consideration has been given to the pros and cons of a range of engineering solutions. A high-level valuation of each potential approach has been summarised for the deliverability, fundability and environmental acceptability of each option. A more detailed appraisal will be required for any shortlisted options. In addition, discussions are being held with the planning team investigating the opportunities to take a more adaptive approach for this part of the coastline.

Risks

Estimated costs in relation to potential schemes are detailed as part of the report however failure to secure the necessary funding through Partnership or contribution Funding is a risk.

As part of the further work needed to build the detail of each scheme there may not be any scheme which is completely acceptable to community.

It is possible that any of the schemes could create additional damage to the area through the delivery of the solution.

Financial

Significant information is required to formulate and developing a full Business Case it will be necessary to secure funding contributions to cover the costs of undertaking this work, estimated to be £150k, and this would remain the case for any of the engineering options suggested.

Recommendations

- To undertake stakeholder feedback and consultation in relation to the survey findings.
- To develop further potential options around adaptation
- To investigate funding opportunities to further develop a full business case.

Area for consideration	**Comment**
Monitoring Officer Consultation:	
Section 151 Officer Consultation:	
Existing Council Policies:	Yes
Financial Implications:	Yes
Legal Implications (including human rights):	Yes
Risk Implications:	Yes
Equality Issues/EQIA assessment:	Yes
Crime & Disorder:	No
Every Child Matters:	No

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FINAL

Hemsby Coast Erosion

High Level Review of Options

Prepared for

Great Yarmouth Borough Council

June 2018

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Contents

Introduction

1.1 Background

The area covered by the Winterton to Great Yarmouth Coastal Management Study is managed as an erosion risk frontage by Great Yarmouth Borough Council. The Council adopted the current Shoreline Management Plan (SMP) in 2012 (although many of the assessments therein were based on 2003 data), which sets out the high-level policy aims for the coastline from North Norfolk to Waveney, including Great Yarmouth. On a changing coastline, such as this one, there is a need, from time to time, to reassess the management approach.

Great Yarmouth Borough Council are seeking funding for an updated study covering the full 17 km of coast from Winterton to Great Yarmouth, to consider the interactions of coastal process and interactions of management approaches throughout. However, a more immediate need has been to consider potential options for the Hemsby frontage; the urgency of the situation heightened by the recent erosion and further loss of properties.

Winterton through Hemsby up to the north part of Scratby are fronted by vegetated soft dunes part of which are designated a Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) and Special Protection Area (SPA). Substantial rates of erosion have occurred in recent years following a period of adverse conditions including the 2013 tidal surge, and more recently in March 2018.

As part of this process, Jacobs have been commissioned by Great Yarmouth Borough Council to undertake a high-level engineering options assessment, supported by an appreciation of coastal processes, providing the Council, the local community and other stakeholders with an independent technical assessment of the problem and the viability of potential solutions to that problem.

This is necessarily a first step in a process to determine the way forward at Hemsby, but a critical one, to enable those parties to have a suitably well-informed basis for reaching a conclusion on the most appropriate approach.

1.2 Scope of this study

This report is to inform the approach to future coastal management at Hemsby by examining possible options and the typical order of magnitude costs for any technically suitable approaches. To do this requires a high-level assessment of the situation at Hemsby in terms of the underlying processes resulting in erosion, and the likely effectiveness of different approaches in the context of those processes.

This first stage does not include any environmental or detailed economic assessment (although a broad assessment of funding requirements has been made). Both are important considerations but the scope and extent of those depend upon the initial findings from this first stage and subsequent direction taken.

The scope of this first stage high level study has therefore included:

- Collection and review of available data pertaining to this study, used as the basis, together with the site inspection, for developing the assessments that follow.
- Visual inspection of the frontage and areas to north and south.
- Meeting with members of the community to gather further information on past changes and any proposed management approaches.
- Review of existing assessments of coastal processes and more recent data, to form an appreciation of processes operating along this frontage including areas to north and south, and

using this appreciation to provide an indication of the coastal change likely to occur during the next SMP epoch with no intervention.

- Identifying a range of approaches to management of this frontage, qualitatively assessing any potential engineering/effectiveness issues with each of those approaches, taking into account the latest analysis of coastal change, and presenting a high-level view on the relative merits of each.
- Providing a high level (order of magnitude) assessment of construction costs for any potential management approaches.
- Providing an estimate of the approximate level of grant aid that might be achieved by the potential management approaches, and thus the likely level of additional funding that might need to be found.

In addition, a supplementary appendix (Appendix D) provides an overview of the erosion issue at Winterton car park and café, and assesses the viability of providing protection to the dunes here.

This report does not recommend the preferred approach for Hemsby; that depends upon a wider range of considerations than covered by this first stage. The key output of this report is the identification of potentially technically suitable implementation measures and their relative merits, which will provide the Borough Council and the community with an independent assessment so that they can together make best-informed decisions on the way forward.

Coastal Erosion Issue

2.1 Introduction

This assessment of options to reduce erosion risk is limited to the Hemsby frontage but coastal change over an extended area to north and south has been considered, to help inform that assessment of options.

This study has explored some key questions, notably what is the nature of change along this shoreline, what is the cause of it, and will it continue? Those questions are crucial to determining whether certain options for coast protection are likely to be effective or not in providing protection at Hemsby.

The review has looked at the origins of the coastline, including: historical and recent changes; key controls on the shoreline and sediment supply; and offshore changes. Information analysed includes: available data on tides, waves and currents; historic maps; aerial imagery; hydrographic surveys of the seabed; and topographic surveys of the beaches, together with any anecdotal information and photographs. Detail on these is presented and discussed in Appendix A, with the key findings relating to the potential causes of changes at Hemsby summarised below.

2.2 Nature of change

2.2.1 Historic situation

Erosion at Hemsby and the loss of properties is not a new occurrence. Accounts of previous changes identify over three lines of chalets within the dunes shortly after the second world war, with many of these being lost (or removed) along the front line of dunes between the 1940s and 1980s, and several more between 1992 and 1997. Erosion has not been confined to single events but has been an ongoing and variable feature of this shoreline for some time. Change has also been episodic, meaning that there have been periods of rapid dune erosion and shoreline retreat followed by periods when the dune front has remained static, but the beach in front has continued to fluctuate in level.

Historical maps indicate that there was probably very little dune here 200 years ago, so these are a relatively contemporary feature; indeed, the presence of a former cliff line behind these dunes is further evidence that they did not exist here in the past. Previous published accounts of the coast in the first half of the 20th century note the changeable and erodible nature of the shoreline between Winterton and Caister, further emphasising that the dunes have not been a static feature over time.

There have also been periods of dune growth and stability, and this was most probably the trend when chalets were built. Over the past 20 years this trend has reversed, resulting in the recent losses along the Hemsby frontage and this study has looked at possible reasons for this change.

2.2.2 Recent situation

Since 1992, there have been regular aerial photographic surveys carried out by the Environment Agency, with annual photographs available from 2003. Whilst the photographs are not always taken at the same tidal level, key changes can be observed; these are described in more detail in Appendix B. Of particular note is the correlation between movement of Winterton Ness and areas of erosion to the south, extending through Hemsby and down to Scratby and California.

Comparing the first aerial (1992) to the latest (2018) shows there has been a significant movement of the ness. As the ness has moved northwards, there has been dune accretion to the north whilst the dunes to the south have eroded, resulting in a large-scale realignment of the coastline from north of the ness to the boundary with Scratby. Whilst erosion of the dunes south of Winterton has gone relatively unnoticed, due to the lack of properties there, erosion at Hemsby has had significant consequences due to properties within the dunes and proximity of the village to the coast.

Beach level data has been collected on a regular basis since 1991 as part of the Environment Agency's Anglian Coastal Monitoring programme. Topographic surveys are undertaken at a minimum of one-kilometre intervals, generally every winter and summer.

From this information, the changes in the shoreline position have been recorded. Figure 2.1 shows the changes in the beach and dune profile along the most affected area south of Hemsby Gap, showing that the dune face has retreated approximately 40 m over the period 1991 to 2018. Although some significant recessions are notable and other periods of relative stability are also seen, erosion has been a constant ongoing process.

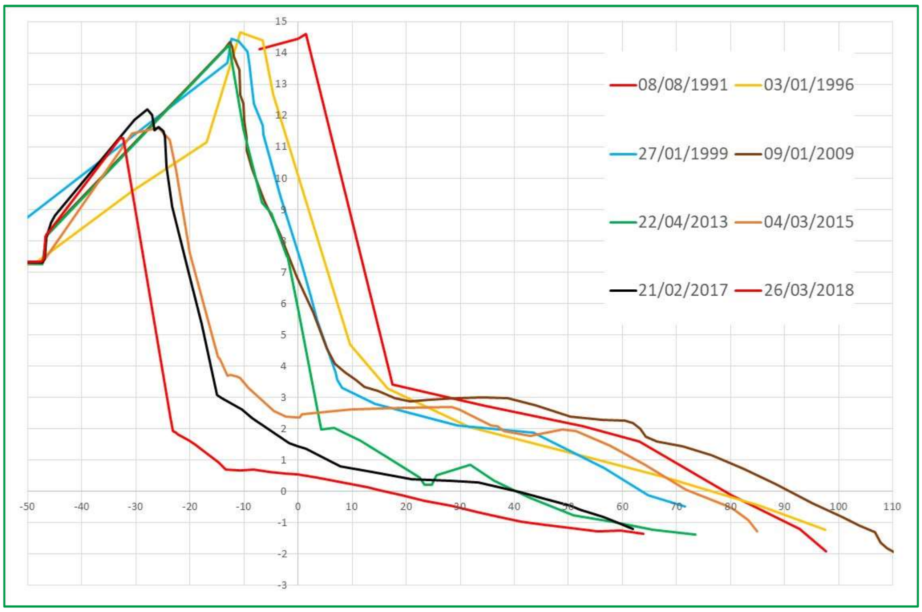

Figure 2.1 Selected dune and beach profiles at Hemsby 1991 to 2018

2.3 Influences on erosion

2.3.1 Hydrodynamic

Sediment transport and resultant changes along the shoreline are due to the action of waves, tides and, to a lesser extent, winds. Waves are the primary mechanism by which sediment is moved along and across the shoreline, with the largest and most predominant waves approaching from the north and north-east. Sediment exchange between the beach and nearshore zones takes place as a result of beach drawdown under storm wave conditions and onshore movement in calmer conditions. Recovery of the beach therefore depends upon how much material is returned to the shoreline and retained post-storm.

This stretch of coastline also has a particularly unusual tidal regime and Hemsby sits within an area where significant differences in tidal height and both current velocities and direction occur over very short distances. The result is an unusually large difference in tidal level between Winterton and Caister, which means that at certain times, a considerable 'head' of water is created. This will create very strong current flows along this shoreline between these points, which is also going to affect the direction and magnitude of sand transport. Surges are also an important factor in driving change along the coast, and the nature of those interactions is more complicated in the southern North Sea than on many other coastlines.

It is notable that the recent significant erosion episodes do not appear to relate to one single type of storm/surge event, further emphasising the challenges at Hemsby to provide a solution that can accommodate these different factors.

2.3.2 Banks and channels

The nearshore bank and channel system, running from Winterton Ness down to Benacre Ness (in Suffolk), has been the subject of numerous studies, establishing it to be constantly changing and dynamic in terms of the height, shape and position of the banks. The size and configuration of the nearshore banks and channels has a significant influence on conditions along the beach by changing the direction and power of the waves as well as focussing their energy on certain spots. They also affect tidal flows through the system and therefore patterns of accretion and scouring.

Significantly, a recent study of the bank system (Barber, 2016) concluded that the influx of sand had resulted in both increased elevation of the banks and their relocation closer to the shoreline, which has 'canalised' tidal flows through the channels. The study suggested that this has resulted in movement of the landward side of certain channels by 150 to 200 m shoreward. Similar recent changes in these banks and channels that would have implications for Hemsby have also been identified by this present study, the consequences of which are discussed in Section 2.4.

2.3.3 Movement of the Ness

Winterton Ness has been a dynamic feature and through historical maps it can be seen how it is not just its extent that has changed over time, but also its form. Early maps show the feature as a three-peaked mass of sand and shingle, which extended further north. Subsequently the ness has developed a more peaked form, with a clearly defined single apex, but there has previously been some redistribution of sediment further south, building up beaches (and possibly dunes) between Winterton and Hemsby. In more recent years (at least since 1946) the feature has been moving northwards. As the ness has moved northwards there has been a reorientation of the coastline to the south.

The reasons for the observed changes in the ness shape and position are not certain but there is a connectivity at the ness with the nearshore bank system and movement of the ness is a response to, or intrinsically linked to, large scale changes to the nearshore bank system.

A bar feature extends from Winterton Ness and runs semi-parallel to the coast. It is not known whether this is a conveyor of sediment. The feature is semi-permanent and it is likely that as the ness has moved, this bar feature has also changed. Associated with the bar is a small tidal channel (runnel) feature between the bar and the dune toe, which gets squeezed and eventually infilled as the bar moves onshore. At certain points during this process this channel feature means there are lower beach levels at the dune toe, potentially increasing vulnerability of the dune to wave erosion.

2.3.4 Sediment supply

The general direction of sediment transport along this coast is southwards. It is believed that the North Norfolk cliffs have been the long-term source of sediment supply to the rest of the shoreline south of Cromer through to Great Yarmouth, as well as to the Great Yarmouth bank system. Previous geological analysis of those cliffs identified that approximately 50 to 60% of eroded material is sand and gravel, with the remaining fines transported offshore in suspension, while the sands and gravel are transported along the shore.

The impact of existing defences

One question is whether the defence of many sections of the cliffs along the North Norfolk shoreline might be causing sediment starvation at Hemsby. Added to that is the potential for impact from the nearshore breakwaters at Sea Palling together with the introduction of groynes along further sections of the frontage between there and Winterton. There has, in the past, been some recharge of the beaches necessary along that frontage, although this has not been required since 2008, suggesting more sand has been moving through this area in recent years.

Although this study has not been able to look at those potential influences in detail, it is considered unlikely that they are having any significant effect on sediment supply to Hemsby, based upon observation of other areas. Since construction of defences to the north, sand has continued to accumulate south at Caister, with infilling of the beach behind the reefs and groynes since the late 1990s, and material has also accumulated in front of California. With no signs of sediment supply depleted to those areas, this sand and gravel must have come via Hemsby to reach those locations. There are also currently substantial accumulations of sand on the northern side of Winterton Ness, which is further evidence that plenty of sand is still present in the system and is moving southwards down the coast past the defences along the Sea Palling to Winterton frontage. Indeed, a question might be whether Winterton Ness is a greater obstacle affecting the rate of sand supply to the Hemsby frontage.

The impact of aggregate dredging

For many years there has been public concern over the effects of dredging and a perception that it is a cause of coastal erosion experienced along the coastlines of Norfolk and Suffolk. Several studies have generally concluded no adverse effect, although some of those have not been universally accepted due to being commissioned by the aggregates industry or The Crown Estate, who licence the dredging. Although the remit of this study does not enable this question to be explored further in any great detail, a brief review has been carried out to see if any direct relationship is apparent between licenced dredging and the erosion of Hemsby.

The areas where aggregate dredging is permitted lie in deeper water and outside of the Great Yarmouth nearshore bank system. If this bank system is not being affected, then links to the shoreline are also less likely. Various past assessments concurred that the nearshore banks are a sink for sediments. In a recent independent study, unrelated to any dredging appraisal, Barber (2016) included volumetric calculations concluding that the Great Yarmouth bank system has seen net growth of approximately 900,000 m^3 per year for the last 40 years, i.e. even with the dredging offshore of these taking place. That amount of growth also exceeds the estimated volume that might come from the North Norfolk cliffs, so there has to be considerable input from elsewhere, e.g. the bank systems much further offshore to the north. That being so, it is likely that the areas outside of the bank system being dredged are also receiving considerable sediment input from further north, and therefore less likely to be drawing material away from the beaches here.

Although there is no definitive proof that the dredging is not having some effect on the banks, and in turn on the shoreline, the information currently available lends itself to the conclusion that there is unlikely to be any direct link between those operations and the present erosion issues at Hemsby.

2.4 Cause of erosion

2.4.1 Changes to the nearshore channel

Although it is unclear whether it is a change in the ness form that generates a change in the banks and channels nearshore or vice versa, a relationship between the two does appear to exist. A similar relationship will also exist between the tidal flows and the bank and channel configuration. The exact nature of those relationships remains unclear, with regard to which is the trigger and which is the reaction, but the consequence of this dynamic behaviour is a significant change in the nearshore channel that lies between Caister Shoal and the shoreline.

Hydrographic survey data collected in 1990, 1999, 2011 and 2016 indicates that some significant changes have taken place in the area offshore south of Hemsby Gap, which would appear to have had an impact upon the beach there. Figure 2.2 shows a cross section through the channel taken from those surveys.

Between 1990 and 1999, the size and shape of the channel was relatively stable, with small changes being no more than might be expected in a highly dynamic and sediment-filled area of seabed. However, by 2011, a significant change had occurred. As Figure 2.2 shows, a vast quantity of fresh sand had accumulated and filled the seaward side of the channel. Further infilling of the channel then occurred between 2011 and 2016, significantly reducing its cross-sectional area.

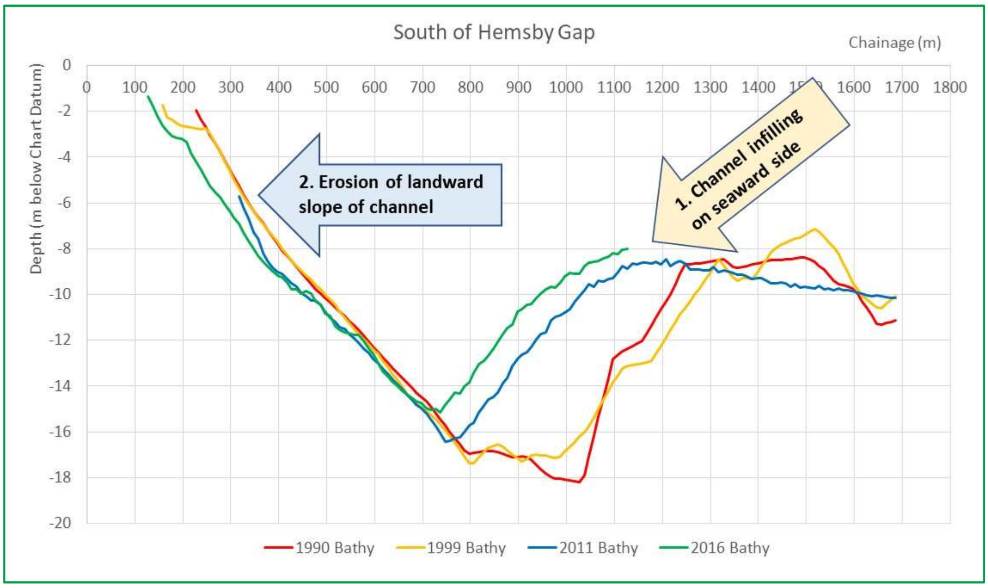

Figure 2.2 Cross-section through nearshore channel directly seaward of Hemsby (South of Gap)

Although we do not (as part of this study) have sufficient information to establish how much of the tidal flow occurs around and through the various channels between the banks, a significantly strong current would have to run along and down the coastline through the nearshore channel as water moves around the Ness, as a result of the exceptionally high difference in water levels between Winterton and Caister. Indeed, the presence of the elongated deep-water channel, which extends southwards from Winterton Ness, has to be a consequence of that flow.

The result of that rapid infilling on the seaward side and reduction in the cross-sectional area would also have had an effect on the strong currents running through this channel, the consequences of which are observed on the landward side of these same survey plots. Between 1990 and 1999, the landward slope of the channel appears to have been reasonably stable, but by 2011 there was very notable cutting into the lower slope occurring (Ch300 m to Ch600 m). By 2016 that cutting back of the slope had extended inshore (Ch200 m to Ch400 m).

This response is unsurprising: as the channel infilled this would create a smaller cross-sectional area for the same volume of water was to pass through, resulting in faster and thus more erosive flow velocities. It is likely that the flow patterns themselves may alter, for example more flow being diverted into other channels, but probably only after a period of transition and readjustment. Therefore, at least initially, the infilling on the seaward side is likely to have resulted in higher flows concentrated further shoreward. In addition, to the north and south the channel retains a similar cross-sectional area, which suggest that the volume of water moving through it on each tide has probably not altered significantly.

2.4.2 Effect of nearshore channel on beach stability

The landward bank of the nearshore channel is also the seaward edge of the shore platform where the beach sits. An observable consequence of the erosion of the landward side of the channel has been the corresponding change in the edge to the shore platform, which has also retreated.

As the nearshore channel has moved landward at Hemsby, resulting in deeper water closer to shore, the shore platform or ‘accommodation space’ for a beach to form and stabilise has been reduced in width, being squeezed between the channel and the dune. To attain an equilibrium, the beach would need to recover that space to be able to fully reform to its natural height and width, which can only occur by occupying some of the space currently occupied by the dunes.

This erosion into the dunes occurs as a natural consequence of the narrower beach, allowing more frequent exposure of the dunes to wave attack. Figure 2.3 shows the corresponding dune position for dates approximating to the year of the bathymetric surveys.

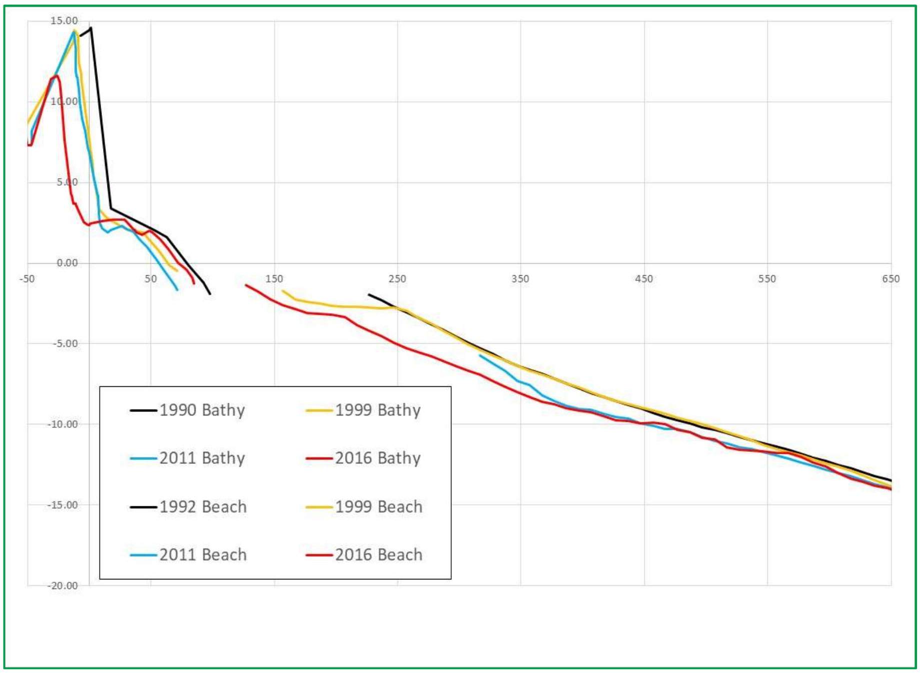

Figure 2.3 Changes in position of dunes relative to changes in position of channel and shore platform

2.4.3 Conclusion

Erosion of the dunes occurs predominately during storm events, but the impact of these events at a local level depends upon conditions prior to the storm. At Hemsby the recent significant erosion episodes in 2013 and 2018 have followed periods of beach narrowing and lowering, which has created optimum conditions for dune erosion.

It appears, however, that the situation at Hemsby is not simply one of the beach lowering and dune erosion, but triggered by an overall landward movement of the wider coastal system at this location, a process called 'trangression', as that system seeks to attain an equilibrium profile from deeper water through to higher ground.

Where the recent problems at Hemsby have occurred, this trangression seems to be linked to considerable infilling of the deep-water channel on the seaward side. This change in the offshore appears to be a critical factor with respect to the narrower beach and erosion. The dune erosion is therefore part of a whole system natural adjustment, with the behaviour of each component – bank-channel-beach-dune – influencing the next.

Transgression itself is not unusual, it is an ongoing process on many coastlines. The combination of factors producing it are however more complex here in terms of the wider influences of the ness, the nearshore banks and the peculiarities of the tidal current regime; these may be accelerating this process compared to many other places.

Interestingly, the unique setting and constantly changing configuration of major coastal formations, mean that this process could even reverse here in the future, with the present erosional trends ceasing, and a return to accretion along this stretch of shoreline. However, such a change is more likely to occur on a decadal timescale and is therefore not pertinent to the present day and near future issues being experienced at Hemsby. So, unless there is a further change in the nearshore deep-water channel, Hemsby is likely to remain vulnerable.

2.5 Future change?

Predictions of future change are complicated in this area by the complexity of the interacting factors affecting change, and even with much more extensive study, uncertainties are going to remain. Therefore, extrapolating recent trends and variations from the monitoring data are considered to be the most reliable estimates of near-term future change at this time.

Projections of future shoreline change have been made based upon the total extent of change measured over the past 10 years, i.e. between 30 and 40 metres. Note that although erosion is continual, the rate is not linear, and this change captures 2 cycles of substantial erosion triggered by events in 2013 and 2018.

Although the projections to the south of Hemsby Gap are based upon recent dune erosion, this may reduce in the future once the former cliff line is reached. Once that is exposed a change in rate and nature of erosion would occur, as the geology is different; the material will no longer be weakly consolidated windblown sand, but denser compacted material. This will have similar characteristics to California which is still very erodible but more resilient than dunes. The exact position of the change in geology south of the Gap is unclear, but from inspection it would appear likely that this will not affect rates for another 10 to 20 years, after which erosion may slow down.

To the north of Hemsby Gap, the rate of dune erosion is not as fast but is still high, and continued retreat would probably see the dunes being breached into The Valley within 20 years. However, the old cliff line, which is visible here, would not be reached until approximately 50 years. There is also a concern relating to flooding, with the perceived threat of a breach along this stretch of shoreline allowing sea water to flow down The Valley into Hemsby. However, remote sensing level data (LiDAR), indicates that ground levels behind the dunes at the south end of The Valley are somewhat higher than any recorded surge levels (including 1953 and 2013), so there should be no immediate flood risk to Hemsby via this route. Nonetheless, that risk would increase once erosion of the dunes immediately to the north of Hemsby Gap occurs and the higher ground currently preventing flooding eventually becomes exposed to erosion from wave and tidal action.

Appraisal of possible solutions

3.1 Appreciating the problem

It is by understanding the nature of the problem that the most appropriate solutions can be found. At Hemsby this has needed a better appreciation of the processes that create the circumstances causing the erosion, summarised in the preceding section. With that knowledge it is possible to assess whether an option will be effective.

Crucially, what is seen at Hemsby is not simply dune erosion but the result of chain reaction of natural movements; the landward movement of the nearshore deep-water channel resulting in a narrowing of the shore platform and beach, which requires a landward movement of the dune face to recover its natural equilibrium size and position relative to the underwater slope. Until that point is reached, the beach offers less protection to the dune face. In addition to this is the effect of Winterton Ness moving northwards and the impact of individual storm events. All these factors have fundamental implications for the effectiveness or otherwise of any potential solutions.

3.1.1 The consequence of coastal change for defence options

Beach levels are constantly going up and down, generally referred to as natural volatility. However, from analysing the beach profile data collected every summer and winter for the past 25 years, long-term underlying trends of change can be observed. As well as showing the change in position of the dune line, those profiles also show how the beach position has altered at the same time. What can be seen is a very clear underlying transgression (landward movement of the whole profile) which corresponds with the movement of the nearshore channel.

To the naked eye the beach may look similar now to in the recent past, but its position has changed and with this the depth of water over the place that beach previous occupied has increased. To illustrate this point, Figure 3.1 compares two profiles from 2009 and 2015, and shows that although the size and shape and size of the beach is similar, because of the ongoing natural transgression, the whole profile has shifted landward. This means that although the distance between the toe of the dune and high water is similar, the point where high water was in 2009 is more than a metre lower by 2015.

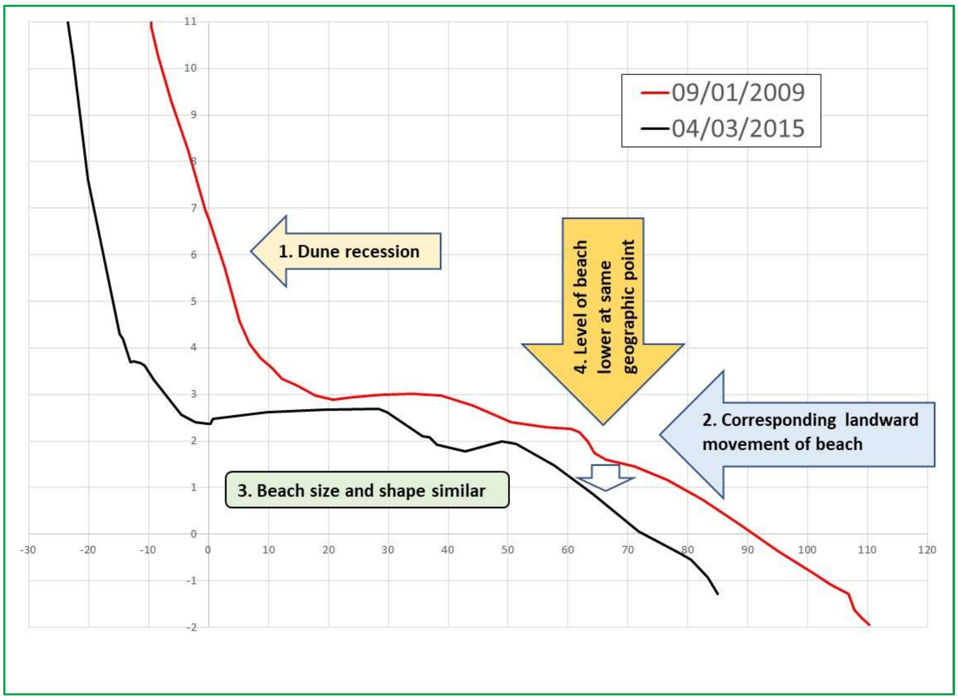

Figure 3.1 Illustration of beach transgression at Hemsby.

This is an extremely important point when considering options and understanding why some approaches may be less suitable than others. To illustrate this, and show how the shoreline would change in future if certain defence types were introduced now, it is useful to look back at recent changes. Figure 3.2a shows the changes in dune position and beach levels south of Hemsby Gap, from February 2013 through to 2018, illustrating the landward progression of dune and beach. In this example, the question is then posed, what would have happened if a structure had been built along the toe of the dunes in 2013, i.e. prior to the earlier large erosion event? The outcome is illustrated in Figure 3.2b.

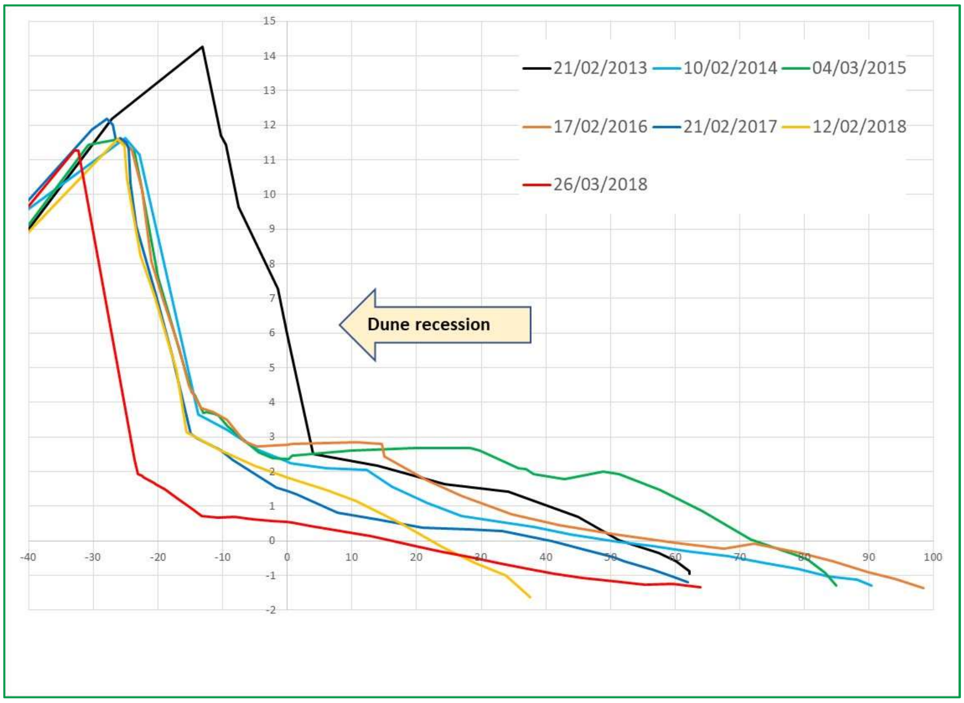

Figure 3.2a Dune and beach profiles south of Hemsby Gap 2013 to 2018.

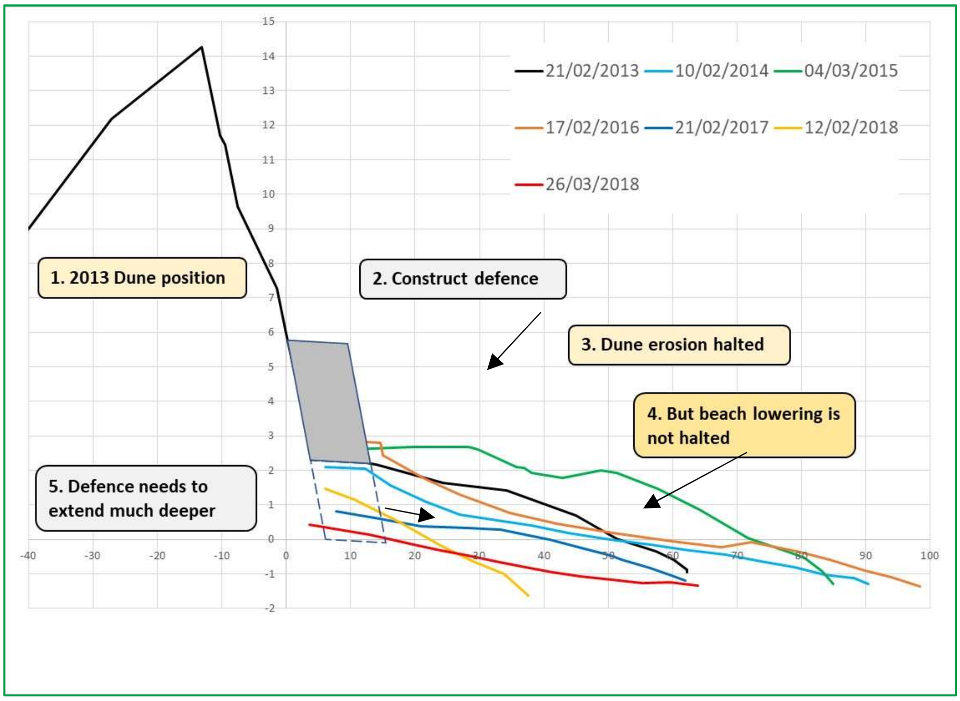

Figure 3.2b Impact of defence construction.

Figure 3.2b shows that although the dune face erosion might be prevented by a defence, the beach changes to seaward would continue as a consequence of the transgression of the whole beach system resulting from continued landward movement of the nearshore channel. That translates to an ongoing lowering at the point where the defences were installed, which would lead to them being undermined and failing, if not bedded deep enough into the beach. This process has already been observed at Hemsby, with undermining of the HexiBlocks and gabion wall. This is independent of any beach scouring that might also arise from wave reflections off the new structure.

In the above example, the defence would have needed to have been founded at least 2 m lower, to accommodate beach changes over just a 5-year period, and remain stable. Although that is perhaps an extreme example, this same process will continue and any structures built now would also need to accommodate such changes and more, to address the continuation of this process, if they are to provide many years of protection. Another consequence of this process is that the accommodation space in which sediment can accumulate is being squeezed even further and there is no means to hold material moving along that stretch of shoreline. Ultimately, that may mean there would no beach in front of the structures.

3.2 Assessment of Coastal Defence Options

Assessments have been undertaken for several different forms of coastal defence; Appendix B provide the following information for each type:

- Description – a summary of the defence type and explanation of how it works.
- Examples of application – other locations where a similar type of defence has been implemented (identifying local examples where possible).
- Likely effectiveness at Hemsby – the assessment of whether that type of defence might be suited to this location and reasons why or why not, taking account of what is now known about the cause of the problems here.
- Other considerations – further information that might be a factor regarding that option.
- Typical costs – costs available from other schemes/locations.

The conclusions from those assessments are summarised below:

Table 1 Conclusions from assessment of defence options (full details provided in Appendix B).

OPTION		SUMMARY CONCLUSIONS OF ASSESSMENT
1	Dune/Cliff Stabilisation	Various techniques exist but none are going to prevent erosion of dunes at this location, and will therefore be **unsuitable**.
2	Gabions/Stone-Filled Mattresses	These can provide some interim protection to eroding face but remain susceptible to undermining and failure. Therefore, would provide a **short-term or interim option but not a long-term solution**
3	Geotextile Sand Containers	Could provide some protection to the eroding dune and compares favourably with other lower cost options in that respect, but will not prevent the loss of beach. Consequently, **potential application here, but probably not a long-term solution**.
4	Rubber Tyres	An approach not proven in a dynamic beach environment, and considered to be vulnerable to instability under aggressive wave conditions and beach changes, so therefore **unsuitable**.
5	Intermittent Blocks	This option is **unsuitable** as an open array of blocks will not prevent erosion at this location.
6	Concrete Seawall	**Potential application here, but with likely unfavourable effects**. Although it could prevent erosion, is likely to accelerate beach loss, so lacking long-term sustainability. Likely to also be considerably more expensive than some of the alternatives.
7	Blockwork Wall	Successful elsewhere but under significantly different conditions. Susceptibility to undermining make it a technically challenging choice here and therefore **unlikely to be suitable long-term solution at this location**.

OPTION		SUMMARY CONCLUSIONS OF ASSESSMENT
8	HexiBlocks	This is **unlikely to be suitable long-term solution at this location**, needing further development to be effective and (like several other 'hard' linear options) will have stability issues due to underlying processes causing loss of the beach.
9	Rock Revetment	Successful elsewhere with similar erosion problems and likely to be effective here, so a **potential long-term solution**. Like all other linear defence options (1 to 13), a revetment from this alone will not prevent the natural beach lowering processes, but it would avoid additional scouring and reduce the rate of beach loss.
10	Rock Berm	Lower cost than revetment, and can be effective to substantially limit erosion (rather than completely halt it). Could therefore provide a **potential short-term fix or a longer-term solution**. Similar to rock revetment, would avoid additional scouring and reduce the rate of beach loss.
11	Other Revetment Systems	Most types would be inadequate for this aggressive coastal environment, or require 'seawall' type toe protection, which could increase scour. Consequently, **unlikely to be suitable solution at this location**.
12	Timber Wave Break	**Unlikely to be suitable solution at this location** as although it might slow the rate of dune erosion for a short time it will not address the beach lowering issue and could exacerbate scouring.
13	Concrete Armour Units	A possible alternative to armour rock but perhaps having less flexibility and higher unit costs, depending on the nature of structure into which they might be incorporated. Simple units (e.g. Tripod) are probably most appropriate if used for linear defence. **Although, potential for application here, use may be better suited to deeper water structures**
14	Beach Nourishment	A beach is a preferred form of defence but in this sediment-rich system it is unlikely that importing additional sand is going to provide the solution. It may provide a short term 'buffer' but is unlikely to remain stable given the driving forces acting to cause the erosion problem, and so **unlikely to be suitable solution at this location without some form of control structures**.
15	Groynes	Control structures (groynes, nearshore breakwaters, or a combination of both) would help retain beach material and provide better protection to the eroding dune face. Therefore, **a potential long-term solution**. Might be part of broader scheme including backshore protection.
16	Nearshore Breakwaters	Control structures (groynes, nearshore breakwaters, or a combination of both) would help retain beach material and provide better protection to the eroding dune face. Therefore, **a potential long-term solution**. Might be part of broader scheme including backshore protection.
17	Sill/Submerged Reef (Perched Beach)	Could help retain some beach material but could also restrict any onshore movement of sand. May be undermined by channel movement and effectiveness subsequently reduced or lost. Therefore, **unlikely to be suitable solution at this location**.
18	Headland Structures	A **potential long-term solution**, being designed to keep strong currents away from the shore and restrict further landward movement of the nearshore channel. This could then enable a wider and higher beach to reform.
19	Sand Motor	Due to the uncertainties associated with the nearshore bank and channel system and the behaviour of this large mass, it would be a high-risk approach that may not work here and could have wider unforeseen consequences. Therefore, **unlikely to be suitable solution at this location**.
Other non-engineering methods for managing erosion risk also exist, including adaptation measures, which may need to be considered. These are outlined in section 3.3.3 of this report.		

As the assessments have demonstrated, a few potential options can be discounted totally, whilst there are several others which are considered unlikely to be suitable for Hemsby. The latter include options where it is not inconceivable to engineer a solution, but the engineering requirements, and therefore costs, to achieve the protection needed at Hemsby would be disproportionally high. It also includes instances where the likely effectiveness of the option will probably be short-lived, or the risks and uncertainties associated with that option are too great to contemplate when other technically suitable options remain.

The remainder of the options typically fall into two groups; those that may offer a potential long-term solution here and those that potentially providing an interim or short-term fix.

Long-term options are essentially permanent works to provide solutions suitably robust to hold the line and reduce erosion risk for at least a few decades. These would involve construction of structures designed to withstand several extreme storm events and accommodate changes in circumstances such as movements of the offshore banks and channels, sediment supply, or shoreline evolution to north and south.

The alternative is to offer some level of protection for maybe 5 to 10 years, i.e. a short-term fix only. Options would still need to be sufficiently robust to minimise the risk of failure over that period, taking account of the continued shoreline erosion and increasing exposure along this frontage, but accepting that some conditions may still exceed their capacity to provide full protection and they are unlikely to continue providing long-term protection. These might be adopted because they are currently achievable within financial constraints, or be installed as an interim protection perhaps whilst a permanent works scheme is developed, funded and constructed.

Further consideration of these options and how they might be used at Hemsby is expanded upon in the section 3.3.

3.2.1 Channel dredging

One further proposal suggested to address the observed problems at Hemsby is to dredge the material being deposited in the nearshore channel (estimated from bathymetric surveys to be up to 5 Million m^3), which appears to have altered the flow regime and thus impacted on beach and dune erosion here. The premise is that this would then return the channel to its former shape and size and therefore reduce the ongoing erosion of the beach. There are however reasons to reject this suggestion.

Foremost, the infilling of the channel on the seaward side is just another link in the chain of events; triggered by much wider coastal system changes occurring across the nearshore bank and channels system from Winterton Ness down to Benacre Ness. As discussed in section 2.3.2, there is widespread change in this highly dynamic system. Consequently, interference in that is likely to be at best ineffective, as fresh sand may simply redeposit in the area from which is was removed to maintain natural balance within the system, and at worst trigger an unexpected change that creates an imbalance in the ongoing adjustment of the system with unpredictable and potentially highly detrimental effects elsewhere.

A further factor to consider is that the present bank and channel configuration may already be tending towards a new equilibrium, which could see some stability return, and disrupting that could sustain rather than address the local issues at Hemsby. The environmental implications of such an operation would also require lengthy and extensive investigation.

Finally, the huge and unpredictable risks associated with such an approach, due to the complexities of the coastal system, together with the high costs involved for an operation, that may be ineffectual (at present rates, dredging 5 Million m^3 would cost in excess of £50 Million), lead to the conclusion that this approach is inappropriate.

3.3 Approaches to Future Management

3.3.1 Dune face protection (linear defences)

A common expectation is that the best way to manage erosion risk to the dunes is to build a structure along the shoreline directly in front of it. This is generally termed a 'linear defence'.

Various options that might provide this erosion risk management approach have been assessed but several of those are considered unsuitable or unlikely to be appropriate at Hemsby, generally for one of two reasons; either they are not expected to be effective as a form of protection, or in many cases they are likely to be de-stabilised by the ongoing changes in the beach. This second point is explained in Section 3.1; unless the linear defences can either adjust and adapt to a changing foreshore, or have foundations well below the lowest levels that the beach might be expected to fall, they will be undermined and collapse.

Only a few approaches are considered likely to be able to be able to effectively accommodate the substantial changes here, with a rock armour revetment, or a rock berm, likely to be the most suited to these conditions. Alternatives to these include the (i) use of concrete armour units to form a bund in front of the dune face, although there are no obvious advantages of that over a rock solution, or (ii) a concrete seawall with a deep piled toe. A seawall does however come with considerable disadvantages, in that it will probably accelerate loss of the already low beach and is also likely to require extensive maintenance in the future. In short, although it might address the erosion concerns, it would not be a logical choice.

The difference between a rock revetment and a rock berm would be the level of protection afforded. A revetment would be much higher and intended to stop further erosion, whereas a rock berm is a lower (and cheaper) structure that is intended to reduce rather than halt erosion, such as that along the California frontage. A rock berm will still be effective and remain stable, but it would be expected that some extreme storm events could overwash it and some erosion of the soft sand behind may still occur. But critically, the berm reduces further erosion at the base of the dunes, reducing the rate of retreat, slowing the removal of loose material behind, and improving the potential for the remaining dune area to stabilise over time.

The primary reason why a rock solution is more likely to provide protection, where other options would not, is that rock structures are dynamic and able to flex and adjust to changes unlike their more rigid counterparts. For example, they are often designed with 'falling toe' to accommodate lowering beach levels – in this situation, rock at the toe would be able to drop into that space and armour against undermining. The high levels of wave energy dissipation with these structures is effective in minimising reflections, and can actually help to counter scouring. These reasons are in part why it has provided to be one of the most widespread and successful forms of shoreline protection over the last three decades.

An interim solution

Providing long-term protection will be expensive and may simply not be affordable (although see further discussion on this in section 4). Therefore, other options that can provide some level of protection at much lower cost may need to be considered, although those come with a proportionally higher risk and expectation of not lasting for a long time. Alternatively, the preferred long-term approach may require further planning, establishing funding sources, plus detailed design and construction. Depending upon how soon a decision on that can be reached, there is still the immediate risks to be addressed, so some interim works may be required.

All of the linear defence options have been considered in terms of their suitability to provide short-term protection, but also keeping costs lower. Most of the same arguments around suitability apply for the short-term, and the level of works required to ensure stability of some of the more rigid types would be extremely expensive. The conclusion once more is that suitable options are only going to be those that have some inherent flexibility.

In addition to a rock berm, described above, other types of protection that might afford short-term or interim protection include geotextile sand containers and gabions (albeit with a modified construction to that at Scratby and Hemsby previously). These could become vulnerable under extreme conditions, and have lesser durability than many other options, so come with higher risk; but they also have more capacity to adapt and provide some level of protection than other alternatives, at a more affordable price. The decision on these is one of balancing cost versus risk, understanding that these are usually going to be only a short-term fix that could last several years without failing, or be heavily damaged in a single storm.

It is also worth considering that these structures could form part of a backstop protection if a beach scheme were implemented (section 3.3.2) or in the case of a rock berm that material could be recovered and re-used in other structures such as groynes or breakwaters.

Other points to note

With any of the linear options, it must be recognised that even now there is a zone of potential instability of a few metres back from the current cliff edge. Indeed, it would be prudent to include some regrading of the dune face as part of implementing any long-term works, which may have implications for some properties and existing access along the top of the dunes.

3.3.2 Holding a beach

Although the dunes, and thus properties, can be protected by a linear defence, a fundamental disadvantage of those is none of them will halt the ongoing problem of beach loss. The natural transgression will continue and the beach will become lower and eventually lost, which amongst other concerns is presumed to be damaging to the very businesses that managing erosion risk at Hemsby would also be seeking to protect.

There is a vast quantity of sand in the coastal system in this area, the problem is that it is not being retained at Hemsby. One factor is the receding shore platform, due to movement of the nearshore channel, but the other is the strong alongshore component of waves and currents moving that material swiftly down the coast. Another management approach would be to interrupt that movement through the introduction of beach control structures to help retain a higher beach, will in turn provide better protection to the eroding dune face.

Whether those control structures should be groynes or nearshore breakwaters, or indeed some combination of both, depends upon the dynamics of sediment movement along this section of shoreline. This is not an aesthetic choice, and determination of which structures would be best is beyond the capacity of this current high-level assessment. But even without the more detailed design to confirm the best option, it is possible to conclude that one of these forms of control in front of Hemsby would intercept sand being transported alongshore and thus encourage a higher beach. This is a sediment-rich system, with a considerable quantity of sand moving through it, so this should happen naturally without recourse to additional beach nourishment.

Combination of defence types

Given the limited accommodation space for a beach, a pragmatic approach may be to combine stabilising enough sand to give an improved beach but not be entirely reliant on that, with a backstop protection buried along the base of the dunes to provide added protection during extreme surge and storm events when some limited beach drawdown may still occur.

That backstop could be to either leave the interim works previously described in place, or depending on the design of the beach, a rock revetment – albeit it would not require the deeper toe to accommodate the lowering previously indicated, so would be considerably less expensive than a linear defence alone.

Headland structures

Although beach control structures would be effective in retaining more sand to provide a bigger beach in front of the dunes, ultimately its capacity to grow will still be limited by the proximity of the nearshore channel. The ultimate solution to that would be to construct much longer structures designed to deflect the current flows, resisting further migration of the channel, and maintaining the width of the shore platform. This type of approach, used in very large river systems, is particularly suited to Hemsby due to the strong shore-parallel currents that are one of the key issues here.

The form of structures that would be most appropriate here are likely to fishtail groynes, originally developed for precisely this purpose. Suitably designed, with these structures it is less likely that any backstop protection would be required, as the groyne effect of these would also enable larger beaches to develop.

3.3.3 Other erosion risk management approaches

In addition to the above approaches, which are designed to reduce erosion risk to Hemsby, other possibilities must also be considered.

Deferred intervention (realignment)

One management approach is to not intervene along the current line, accepting further realignment of the shoreline with some further erosion of the remaining dunes. Other than no intervention at all, this might be the only approach available if funding cannot be sourced now.

A further case for intervention might then be made and can be put in place when further erosion has occurred, for example once the old cliff line is close to being reached, and more property lies within the active risk zone. This could have more chance of attracting government funding (flood and coastal erosion risk management grant-in-aid, FCERM GiA; see Section 4.1.2 for further details) due to the greater volume and value of properties at risk (assuming though that present day economic rules and criteria remain the same). If holding that line is established to be economically viable, and environmentally acceptable, the full range of permanent solutions being discussed now and the arguments for and against those would again apply, including linear structures such as revetments or bunds, as well as measures to control and stabilise the beaches.

One argument for not intervening now is the present configuration of banks and channels may begin to reach a new equilibrium which halts, or even reverses, the present erosional trends. That could see a new period of beach and dune growth and avoid the cost of defences altogether. That outcome is though highly uncertain and, if it does occur, more likely to be on a decadal timescale rather than any immediate switchback, so it is probable that the losses currently predicted to occur in the next 10 to 20 years remain likely.

Adaptation measures

If realignment continues to be the adopted approach, there will be some potential cost in the meantime to people, property and business. Under this approach, adaptation measures could be considered to address the relocation or removal of remaining properties that are built in the dunes, or lie close to the edge of the former cliff line, as well as associated access road, paths, and utilities placed at risk. Indeed, similar adaptation measures would also be considered if a no active intervention policy were adopted.

The focus of adaptation is principally on managing change, most usually to minimise negative consequences rather than ‘firefighting’ as and when situations arise, whilst it also has the potential to provide new opportunities. The Local Government Association (LGA) Coastal Special Interest Group (SIG) (July 2015) defined coastal adaptation as ‘Enhancing our coasts through delivering practical and realistic solutions, which are economically, socially and environmentally acceptable in the long-term.’ Many of the suggested adaptation options for those who own assets at risk need to be seen as part of a package of potential ways forward, rather than individual solutions. There is unlikely to be one solution that is satisfactory to all, and not all approaches are suitable in all locations. A flexible approach is required, so different needs can be recognised.

Several options exist, which would require further development and community discussion. These can generally be split into residential, business and community, and funding approaches. Typically measures might include rollback or relocation of property, community facilities and infrastructure through a range of initiatives, as well as diversification and change of use for the areas affected and businesses. Such measures have been identified as a suitable adaptation approach to coastal change by East Riding of Yorkshire, North Norfolk District Council, Waveney Council and Suffolk Coastal District Council. Planning policy can also be used to identify suitable types of time-limited development for particular locations.

3.3.4 A broader shoreline management approach

The implementation of any approach would need to ensure no detrimental effects elsewhere, such as from Scratby through to Great Yarmouth, particularly if the natural movement of sand were interrupted. This can be determined and addressed through appropriate design.

Another approach however is to consider whether the solution can incorporate other locations as part of a broader management approach. An example of this was implemented several years ago at Caister; building structures to hold the beach locally and protect the seawall, but at the same time holding up sand which resulted in building the beach to the north of those too. This created a more stable environment for the construction of the rock berm at California as well as enabling more material to accumulate in front of that since.

Given the reported value to the local economy of Great Yarmouth Borough, through the number of overnight bed spaces provided along this whole length of shoreline from Winterton to California, an approach that ensures this whole length is suitably protected could have much wider benefits. That approach may be to extend any planned scheme over a longer frontage rather than considering Hemsby in isolation, particularly if the solutions to hold a beach through groynes or headlands are contemplated.

Other Considerations

4.1 Affordability

4.1.1 Costs

One of the key factors determining the appropriateness of any approach to be taken at Hemsby is going to be that of affordability.

Costs of providing the management approaches have been estimated using a range of information sources, but because of the high-level nature of this assessment and the exact nature of requirements at this location to deal with the dynamic and changing conditions, they must be treated as only indicative. Therefore, a contingency of 60% is applied to the costs of all potential approaches to account for a range of variable factors and uncertainties that may be encountered. This is standard practice and a requirement when planning funding needs, with this standard percentage value based upon analysis of a range of previous estimates and actual outturn costs from a large number of schemes.

Costs for protection of Hemsby are based upon an assumption of a 1300 m scheme being required, to include a length of approximately 400 m north of Hemsby Gap, through to 50 m south of the Newport/ Scratby boundary. The expected costs are shown in the table below, defined as the likely upper and lower bounds of the range of costs that might be required to implement any of the potential management approaches.

Table 2 Expected costs associated with different approaches.

Approach	Base Cost Estimate (Range)	Total Cost (including Optimism Bias)
Dune Face Protection (Linear Defences)	£8.4 to £11.7 Million	£14 to £18 Million
Beach Retention	£11.8 to £20.0 Million	£20 to £30 Million
Interim Solution	£2.5 to £5.6 Million	£4 to £9 Million

The costs for delivering a broader management approach have not been calculated, as that would be subject to further investigation and the approach taken, but a simple pro-rata of the costs for the options at Hemsby would be indicative.

Costs for realignment through later interventions (i.e. not building any defence structures today but perhaps in the future) would be similar to any of the above, but deferred for a number of years.

Adaptation costs associated with this or no intervention have also not been determined at this time. Given the complexities of the situation and the fact that decisions on how to proceed here are yet to be made, it would be impossible to conclude or infer those at this stage.

4.1.2 Funding

Flood and coastal erosion risk management grant-in-aid (FCERM GiA) is sourced from central government and is administered through the Environment Agency. Flood Risk Management Authorities (RMAs) - the Environment Agency, English local authorities and Internal Drainage Boards (IDBs) can use it for a range of activities that help reduce the risk of flooding and coastal erosion but allocation is managed through the Regional Flood and Coastal Committees (RFCCs) based on a competitive partnership funding score. A Partnership Funding calculator is used to determine any shortfall in funding that will need to be found from other sources.

For this study a high-level assessment of potential qualifying benefits has been completed and Partnership Funding calculations undertaken to highlight the additional funding that may be required to be found from alternative sources. This assessment is very preliminary to establish order of magnitude funding levels however, and it would be necessary to undertake a more detailed review of benefits and costs should it be decided to proceed with a formal application for FCERM GiA funding.

Benefits are the damages averted. Therefore, management approaches that would reduce the risk of erosion along the frontage for the entire 50-year appraisal period (including the 'dune face protection' and 'beach retention' approaches) would avert most of those losses, and would consequently be a direct benefit of those approaches. Approaches that reduce the risk of erosion for less than 50 years would avert some of the damages and therefore generate some benefits but there would remain some damages.

It is assumed for the benefits of calculation that interim solutions would delay the onset of erosion from between 10 and 20 years, depending on the level on investment. Note that the calculations presented here are based purely on property losses; no other benefits have been included.

The tables below present a summary of the results. Slight differences in some costs here and those in the previous table result from the calculation of Present Value (PV) costs and benefits, which takes account of the timing of investments and losses. Values are also mostly rounded to the nearest £Million to reflect the high-level nature of the calculations at this stage.

Table 3 Summary of Present Value (PV) damages and benefits associated with each approach.

Approach	PV Damages	PV Benefits
Do Nothing	£13 to £16 Million	£0
Dune Face Protection (Linear Defences)	£0	£13 to £16 Million
Beach Retention	£0	£13 to £16 Million
Interim Solution	£6 to £12 Million	£3 to £8 Million
Realignment (defer until Year 10)	£3 to £4 Million	£9 to £13 Million

The following table lists the level of FCERM GiA that might be attracted by each approach, together with the level of other contributions that would need to be sourced for those to proceed.

It should be noted that most of these options will not attract a benefit cost ratio (BCR) of greater than unity.

Table 4 Level of FCERM GiA that may be attracted, for each approach.

Approach	Potential FCERM GiA (PV)	Partnership Contribution Required (PV)
Dune Face Protection (Linear Defences)	£ 3.0 Million	£10 to £15 Million
Beach Retention	£ 3.0 Million	£15 to £27 Million
Interim Solution	£1.6 Million	£2 to £7 Million
Realignment (defer until Year 10)	£2.4 Million	£10 to £11 Million

4.1.3 Partnership Funding

In England, flood and coastal erosion projects are funded by a range of sources based on the benefits they deliver to people, the wider community and businesses. This is called the 'Partnership Funding' model.

There can be other funding options available when flood and coastal projects are able to deliver a range of benefits. These can include reducing risk and creating new opportunities for individual private businesses and providing wider benefits to the local / regional economy, such as regeneration, business growth and employment opportunities. In East Anglia, a number of coastal schemes have been completed recently or will be shortly, that have secured funding from multiple sources and have delivered a range of benefits to businesses and the wider community. Further details on some of those are provided in Appendix C. Some of those examples may also be of interest to Great Yarmouth Borough Council. If a large proportion of the holidaymakers coming to the area base themselves in Hemsby, Scratby and California, but then spend their money across the wider area, any strategy to maintain this base as an attractive visitor destination may have borough-wide or county-wide benefits, and also attract investment through those channels.

4.2 Environment

Impacts on the environment of any of the management approaches have not been examined at this initial stage, with the focus first on short listing those approaches that might be technical suitable and the likely costs of those.

Any proposals for intervention along the Hemsby frontage will however require an assessment of environmental considerations, in line with current legislation, to establish the potential for adverse effects.

There are well defined processes in place for such assessments, which would need to be followed.

4.3 Shoreline Management Plan policy

The Shoreline Management Plan (SMP2) policy for the wider frontage including Hemsby is presently 'Managed Realignment', although implementation of that involved no active intervention for the most part. If it were proposed to introduce any scheme of the types discussed in this study, then policy change to permit (perhaps rather than require) appropriate intervention would be a step that needs to be taken as part of the planning.

SMP policy can be reviewed where there are sound and justifiable reasons to do so, it is technically acceptable, and there will be no detrimental impacts of the change to the environment. There is a process that exists for such circumstances. Note however, this will not alter the funding situation or eligibility for FCERM GiA. Any scheme would still be required to provide the same economic justification regardless of SMP policy.

Next Steps

This report sets out various approaches that might be taken to address the issues at Hemsby. The potential solutions presented, and the rejection of other options, are based upon the latest understanding of the mechanisms resulting in erosion at Hemsby. The conclusions of this assessment are a range of approaches with different costs and outcomes. Some of those outcomes are long-term erosion risk management, others just short-term; some outcomes include maintaining a beach frontage, others do not.

This is however, a high-level assessment necessary to rapidly gain an understanding of the causes of the problems occurring at Hemsby and from that identify the likely appropriateness of potential options. Although the assessment provides sufficient knowledge to reach the conclusions presented here, the precise development of any scheme must include more in-depth analysis of some of these aspects (e.g. modelling tidal flows and effects on those of any beach management approach) to ensure that the nature of that scheme and the details of the works are appropriately designed to accommodate these conditions at Hemsby.

In that respect it would be prudent to also continue with the originally planned assessment of the entire coast from Winterton to Great Yarmouth as part of the design process. This would ensure that the understanding of coastal process and interactions of management approaches throughout are complimentary; indeed, it may also be that a broader scheme extending beyond the boundaries of Hemsby is the most appropriate approach. This also recognises the continued uncertainty relating to processes influencing evolution of the highly dynamic offshore banks and channels, the nesses, and tidal flows across the coastal system right through from Winterton to Benacre.

Whilst this report now enables a better-informed and focussed debate on the way forward, this study does not provide the ultimate solution; the decision on how to proceed must rest with the Borough Council, the local community and other key stakeholders. Although a long-term solution is likely to be preferable to many concerned, costs and benefits are a key differentiator between different approaches and affordability will be crucial to the decision. All options to intervene here will fall short of the funding that central government funding would presently provide, so contributions from other sources are going to a necessity.

By working in partnership with the range of organisations with an interest in the area, and by using the findings of the studies above to inform discussions, the potential viability of management approaches from a funding perspective can be identified. A practical first step that has proven to be successful elsewhere, is to conduct an initial map of beneficiaries and benefits that would be delivered by potential scheme options. However, a short-term solution may be the most that can be achieved, or needed in the interim, while a decision on the long-term future can be reached.

Further engagement on funding options, possibly including consideration of the Borough’s wider economic strategy and the part Hemsby has to play within that, is therefore an essential next step in moving this forward.

FINAL

Appendix A: Coastal processes and understanding of shoreline behaviour

Prepared for

Great Yarmouth Borough Council

June 2018

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Contents

This appendix

This Appendix looks at factors that affect changes along the shoreline today, how the coastline at Hemsby, and adjacent shorelines, has changed over time and considers possible reasons for this change. This should help us understand how the coastline may change in the future and will also inform decisions we make on its future management.

As part of this appraisal, we have used information from:

- old maps of the coast and charts of the seabed
- aerial photographs of the shoreline – the oldest of which date back to the 1940s
- monitoring data which has recorded how beach levels and the position of the cliffs and dunes have changed over time
- photographs provided by residents of Hemsby and the surrounding area
- anecdotal information and published reports, which have considered changes along this shoreline and the processes that may be affecting them.

Coastal setting

2.1 Location

Hemsby is located to the south of Winterton Ness on the east coast of England. The shape of the coastline here is convex in shape, which due to both how this shoreline formed in the past and the processes that now continue to shape it.

Considering the shoreline from Winterton to Caister, the current coastline is characterised by high dunes fronting former cliffs, which terminate south of Hemsby to expose sand-rich, near-vertical cliffs. The beaches are mainly sandy, but include a component of shingle, which is occasionally exposed.

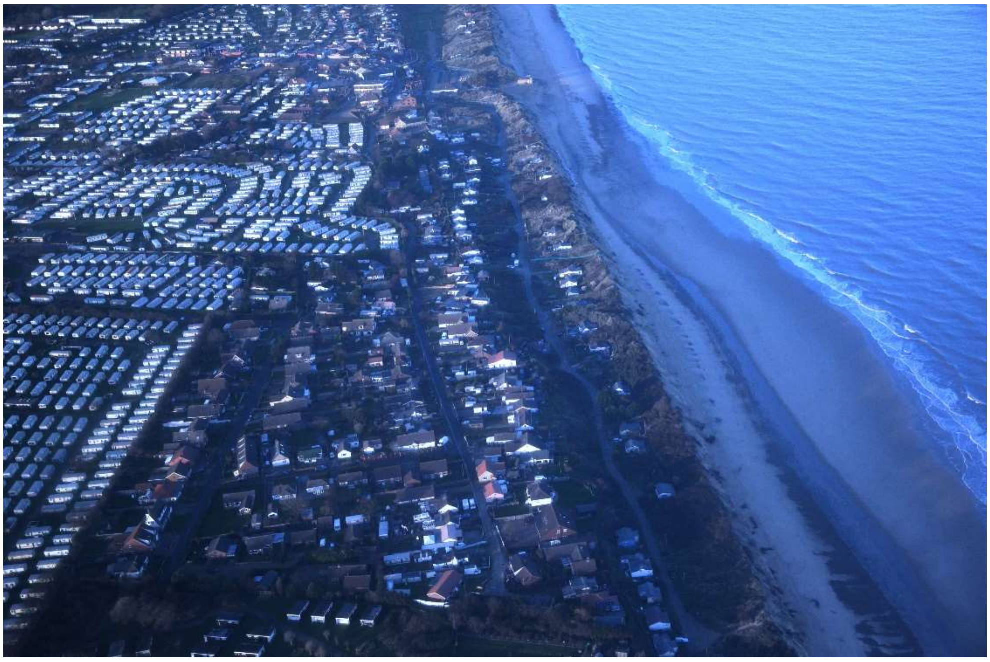


Figure 1 Hemsby, looking northwards. Oblique photograph taken 2016.

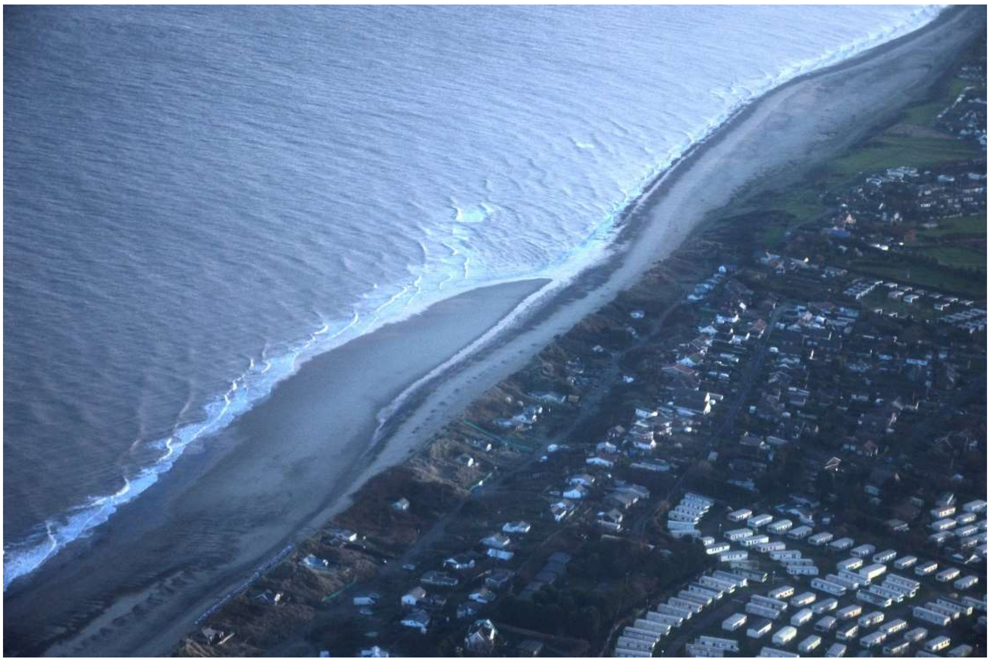


Figure 2 Hemsby, looking southwards. Oblique photograph taken 2016.

Offshore, but occasionally visible during low tides, lies a sandbank and channel system, known as the Great Yarmouth Banks (Figure 3). These banks extend from Winterton Ness to Benacre Ness and lie to the south, and inshore of, a larger group of mainly linear banks, the Norfolk Banks. They are mostly formed of sand (Cloet, 1963) but there are occasional patches of shingle and shell (Robinson, 1966).

The banks are a significant sink for sand in the Southern North Sea (Cooper et al., 2008) and they are estimated to be around 620 million m^3 in volume. The banks roughly follow the shoreline and are interlaced with flood and ebb channels (Robinson, 1966) at fairly regular intervals.

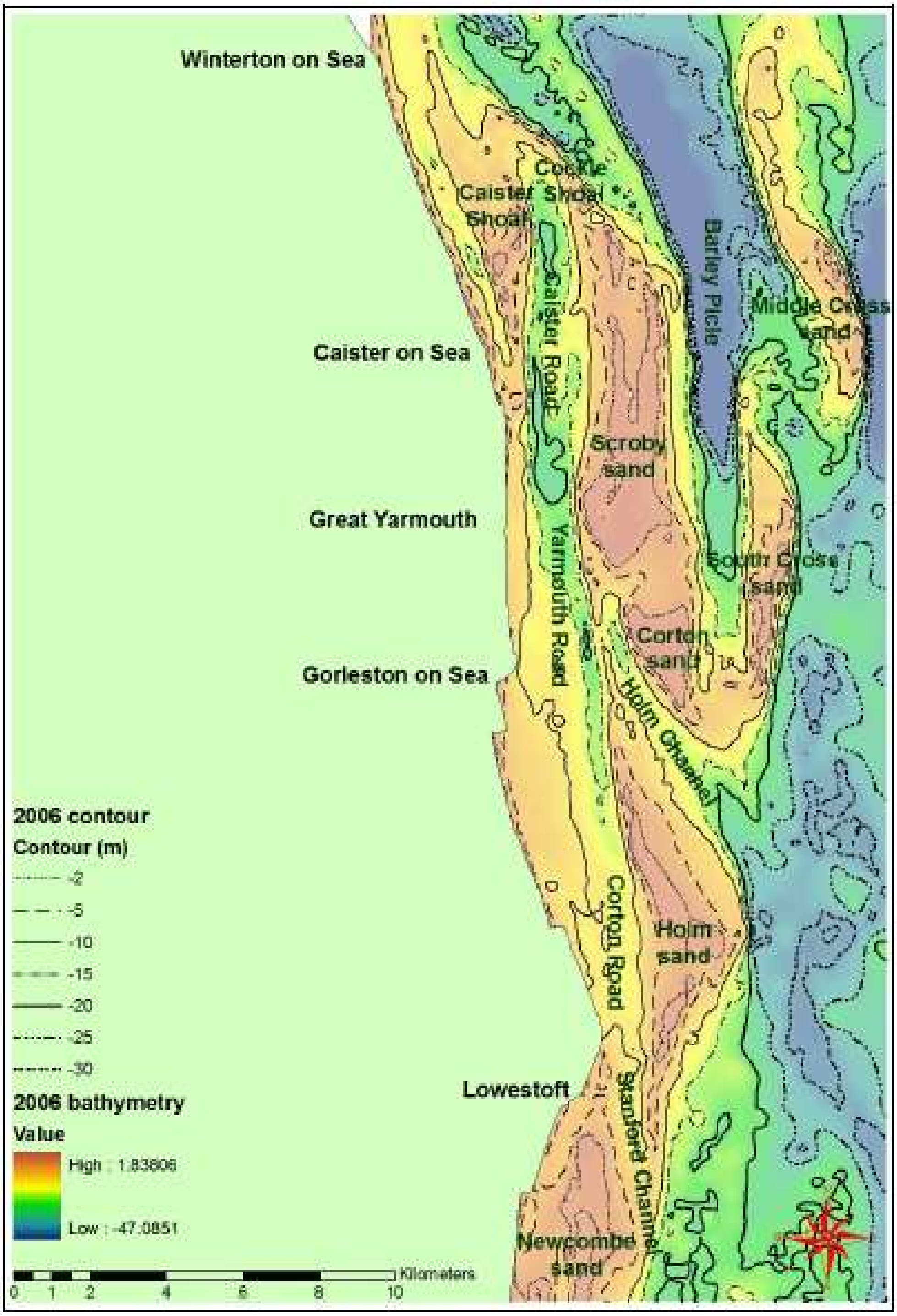


Figure 3 Sandbanks and channel features of Great Yarmouth Banks (taken from Bakare et al., 2010; based on 2006 bathymetry)

2.2 Key controls on the shoreline

Sediment transport and changes along the shoreline are due to the action of waves, tides and, to a lesser extent, winds. Sediment transport in coastal waters depends primarily on the strength of the currents and the oscillatory velocities at the seabed produced by waves (HR Wallingford, 2002). The waves stir up the sediment (aided by currents), which is then transported by currents. In the Southern North Sea, tides are the dominant factor in generating currents.

Along the beaches, waves are the primary mechanism by which sediment is moved along and across the shoreface; strong wave-generated currents occur where the waves break. Waves along this coastline approach predominately from the north and north-east and this is the direction of the longest fetch, with the highest waves also coming from this direction (Bakare et al., 2010). Sediment exchange between the beach and nearshore zones takes place as a result of beach drawdown, mainly during storm wave conditions, and onshore movement in calmer conditions. Recovery of the beach therefore depends upon how much material is returned to the shoreline post-storm. The beaches along this frontage are extremely volatile (discussed further in section 3.2.3) and respond rapidly to changes in prevailing conditions; up to 4 m differences in beach height have been recorded, with 2 m following storms.

Tidal action is a key process in the North Sea, dominated by the semi-diurnal principal lunar component (M2), although other components are present to a lesser extent (ABP, 1996). Numerical models have shown the M2 tidal wave to propagate counter-clockwise around various amphidromic points (where tidal range is zero) within the North Sea (ABP, 1996). The presence of two amphidromic points in the Hemsby region results in a complex tidal regime (Halcrow, 2002a). The coast at Hemsby can be described as being meso-tidal and the tidal range decreases along the coast; at Winterton on Sea there is a range of 2.6 m and 1.4 m for the mean spring and neap tides respectively, whilst at Lowestoft the range reduces to 1.9 m and 1.1 m for the spring and neap tides respectively (Horrillo-Caraballo and Reeve, 2008). The tidal wave enters mainly from the north, follows the UK coast at the right hand and returns along the Dutch, German and Danish coast. In the southern North Sea, the tide is also influenced by the tidal wave entering through the Channel. The shape and shallowness of the North Sea means that the tides become distorted as they propagate southwards, meaning tidal rise becomes faster than fall.

Figure 4 shows tidal level data for Winterton and Caister and illustrates that even over this short distance there is a significant difference in peak tidal levels between the two sites. Figure 5 illustrates that there is a diurnal inequality at both sites, which is more apparent during Spring tides and is more evident at Winterton (shown in blue) than at Caister (shown in orange); here up to a 0.6 m variation in water level between consecutive high tides and low tides occurs. This is likely to affect both the flow of water and the direction and magnitude of sand transport.

There is also a difference in the time of peak flood and peak ebb of around 40 to 50 minutes (Spring tides), which means there are periods when the tide is ebbing at Winterton but still flooding at Caister, and vice versa. The flood tidal stream offshore runs almost parallel to the coast in a southerly direction, whilst the ebb tidal stream runs northwards. This difference in peak flows means that there is a greater difference in water levels between the two sites at certain states of the tide: this is shown in Figure 6. For the majority of the tidal cycle the level is greater at Winterton than at Caister, with a maximum difference of 1.1 m occurring around the times of peak flood.

The tidal curves are also asymmetrical, which is slightly more apparent at Winterton than Caister; at Winterton the flood tide is of shorter duration that the ebb tide, which potentially mean that current speeds during flood are also faster. Previous reports also conclude this: when considering the banks system as a whole, average tidal flood current velocities reach a maximum 4 hours before high waters, at 1.75 m/s on spring ties and 0.9 m/s on neap tides (Horrillo-Caraballo and Reeve, 2008). The ebb tidal velocities reach a maximum around 2 hours after high water: 1.45 m/s on spring tides and 0.82 m/s on neap tides (Horrillo-Caraballo and Reeve, 2008). Tidal asymmetries also vary between Spring and Neap tides (Robinson, 1966, Huthnance, 1973).

All these observations indicate that tidal dynamics within this region are extremely dynamic; Hemsby sits within an area where significant differences in tidal height and both current velocities and direction are believed to occur over very short distances. The nearshore banks and channels are a key reason for the complex tidal flows that are experienced along this shoreline and the wider coast down to Benacre Ness.

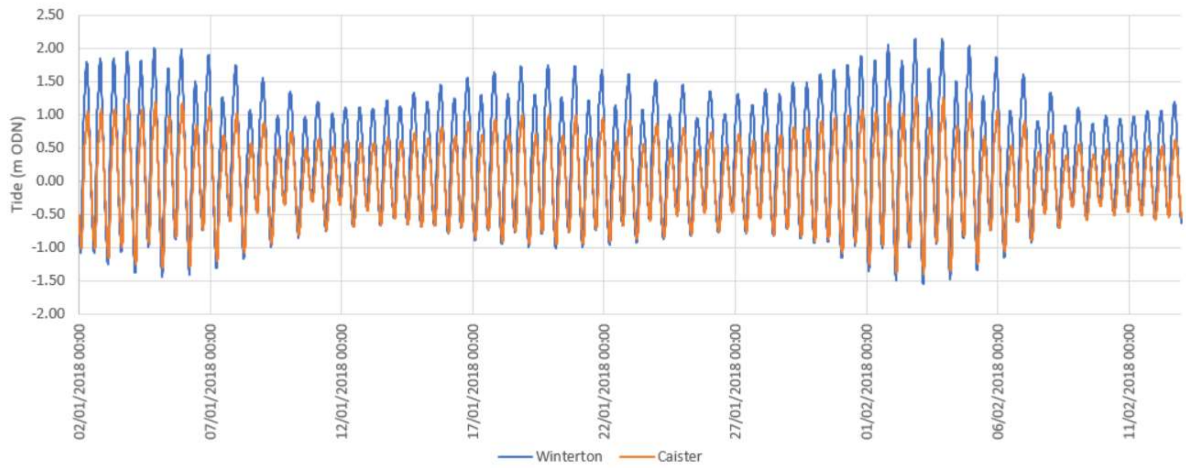
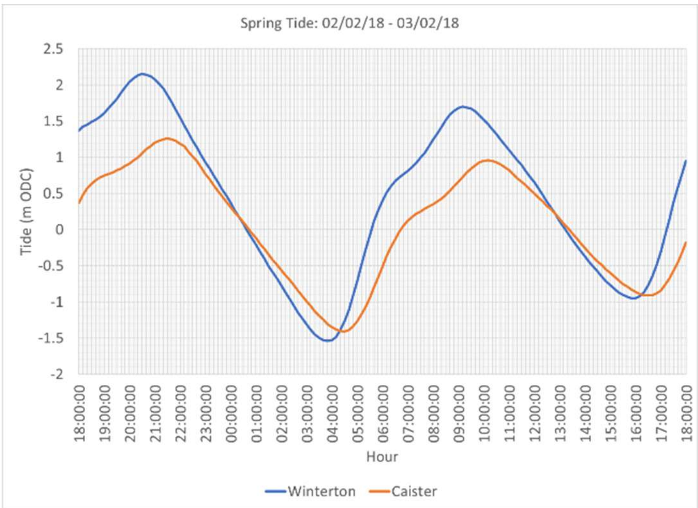
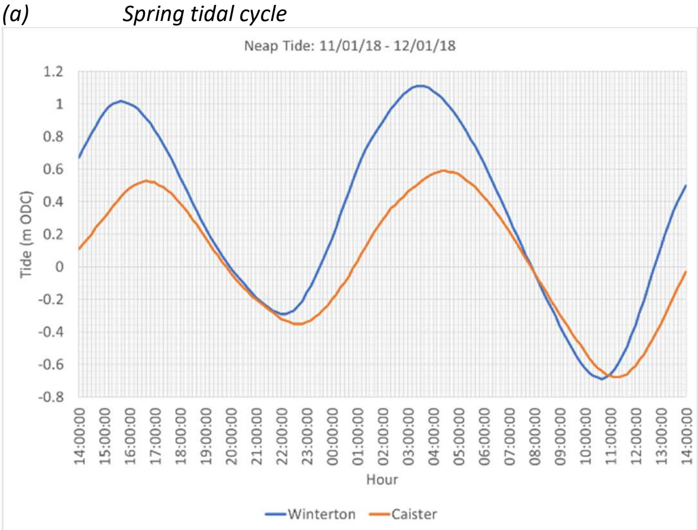


Figure 4 Tidal data for January 2018, for Winterton (blue) and Caister (orange) showing reduction in tidal range in a southwards direction and also the difference between spring and neap tides.



(a) Spring tidal cycle



(b) *Neap tidal cycle*

Figure 5 Tidal data for Winterton and Caister, showing asymmetry in tidal amplitude.

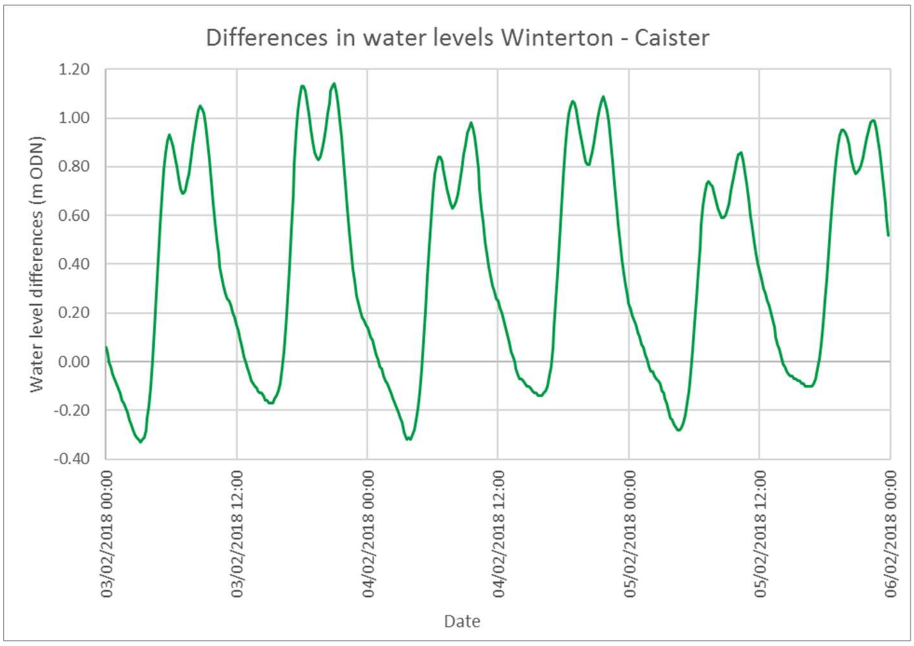


Figure 6 Differences in tidal level at Winterton and Caister, over a three-day period.

The main flow in deeper water essentially follows the curve of the coast as it moves from north to south on the flood and vice versa on the ebb. However, within the bank system, flows are more complex and subject to change as the banks and channels coalesce and diverge. Cooper et al. (2008), identified two main flood and ebb channels, but with subsidiary flows (see Figure 7) such as within Caister inshore channel, which lies between Hemsby shoreline and Caister Shoal.

The shape and form of the nearshore banks has a significant influence on conditions along the beach. There are several ways the banks and channels may have an influence; these apply to the wider frontage between Winterton Ness and Benacre Ness:

- the banks can reduce energy conditions at the shoreline by dissipating wave energy as waves pass over the banks
- the banks may also result in wave refraction, possibly resulting in focusing of wave energy along part of the shoreline and local divergences in sediment transport
- the banks and channels also affect tidal flows through the system, such that when a channel narrows, tidal velocities increase and may result in scouring. Similarly, when a channel runs close the shoreline, tidal flows can cause erosion of the landward slope of the channel, which is effectively also the seaward end of the beach
- channels may also allow deeper water to penetrate closer to the shoreline, which may allow larger waves and an increase in local wave energy.

Further discussion on bank and channel changes is included in Section 4.2.

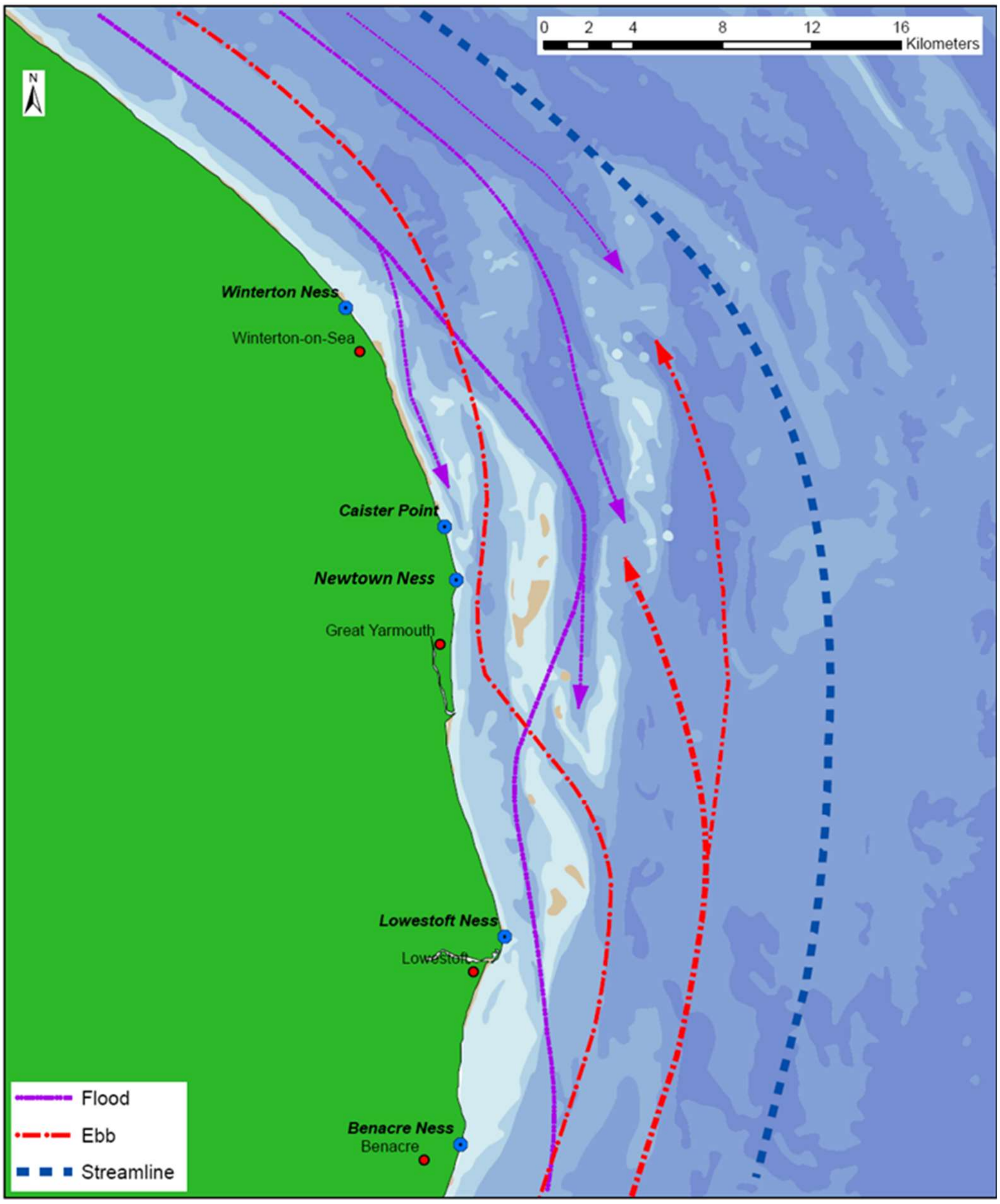


Figure 7 Patterns of flood and ebb flow through the bank system. Taken from Barber (2016, modified from Cooper et al. (2008)).

Surges are also an important factor in driving change along the coast: the earliest recorded surge event took place in 1218 when severe flooding of the Dutch coast claimed the lives of over 100,000 people (Van Malde, 1997; HR Wallingford, 2002). The vulnerability of this coastline to surge events is due to the shape of the North Sea: it is open to the North Atlantic at its northern end but effectively forms a closed basin at the southern end and is also relatively shallow (the average depth of the North Sea is in the region of 40 m) (HR Wallingford, 2002).

External surges result from pressure gradients travelling from the deep North Atlantic waters onto the shallow continental shelf and by strong winds to the north of Scotland causing an increase in tidal levels (Pugh, 1986). There are two categories of external surges: south-east tracking and east tracking (Muir Wood et al., 2005) The 1953 event is a prime example of a south-east tracking external surge, whilst the 1976 event was an east tracking external surge.

In addition, the North Sea basin is also prone to the generation of 'internal surges'. These events usually occur in response to north or north-west winds produced by low pressure over the continent and areas of high pressure to the west of Ireland (Pratt, 1995). They are less common than external surges, but can produce more severe events (HR Wallingford, 2002). The surge event of February 1993 was a classic example of an internal surge: this affected much of the east coast of England and during this event there was erosion of the dunes at Hemsby resulting in houses being lost to the sea (HR Wallingford, 2002).

Surges can therefore be produced by different mechanisms and different prevailing conditions, which is why this region is prone to frequent and intense surge activity (HR Wallingford, 2002). Major surge events are noted to have occurred in 1817, 1883, 1897, 1912, 1928, 1938, 1949, 1953, 1976, 1978, 1982 and 1993 (Pye and Blott, 2006; HR Wallingford, 2002) and more recently in 2011, 2006, 2013 and 2018.

As well as affecting wave heights at the shoreline, surges can also increase the potential for sediment transport (Hequette et al, 1995). It is therefore likely that considerable offshore sediment transport takes place during surge events although factors such as shoreline configuration and seabed topography will also control this process.

The relationship between surge events and shoreline response is not, however, simple: in addition to the variable way in which surges can develop in the North Sea, the tide–surge–wave dynamics generated during a storm also interact with varying nearshore bathymetries (Spencer et al., 2013), meaning shoreline response along even short distances can vary considerably.

2.3 Sediment supply

At the large scale, this shoreline is far from being sediment starved. It has been estimated that the North Norfolk cliffs supply about 400,000 m^3/year of sand into the littoral zone (HR Wallingford, 2002), together with smaller amounts of fines and shingle. The fines are transported offshore in suspension, while the sands and gravel are transported along the shore and also in the offshore area.

Winterton Ness represents a significant store of both sand and shingle along the frontage and there is potential that this is redistributed during periods of erosion and movement of the ness, between Winterton Ness and the nearshore. The sea bed is largely sandy and the high tidal currents and shallow water result in a mobile seabed environment adjacent to the coastal area (HR Wallingford, 2002). The sand banks themselves are a key sink for sediment. It has been calculated that the total volume of sand within these banks is closely approximated by the volume of sand lost from the nearby Norfolk cliffs over the last 5,000 years (Clayton 1989). Barber (2016) estimated that around 32 million m^3 has been added to the seabed over 40 years.

The general direction of sediment transport along the beach is in a southwards direction. Fine sediment is moved offshore in suspension and there is evidence of a large eastwards plume carrying suspended sediment offshore in this area (ABP, 1996, Dyer and Moffatt, 1998). The plume is much more defined in winter and coincides with the location of the north Norfolk offshore banks (HR Wallingford, 2002.

Movement of sediment within the banks is more complex and driven by the balance between ebb and tidal currents, which in turn are affected by the position of the banks and channels. There are sediment pathways around each of the sandbanks and connections with the shoreline at Winterton Ness, Caister Ness, Lowestoft and Benacre Ness (HR Wallingford, 2002). There remains dispute whether the nesses represent zones of net onshore or offshore movement, but it is known that there is a high degree of connectivity at these locations. Seabed indicators at Winterton reportedly show a movement of material south into Cockle Shoal, whilst further south there are other linkages at subtidal spurs between the shore and Caister Shoal (HR Wallingford, 2002). Along the rest of the shoreline, there is not believed to be a connectivity between the shore and the banks and it has been suggested that this is due to the fast flowing tidal current sub-parallel to the shore, which may inhibit any on-offshore transport mechanism (Coughlan et al., 2007). However, Barber (2016) does suggest that any material drawn down from the beach during storms could be moved into channels, where they lie close to the shore, and that this is a potential mechanism by which beaches become depleted along this otherwise sediment-rich shoreline.

It is reported that under both spring and surge tides the main stream of sediment is quite broad extending some distance offshore. From Winterton Ness, and extending as far south as Caister, an inshore bar frequently forms parallel to the beach; this feature lies well within the overall zone of sediment movement (HR Wallingford, 2002). Modelling undertaken as part of the Southern North Sea Sediment Transport Study (SNSSTS; HR Wallingford, 2002) found that whilst the pattern of sediment flow is relatively shore-parallel over much of the coast it tends to hug the coast closer to Winterton Ness.

Shoreline change

3.1 Origins of the coastline

The cliffs, dunes and beaches along this shoreline have been inherited from retreat of extensive ice sheets from the last glacial period. When the last glacial period was at its peak around 21,000 years ago, sea levels were over 120 m lower than today (Fairbanks, 1989) and Britain was connected to Europe, because water was locked up within the ice. As the ice started to melt, it left behind vast amount of gravel, sands and muds. Melting of the ice sheets led to a rapid rise in sea level, flooding the area of dry land between Europe and Britain and creating the North Sea, and around eight thousand years ago, the land that had existed between Britain and the rest Europe disappeared altogether.

As the sea reached more upland areas, these were eroded producing the first cliffs. This new coastline may have been between 10 and 40 km seaward of the modern coastline (Cooper et al., 2006). At this stage it is thought that the rate of shoreline recession slowed down significantly. Erosion of these cliffs would have released sediments, allowing the formation of beaches enclosing the low-lying marshlands which lay inland. The shoreline between Hemsby and Caister sits on top of one of the upland areas, which would have lain to the north of the Yare mouth.

As recently as the 5th Century, the mouth of the Yare disgorged in an easterly direction, without turning parallel to the coast towards Gorleston. Development of a spit, possible composed of both sand and shingle, progressively forced the mouth southwards, enclosing the low-lying area behind.

Today's landscape records changes in the past; the remnant headlands of the Northern Upland, which previously extended seawards from the area of Caister to Winterton, and the Southern Upland (between Gorleston and Kessingland) remain key controls on large scale change and between them lies the buried valley of the River Yare.

It is believed that the banks that lie offshore of today's coastline did not form until relatively recently, possibly in the last 1,000-1,500 years (HR Wallingford, 2002). It is possible that the nesses formed around the same time.

3.2 Historical and recent change

3.2.1 Evidence from historical maps and accounts

The Domesday Book records the presence of both Winterton and Hemsby village in 1086, when there was a church and two salt houses at Hemsby, but archaeological evidence indicates that there was settlement in the area from a much earlier period (Norfolk Heritage Explorer). During this period, the area looked very different from today, with the areas between Winterton and Caister lying on slightly raised land surrounded by marshland and bounded by the wide mouth of the Yare to the south, the north boundary of which lay at Caister, and a shallow estuary to the north, known as the Isle of Flegg. Flegg is believed to be an old Danish term referring to marshland.

It is not until the 16th century that we have any illustration of how the coast looked. One of the earliest maps of the coastline dates from 1574 and was produced by Christopher Saxton; this mapping was later used and 'augmented' by John Speed to produce his set of county maps published in 1611. It is at scale of approximately 3 miles to the inch, so its level of detail is limited but it does show Hemsby (referred to as *Hemmesby*) lying to the south of an extensive promontory named *Winterton nesse*.

In 1797, a more detailed map of the county was published by Faden, at a scale of 1 inch to the mile. This illustrates that at this time, there was a belt of dunes (*Marum Hills*) which extended from a place referred to as *Winterton Ness lights* to just north of Hemsby. Rather than a smooth single-peaked feature, the ness is shown as a series of three promontories, stretching over a larger distance than the current ness. At this time, the settlement of Hemsby (*Hemesby*) is shown a linear settlement set back from the coast edge, but there is no mention of Newport. Although it is not clear at this scale, the map does not appear to show any dunes present at Hemsby but this location does seem to mark the transition zone between a dune system at Winterton and sand cliffs which are shown to extend further south towards Scratby.

A later, more detailed, map is available from the early 1800s (possibly 1817), by Charles Budgen (Figure 8). This also shows the three distinct nesses in the region of the current Winterton Ness, the shape of which suggest a southward movement of material. Based on the field boundaries, there is evidence that erosion of the cliffs had subsequently occurred along the Hemsby frontage. It is not clear whether there are dunes along the frontage at this time, but the maps do indicate a vegetated or scrub area, which roughly corresponds to the location of The Valley.

The first Ordnance Survey mapping is from 1884 - 1890 and includes the first mention of Newport. By this time, the map indicates sand dunes are present to both the north and south of the current beach entrance, extending just past Newport, which has enclosed The Valley. The subsequent map from 1901-1910 shows some growth of the dunes, but it is not possible to identify individual ridges. At this time, the coast was still undeveloped and there were no properties along most of the frontage, apart from the "Cottage on the Cliff" at Newport. The Crescent and St Thomas's Road were just being developed.

A historical account by Wheeler, in 1902 noted "*Between Winterton and Winterton Ness the sand-hills widen out to about 400 years, and south of the village are backed by low cliff of chalky boulder clay overlying sand, which extends for nearly 3 miles. Beyond this to Ormesby the sand hills are backed by low cliffs of clay and sand*".

Between the 1884-1890 and the 1951-1960 Ordnance Survey maps, the landscape of the coast changed significantly: the resorts of Hemsby and Newport developed and a string of properties were constructed along the original cliff line. The maps also indicate further dune growth and there are chalets shown along the ridges – based on their distribution, two to three ridges of dunes may be present between the beach access at Hemsby Gap and Newport. The chalets also extend further north along The Valley. Further north, along the Winterton frontage, there was accretion along the dunes between the two editions, meaning the Lifeboat Station lay inland from the coastal edge.

Over the same period, whilst Hemsby had been accreting, there was erosion at Scratby and at Caister, although at Caister this may have been the result of works undertaken to protect the railway line causing downdrift erosion.

Figure 8 Early drawing of the coastline, assumed to date from 1817, by Charles Budgen (available from British Library online catalogue;www.bl.uk/onlinegallery/)

An account by Steers from 1948 reports that "*Dunes run on south to Hemsby and Scratby, but erosion is serious at and north of Caister, where the sea is eating into the soft cliffs of boulder clay and gravels*." He also observed that "*To the north-west of the village (Winterton) there are extensive dunes, and to the south the old cliffs are fronted by a hollow, on the seaward side of which there are long ridges of dunes. Erosion begins again at Hemsby and between that place and Caister is often serious*."

From the historical Ordnance Survey maps, the mapped position of high water mark has been extracted. These are shown in Figure 9 below, with (a) the latest OS mapping and (b) the 2018 aerial photograph used as backgrounds. The figure shows that there has been a large-scale realignment of the shoreline over the past 130 years. To the north of the ness there has been net retreat, whilst to the south of the ness, there was a period of growth followed by net retreat. The ness itself has distinctly changed in form from a more elongate configuration to a distinct peaked form. This pattern of change also concurs with earlier maps, for example Budgen's 1817 edition (see Figure 8) which showed the ness formerly consisted of a more elongate feature with a number of protrusions, rather than a single pronounced point.

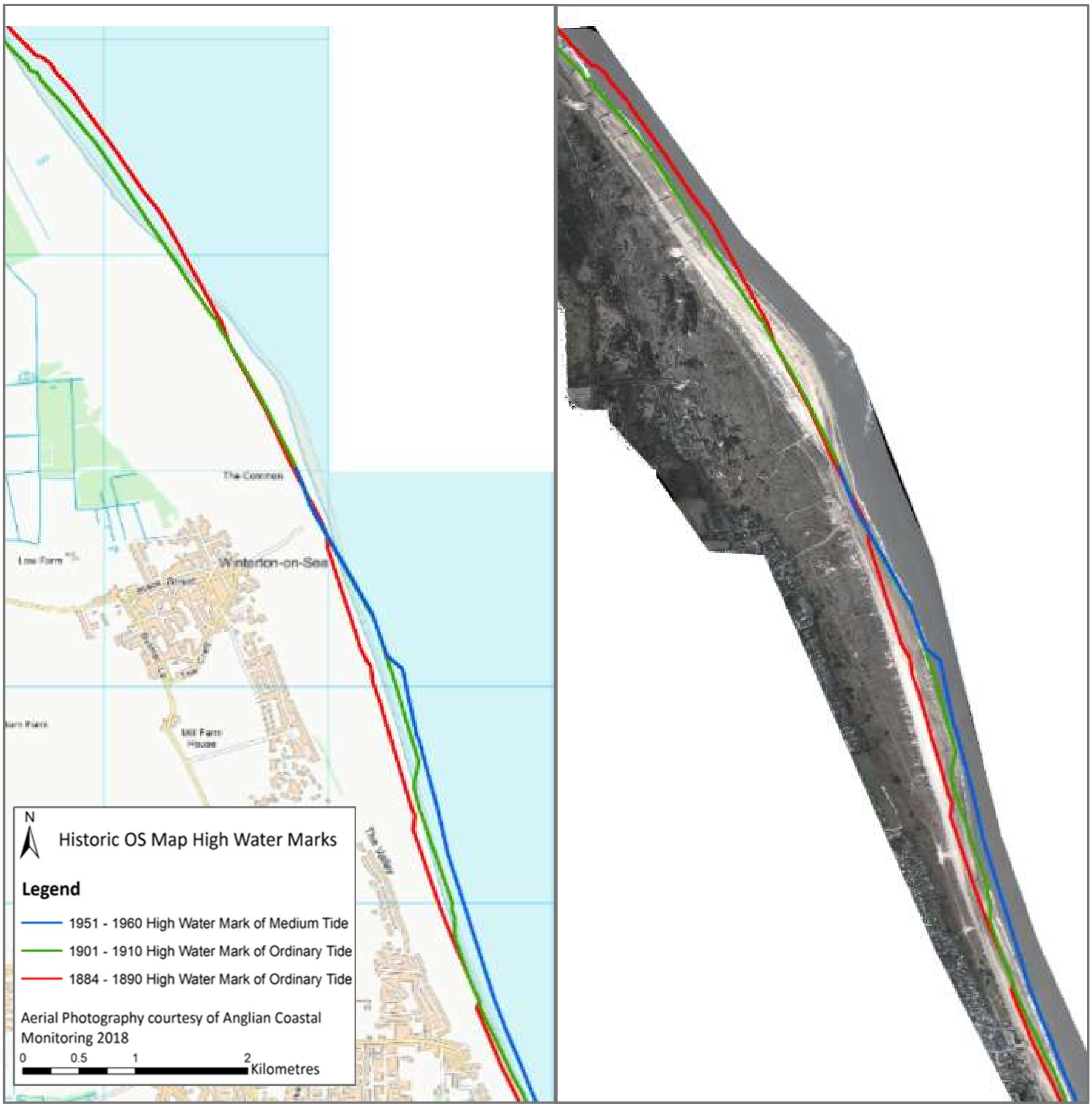


Figure 9 Changes in the position of mean high water, derived from historical Ordnance Survey mapping. Note that the definition of the mapped line changed between the 1901/1910 and 1950/60 map editions, but it is assumed that they can be taken to mean the same i.e. the tide lines half-way between neaps and springs; however, the limitations of the data sets should be recognised.

3.2.2 Evidence from aerial images

Some of the earliest aerials of this coast date from 1945-6, when the RAF photographed almost all of the country as part of a National Air Survey (available on-line from http://historic-maps.norfolk.gov.uk/mapexplorer/). This corresponds well to the Ordnance Survey mapping of 1951-1960 and shows well-vegetated dune ridges in front of Hemsby, with three lines of chalets within the dunes. The image does illustrate that the dunes were susceptible to erosion at the beach entrance, where there are extensive areas of bare sand.

The subsequent aerial images from 1988 (available on-line from http://historic-maps.norfolk.gov.uk/mapexplorer/) show that between the 1940s and 1980s there was erosion of the dunes immediately north and south of the beach access at Hemsby Gap, which resulted in the loss of around 30 m of frontal dune and the most seaward row of chalets. This zone of erosion stretched as far south of the end of Newport Road. South of here, along The Esplanade, there was accretion along the toe of the cliffs. Over this same period, the images show that there were significant changes along Winterton Ness; although changes to the frontal dunes were generally small south of Edward Road, there was accretion at Beach Road, but erosion to the north. This resulted in an overall change in plan form of the ness, moving from an elongated form to a more peaked form.

Since 1992, there has been regular aerial photographic surveys carried out by the Environment Agency, with annual photographs available from 2003. Whilst the photographs are not always taken at the same tidal level, key changes can be observed; these are summarised below:

- Between 1992 and 1997, all along the frontage between Winterton café and the start of Scratby there was erosion of the frontal dunes. There appears to have been loss of chalets along the Marrams, to the north of Hemsby Gap. South of Scratby, very limited change is evident, with the key exception being behind the Caister fishtail reefs, where there was beach growth. Winterton Ness shifted northwards, resulting in a narrower beach adjacent to the café.
- Between 1997 and the next aerials from 2003, there had been significant erosion in front of Winterton café and car park, with the northern edge of the carpark now eroding. The ness moved north and there is also evidence that the beach further north, along the groyned frontage, had grown. The narrowest part of the beach at this point lay slightly north of its position in 1997. Between Winterton café and Hemsby Gap, the aerials show the beach had grown, with some dune accretion evident along the Valley frontage. South of Hemsby Gap, a more variable pattern of change is evident: erosion of frontal dunes immediately south of the Gap, but some accretion further south. Along the northern end of Scratby frontage there was development of a blowout feature, whilst to the south some accretion occurred; by this time the three reefs at Caister had been constructed and a significantly wider beach was present with further growth evident from the embryonic dune developed along the backshore.
- By 2005, there had been further erosion along Winterton café and car park, and just to the south, while the apex of the ness had moved further north. Along the rest of the frontage there is little change evident.
- The aerials from 2008 show that the apex of the ness remained in a similar position to 2005. Over this period there had, however, been some several metres of erosion between Winterton café and Hemsby Gap. Further south, along Hemsby frontage, little change is evident, apart from at the boundary with Scratby, where localised erosion had occurred. Erosion here and previous erosion at the Gap means that at this time the Hemsby shoreline bulged seawards slightly, out of alignment with the adjacent shorelines. Although the aerials do not indicate change along the Hemsby frontage over this period, the frontal dunes were poorly vegetated, suggesting some activity. Further south, there is evidence that some overtopping damage has taken place behind the rock revetment at the southern end of California, whilst at Caister there was further growth and development of dunes behind the reefs.
- Between 2008 and 2011, there was limited change in the position of the ness apex, but the beach to the south widened, possible due to a nearshore bar becoming welded to the coast. This resulted in recovery of the dunes along the Marrams and evidence of new embryo dune growth. Along the Hemsby frontage, there was no consistent erosion along the whole frontage, but in a couple of areas there appears to have been loss of dune, with the formation of small blowout features. Similar features are also evident further south at Scratby. The aerials suggest that along the California frontage the beach was particularly narrow in 2011, but the backshore has remained protected by the rock revetment. At Caister there was further growth and development of dunes behind the reefs.
- The aerials from 2014 post-date the December 2013 storm, when properties were lost along the Hemsby frontage. They show that the ness had moved slightly further north over this

period, with some erosion evident to the north of Winterton café and car park. The beach in front of the Marrams had remained wide, as observed in 2011, and this area of greater width actually extended southwards. The photographs show there had been significant erosion along the whole frontage from the Valley to the boundary with Scratby over the period. This erosion effectively straightened the coastline, removing the slight bulge in alignment noted from the 2008 aerials. Several properties have been lost from the dunes. Along the Scratby frontage, little change is evident, whilst along California there appears to have been improvement in the beach, with the lower part of the rock revetment now buried.

- The latest aerials from 2018 show that there appears to have been further movement north of the ness, which resulted in erosion north of the Winterton café and car park. Further erosion has also occurred along the car park frontage, with tank traps now along the base of the dune cliffs. As a result of the changes, there is a new shoreline alignment, with the coast south of Winterton café and car park, i.e. the Marrams, now appearing to form a slight bulge compared adjacent frontages. The beach here also appears narrower than previously. Erosion of the coast along the Valley means that the sites of two blowouts are now at the shoreline, meaning erosion here could accelerate due to increased exposure to waves and winds. South of Hemsby Gap, there has been further erosion of the dunes and only a very narrow ridge exists between the shoreline and St Mary's Road. Further south along Scratby the aerials suggest a slightly wider beach. Conversely, a narrower beach is present along the rock revetment at California.

Comparing the first aerial (1992) to the latest (2018) (Figure 10) shows there has been a significant movement of the ness over this relatively short period. At the same time there has been a realignment of the shoreline to the south: as the ness has moved northwards, there has been dune accretion to the north whilst the dunes to the south have eroded, resulting in a large-scale realignment of the coastline from north of the ness to the boundary with Scratby. Whilst erosion of the dunes south of Winterton has gone relatively unnoticed, due to the lack of assets here, erosion at Hemsby has had significant consequences due to properties within the dunes and proximity of the village to the coast. Comparing the 1992 aerial to the 1946 and 1988 aerials available from historic-maps.norfolk.gov.uk/mapexplorer, shows that in 1946 the ness lay further south, with its apex south of Winterton Beach Road, whilst in 1988 was in similar position to 1992. Between 1948 and 1988 the apex of the ness appears to have moved around 40 m, which is approximately 1 m/year. Between 1988 and 2018 the estimated change in position is around 55 m, which is approximately 1.8 m/year, suggesting that the ness has accelerated slightly.

A key feature of interest shown by the aerials is a bar which extends southwards from Winterton Ness (see Figure 11). Due to the aerials being taken at variable states of the tide it is difficult to consistently compare between years; however, from the sequence of photographs this feature appears to be semi-permanent in form. At times it appears to become welded onto the shoreline, creating a wider beach, at other times it is a distinct ridge feature, separated from the main beach by a channel (runnel).

Commonly this type of feature is evidence of a downdrift feed of material; whereby material is moved alongshore along the feature, which is spit-like in form, before being pushed up the beach to build the upper beach area. Subsequently this material may be drawn back down the beach and moved further downdrift by the same process. Here, however, this does not seem to be the case, as illustrated by a sequence of aerials between 2011 and 2014 in Figure 12. The yellow circle shows the same area in each photograph, whilst the red circle indicates the end of the bar/spit feature. Between 2011 and 2012 the feature seems to be progressive growing southwards, indicating a possible supply of sand to this frontage. However, in 2013 the feature seems to have disappeared and there is no evidence that beaches along the frontage have benefited from an influx of sand. The 2014 aerial subsequently shows the re-emergence of the feature. Two possible explanations are (1) the bar is simply a cross-shore feature which periodically grows and then regresses, but fundamentally remains semi-fixed in volume and position, (2) the bar does present a conveyer for sediment, but that between Winterton and Hemsby Gap there is no mechanism for further alongshore transport with potentially material being lost offshore rather than being moved further alongshore or onshore.

Figure 10 Comparison of 1992 and 2018 aerial, showing the northward movement of the ness over this time.

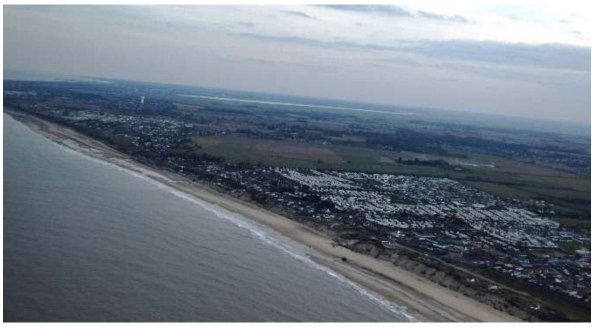


Figure 11 Oblique images showing the nearshore bar feature and intervening runnel (small channel) from 2014 (left) and 2018 (above)

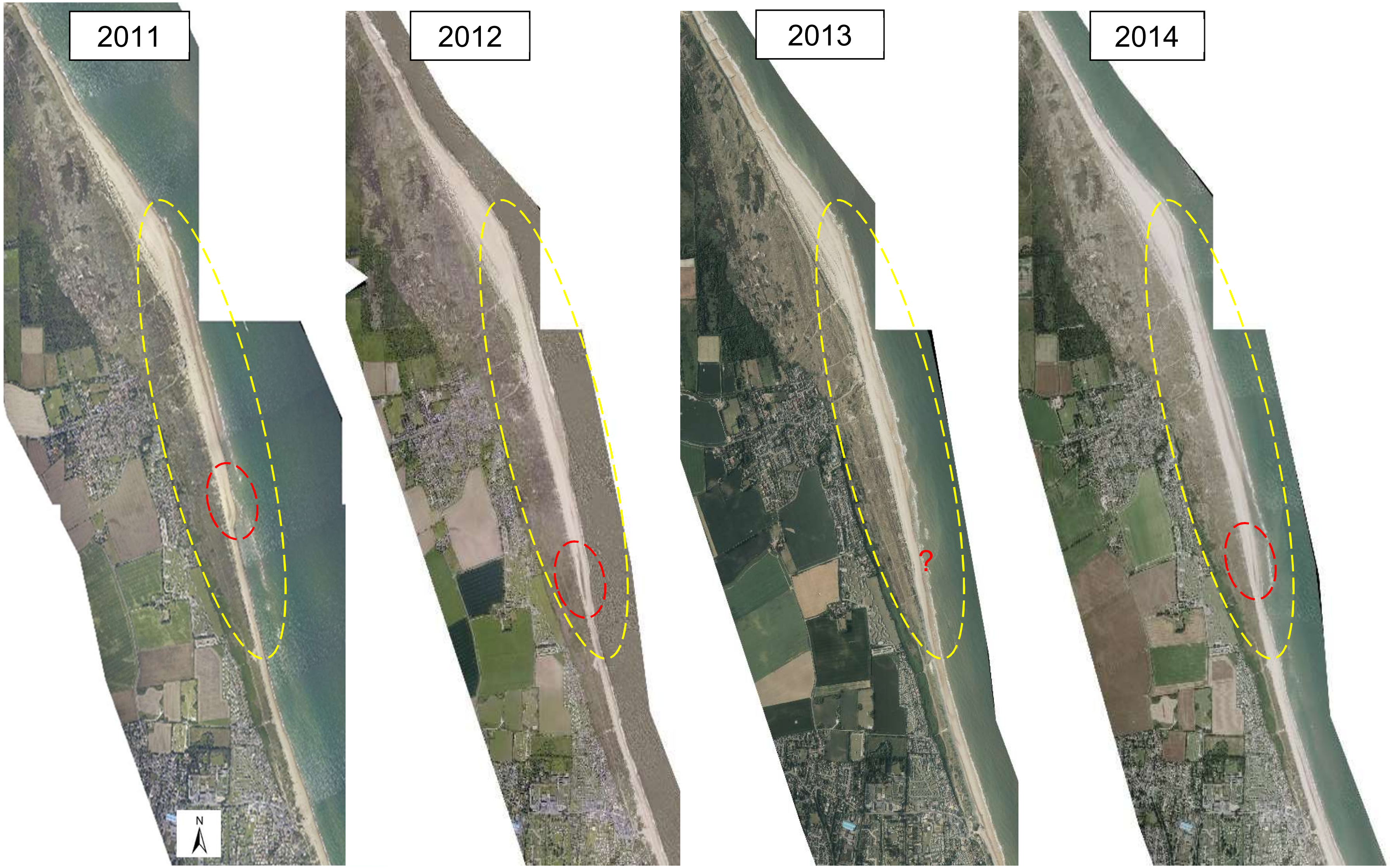


Figure 12 Aerial sequence from 2011 – 2014. Images © Anglian Coastal Monitoring. The yellow circle indicates the same position on each photograph, whilst the red circles show the terminal end of a bar/spit feature protruding from the ness.

3.2.3 Beach monitoring data

Beach level data has been collected on a regular basis, as part of the Environment Agency's Anglian Coastal Monitoring programme, since 1991, when topographic surveys were undertaken at one-kilometre intervals, named N***. Additional transects were added in 2003 and, since 2011, transect lines spaced at approximately 200 m intervals (named HW***) have been surveyed in the summer and winter seasons every year. The transects typically extend from a minimum of 20 m inland of the sea defence (structure or cliff edge) to the Mean Low Water Spring level, taking elevation measurements at every 10 m or every change in gradient or substrate. Topographic surveys have a 10 mm vertical accuracy (Environment Agency, 2016). Annex 1 includes maps showing the location of the beach profiles.

The sections below summarise key changes observed from the beach level data, with accompanying graphs showing selected surveys only.

North of Winterton Ness (groyned beach): [profiles HW310 to HW333, including N092]

Along this stretch the backshore position is defined by a seawall, which continues northward towards Happisburgh (Figure 13). There has therefore been no change in this shoreline position over time. Beach levels in front of the seawall fluctuate and can change by over 2.5 m between surveys, indicating extremely volatile beach conditions. There is no net trend of either accretion or erosion evident from the data sets and for much of the frontage, the latest data from 2017 lies within the range of beach levels observed previously.

Figure 13 North of Winterton Ness, along the groyned section of beach. Photograph taken during site visit April 2018.

Winterton dunes (north of Beach Road) [profiles HW334 to HW361, including N093, N094]

The beach transects indicate a change in behaviour to the north and south of the current apex of the ness, around profile HW348. To the north there has been net accretion, resulting in an increase in beach width. The longest data set available, for profile N093, shows that since 1992 the upper beach (above mean sea level) has increased in width by around 120 m (Figure 14). As the beach zone has increased, this has enabled the development of 'embryo' dune ridges (see Figure 15), due to windblown transport of sand landwards.

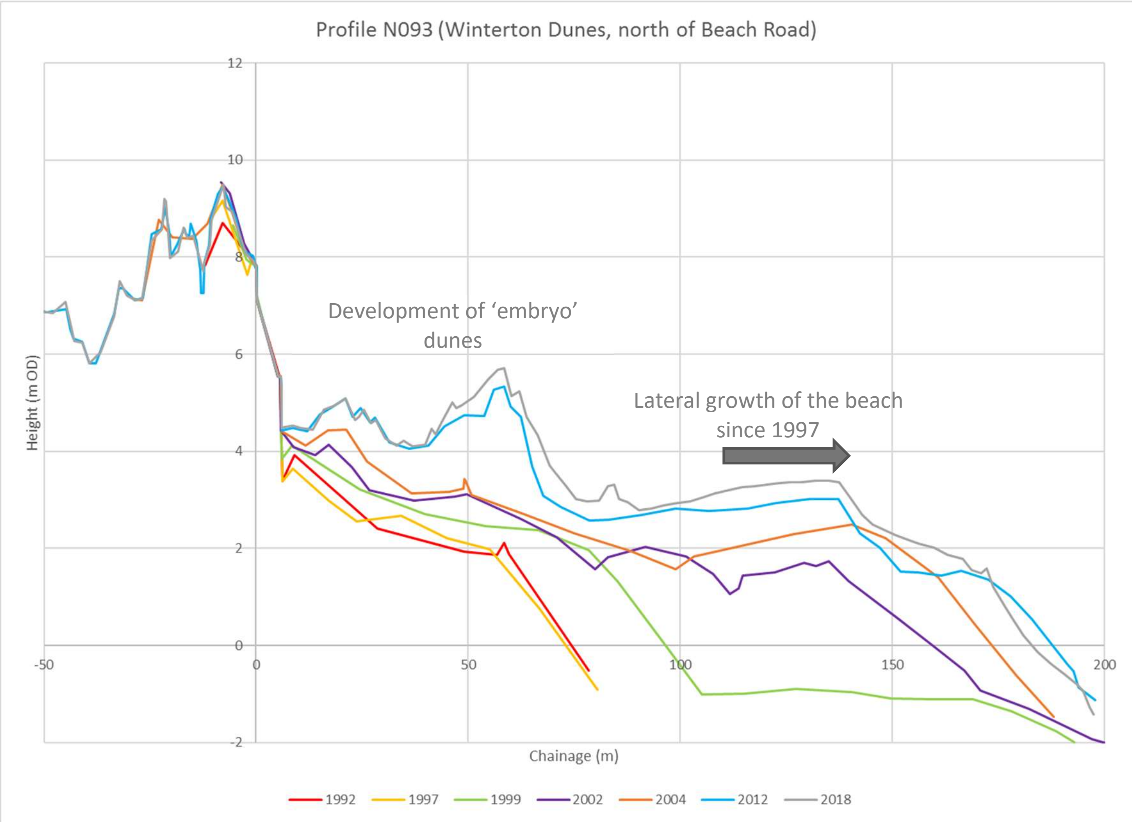


Figure 14 Accretion at profile N093, located 1 km north of Winterton Beach Road.

Figure 15 Embryo dune development along Winterton Ness, showing how a series of new ridges are being created. Photograph taken during site visit April 2018.

To the south of the apex, the profiles show that there has been general narrowing of the beach over time, with frontal dune erosion. Close to the apex, the beach data shows a change in trend occurred around 2006, from accretion to erosion. The net erosion trend becomes more evident towards Winterton Beach Road and data from profile N093, shows this trend (see Figure 16): here there has been 50 m of dune erosion since 1999. There has also been a fall in beach level at the toe of the dune as the shoreline has retreated. This means there has been a net reduction in upper beach width and the dune fronts are therefore vulnerable to further wave erosion.

Typically, the data shows seasonal variation, with build-up of beaches during the summer, through onshore movement of sand ridges, and drawdown of material in winter, creating a more concave profile.

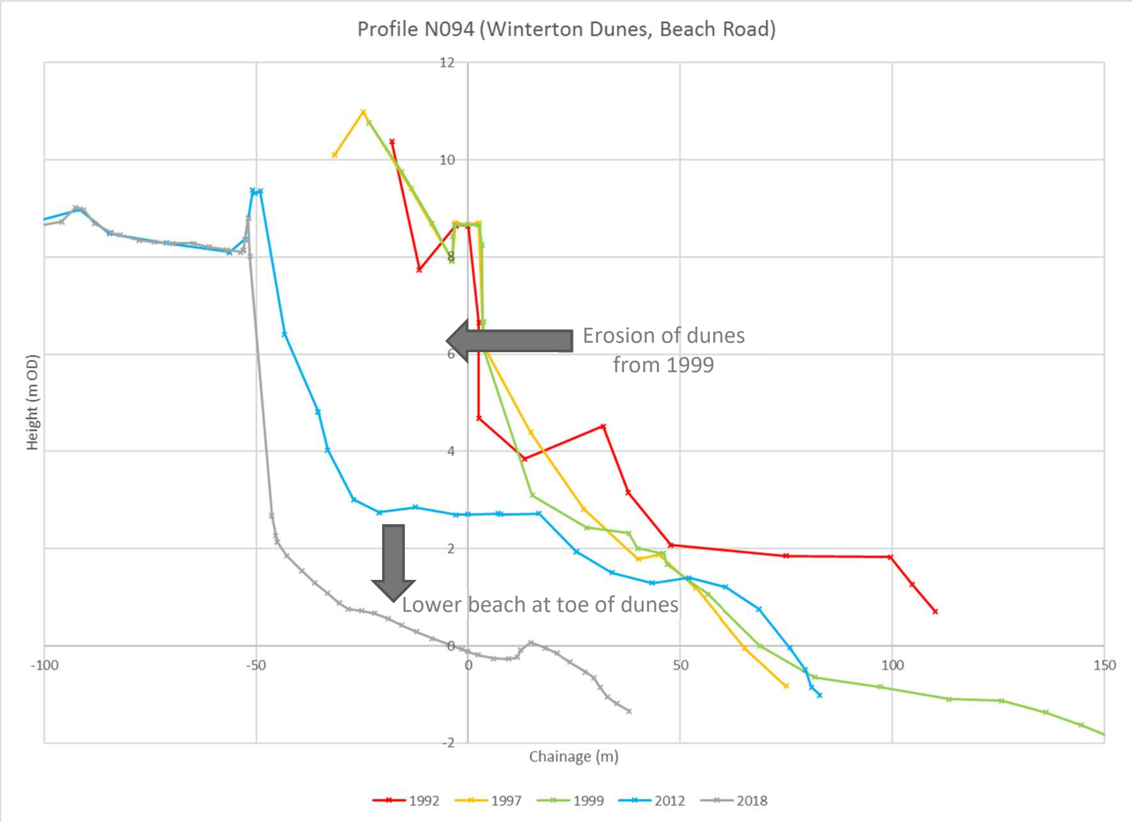


Figure 16 Beach transect at Winterton Beach Road (N094), showing net erosion and dune retreat over time.

From the data it is possible to identify two storm events: winter 2011 and winter 2013. Many of the profiles show that there had been cliffing across the foredunes and a draw-down of the beach following winter 2011, due to a storm on the 27th November 2011, which caused coastal flooding along parts of the east coast of the UK, including Norfolk (Haigh et al. 2015). The Spring 2014 survey shows foreshore levels dropping by up to a metre, compared to the previous survey, associated with the 5th December 2013 event. Just to the north of Winterton Beach Road (profile HW359), up to 10 m of dune erosion occurred as a result of this storm

Winterton Dunes (south of Winterton Beach Road) [profiles HW362 to HW396, including N095, N096]

Along this section, rather than progressive erosion or accretion, the data show that there has been a period of dune erosion, followed by a period of stability and a recovery in beach levels, before another period of dune erosion. Data for profile N095 (Figure 17) show that by 2000 the most seaward dune ridge that was present in 1992 had been lost, meaning over 50 m loss of frontal dune over this time period (equivalent to around 6 m/year). The upper beach at the time of dune erosion is extremely narrow and steep, possibly suggesting the position of a channel close to the dune toe (although the data set does not extend far enough offshore to confirm this).

There was further erosion until around 2006. Since then, the frontage dune face has remained fairly unchanged in position. There is evidence of an influx of sand (recorded in the 2009 data set, shown below in pink), which is possible evidence of the formation of a beach bar. More recently beach levels have dropped again.

Currently the dunes south of Winterton Beach Road are fairly well vegetated (Figure 18), but there are signs of previous dune erosion and subsequent recovery, suggesting that this frontage has received sand in recent years, allowing some dune recovery.

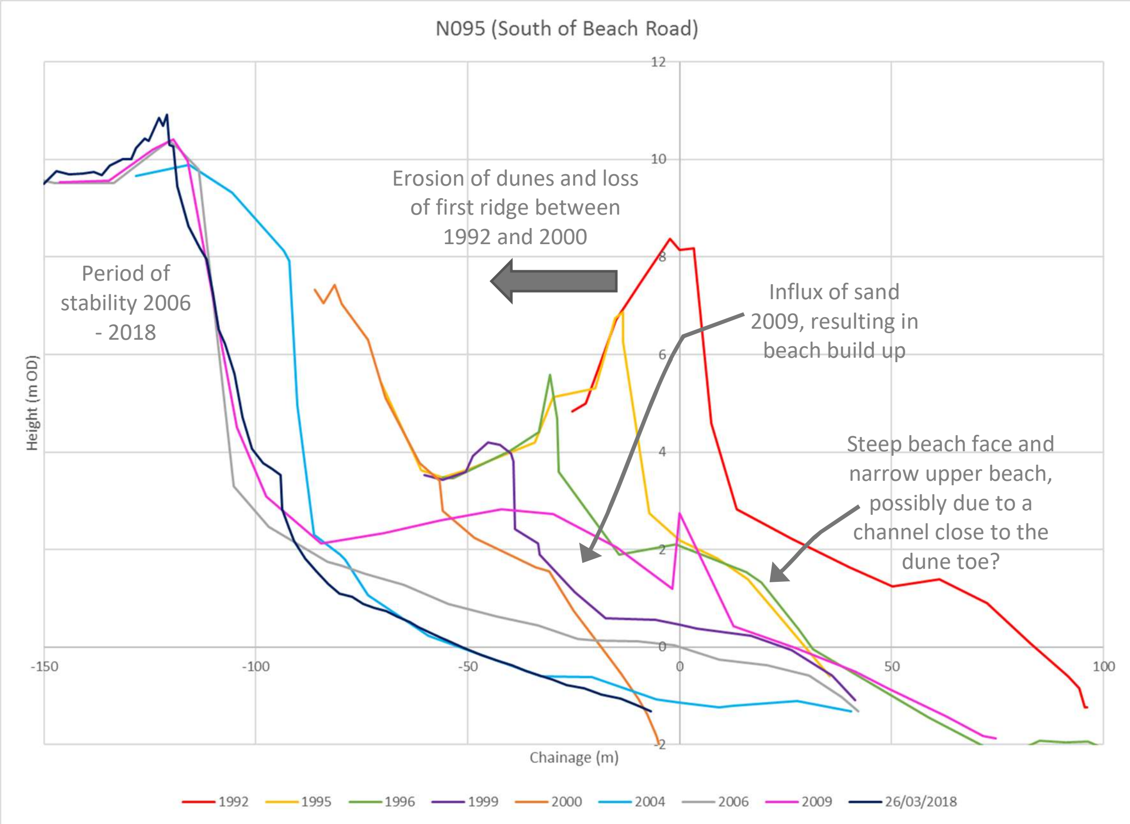


Figure 17 Beach profile N095, south of Winterton Beach Road.

Figure 18 South of Winterton Beach Road, dunes indicate past periods of erosion but also some subsequent build up and dune growth. Photograph taken during site visit April 2018.

Profiles further south show a similar pattern, with narrowing of the beach and dune erosion up to around 2006, then beach recovery and little change in terms of the dune position since this time.

Data for profile N096 (Figure 19) show that at this location there was a net trend of erosion between 1992 and 2008, albeit episodic, with periods of rapid erosion, followed by relative stability. Since 2008, however, the dunes have remained fairly stable in position, and beach levels at the base of the dunes have increased.

Rates of erosion have varied along the frontage, but erosion prior to 2006 tended to be episodic and between surveys (i.e. around 6 months) over 10 m of erosion is possible. Between 1992 and 2008 there was a total of around 78 m retreat of the dune toe, which equates to an average rate of approximately 4.5 to 5 m/ year.

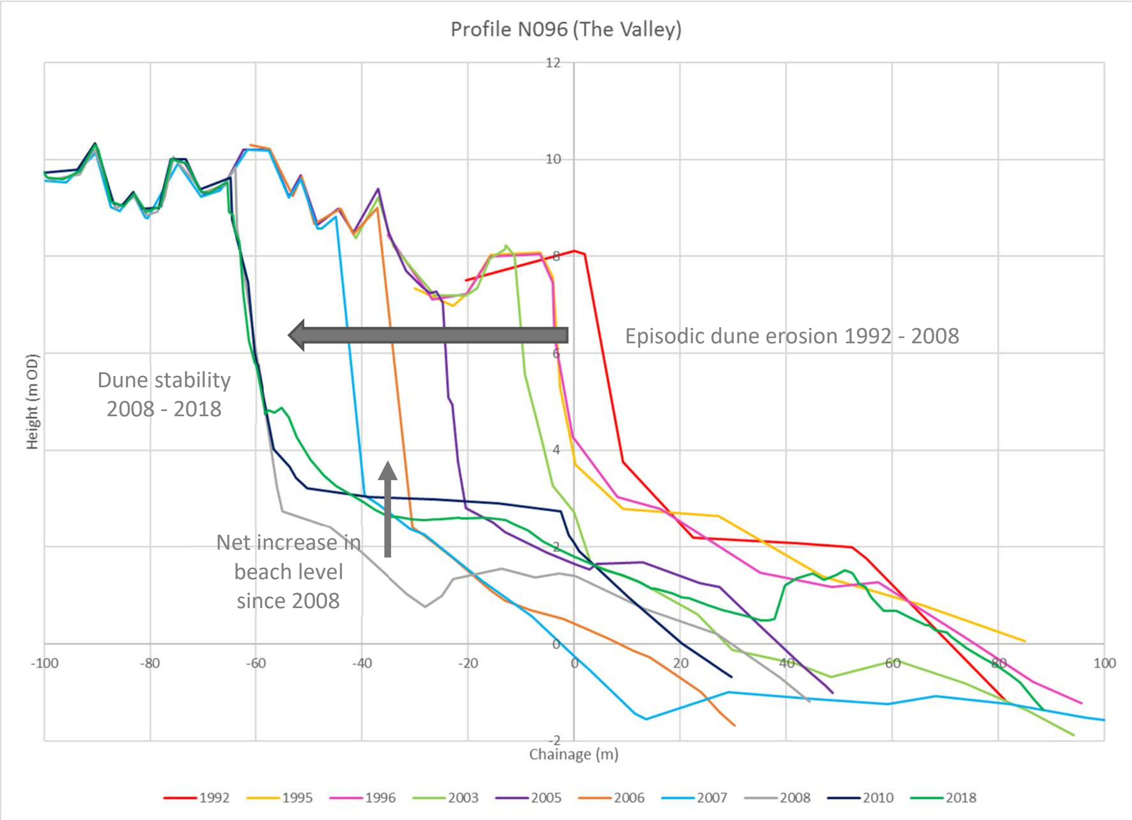


Figure 19 Beach profile N096, south of Winterton Beach Road (The Valley).

Hemsby (north of Hemsby Gap) [profiles HW397 to HW413, including N097]

Data for profile N097 (Figure 20), along the Valley (north of Hemsby Gap), show that erosion has been ongoing since the earliest survey in 1992, but that change has been episodic. There was erosion between 1992 and 1997, followed by a period of stability until 2002, when erosion of the dunes again occurred. Between 2002 and 2007 there was another period of stability, erosion in 2008, then another period of stability in 2009. Erosion of the dunes occurred in 2012 and 2014, then again in 2017. Between 1992 and 2013 the most seaward dune ridge has been lost, resulting in a net loss of more than 45 m of frontal dune. There has been beach retreat as the dunes have eroded, with some evidence of beach narrowing.

A similar pattern is shown in the shorter data sets; many of these show that dune erosion occurred between 2012 and 2013 surveys, with over 15 m erosion recorded at some locations. As the dune has retreated, the beach profile has also translated landwards. Unlike along the beaches further north, there is little evidence of material moving onshore. Many of the profiles also indicate a recent fall in beach levels between 2017 and 2018 surveys.

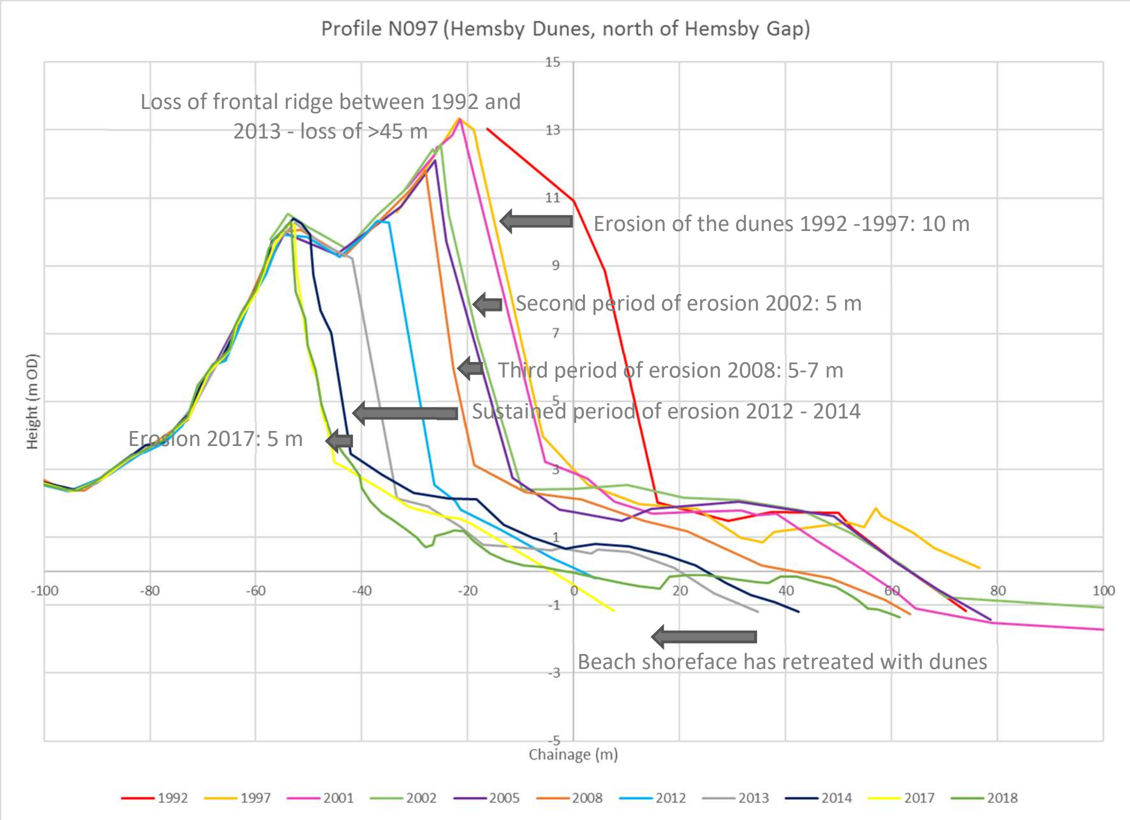


Figure 20 Beach profile N097, north of Hemsby Gap.

Hemsby (south of the Gap) [profiles HW414 to HW430, including N098]

Many of the profiles along this stretch indicate dune erosion between 2012 and 2013, with up to 18 m erosion recorded (at profile HW417). Further erosion of the dune occurred in 2016/17 and again in 2017/18, when the post storm data recorded the large drop in beach levels.

Data for N098 (Figure 21), south of Hemsby Gap, show that there was erosion of the dunes between 1991 and 2005, which resulted in around 15 m retreat over this period (equating to around 1 m/ year). The dunes then experienced very little change between 2005 and 2013, although beach levels continued to fluctuate. The August 2013 survey (shown in purple) indicates a very low beach at this point, which is unusual for a summer profile, when it would be expected that beach levels would be building. Between the surveys of August 2013 (purple) and December 2013 (orange), there was significant cut back of the dunes, resulting in loss of the most seaward ridge, and retreat of the dune face by around 18 m. Some further, but less severe, erosion occurred between 2013 and February 2018, but the February 2018 data indicate again very low beach levels in front of the dunes and a much steeper beach face, preceding the erosion in 2018, which resulted in around 9 to 10 m retreat.

To compare the beach levels, data from February 2018 and January 2002 have been plotted against March 2018 data, but the transect lines have been shifted landwards to align the dune toe (Figure 22). This illustrates the difference in beach level at the toe over these three dates and shows that the latest level recorded is more than 2 m below that at the toe in 1992.

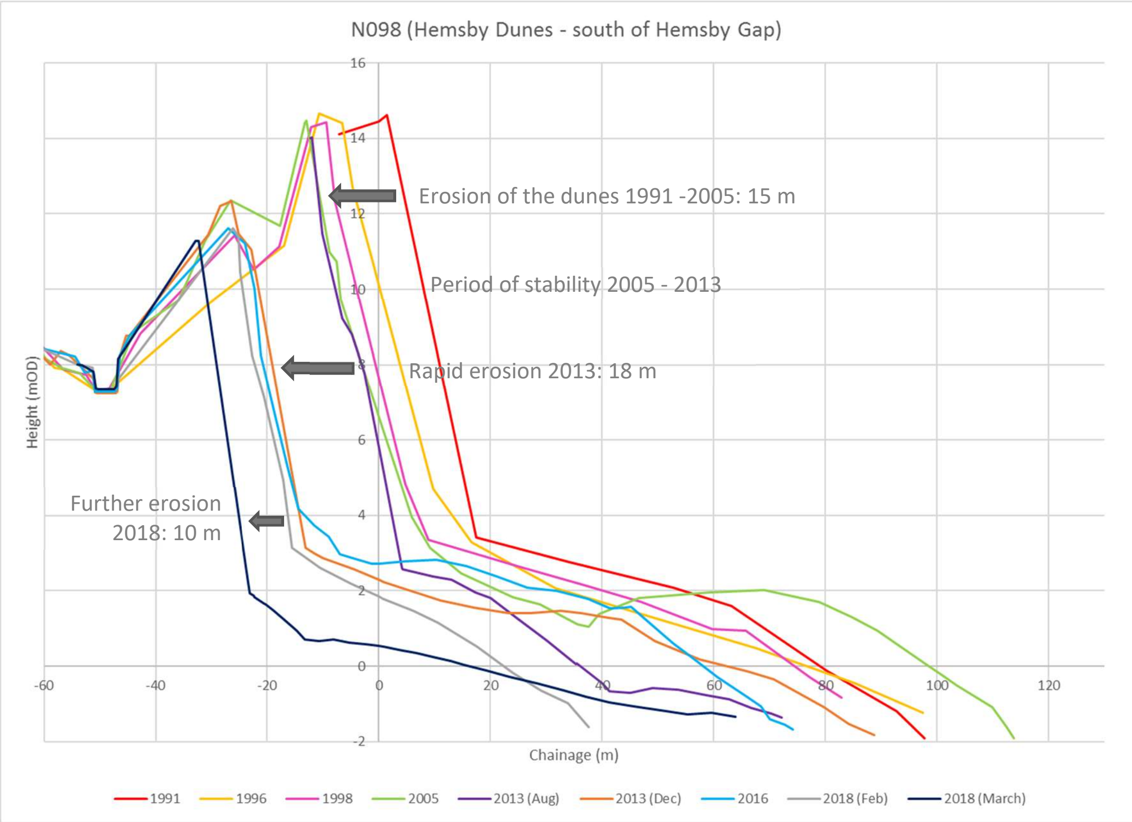


Figure 21 Beach profile N098, south of Hemsby Gap.

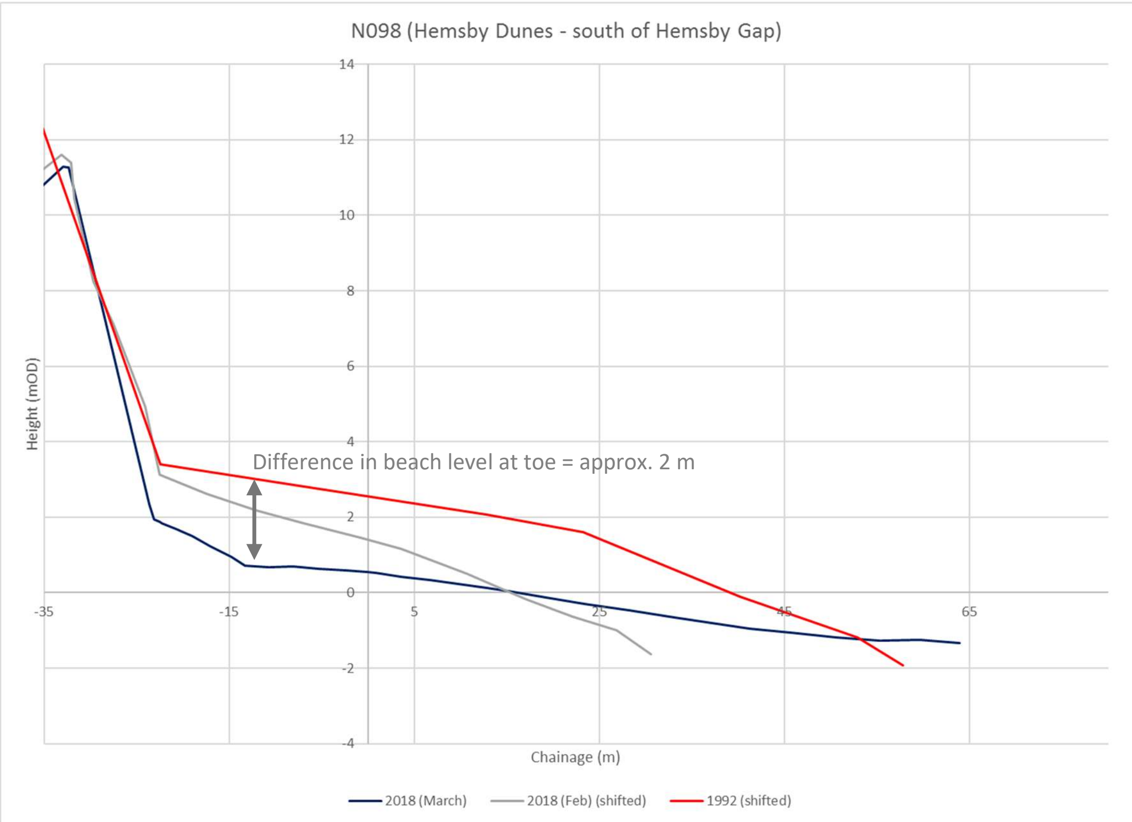


Figure 22 Beach profile N098, south of Hemsby Gap. Data for Feb 2018 and 1992 have been shifted landwards to align the dune toe to illustrate the difference in beach level at the toe between surveys.

To assess how the beach has changed over time the cross-sectional area between the base of the dune to where the beach meets the -1 m OD contour has been calculated for each survey (see Figure 23).

The results from this analysis are shown in Figure 23. At this location there is no noticeable seasonal change in cross-sectional area. Between 1991 and 2004, despite there being erosion of the dunes (as shown in Figure 21), there was little net change in cross-sectional area, suggesting a translation in beach rather than any trend of narrowing or widening. Between 2005 and 2008, there was an increase in beach cross-sectional area, followed by a rapid decrease in beach area between 2008 and 2013, with the lowest area recorded in 2013. The data show subsequent beach recovery, followed by another period of decreasing area from summer 2015 to present.

Considering the data shown in Figure 21 and Figure 23, it is evident that when the beach is building the dunes experience stability, there is then a lag time between beach levels starting to fall and dune erosion. Following dune erosion, there appears to be potential for beach (and dune) recovery, but more data are required to assess whether this will be the situation following the erosion in 2018.

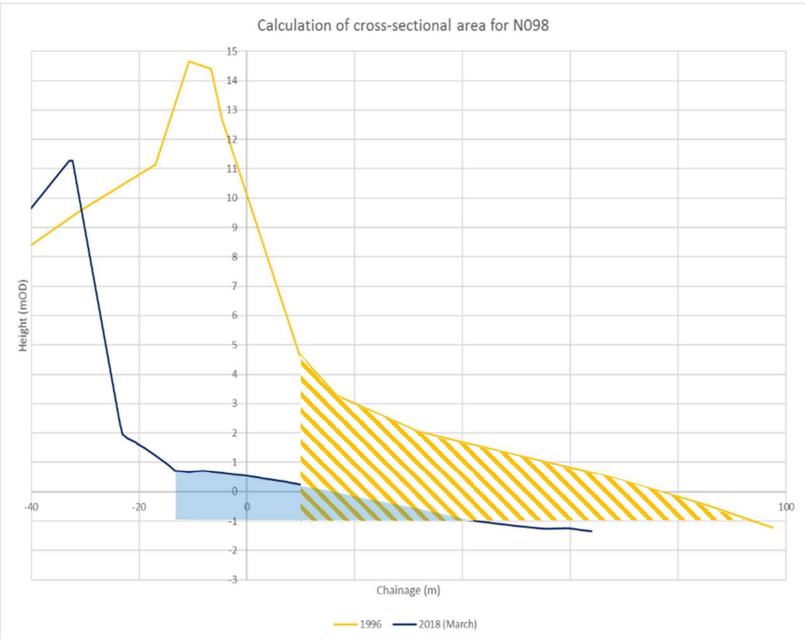


Figure 23 Calculation of cross-sectional area between the dune toe and - 1 m OD contour by survey.

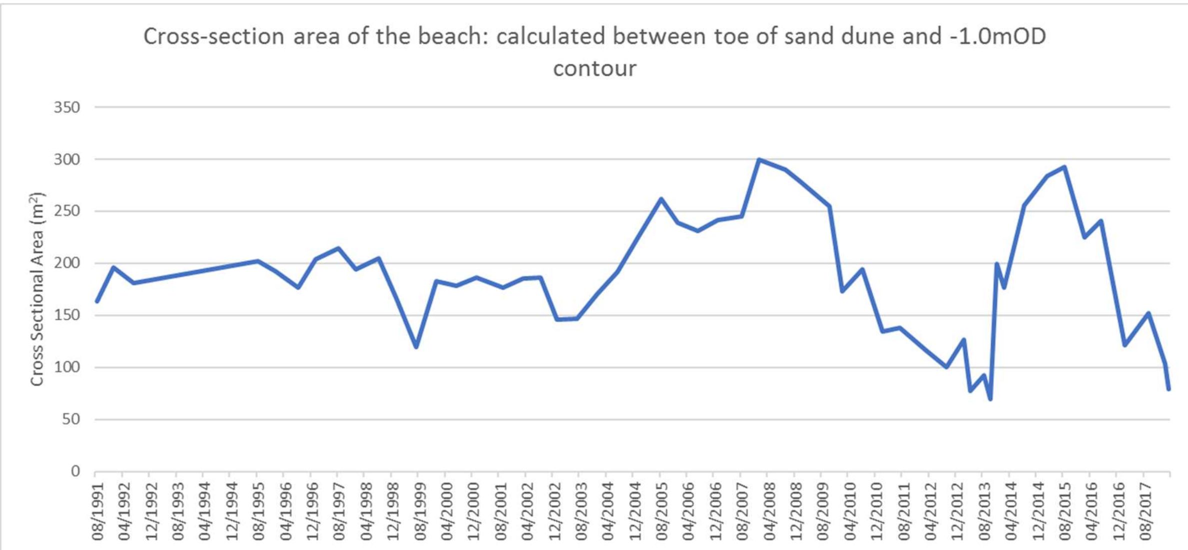


Figure 24 Changes in cross sectional area of the fronting beach at N098, south of Hemsby Gap, over time.

The beach transect data show very little variation in dune steepness over time. From the site visit and available photographs, it is evident that failure is through undercutting followed by slab failure. Subsequent avalanching can occur along the steep scarp face, but the overall slope of the face remains steep (see Figure 25). Given time, further slumping could occur allowing the dune face to reach a more stable slope.

Figure 25 Erosion of the dunes at Hemsby.

Scratby and California [profiles HW431 to HW464, including N099 and N100]

Along much of the Scratby frontage there has been very little change in cliff position, but significant variation in beach level. Site photographs, do, however, indicate that there is evidence of overtopping and erosion of the lower cliff slopes, but this detail is not picked up by the survey data.

At N099 (see Figure 26) the data shows that there was a drop in the level of the beach at the toe of the cliffs between 2007 and 2008; prior to this the beach had remained fairly stable. There has been no subsequent recovery. Around the 2 m contour, which is the approximate position of HAT (highest astronomical tides), beach levels over time have varied by 4 m, which is a considerable variation.

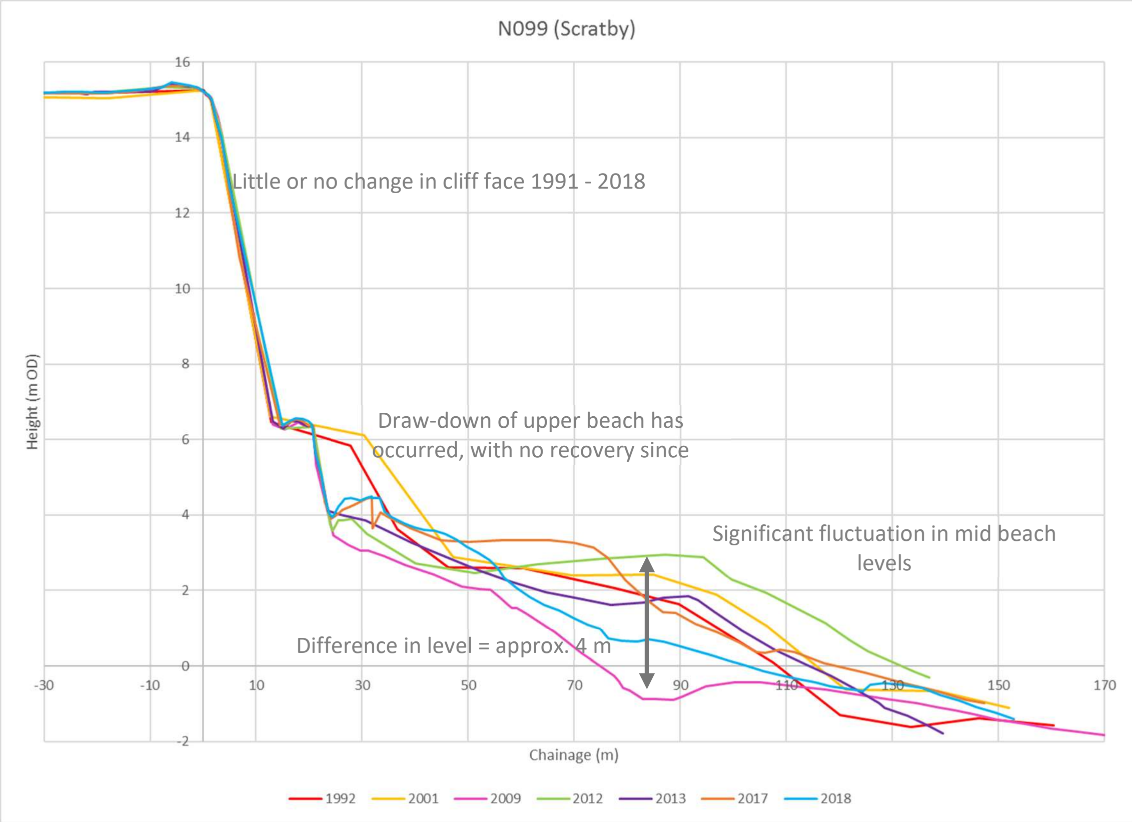


Figure 26 Beach profile N099, Scratby showing little change in cliff position but considerable variation in beach level.

This trend continues along the defended frontage and the beach widths and levels along this frontage show considerable change over time. The pattern of change is episodic: a period of growth is subsequently followed by a period of loss. Many of the profiles indicate a reduction in beach width between surveys in 2014 and 2015, followed by a subsequent growth in 2016/17. This may indicate that this frontage receives pulses of sand, but it is not clear whether these are a cross-shore transfer or longshore transfer of sand.

California to Caister [profiles SS001 to SS030, including N101 and N102]

There has been no change in backshore position, due to defences, but beach level north of the reefs is volatile, as observed for the shoreline to the north. Data for N101 indicates a similar episodic pattern of change to N100, with a growth in beaches recorded in 1996 after which the beach remained fairly stable until 2012, when there was a fall in beach level. Since then there has been some recovery in beach levels. Further south, changes relate to construction of defences: namely Caister Y-shaped groynes in 1994, and Caister reefs in 1999. At profile N102, the data indicate that there was beach loss recorded up to 1999, but that since then there has been progressive growth, initially in terms of beach width and the beach level, with development of embryo dunes along the backshore.

3.2.4 Anecdotal evidence

A recent account of the coast (albeit non-scientific) by Weston and Weston (1994) records the following: "*Moving on, I found more evidence of destruction at Newport. Several seaside properties had either been damaged or were in danger of becoming so, some with only a few feet between them and the drop to the beach. Scattered around on the beach and cliff, I saw the remains of glass, timber, asbestos, sandbags, ceramic tiles, china, furniture, water tanks and many other possessions as erosion had caused their former surroundings to topple over the cliff edge….. The high-water mark of a recent tide showed where waves had reached the base of the cliffs…*" The account goes on to then discuss Hemsby, stating "*Erosion has been a long-term problem here and in recent years particularly has caused several properties either to collapse onto the beach or become likely to do so.*

When visiting in early 1994 I discovered at least 15 properties in various states of decay some of which were precariously hanging over the top of the sandhills." In his final comments on Hemsby, he notes that scouring of the sandhills in 1971 revealed a WW2 bomber believed to have crashed in 1942/3, and a few years later on another part of the beach the timbered remains of a ship, possibly up to 200 years old, were uncovered.

Various historical photographs have been kindly provided by local residents; a collection of these are shown below.

Figure 27 Hemsby beach bungalows, believed to date from the 1930s. There is little vegetation along the dunes, but this may be evidence of erosion or due to trampling damage

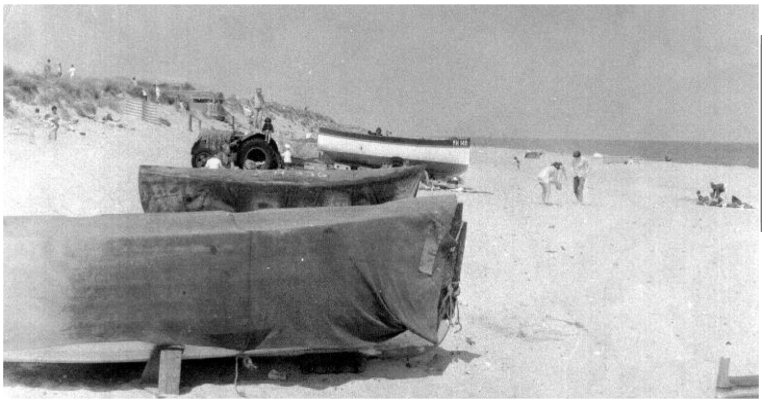


Figure 28 Winterton beach, possibly from the 1970s/1980s. In the foreground the dunes do not show signs of cliffing, but are sparsely vegetated, those in the background appear steeper and possibly cliffing

Figure 29 Erosion of the dunes in 1983 caused the loss of beach chalets. It is uncertain where exactly this photograph was taken.

Figure 9 More recent erosion (2013) has caused further loss of properties. Near-vertical dune faces have formed during the storm events, undermining the chalets.

Source: http://www.savehemsbycoastline.co.uk/

3.3 Discussion

Changes along Winterton Ness

From the mapping it is evident that Winterton Ness has changed in location in the past, but unlike Benacre Ness along the Suffolk coast, instead of moving in a single direction, the feature has tended to fluctuate within a fixed zone and change not only in extent but also its shape.

A previous report (May, 2003) also looked at how others have reported change at the ness and summarised the findings as shown in Figure 30. The historical maps appraised as part of this work support the idea presented by Halcrow (1988) which showed a change not only in the direction of growth but also in the ness form, moving to one which is more peaked.

The more recent data from the beach level transects and aerial images show that between 1992 and 2018 there has been shoreline accretion around 1 km north of Winterton Beach Road, as far north as the groyned beach, whilst to the south of this point the net trend has been for accretion. This has effectively meant a northward movement of the ness, which is clearly illustrated in Figure 10. As the ness has moved north, it has led to a significant reorientation of the coastline to the south, and response of the shoreline has progressively moved downdrift.

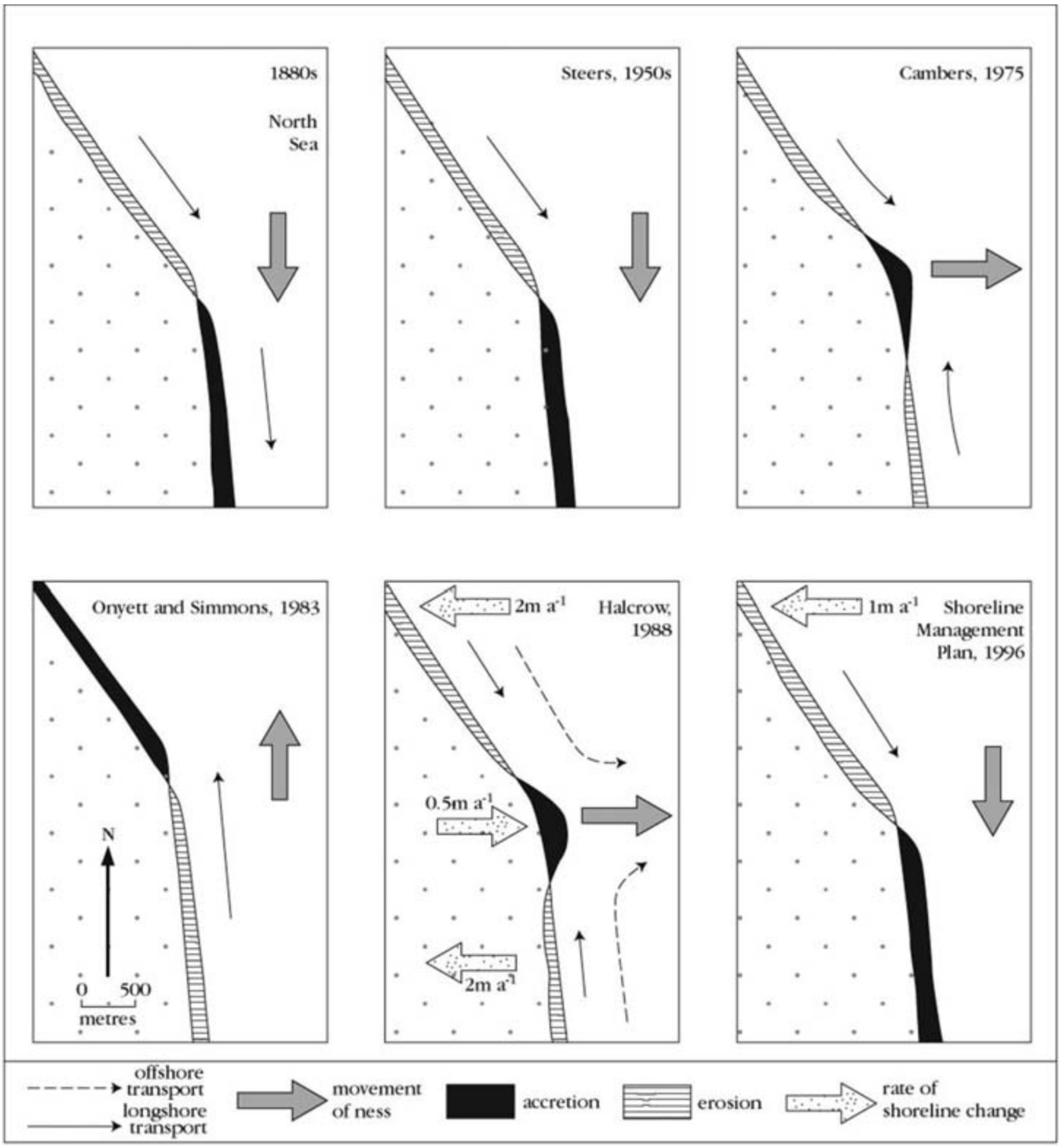


Figure 30 Different interpretations of the sediment transfers at Winterton Ness, taken from May (2003). In the 1880s, according to Steers (1964a) and the Shoreline Management Plan (North Norfolk District Council et al., 1996), net sediment transport was southwards and the ness moved in the same direction. Others have suggested that transport is from the south, and Cambers (1975) and Halcrow (1988) agree on transport from both south and north with a transfer offshore and the ness extending seawards.

The reasons for the observed changes in the ness shape and position are not certain but its connectivity to the bank system would suggest the change is likely to be linked to changes in the ebb and tidal currents. However, it is uncertain whether it is a change in the ness form that generates a change in the banks and channels nearshore or vice versa. If the former is the case, then changes to the ness may alternatively relate to fluxes of sediment supplied from further north or driven onshore. Section 4 discusses changes to the banks in more detail.

The semi-permanent location of the ness is also not well understood, but it has been suggested that this could be due to underlying geological controls. The ness is situated on the remnant northern upland and its various positions over this period may therefore be related to this shallower, more erosion-resistant sector of the sea floor (HR Wallingford, 2002).

3.3.1 Changes between Winterton Beach Road and Scratby

Historically, based on OS mapping of the high water mark, there appears to have been accretion along this frontage. Comparison of the 1884–1890 and 1951-1960 data shows there was a notable increase in beach width (and possibly dune area) over this time period. Over this time period, the shape and position of Winterton Ness was very different from today and it seemed to form a much wider, less peaked feature.

The onset of erosion is uncertain and it is possible that there have been various phases of erosion and accretion not captured by the historical information available. However, aerial images from the 1940s shows that at this time there were well vegetated dune ridges in front of Hemsby, with three lines of chalets within the dunes, although a report from 1948 mentions erosion of the dunes at Hemsby. By the 1980s there had been erosion of the dunes immediately north and south of the beach access at Hemsby, which resulted in the loss of around 30 m of frontal dune and the most seaward row of chalets. This zone of erosion stretched as far south of the end of Newport Road.

More recent data show that dune erosion is commonly episodic rather than constant, with periods of rapid dune erosion followed by periods when there little change in dune position has occurred. Rates of erosion also vary along the shoreline, both over time and spatially. Some areas have experienced little change, whilst others have eroded. For example, between 2005 and 2013 the dunes south of Hemsby Gap experienced little change, with more dramatic erosion occurring in 2013, whilst north of the Gap there was a sustained period of erosion 2012–14, followed by a period of little change up to 2017. In 2017-18 there was 5 to 10 m erosion along Hemsby, whilst further north the dunes were stable. Most recently, there appears to have been a southward progression of the erosional trend, with south of Hemsby Gap experiencing some of the largest rates of erosion during the recent storms, whilst areas further north changed very little.

Failure of the dunes is through undercutting and slab failure, such that the steep dune cliff is simply cut back, maintaining a similar profile. The data for Hemsby shows that up to 18 m of erosion can occur during a single season, and possibly as a result of a single event. The most recent event in 2018 resulted in around 10 m retreat at Hemsby.

As the dunes have retreated, so has the beach in front. However, data for south of Hemsby Gap show that falling beach levels commonly proceed a period of rapid erosion. Looking at trends it appears that when the beach is building the dunes experience stability, there is then a lag time between beach levels starting to fall and subsequent dune erosion. There can then be beach recovery; however, there is no data yet available to confirm whether the beach has recovered following the recent erosion in March 2018.

The change in beach condition may also be linked to changes to the bar, which extends southwards from Winterton Ness. This seems to be semi-permanent feature, which at times appears to become welded onto the shoreline, creating a wider beach, whilst at other times it is a distinct feature, separated from the main beach by a channel. It is uncertain whether this bar is a conveyer for sediment, but it does appear to have some local control on the beaches.

3.3.2 Changes south of Hemsby

To the south of Hemsby, much of the backshore has been fixed in position by defences. The beach in front of the defences remains, however, extremely volatile and there the beach level data suggests that the beaches receive pulses of sediment which are then subsequent removed. These are not simply seasonal changes, but it is not clear whether this is a cross-shore transfer of sediment or longshore supply, or a mixture of both.

There does not seem to be a direct link with erosion along the Hemsby frontage, otherwise following the 2013 storm, when there was significant erosion of the dunes, a build-up would have been expected along the Scratby frontage, which is not particularly evident.

Offshore changes

4.1 Introduction

The visible part of the shoreline is only part of the coastal system and, particularly on this coastline, where banks and channels lie close to the shoreline, considering the supratidal, intertidal and subtidal zones is vital to understanding the drivers of changes seen along the exposed beach and backshore.

The bank system effectively forms an umbrella reaching down from Winterton to Benacre (Scroby, Holm and Newcome) (see Figure 31) within which is a complex circulation and re-circulation of sediment between the shore, the inner banks and the outer banks (HR Wallingford, 2002).

Although the banks and intervening channels are dynamic, there does appear to be some geological control on their behaviour, which links back to the origins of this coastline. As explained in Section 3.1, formation of the banks is believed to post-date the development of the coast in a location similar to today's. The banks therefore sit on top of the submerged remnants of the uplands which extend inland and upon which now sit Caister to Winterton (and Gorleston to Kessingland further south). Between these uplands was the River Yare Valley, which is now disconnected from the Yare. It is thought that the more volatile elements of the sandbank system are those that lie over the now buried valley of the River Yare, where the sand thickness is greatest, and consist of South Scroby, Corton Sands and Holme Sands (HR Wallingford, 2002). More stable areas, such as Winterton Ness, are thought to be associated with the more resistant remnant uplands. Although the banks and channels within the bank system are subject to significant change, the overall position of the system has remained fairly static, lying between the two former uplands.

Travelling north to south, key features within the area of interest are:

- Winterton Ness shoal – although this is not formally recognised as a feature on the UKHO charts, a shallow area lies to the north of the ness.
- Hemsby Hole – this lies within the channel that lies inshore of Caister Shoal. This channel extends just south of Caister. It does not have a specific name on the charts, but has previously been referred to as Caister inshore channel (Barber, 2016). Here there are depths of up to 18 m below Chart Datum.
- Cockle Gateway – this is an area of deeper water offshore of Winterton Ness.
- Caister Shoal – this is the main bank that lies offshore of the study area. It extends from Winterton to Newtown and at its northern end currently merges with Cockle Shoal.
- Caister Road – this is the main flood channel, which lies between the banks of Caister Shoal and Scroby Sands, which is up to 20 m (below Chart Datum) deep.
- Scroby Sands – This lies offshore of Caister Shoal and is made up of South, Middle and North Scroby Sands, which are connected at the 5 m contour below Chart Datum.

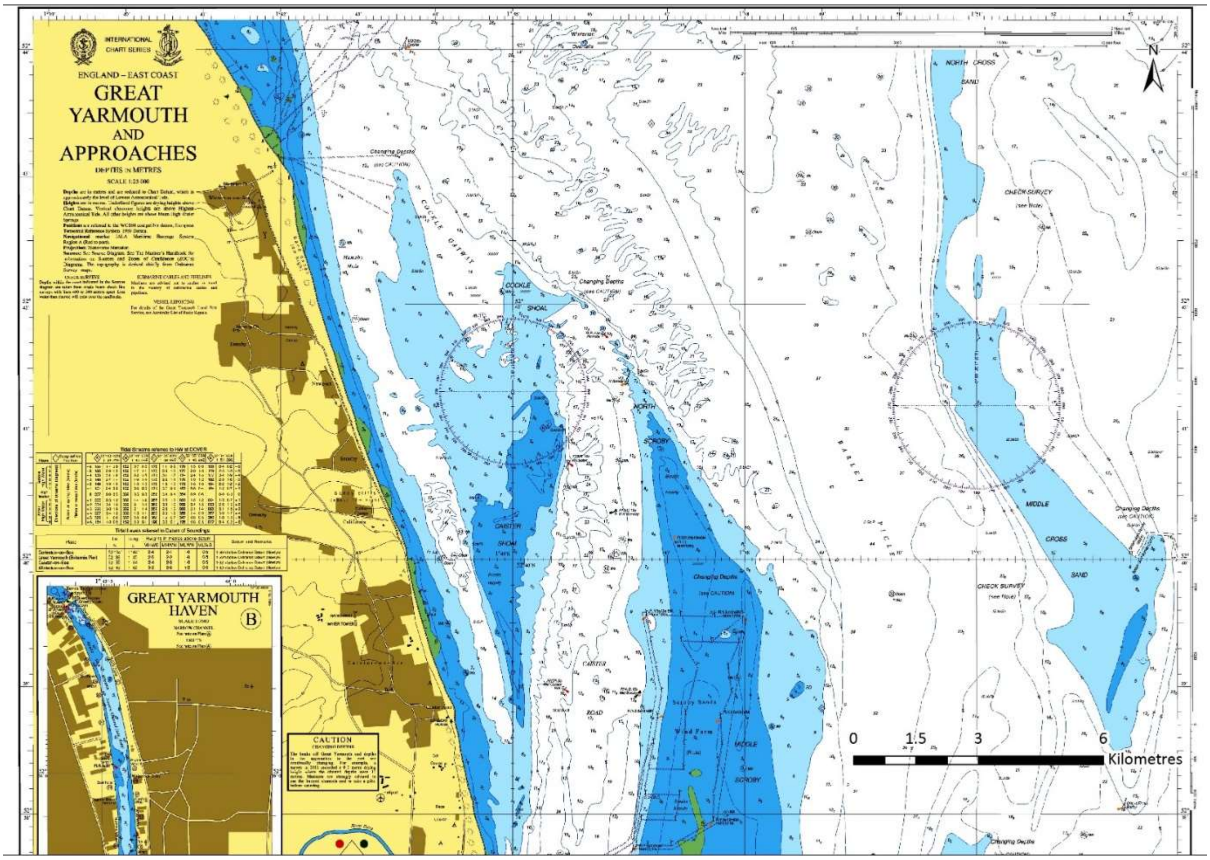


Figure 31 2018 Hydrographic Chart showing the nearshore banks and channels. © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.GOV.uk/UKHO).

4.2 Key changes in the bank system

4.2.1 Evidence from historical charts and previous studies

The UK Hydrographic Office have produced charts covering this area on a regular basis since 1825. The most recent edition is from 2017, but it should be noted that it is not usual for the whole chart to be updated at one time, so a chart contains data from a number of sources and from various dates.

There have been numerous studies that have used these charts to look into the movement of the banks and changes to the bank system over time, including: Dolphin et al. (2007), Park and Vincent (2007), Thurston (2011), Coughlan (2008), Horrillo-Caraballo and Reeve (2008), Cooper et al (2008) and Bakare et al. (2010) and the Southern North Sea Sediment Transport Study (HR Wallingford, 2002). Most recently, a study has been undertaken by Barber (2016) which considered the complex relationship between the various components of the bank system and the influence of changes in tidal flows across the area, focusing on changes that have taken place over the past forty years (1974 to 2014).

Although the sand bank system constantly changes and is dynamic in terms of the height, shape and position of the banks, Horrillo-Caraballo and Reeve (2008) suggest that the fact that it has remained in situ for at least 170 years indicates that it has some form of dynamic equilibrium.

Various studies have concluded that over the past 170 years the greatest changes are around the flanks of the sand banks, whereas the major channels appear to be more stable features (Horrillo-Caraballo and Reeve, 2008; Bakare *et al.*, 2010) (see Figure 2), with the exception of Holm Channel, which is affected by changes in the banks. The shallower areas of the sand banks are continuously changing due to strong interactions with waves and currents, particularly during storm conditions (Park and Vincent, 2007).

There is general agreement within recent studies that there has been a long-term increase in the volume of sediment of the sand bank system as a whole (Horrillo-Caraballo and Reeve, 2008), which also agrees with earlier studies (e.g. Clayton et al., 1983; Halcrow, 1999). Barber (2016) argues that this growth means that the changes observed today are unique to the present status of the banks, rejecting the concept of a cyclical pattern of change. The maximum height of the banks appears to have a natural limit, beyond which wave action tends to remove material. This is around Chart Datum (Barber, 2016). Therefore, to accommodate influx of sediment, the banks increase in width and length.

A key observation from a number of studies is that the changes in banks and channels observed at a local level actually form part of a larger scale change to the whole bank system. It has also been suggested that large scale changes to the bank system may be driven by upstream adjustments, such that changes offshore at Winterton Ness then affect changes throughout the bank system to the south.

Within the bank system itself, patterns of sediment exchange are predominantly driven by tidal flows. These in turn are affected by the shape and position of the banks, which result in a complex residual flow field. As the configuration of the banks changes, so does this flow (Horrillo-Caraballo and Reeve, 2008) and therefore also potential sediment transport. This in turn induces further changes to the bank system itself, so is self-perpetuating. Tidal residuals are not the only process that can drive the evolution of sand banks. Although the role of waves on submerged sand banks is likely to be small, over the shallower sand banks, waves become more important, and have a key role in agitating and re-suspending sand for tidal currents to transport and through this process, influence both the net sand flux and bed evolution (Park and Vincent, 2007; Barber, 2016).

The following conclusions relating to this frontage have been extracted from Barber’s 2016 study, which also draws upon previous work:

- The presence of shore-parallel tidal flows along this coast means that tidal controls on beach behaviour and shoreline locations is significant.
- Over the past 40 years (1974 to 2014) there has been an influx of sand into the banks, resulting in growth of the banks; in particular, Caister Shoal, Scroby Sand and Holm Sand (to the south of this study area). An estimated 900,000 m^3 of sand is added to the bank system each year (equating to around 32 million m^3 added to the seabed in the Great Yarmouth Banks area over 40 years).
- As these banks have grown, this has led to a concentration of tidal flows within the main channels (‘Roads’), either side of the banks. The deepest parts of the channels have remained generally the same, so in response to an advancing bank, the shoreline edge of the channels has moved landwards. This has also led to a general straightening of the channels, but there had also been lowering of the “terminal bars” at either end.
- Although tidal currents are weaker along the side of the channels (due to frictional effects), the shallower water allows waves to agitate the sand such that lower tidal currents are able to mobilise and transport sand away into deeper water.
- Through this process, in locations where channels lie close the shoreline, sand eroded from beaches during storms may be drawn down into the channels and transported away into deeper water. This sand is then no longer available for return to the beach in the summer.
- As a channel moves shorewards, the subtidal zone is lowered which will reflect back onto beach levels, resulting in beach erosion.
- If in the future the banks lower again, there will be “less compression of flows”, with more cross-flow over the banks and more tidal exchange with the offshore.
- Caister inshore channel is a potential mechanism by which sand is supplied to Caister Ness during flood tides. Ebb tides will redistribute some sand northwards, but rather

than moving moved onshore this is likely to have been moved onto Caister Shoal, resulting in further growth of this bank landwards.

- Reshaping of Caister Shoal between 1990 and 2005 and retreat southwards of North Scroby are likely to have increased wave exposure at Hemsby.
- Development of Winterton Ness (1991 – 2000) is likely to be linked to the movement of tidal energy further offshore, which will have altered sand transport alongshore and tidal flow directions alongshore and tidal flood flow directions south of the ness towards Caister. This may explain the channel relocation and movement westwards. Sand moving south will be diverted offshore by the ness, meaning less sand supply to the south. Sand diverted offshore is likely to be moved into Caister inshore channel, which itself may be influenced by the ness changing channel alignment.

Barber (2016) also presented a series of charts, including a comparison of the -10 m, -5 m and -2 m contours between 1974 and 2013. This shows that:

- Landward movement of the Caister inshore channel between 1974 – 2013, accompanied by some infilling of the channel over time.
- The Caister inshore channel has also lengthened to the south, with deepening occurring at the southern end of the channel between 1974/80 and 1990, possibly suggesting greater flows at this location.

4.2.2 Evidence from recent surveys

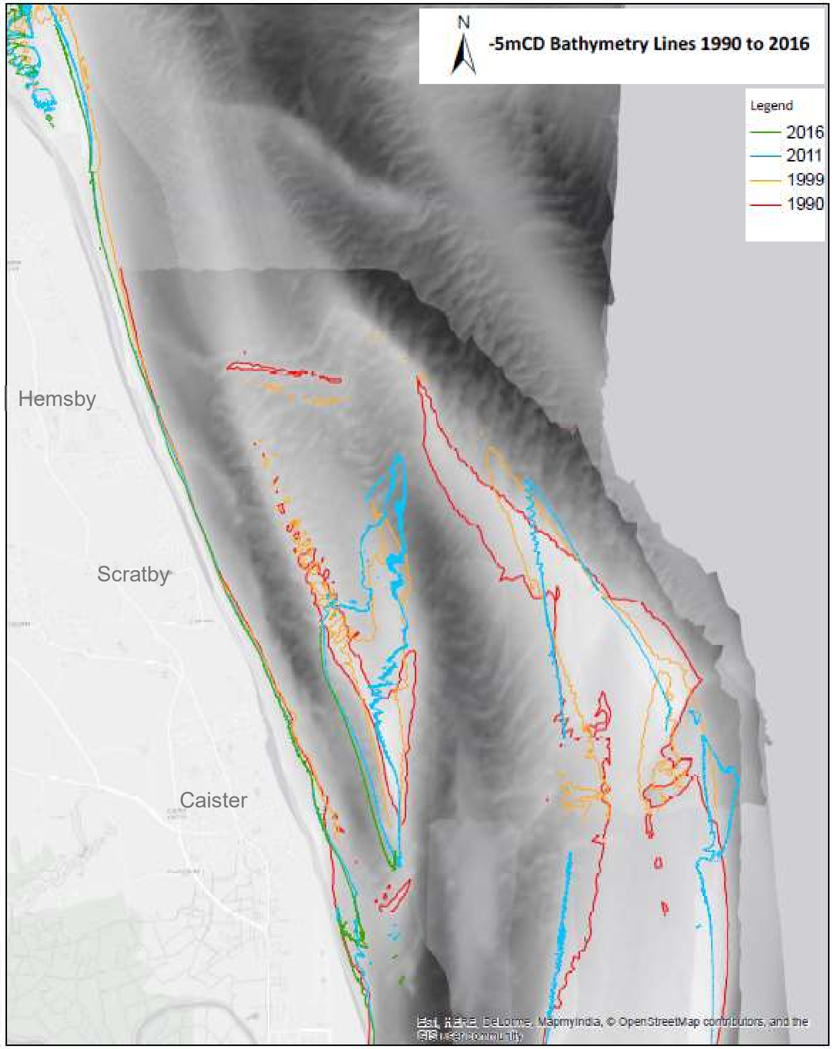
More recent, site-specific, surveys are undertaken on a regular basis by the Hydrographic Office, covering features that are of interest in terms of navigation, including Cockle Shoal. Reports from these surveys are available on-line (https://assets.publishing.service.gov.uk/), with the most recent one published in 2016 (UKHO, 2016). Key conclusions from this report are:

- The northern end of Caister Road (referred to as Caister inshore channel in this report) has continued to narrow at an accelerated rate since 2014, due to migration of Caister Shoal by around 400 m north-north-east.
- In the vicinity of Hemsby Buoy the depth has increased by 1.7 m in 2016 compared to 2014.

Hydrographic Office multibeam echo sounder data sets are also available from the INSPIRE (Infrastructure for Spatial Information in Europe database). These provide a detailed picture of the seabed and features and cover part of the bank system. For the area of interest, data are available for 1990, 1999, 2011 and 2016. Bathymetric contours have been generated from these data sets to appraise how the banks and channels close to Hemsby have changed in recent years; these plots are shown in the Figure 32.

The -5 m CD plot shows that over the period 1990 to 2016 the 5 m contour has moved landwards along the whole coastline from Hemsby down to Caister, with the largest changes experienced at Hemsby. This has been accompanied by onshore growth movement of the landward flank of Caister Shoal, shown on the -10 m CD plot. Adjacent to the shoreline at Hemsby, the movement of the bank has been greater than the shoreward movement of the 5 m contour, meaning that Caister inshore channel (which lies between Caister Shoal and the shoreline) has become squeezed. Also of note is that the northern extent of Caister Shoal, as defined by the -10 m contour has reduced, potentially meaning this northern part is more exposed to the wider channel.

These changes are more evident from transect data (see Figure 33): the graph for South of Hemsby Gap particularly shows how extension of Caister Shoal landwards has resulted in a narrowing of the intervening channel, which has also shallowed over time. Further north along The Valley, the data indicate that the channel which lay close to the shoreline has become infilled, with a net flattening of the seabed here.



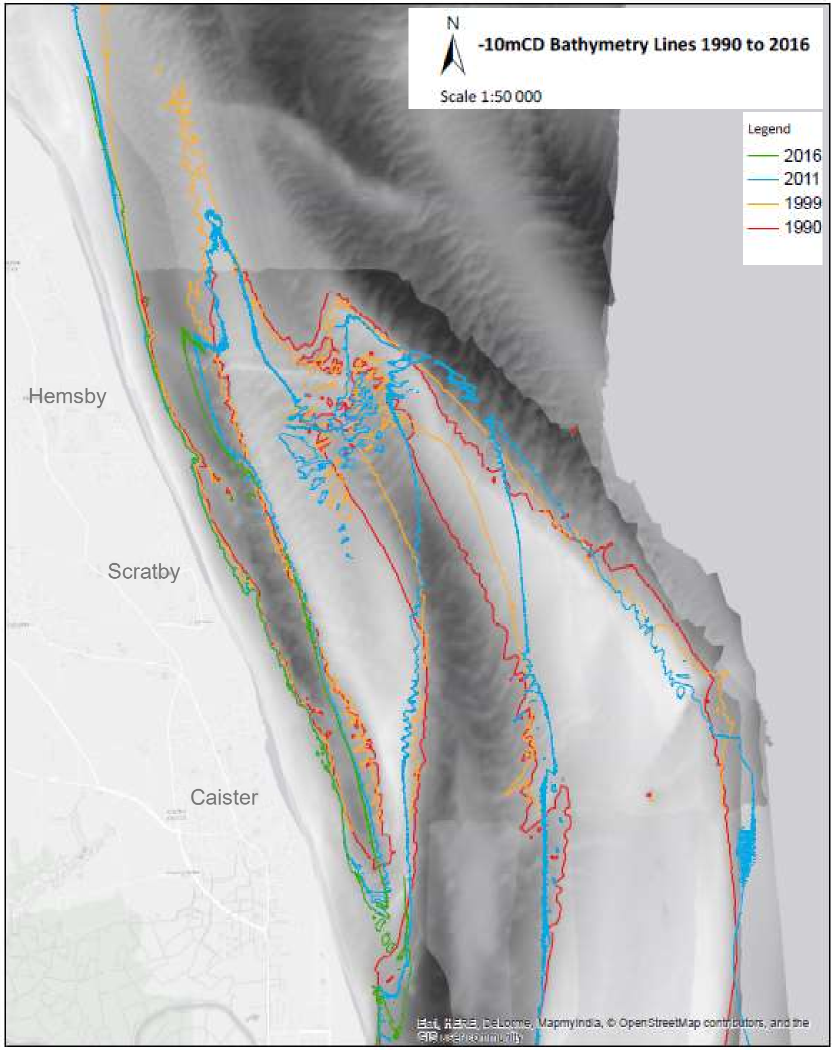


Figure 32 Contour plots using UKHO multibeam bathymetric data for years 1990, 1999, 2011 and 2016. Bathymetry data ©Maritime and Coastguard Agency

Figure 33 Transects through the bathymetric data showing changes in nearshore bed levels: years 1990 (red), 1999 (yellow), 2011 (blue) and 2016 (green).

4.3 Discussion

Although the overall location of the banks system has not changed at least over the past 170 years, within the system the banks and channels are extremely dynamic and changes in one area are linked to, or are reflected in, changes in another area. The banks have been a long term sink for sediment and it has been argued (Barber, 2016) therefore that the current situation is not one that has been experienced previously. The height of the banks is limited by wave action, therefore the increase in sediment is accommodated by an increase in width and extent. This in turn affects the intervening channels and also the flow of water and sediment through the channels.

Detailed data available for the local area for 1990, 1999, 2011 and 2016 shows landward movement of a low water channel towards Hemsby. This potentially has had a significant impact on the adjacent Hemsby frontage through:

- creating a zone of deeper water, resulting in large waves closer inshore,
- increased flows through the channel, due to a narrower cross-section but same volume of water needing to pass through the channel, which in turn will increase capacity of the flow to erode sediment,
- both the increase in wave and tidal energy closer to the shoreline may enable the offshore removal of sediment drawdown from the beaches, reducing recovery and leaving them depleted prior to winter storms.

Reportedly (Barber, 2016), there has also been opening up of the channel through lowering of the “terminal bars” at either end, such as Cockle Shoal, which may mean more significant flows through the channel.

Movement of the channel does correspond to erosion of the dunes; however, erosion has been continuing, albeit on an episodic basis, since at least the 1950s. It is likely, therefore, that this is not the only factor that influences change along this frontage. Looking at longer term data, Barber (2016) suggests that reshaping of Caister Shoal between 1990 and 2005 and retreat southwards of North Scroby are likely to have increase wave exposure at Hemsby.

At the northern end of the frontage, between Winterton and Hemsby, the low water channel appears to have moved further away from the shoreline, or infilled, with a shallower nearshore having developed since 2011. This corresponds with a period of stability along this frontage, which has been the case since 2008 (see Figure 19). Conversely further north, the seabed has reportedly deepened, potentially opening this area up to the wider offshore zone.

It is uncertain how long the current situation will last or whether there may be further onshore migration of the low water channel. It has been hypothesised (Barber, 2016) that this will depend upon changes within the wider bank system, as this ultimately determines how water flows through the system and whether it becomes compressed within channels closer to the shore. In turn this may affect, or be affected by changes at Winterton Ness. It is therefore possible that the channel may move away from the frontage again, or conversely could continue to be pushed towards the shoreline.

Discussion and summary

5.1 Introduction

There are a number of key messages that emerge from this high-level analysis of available data. It should be noted, however, that some of the concepts and ideas presented here require further investigation. There also remains a great deal of uncertainty, partly due to lack of data, for example:

- There is only historical OS mapping for certain time steps and some caution must be applied when interpreting tidal lines, given the assumptions that were made at the time of mapping - particularly along this coastline where tidal conditions vary significantly along the study frontage.
- Both aerial data and beach transect data only provide a snapshot of beach levels and in volatile environments such as this one may only reflect conditions of a few hours or days rather than the previous 6 months.
- We lack data for the zone between mean low water and the -5 m CD contour - this is a difficult zone of the beach to monitor, but is potentially where much of the sediment transport and changes take place. This is not just an issue on this coastline, but for much of the UK.
- Due to the lack of available inshore wave data it has not been possible to examine the possible links between wave direction, height and period with changes observed at the shoreline.

5.2 Key messages

1. Current issues along this coastline are inherited from how this coastline was formed - cut into soft sand-rich cliffs and fronted by sand dunes, which provide little resistance to wave action, when exposed to direct attack.
2. Key controls along this coastline are as follows:
    - Tides – this stretch of coastline has a particularly unusual tidal regime for a number of reasons: (i) the shape of the North Sea basin affects how the tidal wave propagates through the area and this is also influenced due to tides entering from the English Channel, (ii) the nearshore banks affect the balance of flood and ebb flows and where in the system these flows are dominant. The result is a relatively large difference in tidal level between Winterton and Caister, with a difference in the time of high and low water between the sites: Hemsby sits within this zone. This potentially means that a 'head' of water is created, which would be expected to cause pressure on the system.
    - Waves – these commonly approach the coast from the north and north-east, but there will be occasions when other directions are dominant. The banks and channels also have an influence on the waves before they reach the shoreline: previous studies have looked at the potential for the banks to provide both protection to the inshore area but conversely potentially focus wave energy at the shoreline. Particular alignments of the channels may also allow larger waves to penetrate closer to the shoreline.
    - Storm surges: the southern North Sea is vulnerable to surge surges, which can be generated both internally and externally. This means that each storm event may be different from the previous one, in terms of generated wave heights, direction and duration. The local bathymetry also has an influence, meaning there is also complex relationship between surge events and shoreline response, such that shoreline response along even short distances can vary considerably. The storms of December 2013 were a key event along this frontage and caused several metres of dune erosion along much of the frontage.

- The nearshore banks: as discussed above, the system of banks and channels has a profound influence on shoreline behaviour along this frontage, through influencing inshore waves, tidal currents and sediment transfer.

3. The historical maps, seabed charts, aerial photographs and beach monitoring data all indicate that there have been significant changes along this coastline which have meant both advancement of the shoreline and subsequent retreat. Since at least the 1940s, the main trend between Winterton and Hemsby has been one of erosion. This has been episodic meaning that there have been periods of rapid dune erosion and shoreline retreat followed by periods when the dune front has remained static, but the beach in front has continued to fluctuate in level. The data also show that the rate and timing of erosion is not the same along the whole frontage: for example, there have been periods when erosion has been ongoing south of Winterton, whilst the dunes at Hemsby have experienced little change. Whilst erosion of the dunes south of Winterton may have gone relatively unnoticed, due to the lack of assets here, erosion at Hemsby has had significant consequences due to properties within the dunes and proximity of the village to the coast.

4. As the dunes have retreated there has also been a retreat of the beach, with the whole profile translating landwards. In places there has also been a lowering of the beach at the toe of the dunes; however longer term data shows that there is potential for beach recovery.

5. Based on the available evidence, there are a number of factors which are driving or influencing the current erosion along the Hemsby frontage:

   - Movement of Winterton Ness –this has also been a dynamic feature and through historical maps we can see how it is not just its extent that has changed over time, but also its form. Early maps show the feature has a three-peaked mass of sand and shingle, which extended further north. Subsequently the ness has developed a more peaked form, with a clearly defined single apex, but there has previously been some redistribution of sediment further south, building up beaches (and possibly dunes) between Winterton and Hesmby. In more recent years (at least since 1946) the feature been moving northwards and is possibly moving faster now than previously. As the ness has moved northwards there has been a reorientation of the coastline to the south: this is also seen along the Suffolk coastline, south of Benacre Ness. There are a number of possible reasons for this:

     - As a store of sediment, the ness is holding up sediment sourced from erosion to the north that otherwise would be moved southwards, such that beaches in its lee are effectively being starved of sediment.

     - There is a connectivity at the ness with the nearshore bank system - there remains uncertainty whether the nesses represent zones of net onshore or offshore movement, but potentially material from the system is being lost at the ness again reducing feed to beaches to the south.

     - Movement of the ness is a response to, or intrinsically linked to, large scale changes to the nearshore bank system (see below). This may infer movement of tidal energy further offshore, which will have altered sand transport alongshore and tidal flow directions alongshore and tidal flood flow directions south of the ness towards Caister (Barber, 2016).

     - The main flow in deeper water essentially follows the curve of the coast as it moves from north to south on the flood and vice versa on the ebb and there is a subsidiary flow within Caister inshore channel, which lies between Hemsby shoreline and Caister Shoal. Movement of the ness may have facilitated the movement of this channel further inland as flow around the ness will have changed.

     - The bulk of the ness may have previously provided some localised shelter from waves from the north; as it has moved northwards exposure conditions along the Hemsby shoreline may have increased.

- A bar feature extends from Winterton Ness and runs semi-parallel to the coast. It is not known whether this is a conveyor of sediment. The feature is semi-permanent and it has been difficult to determine from aerial photographs how this has changed in form over time, due to the timing of the photos relative to the tidal state. It is likely, however, that as the ness has moved this bar feature has also changed. Associated with the bar is a small tidal channel (runnel) feature between the bar and the dune toe, which gets squeezed and eventually infilled as the bar moves onshore. At certain points during this process this channel features means there are lower beach levels at the dune toe, potentially increasing vulnerability of the dune to wave erosion.

- Changes to the nearshore bank system – there has been recent acceleration in the landward movement of a low water channel towards Hemsby shoreline. This is consistent with larger scale changes within the bank system. This channel is a conduit for subsidiary flows and during flood flows will move sediment away from the frontage. There is potential, therefore, that material draw-down the beach during storms is moved away from the coast, limiting beach recovery (this process has also been suggested by Barber (2016) for the Corton frontage in Suffolk). Changes in cross-sectional area at Hesmby (see Figure 24) does indicate that prior to the significant erosion in 2013, the beach had been reducing in area (width and height). Following the storm there had been subsequent build-up of material, before a further fall prior to the erosion in 2017 and 2018. This mechanism may form part of this process. Recent narrowing of the channel is likely to have further concentrated flows, meaning faster flows during the flood tide. Another consequence of the channel moving closer inshore is that deeper waves may reach the shoreline, particular during surge events.
- Storm surge events – although there is not a consistent shoreline response to these events, the data does indicate that erosion is predominately a result of recognised storm periods. How the coast responds is likely to depend upon a number of factors such as:
  - angle of wave attack
  - wave height and period
  - duration of the storm and frequency of any return event
  - bank and channel configuration at the time of the storm
  - beach conditions prior to the storm.
- Volatile beaches - whilst the frontage as a whole is not sediment-starved, beaches along this frontage are extremely volatile and respond rapidly to changing conditions, with changes in beach level of up to 4 m recorded over time. Any future management of the shoreline therefore needs to take account of this scale of change. Linkages along the coast are not well understood – there is some evidence that material may move down the coast in pulses, but the role of the bar feature, connected to Winterton Ness, is not clear. There is also a possible connection between the banks and shoreline at both Winterton and Caister Ness. Any coastal defence here therefore need an associated monitoring plan to appraise possible impacts on adjacent frontages to ensure a strategic approach to managing the whole shoreline. This plan would also need to include monitoring of the nearshore zone and in particular the Caister inshore channel.
- In summary, movement of the ness and associated changes to the bank and channel system appear to be driving large scale changes along this coastline. Erosion of the dunes has been predominately during storm events, but the impact of these events at a local level depends upon conditions prior to the storm. At Hemsby the recent erosion in 2013 and 2017/18 has followed periods of beach narrowing and lowering, which has created optimum conditions for dune erosion. This lowering trend may also be related to removal of beach material, drawn-down during winter storms, via the nearshore channel and/or position of the bar feature, which leads to development of a runnel close to the shoreline.

6. In terms of future changes along this coastline:

    - Unless there is a further change in the channel position, Hemsby is likely to remain vulnerable. There is also a risk that there will be increasing pressure along the Scratby to California frontage, particularly as there has been deepening of the channel at the southern end of the channel, which may be indicative of faster flows. The recent rapid retreat of Hemsby compared to a more stable coastline north of Hemsby Gap means that currently the Valley area to the north of Hemsby Gap is now lying slightly seaward of adjacent areas. Adjustment of this section may be expected in the future (but this may also depend upon changes along the bar feature); particularly vulnerable areas are where gaps or blowouts are already present, which would potentially enable inundation of flood waters to The Valley behind.
    - The controlling mechanism on the movement of Winterton Ness remains unknown. It is possible that it will remain in its current location, move further north or even start to move south again. Similarly, the implications for the Hemsby frontage are not simple to appraise, as changes at the ness are believed to have implications for the wider bank system and flows through the channels, which in turn affects distribution of sediment and bank growth.
    - Even if the situation continues as today, future rates of erosion are difficult to predict, given the episodic nature of change – whilst annual rates of retreat can vary from 1 m/year to 6 m/year at different places along the shoreline, during a single events slab failure of the dunes means that there can be significant losses: up to 18 m retreat was recorded in one location between 2013 and 2014. Future rates of dune erosion are therefore dependent upon the frequency and magnitude of future storm events, combined with beach condition at the time of the storm. Along much of Hemsby frontage there is now only a single line of dunes before the original cliff line becomes exposed again. This cliff is expected to be similar in composition as those to the south, i.e. sand-rich, therefore will continue to offer limited resistance to wave erosion. Slower rates from those along the dune coast would, however, be anticipated.

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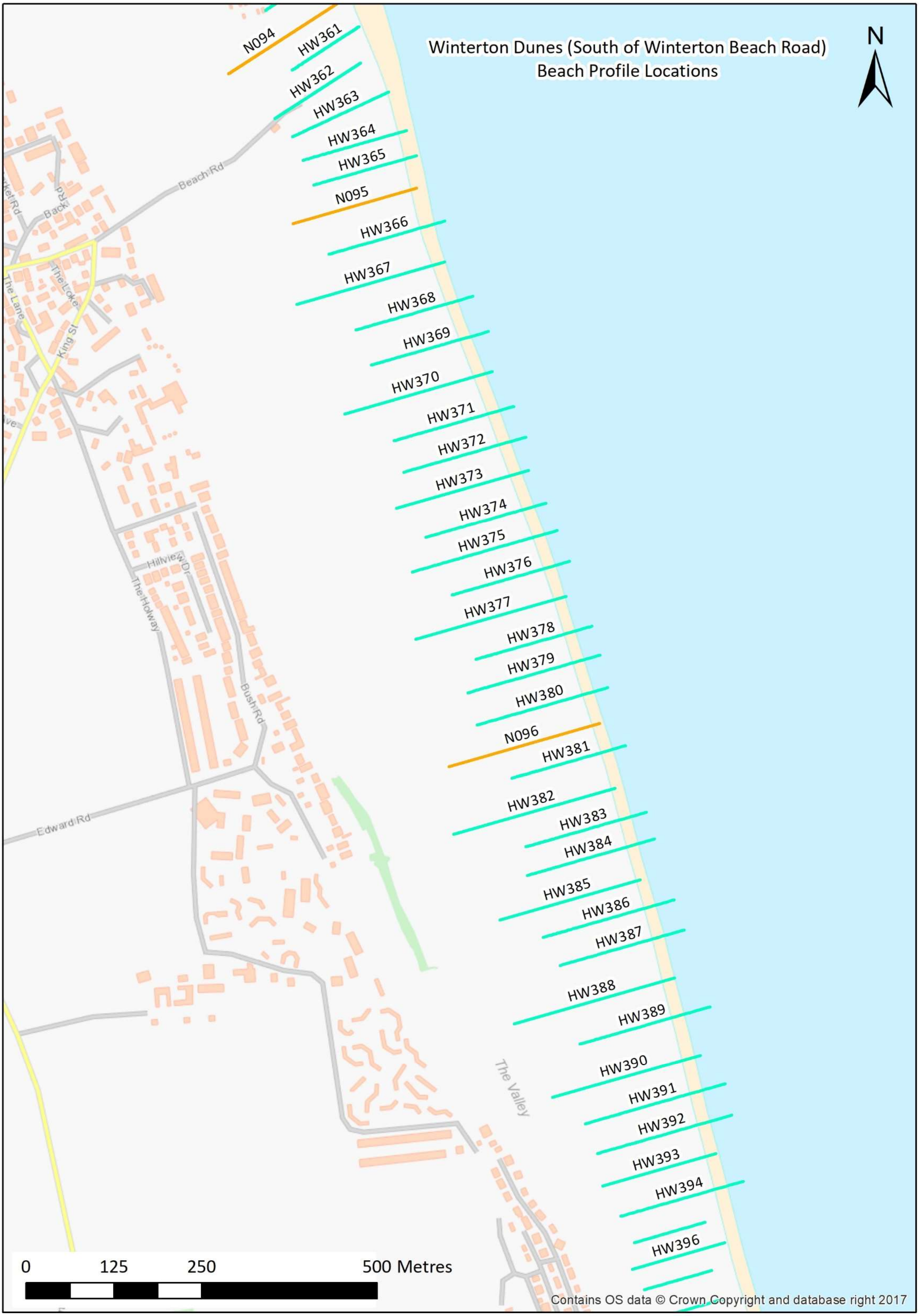
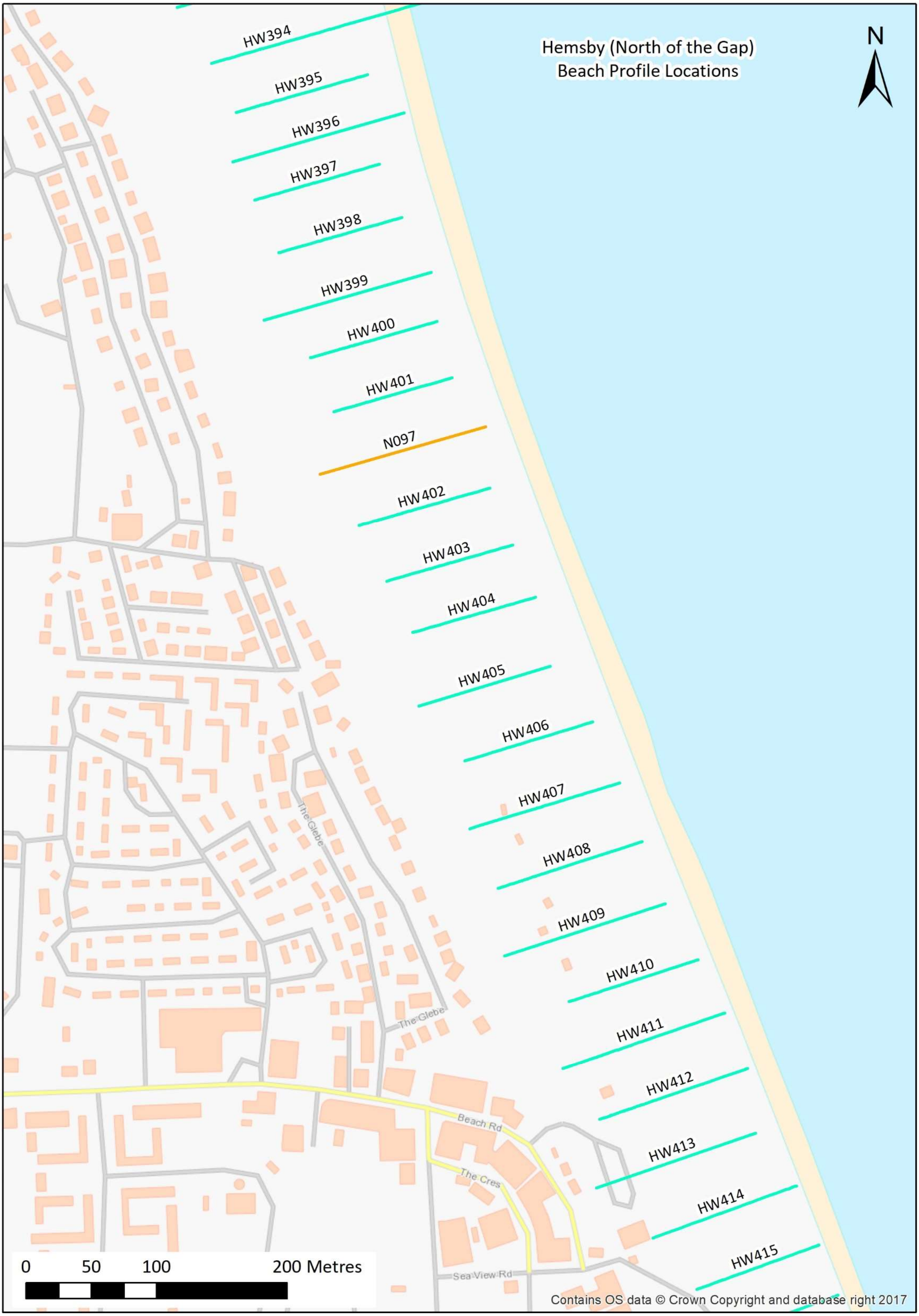
Annex 1: profile locations

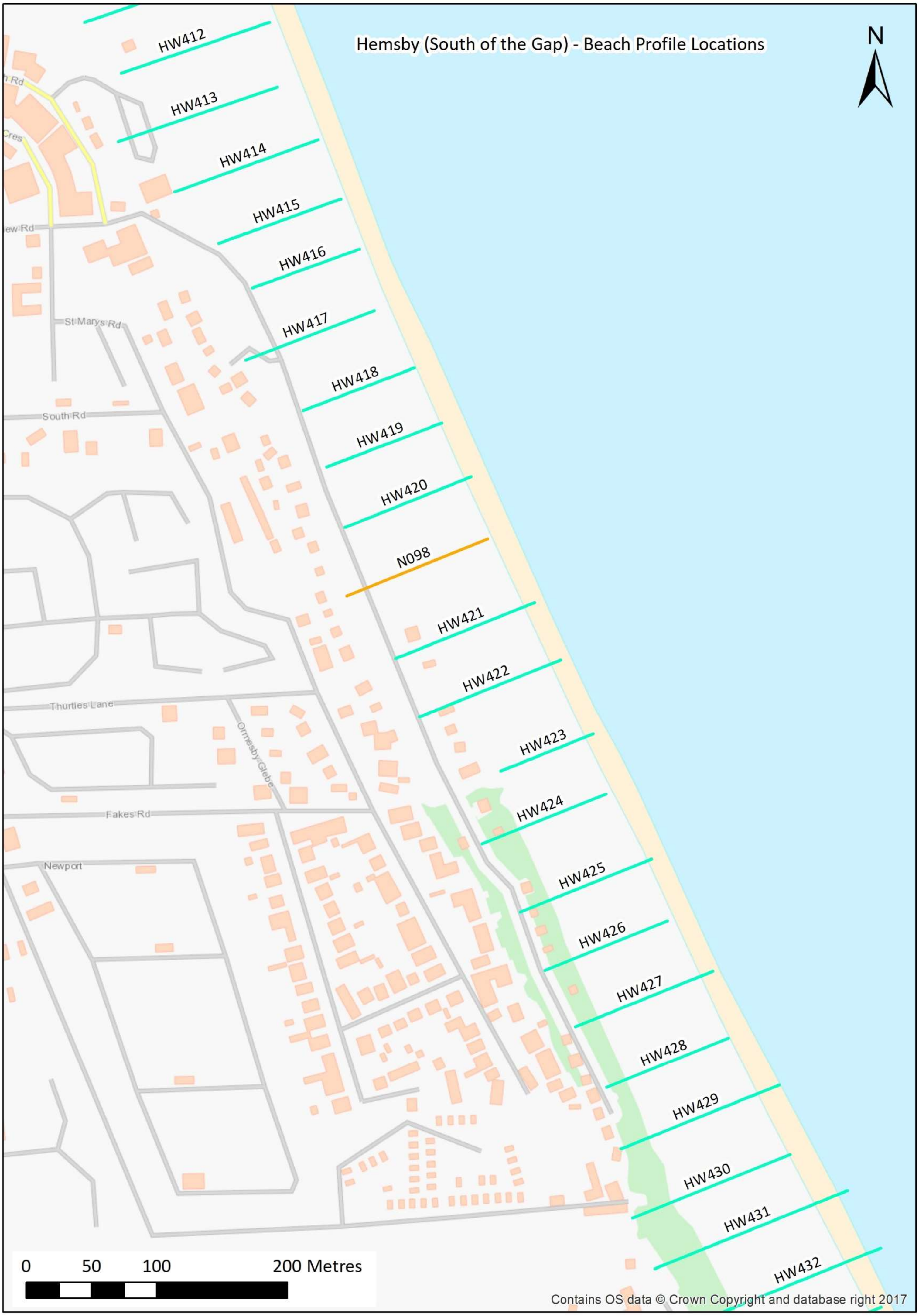
North of Winterton Dunes - Beach Profile Locations
N
HW308
HW309
HW310
HW311
HW312
HW313
HW314
HW315
HW316
HW317
HW318
HW319
HW320
HW321
HW322
N092
HW323
HW324
HW325
HW326
HW327
HW328
HW329
HW330
HW331
HW332
HW333
HW334
HW335
HW336
HW337
HW338
South Wood
0
100
200
400 Metres
Contains OS data © Crown Copyright and database right 2017


Winterton Dunes - Beach Profile Locations
N
HW332
HW333
HW334
HW335
HW336
HW337
HW338
HW339
HW340
N093
HW341
HW342
HW343
HW344
HW345
HW346
HW347
HW348
HW349
HW350
HW351
HW352
HW353
HW354
HW355
HW356
HW357
The Common
HW358
HW359
HW360
N094
HW361
HW362
HW363
0
100
200
400 Metres
Contains OS data © Crown Copyright and database right 2017

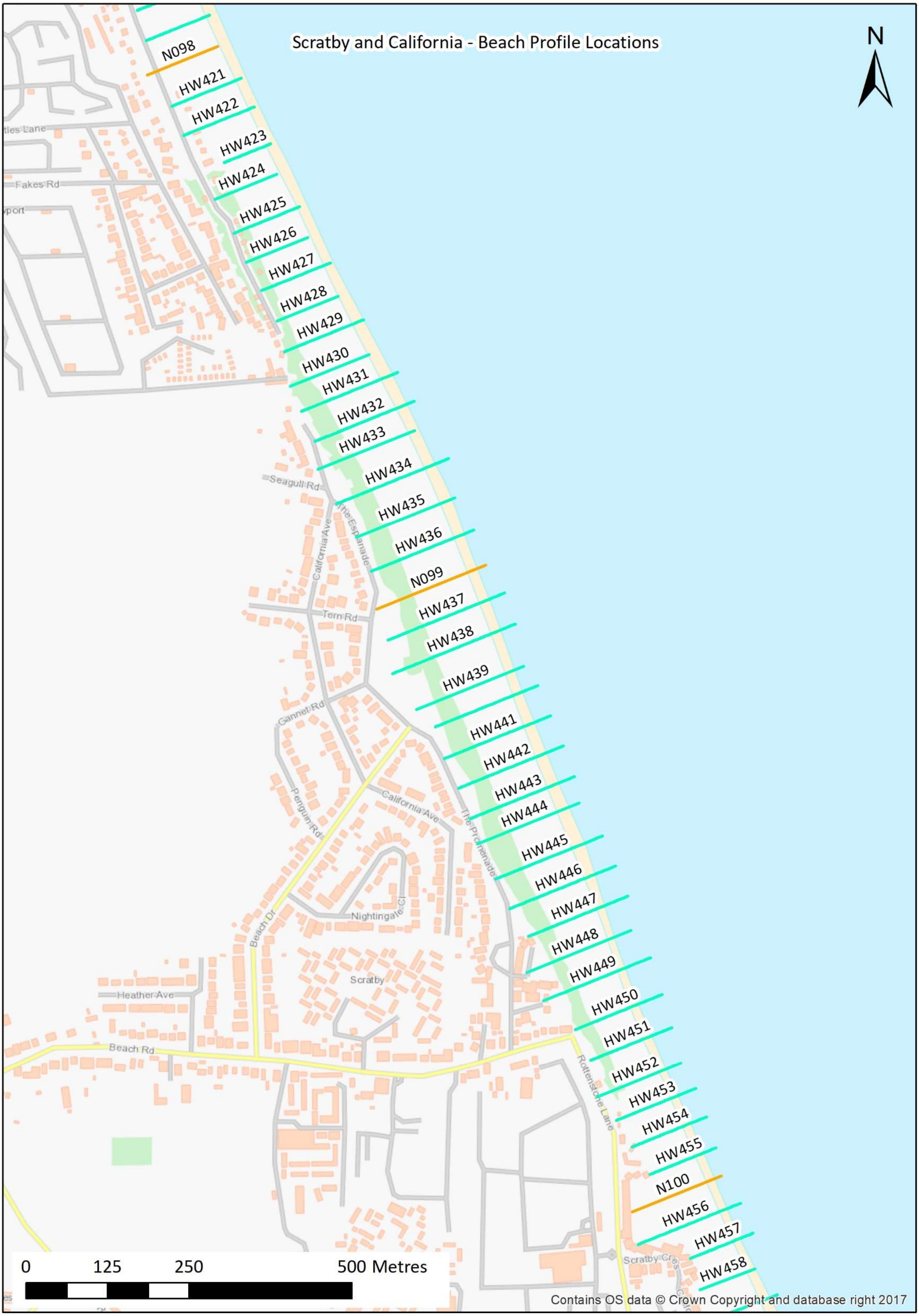


Winterton Dunes (South of Winterton Beach Road)
Beach Profile Locations
N
N094
HW361
HW362
HW363
HW364
HW365
N095
HW366
HW367
HW368
HW369
HW370
HW371
HW372
HW373
HW374
HW375
HW376
HW377
HW378
HW379
HW380
N096
HW381
HW382
HW383
HW384
HW385
HW386
HW387
HW388
HW389
HW390
HW391
HW392
HW393
HW394
HW396
Beach Rd
Back Rd
The Loke
The Lane
King St
Hillview Dr
The Holway
Bush Rd
Edward Rd
The Valley
0
125
250
500 Metres
Contains OS data © Crown Copyright and database right 2017


Hemsby (North of the Gap)
Beach Profile Locations
N
HW394
HW395
HW396
HW397
HW398
HW399
HW400
HW401
N097
HW402
HW403
HW404
HW405
HW406
HW407
HW408
HW409
HW410
HW411
HW412
HW413
HW414
HW415
The Glebe
The Glebe
Beach Rd
The Cres
Sea View Rd
0
50
100
200 Metres
Contains OS data © Crown Copyright and database right 2017



Hemsby (South of the Gap) - Beach Profile Locations
N
HW412
HW413
HW414
HW415
HW416
HW417
HW418
HW419
HW420
N098
HW421
HW422
HW423
HW424
HW425
HW426
HW427
HW428
HW429
HW430
HW431
HW432
St Marys Rd
South Rd
Thurtles Lane
Ormesby Glebe
Fakes Rd
Newport
0 50 100 200 Metres
Contains OS data © Crown Copyright and database right 2017



Scratby and California - Beach Profile Locations
N
N098
HW421
HW422
HW423
HW424
HW425
HW426
HW427
HW428
HW429
HW430
HW431
HW432
HW433
HW434
HW435
HW436
N099
HW437
HW438
HW439
HW441
HW442
HW443
HW444
HW445
HW446
HW447
HW448
HW449
HW450
HW451
HW452
HW453
HW454
HW455
N100
HW456
HW457
HW458
Fakes Rd
Seagull Rd
California Ave
The Esplanade
Tern Rd
Gannet Rd
Penguin Rd
California Ave
The Promenade
Nightingale Cl
Beach Dr
Scratby
Heather Ave
Beach Rd
Rottenstone Lane
Scratby Cres
0 125 250 500 Metres
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FINAL

Appendix B: Assessment of coastal defence options

Prepared for

Great Yarmouth Borough Council

June 2018

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Contents

This appendix

This Appendix looks at the suitability of different types of defence that might be considered for the Hemsby frontage. These are:

1. Dune/cliff stabilisation
2. Gabions/stone filled mattresses
3. Geotextile sand containers
4. Rubber tyres
5. Intermittent blocks
6. Concrete seawall
7. Blockwork wall
8. HexiBlocks
9. Rock revetment
10. Rock berm
11. Other revetment systems
12. Timber wave break
13. Concrete armour units
14. Beach nourishment
15. Groynes
16. Nearshore breakwaters
17. Sill/submerged reef (perched beach)
18. Headland structures
19. Sand motor

The following assessments are provided for each of the above, presenting details as follows:

- Type – nature of defence being described and assessed
- Description – brief explanation of the defence type and how it works
- Examples of application – other locations where a similar type of defence has been implemented (identifying local examples where possible)
- Likely effectiveness at Hemsby – assessment of whether or not this might work at this location and reasons why
- Other considerations – any other points that might be a factor in making a decision on this option
- Typical costs – costs from other schemes/locations (but not necessarily the full costs of applying at Hemsby, which the main report addresses).

Assessments

TYPE:	Dune/Cliff Stabilisation

DESCRIPTION:

A variety of techniques exist for stabilising the face of dunes by trapping windblown sand, including:

- dune planting – adding vegetation such as marram grass;
- dune thatching – using brushwood or forestry cuttings;
- dune fencing – timber palisades bound together;
- bitumen spraying – temporarily fixing the dune surface through adding binding material.

Other techniques used on eroding cliff faces can include soil nails and surface water drainage, but those are not going to be suitable on this soft and non-cohesive erodible surface.

EXAMPLES OF APPLICATION:

The example here shows the use of dune fencing along the upper beach and at the toe of the dunes (source: *Scottish Natural Heritage (2000) "A Guide to managing coastal erosion in beach/dune systems*).

More locally, dune fencing has been undertaken to the north of Hemsby, at what is known locally as, the Crater to encourage dune growth.

LIKELY EFFECTIVENESS AT HEMSBY:

These measures typically only work where they enhance natural dune recovery in a relatively low energy environment, not one where the toe of the dune is being regularly eaten away by wave action and that wave energy is too high to be resisted by the natural dune system.

In summary, these are not going to be effective at Hemsby, where aggressive wave action will simply remove these attempts to stabilise the dune face.

OTHER CONSIDERATIONS:

None.

TYPICAL COSTS:	Not applicable.

TYPE:	Gabions/Stone-filled Mattress

DESCRIPTION:

Gabions are wire, PVC coated or HDPE cages, which are filled with small rock, stone or cobbles to build a wall or revetment (either vertical or on a slope) along the erodible edge of the upper shoreline.

Being permeable, due to the stones, they help to both absorb and dissipate some wave energy. Being flexible, they can also adjust and reshape to a limited extent without losing their integrity. That however is also their weakness; any beach lowering resulting in settlement can lead to them becoming stretched and splitting open, at which point they become ineffective. Corrosion of the steel mesh is an issue in a saltwater environment, whilst another problem can be the susceptibility of the cage to abrasion, especially in a highly aggressive shingle environment, again leading to the units become split and failing.

For these reasons, gabions are widely recognised as being not ideally suited to the open coast, but can offer some short-term protection where other options are not available, having the advantage of being reasonably easy and inexpensive to construct, and using local materials to fill them where available.

A recent variation on gabions has been rock rolls and rock bags (e.g. Kyowa Bags), which are geosynthetic mesh sacks filled with small rock or stone. These have been used for short term protection in areas of scour, e.g. used as emergency works along the Thames, or in deeper water to provide anti-scour protection. But, the suppliers themselves note concerns over use in areas significantly influenced by direct wave impact: the stone is regularly moved by the waves and that action can lead to abrasion of the mesh, which will result in holing and thus failure as the structural integrity is immediately lost.

EXAMPLES OF APPLICATION:

These have already been used at the southern end of Hemsby and along the Scratby frontage, built in the form of a near vertical wall.

As can be seen in the second photo, beach lowering (as a result of 2018 storms) has led to their undermining and consequential overturning, illustrating one of the main issues with any type of linear defence along this coast unless a suitably deep and robust foundation/toe is provided. Other issues with gabions, namely stretching and splitting apart, are illustrated by the third photo.

Another application on a similar coastline is at Thorpeness (Suffolk) where they have been laid on the slope at the base of an eroding soft cliff. As can be seen in the second photo, they have helped protect the toe but there has still been some slumping of the upper cliff.

LIKELY EFFECTIVENESS AT HEMSBY:

Gabions/stone-filled mattresses are not an ideal solution on the coast, but are recognised as being a means to offer a period of added protection where other options are too expensive or difficult to provide, with the understanding that these could last a few years under some conditions, but could also be significantly damaged by the next major storm event.

As with other linear options, these will not address the natural foreshore lowering process, but due to the dissipative characteristics of these structures upon waves, there would be less beach scouring than some alternatives. These would, however, need to be trenched into the beach to a depth sufficient to prevent undermining and deformation.

Although deformation and scour may be experienced in any configuration, if placed near-vertically (wall fashion), these are more susceptible to collapse and failure. This has been observed on this same stretch of shoreline already in the most recent storms. So, placing on a slope, or in a stepped arrangement would be advisable, albeit more costly due to the greater number of baskets. There would also be a need to import more stone/rock to fill these baskets.

In summary, if an interim fix needs to be found whilst a longer-term solution is being sought, then this could be an option to consider. But it is not a long-term solution and carries risk of potentially being damaged by storms, but no more so than many other interim options. The advantage of this approach that these structures may be easier to repair or replace than some of those alternatives.

OTHER CONSIDERATIONS:

None noted.

TYPICAL COSTS:	The 900 m of gabion wall at the south end of Hemsby and along the Scratby frontage cost approximately £620,000 in 2015/16, which equates to just under £700 per linear metre. However, costs will depend upon the size of the wall; a larger (wider and deeper) structure would be advocated, even for short-term protection.

TYPE:	Geotextile Sand Containers

DESCRIPTION:

There has been an increasing use of sand-filled geotextiles in recent years in many countries around the world, mostly outside of the UK. Although these may be seen as a new development, they have been in use for over 20 years and aspects of their design and implementation have evolved over that time through monitoring of performance and investment in Research & Development.

These containers are formed from UV-stabilised geotextile fabric and filled with locally obtained sand, i.e. from the site itself. They can vary considerably in size from less than a tonne to several tonnes in weight and range from individual (but large) bags through to geotubes, which can be 20 m long. This lends itself to a high level of flexibility in terms of the configuration of the defence structure required at any particular location.

These create their mass by being filled up with sand which cannot then be mobilised, and being of large size they are not easily displaced by waves and therefore able to offer some resistance against a breach. There is the potential to be susceptible to vandalism, and once torn or split their ability to retain the sand is lost and so is their effectiveness. However, reports on some of the recent improvements include: using more vandal-deterrent fabric (more puncture resistant whilst retaining necessary permeability), advances in stitching techniques/control, and better understanding of the optimum sand fill ratio to achieve best hydraulic stability.

The effectiveness is highly dependent upon the quality of the product and installation. There are now several specialist companies who manufacture and install these systems, having developed a valuable understanding and expertise on critical specific aspects for their success.

EXAMPLES OF APPLICATION:

There are numerous examples from around the world, including in Australia, USA, Asia and Europe. The photographs to the right are an example of a geotube scheme on the Atlantic coast in Portugal *(reproduced with permission of Tencate Geosythetics)*.

Problems occur where the products are poor, not vandal-proof, filled with shingle or placed on shingle beaches, where abrasion or tearing of the bags can occur. The experience at Thorpeness, Suffolk (left) is an example of such problems, illustrating how quickly some installations can be ineffective if they are not the right system and product or not installed by a specialist with the right equipment and skills.

LIKELY EFFECTIVENESS AT HEMSBY:	
Geotextile containers filled with sand are becoming more widely used as means to offer protection where other options are less viable or too expensive. In other locations where used to protect dunes, these containers might be buried and exposed only under extreme conditions, providing that essential barrier at the time of need. However, they would most probably be permanently exposed at Hemsby due to the loss of beach and lack of sand retention here. Like other linear options, a barrier or wall built of these at the base of the dunes is not going to prevent the foreshore lowering problem, although these structures may be able to adapt better than some alternatives. Reports into their application discuss improved products, which have the ability to elongate without splitting open, such that they may adapt better to changing beach levels. There is also an advantage in that the structure can always be added to later if further adjustments or additions are required. Consequently, the best form of the structure and nature of containers used (e.g. larger tubes or smaller bags) would need to be considered as part of the design. In summary, this may be worth consideration, and compares favourably with some of the alternative lower cost options, although it should probably still be regarded as an interim solution rather than the long-term answer. These will require some maintenance and replacement in the future and if beach level lowering continues to be as extreme as current trends indicate, not only will that potentially lead to undermining beyond a level the containers can extend to, but also access to undertake their replacement, in say 25 years, may no longer exist.	
OTHER CONSIDERATIONS: As they are likely to be permanently exposed at Hemsby, geotextile sand containers may not be considered to be an aesthetically desirable option by some. Although newer products have been developed to be more vandal proof, this is still a risk that would need to be considered. This section has considered geotextile sand containers for use in a linear wall, but they could also be used in other ways for coastal defence, including creating groynes and submerged breakwaters.	
TYPICAL COSTS:	Costs will depend upon the size of the structure to be built and the nature of the containers used, but as an approximate guide, costs for other applications have been in the range of £30-£40 per m^3, so a wall built of these at Hemsby might be of the order of £2,000-£2,500 per linear metre. Whilst cost rates will vary around the world, information on one scheme in Australia, identified the material, placement and ongoing maintenance costs for structures made of these to be approximately half of that for the equivalent rock scheme. However, that was based upon a 25-year life expectancy, so if a 50-year design life was sought, the whole life costs would be similar to rock.

TYPE:	Rubber Tyres

DESCRIPTION:

One proposal has been made for tyres at the base of the dunes, based upon other schemes where they have been lashed together in a honeycomb pattern constructed in a trench, or variants on that idea. The tyres might be infilled with sand or stone, to add to the stability, or concrete could arguably be used.

Although used in some open sea situations (submerged reefs off the coast, seabed pipeline protection), various reports suggest that their application is considered to be better suited to sheltered low energy environments where high wave activity is not high, for example in estuaries or along river banks.

A guide on managing shorelines produced by Scottish National Heritage (2000) notes for example "*Tests made in the USA categorized the wave height range under which tyres could be used as being below 2 feet (less than 0.6m)*".

EXAMPLES OF APPLICATION:

Previous applications for erosion problems appear to be river/estuary channels, as floating breakwaters, or beneath the sea as scour mattresses or submerged reefs. No example of a successful installation in an open coast environment has been identified.

A research report (SR669) produced by HR Wallingford in 2005 looked into the sustainable reuse of tyres, highlighting one application in the USA, but concluded "*tyre and post revetments have been built to prevent coastal erosion but with limited success…. washout of fill from the tyres by wave action reduces their weight, allowing them to become displaced relative to one another.*" That same research report also notes that model testing of a tyre bale revetment under wave action concluded "*that they weigh too little to withstand even moderate wave forces without substantial anchoring.*" As such the only potential use advocated by that report was as a possible hearting material (e.g. tyre bales within the core of a rock structure or barrier beach as an alternative to fill), but also noted the outstanding need to better understand the potential long-term deformation of these under the weight of the overlying material.

The beneficial use of waste tyres as a defence has also been explored by the Environment Agency and tested in areas such as Broadland, where they have been installed in various designs and their performance monitored over a period of years. However, the monitoring has not been wholly in favour of the use of tyres as a form of bank protection. The tests were found to have expensive installation and maintenance costs. Tyres also degrade over time, with the action of salt water and release chemicals into the water environment; the steel reinforcement rusts and could be cause for health and safety concerns.

For sea defences, the Environment Agency also tested the use of tyres enclosed in a strong steel cage. However, in this harsh environment it was found that the steel rusts quickly and there is the longer-term risk that the tyres can break free. There are also environmental and visual considerations to take into account.

LIKELY EFFECTIVENESS AT HEMSBY:

Previous examples of application appear to be mainly in lower energy environments, not conditions similar to the highly aggressive and dynamic conditions experienced on the open coast such as on Hemsby beach. There are question marks over how the tyres can remain safely held

together under extreme wave forces, and how a wall built of these would remain stable under volatile and lowering beach levels. If the tyres break lose then waves could readily carry those over a considerable distance, both along the coast and onto the seabed. Sediment may accumulate within the body of the tyre, and help reduce the rate of erosion behind the wall, but tyres will not address the foreshore lowering problems; indeed they will be reflective and potentially exacerbate local scouring from waves. Promotors of this approach note that “if, in exceptional circumstances, some scouring takes place, the tyres will settle to accommodate it and a further course of tyres added”. However, even if these remain stable, there would be that ongoing commitment to adding more layers once they had dropped to the new level, with a tyre wall of considerable height developing. The stability characteristics of a tyre wall several metres high are untested. In summary, there is no doubt there is a growing problem with the disposal of old tyres, and approaches seeking to recycle those are to be applauded. But installing these as a form of coastal defence in an environment such as Hemsby, where their stability and effectiveness is questionable, is not necessarily the right solution.	
OTHER CONSIDERATIONS: A defence built of tyres will be visually intrusive and probably not compatible with the impression of a beach that the local tourist businesses are seeking to promote. Although tyres can degrade, like plastics, rubber is not naturally biodegradable so there would be concerns over long term damage to the water body and marine life. Even if previously deemed acceptable to use tyres in the sea (e.g. for outfall protection), there is likely to be much more opposition now as awareness of this potential grows. A further issue with tyres is the release of toxic waste gases if they are set alight, and the difficulty in dousing that fire. Unfortunately, beach fires. even where prohibited, and vandalism, make this an unfortunate but real risk in coastal locations.	
TYPICAL COSTS:	Not applicable.

TYPE:	Intermittent Blocks

DESCRIPTION:

In emergency situations a reactive approach can to create a barrier to prevent further erosion. One of the easiest and quickest form of is to lay any large blocks along the backshore. Commonly such works look to make a small amount of material go as far as possible by placing these in an open array, either intermittently or adjacent to one another.

Such blocks may already be available (old WWII tank traps for example have been utilized in this way) or concrete blocks may be produced for the purpose. In other instances, large rocks might be used if they are available, and even large pieces of building rubble have been used in places.

This arrangement is quite distinct from a wall or revetment, as the blocks have little if any interface with one another, so the barrier lacks the overall structural integrity that is gained from more formal defences. Consequently, these tend to be haphazard structures, with no design involved.

EXAMPLES OF APPLICATION:

An example of this approach already exists on Hemsby beach, with the novel idea of using large aggregate bags as forms into which concrete has been poured. These still remain in place, although they are now at a lower level as the beach levels dropped and the scouring by waves have probably further induced their settlement. Crucially, they have not prevented erosion of the dune face behind.

Further north, at Winterton car park, large blocks have fallen onto the beach, but in a random and disconnected array. This illustrates that even where the blocks themselves are massive, the individuality of the open array significantly compromises their effectiveness with little if any difference in the beach level landward of them after a storm, and active erosion taking place behind them.

LIKELY EFFECTIVENESS AT HEMSBY:

The lack of effectiveness of this type of approach at Hemsby is already demonstrated by the well-intentioned but ultimately unsuccessful application of concrete filled bags over two short lengths, as well as the limited effect of the larger blocks that have fallen onto the beach at Winterton.

The spacings resulting from the open array does little to break up the wave energy compared to blocks placed in a close array. Individually, they are generally too small to have a significant effect on the waves, which tend to pass through and over them. Indeed, they will most likely exacerbate scouring around their base, liquifying the sand and adding to their settlement.

A better use of such blocks is in a bund or revetment form, e.g. irregularly placed at least two to three blocks wide and high to have greater structural integrity though the friction and interlock with other units. This will also create spaces between the blocks that will dissipate the wave

energy more effectively. This is effectively a 'low tech' type of concrete armour unit (or rock armour) defence structure, which is assessed elsewhere in this document. In summary, an open array of blocks is not going to provide effective protection at Hemsby, not even as a short-term option.	
OTHER CONSIDERATIONS: None.	
TYPICAL COSTS:	Not applicable.

TYPE:	Concrete Seawall

DESCRIPTION:

Seawalls can vary in shape and detail, but are generally a vertical or near vertical impermeable structure built of reinforced concrete. Seawalls are designed to withstand extreme wave attack, and are constructed to be higher than the most extreme water levels and will often include a recurve or bullnose on the upper walls to help reflect most of the wave energy back seaward rather than over the wall.

The lower wall may be sloped or incorporate a series of steps, and in all cases a well-constructed toe is critical (past research has identified undermining and toe failure as the most common reason for coastal defences to fail). The toe of a seawall is often constructed with steel sheet piles, designed to prevent movement of the base of the wall, loss of fill from beneath the wall, and provide overall stability to the wall when beach levels fluctuate.

Except on rocky shores, a common problem with seawalls can be scouring of the beach/foreshore in front of the wall due to their highly reflective nature; along many older walls rock toe has been placed at the base of the wall in front of the sheet piling, to help limit the extent of this.

Although the construction of seawalls was popular in the past, and they are still sometimes appropriate as part of the defence system in more urban areas where a formal line of defence is required, or where deeper water exists, seawalls are now regarded to be detrimental to the stability of beaches on soft and dynamic shorelines, so are not widely favoured.

EXAMPLES OF APPLICATION:

There are numerous examples of seawalls around the UK, in a range of different forms, although one of the most common is that with a recurve wave wall at the rear, as seen in this example at Southwold.

As described above, frequently there are scour problems in front of these seawalls on soft shorelines with low beaches. This often requires further works to reduce wave reflection, scouring and subsequent failure; rock is often placed in front of the sheet piling (e.g. right, along section of the Happisburgh to Winterton frontage).

In contrast, south of Hopton on the Norfolk Suffolk boundary, the consequences of a seawall failure where such adaptation was not undertaken can been seen here. This is a stark illustration of the longer-term vulnerability of these structures on a coastline where there are similar issues with an eroding beach and transgressive shoreline, which the seawall alone will not address.

LIKELY EFFECTIVENESS AT HEMSBY:

A seawall could provide stability and halt the backshore dune erosion at Hemsby, but it will not prevent the ongoing issue of foreshore changes. Unless the pattern of coastal processes alters there is likely to be further foreshore lowering due to natural process, with a seawall further exacerbating that situation due to the high levels of wave reflection off the wall. That would require extremely deep toe piling, quite probably a rock toe or other measures to limit that scour and prevent undermining. The consequence of this could be a frontage which is protected but with no beach – with the sea reaching at the wall at all states of the tide.

Corrosion of steel exposed to a saltwater environment, and especially Accelerated Low Water Corrosion (ALWC) is another well-recognised and widely reported problem that limits the lifespan of these structures unless they either remain buried, or significant refurbishment at significant cost is allowed for in the future. With low and potentially falling beach levels at Hemsby, this would be another concern.

In summary, a large concrete seawall at Hemsby could provide several decades of protection to the eroding dune face, but only at considerable cost, both in terms of the construction and maintenance of what would need to be a substantial structure and in terms of the potential loss of any useable beach.

OTHER CONSIDERATIONS:

Seawalls are generally one of the most expensive forms of coastal defence.

The complete loss of beach that will probably result is expected to be detrimental to the tourism industry that is so important to the local economy.

Exacerbating the scouring along this frontage and having a deeper water frontage could disrupt the littoral transport regime, to the detriment of Scratby and frontages to the south.

TYPICAL COSTS:	One ongoing seawall scheme in North-West England is costing approximately £15 Million for approximately 1 km, another is costing approximately £60 Million for 2 km of defence (i.e. £30,000 per linear metre). A recently constructed scheme in North-East England is reported as costing approximately £9 Million for 800 m of seawall (i.e. just over £11,000 per linear metre), although this did not require the deep toe that would be required at Hemsby, which would add at least another £3,000 to £4,000 per linear metre.

TYPE:	Blockwork Seawall

DESCRIPTION:

An alternative to the more common reinforced concrete seawall described elsewhere, is a blockwork wall. These structures are built, as the name suggests, from (unreinforced) individual precast blocks placed in a brickwork fashion, as might be seen in regular wall.

Some traditional seawalls were blockwork built in a similar fashion (albeit from masonry not concrete blocks), and this is a technique still used extensively elsewhere, such as Dubai where large vertical deep-water walls are desired, e.g. for ports and marinas, and reinforced concrete is not suitable due to the high salinity of the seawater.

Some proprietary systems using this technique have also been developed, for example T-Blocks, providing a modular interlocking system using blocks of regular shape and size. In the case of the T-Blocks, these can also be constructed to provide an irregular face to the waves and thus reduce wave reflections compared to a flush vertical face.

The blockwork walls originally built around the UK would have been built with a footing, but not piled, and at a depth not anticipated to be exposed, although that has not always been the case and works to provide additional stability have been required in several instances. In many cases these types of walls were built in areas where there was a rocky foreshore, so undermining was less of a risk. Those built more recently in the Gulf are generally built on a base of placed rocks, but these are typically deep-water structures and not subject to scouring or lowering of the bed at the toe.

EXAMPLES OF APPLICATION:

A traditional blockwork seawall in the UK is shown to the left, with a recent blockwall wall construction in the Gulf shown to the right.

The only known application of the T-Block is in North West England at Whitley Bay.

Image courtesy of Poundfield Products and Hall Construction Services.

LIKELY EFFECTIVENESS AT HEMSBY:	
One of the advantages of this type of structure over some others is that it is modular construction, so very easy and quick to install once the concrete blocks are cast. The arrangement of the blocks can also be made to present an irregular face and thus reduce wave reflections compared with a smooth face, but they still present an impermeable barrier and will still have much higher wave reflections than a permeable structure designed to dissipate the wave energy. Consequently, they will still be prone to some potential scouring action in addition to any natural foreshore lowering. Foreshore lowering and accommodating that within the design is the major disadvantage of these type of structures, and determining a suitable foundation is problematic. The significance of having a suitable toe is also highlighted in an early report testing the stability of the T-Block (HR Wallingford), although would be a similar consideration for all forms of blockwork wall. That report noted a permeable foundation led to the collapse of the test section, whilst on other tests there was a tendency for the wall to tilt forward slightly due to some loss of the surface of the underlayer. Any direct comparison with the construction of blockwork walls at other locations must consider the differences in the local setting. For example, the T-Block wall built in Whitley Bay is believed to sit above a rocky foreshore, which will not be prone to the same extremes of foreshore volatility and lowering that can occur at Hemsby, and thus a stable foundation could have been more readily provided. Others built, for example in the Gulf, are generally deeper water structures, where the base is again not subjected to significant changes in bed levels that could undermine and destabilise those walls. In summary, although the structure can be trenched in to some depth to allow for several years of lowering, the seasonal volatility combined with the natural reduction in levels here mean that this will be a time-limited solution and failure, if it occurs, could be fairly instantaneous.	
OTHER CONSIDERATIONS: The loss of beach that will probably result is expected to be detrimental to the tourism industry that is so important to the local economy.	
TYPICAL COSTS:	Media reports that the 50 m long blockwork wall in Whitley Bay cost £210,000. However, a much more substantial structure would be required at Hemsby.

TYPE:	HexiBlocks

DESCRIPTION:

HexiBlocks are hexagonal-shaped reinforced concrete blocks, weighing just under 5 tonnes, with an opening through the centre of the block. These were an innovative approach developed specifically for Hemsby to address the erosion issues following the storms of 2013.

The concept is based upon sound scientific principles – creating voids to dissipate the energy of waves striking the blocks, rather than reflecting those waves seaward and exacerbating scouring as a vertical seawall might.

The trial structure built at Hemsby involved 150 blocks, placed two blocks high, with a second row behind placed in a longitudinal manner to prevent water shooting straight through to directly erode the dune face behind. The structure was placed on geotextile matting, which also ran up the back, with the whole structure bedded at a level of +0.6mOD – on the basis that +0.8m was the lowest recorded level of that section of beach at that time (although the source of that information though is unclear) – which it was felt would ensure undercutting would not be a problem.

It must be noted that this built configuration was an adaptation of the original design concept, due to the limited availability of funds for the trial. The original design was to stack the blocks three high, to improve the compressive strength of the wall, and for the rear blocks to have their openings also facing seaward but offset in order to further break up the wave as water passed through the openings in the front row and also to provide more support to the front row so the latter would be less likely to ride up and move under heavy seas.

One evolution of the design proposed by the designers, since the trial, is to taper the holes to form a trumpet effect to speed up the removal of seawater entering the holes and prevent that damaging the dunes.

EXAMPLES OF APPLICATION:

The only (known) application of the Hexiblock has been at Hemsby, although the principles behind this novel idea follow a tried and tested concept; units using those same principles have previously been developed and successfully used in at least 20 to 30 other locations around the world in the past, notably units called the Seabee, the Cob and the SHED (see 'Other Revetment Systems' elsewhere in this document).

However, the similarity ends there; those other units are placed on a slope and dissipate the wave as it runs up and over the slope. The Seabee, SHED and Cob units are all single layer, pattern-placed units of high porosity, which achieve high stability through the friction with neighbouring units due to the close placement. They also benefit from being placed on top of a layer of rock, which is critical to their performance as this further dissipates the water going into the voids in a multitude of directions rather than funneling it through in a single direction; indeed in the case of the Cob and SHED they also had openings to their sides and top and bottom, to further dissipate energy. Those other units have also undergone extensive laboratory testing to ensure their characteristics provide the optimum hydraulic performance.

Following the 2018 storm damage, the condition of the HexiBlock wall at Hemsby was inspected. As the photographs below illustrate, there had been considerable displacement of units and clear signs of undercutting and scouring beneath the units in the absence of any foundation, evidenced by them pitching seaward. Although these may have reduced the extent of erosion at the dune face, compared to adjacent stretches, there was still very clear and notable active erosion and loss of dune. In the context of assessment criteria used to categorise the condition of defences, this wall would be considered to have failed.

LIKELY EFFECTIVENESS AT HEMSBY:

In considering the effectiveness of HexiBlocks at Hemsby, it must be acknowledged that the existing wall was just a trial, from which lessons are inevitably going to be learned. It must also be recognised that the trial structure was somewhat different to what the designers intended. Assessment on effectiveness is therefore made on what the full wall would comprise, although the outcome of the trial has provided some useful detail to inform that.

Dealing first with the fundamental issue at Hemsby, the foreshore lowering occurring as a natural process is one that any linear defence structure is not going to halt even though the HexiBlock is less likely to exacerbate scouring. But, like blockwork walls (see separate assessment), accommodating foreshore lowering within the design is going to be a problem with any type of rigid structures, compared to some of the more flexible and dynamically adjustable forms of defence, and determining a suitable foundation is problematic. The only real option would be to trench the blocks in at some considerable depth based upon forecast trends in beach change, which will obviously increase the cost of the wall. The other aspect to be considered in this context is the provision of a firm base upon which to found these blocks, as the trial again

illustrates. In the same way we would not contemplate constructing a brick building directly on sand without any foundation, a wall of this size needs to be constructed with similar consideration. Any such wall really ought to be placed on a bedding layer of rock or concrete, and even then there could be a risk of undermining in the longer term. This is especially important if the integrity of the wall depends on the interaction (friction) between individual blocks, as differential settlements would compromise that. A second question arises over the effectiveness of the concept for dissipating waves. As described earlier, other systems have done this effectively, but have two significant differences; they lie on the slope, so break the wave as it flows over them, and they are unpinned by a rock layer which also has a critical role in dispersing the wave energy. In contrast, a HexiBlock wall is a vertical structure and the waves impact this directly with nowhere else to go other than through the holes. As a consequence, it is considered the openings are more likely to result in a jetting action of the water through the blocks, with no features to disperse those jets randomly in other planes. That might be improved by placing rock (possibly even gabions) behind the second row of blocks. If a scheme were to proceed with these units, then there are some further design refinements that ought to be considered (although these are not necessarily exhaustive). For example, an observation from the trial is that the current design of the HexiBlock is probably too light and the weight of these units need to be greater for the wave conditions experienced here. Extreme storm waves can displace some of these units, and with that the overall wall integrity rapidly diminishes. Indeed, a change in the configuration of these to have a greater surface area abutting adjacent units might also be considered. Another design refinement would be to seek an alternative to steel reinforcement, e.g. using fibre products instead, due to the aggressive effects of salinity on steel in a maritime environment. In summary, the HexiBlock is a novel idea and based upon some good principles. But, the considered opinion is that it does require further design development to be effective as an energy dissipating defence structure. Notwithstanding that, the underlying issues causing the erosion at Hemsby are going to present a significant stability issue for a number of defence types, not just the HexiBlock. Consequently, it is unlikely that this can provide the long-term solution for Hemsby.
OTHER CONSIDERATIONS: The developers of this unit indicate a period of approximately 2 years would be required to supply and construct a scheme over a distance of 2 km. This is a very long duration for a scheme of this size.

TYPICAL COSTS:	Based upon current design proposals the estimated cost for 2 km of HexiBlock wall is £4.8 Million. However, to be successful, a considerably deeper wall plus foundation would be needed, and some addition to the rear of the wall would also be required, which will add considerably to those costs.

TYPE:	Rock Revetment

DESCRIPTION:

A rock revetment will typically comprise two layers of large armourstone, generally in excess of 2 to 4 tonne and even up to 10 tonne depending upon the size of waves, with a bedding layer of smaller rock beneath, either sitting on a geotextile fabric or more traditionally a stone filter layer. The revetment should be built high enough to limit wave run-up and overtopping to an acceptable level during extreme storm events, and founded deep enough to limit undermining from both episodic and long-term beach lowering.

These structures work by dissipating the power of the waves, through the gaps between rocks, whilst each rock being of suitably large mass, and with some internal friction between them, ensures that in the main they will not be dislodged during extreme storm events (although their design allows some isolated and occasional displacement, within tolerable limits).

A rock revetment is also a 'dynamic' and flexible structure, so can naturally accommodate some movements and readjustment that may result from large wave impacts and/or foreshore lowering. In the latter case, a 'falling toe' is often designed to ensure that undermining will not occur and the integrity of the revetment remains intact.

Rock of suitable quality will have a largely unlimited material life, and structures correctly designed using this material are unlikely to require much maintenance. Where there is a beach in front of the revetment, if the occasional rock is displaced it can usually be picked up with an excavator and subsequently re-placed relatively easily.

EXAMPLES OF APPLICATION:

Rock revetments (either directly on a cliff face or on the face of a pre-formed bund) are one of the most common forms of coastal protection constructed over the past 30 years, and there are countless examples of them being successfully used right around the world.

One local example is at Hopton (right). This is part of a broader scheme which also includes some beach control structures

Importantly, whilst rock schemes are simple structures, they require specific and careful design and good quality controlled construction; as with any structure their success or failure depends on the application of specific and precise design and construction internationally established rules and standards. Many rock structures not designed or placed to these standards, and therefore fail to perform adequately: there are misconceptions that the placement process involves simply 'dropping' rocks in the sea or on the beach.
LIKELY EFFECTIVENESS AT HEMSBY: A rock revetment at Hemsby would likely provide effective long-term protection to the eroding dune face, although some regrading of the sand slope may first be required to provide a stable base upon which to construct (this would also reduce the width of the revetment extending across the upper beach). Through dissipating wave energy, the revetment will reduce wave run-up and dune face erosion behind, whilst also reducing wave reflection to limit the scouring effect of those waves on the beach. These structures can also be modified or extended to account for future shoreline change, so flexibility is retained into the future. Whilst successfully limiting further erosion of the dune face, like other defences this will reduce the volume of sand deposited on the beach, so maintaining a beach will be solely dependent upon sediment from other sources (longshore drift from the north for example). However, the effect of this is unlikely to be too significant as the throughput of sand from elsewhere along the coast is much greater than the day-to-day contribution coming from erosion at Hemsby. Like all the other linear defence options, a rock revetment will not halt the foreshore lowering occurring as a natural process, so will not prevent any loss of beach, but it will not exacerbate losses in the same way as a vertical seawall or other solid structure might. In contrast, in some settings, rock structures have been observed to help accumulate sand locally. In summary, a rock revetment would be a very suitable form of defence to limit erosion of the dune face and provide long term protection to the village of Hemsby, and has inherent flexibility to accommodate future changes. However, although not exacerbating foreshore erosion in the same way that some other defence forms would, if natural processes continue to result in foreshore recession and lowering, then the consequence may be a defended coastline but with a smaller beach in front of the structure, as for other solutions.
OTHER CONSIDERATIONS: Armour rock is sometimes perceived to present a safety risk, due to people wishing to climb on them or even into the gaps where those are large, with a risk of becoming trapped. Consequently, this is sometimes an unpopular choice on recreational beaches, although they remain one of the most commonly used materials in such areas. Approaches to reduce this risk can be considered during the design and construction phase. Public access to the beach over rock works is an aspect to be addressed, although a variety of design solutions exist to accommodate this. Rock solutions retain the flexibility to accommodate future design modifications if necessary.

TYPICAL COSTS:	Prices varies depending upon size of revetment (height, width, depth) and unit rate for rock which can also vary considerably, but typically coastal revetments will cost between £5,000 and £10,000 per linear metre.

TYPE:	Rock Berm

DESCRIPTION:

Compared to a rock revetment, a toe berm will be of lower elevation, requiring less material and therefore generally less expensive.

Where this differs from a revetment is in its height and design when exposed to extreme sea levels and extreme waves. Although designed to not fail structurally, a degree of overwashing of the structure is accepted under those conditions, which will result in some occasional but limited erosion of the exposed cliff (or dune) face behind. Material from the eroded slope then accumulates behind the berm and provides a sacrificial buffer between then and subsequent storms. Ultimately, a position is reached where very limited further erosion of the cliff top is likely to take place.

Principles of these structures are however similar to a rock revetment: they consist of two layers of large armourstone with a bedding layer of smaller rock beneath, usually sitting on a geotextile fabric; they work by dissipating the power of the waves through the gaps between rocks, whilst each rock being of suitably large mass and with some internal friction between them; they are a 'dynamic' and flexible structure, so can naturally accommodate some movements and readjustment; they have a largely unlimited life and unlikely to require much maintenance.

EXAMPLES OF APPLICATION:

An example of this type of structure can be found a short distance along the coast at California.

The rock berm there appears to be working very effectively and as intended. Some limited erosion does still take place, but the structure remains stable, and there is a small beach along much of the frontage in front of the berm, although that beach is also in part due to the works implemented at the northern end of Caister.

A variation on this, albeit a much larger structure, has also been constructed at Fairlight in East Sussex. There a more substantial bund was built away from the cliff toe.

LIKELY EFFECTIVENESS AT HEMSBY:	
A rock berm at Hemsby could certainly limit the day-to-day exposure of the dune face at Hemsby and thus the smaller but regular cut back at the base of the dunes, but some erosion may still occur during extreme events. At California, the area behind is a consolidated cliff and, although only sandstone and still erodible, it is more resistant than that at Hemsby and impacts from these large events will be less. At Hemsby the exposed face is dune, so less consolidated, very unstable, and offering no resistance to any wave or current action on it. Therefore, although a berm will provide some protection, the area behind is more likely to be a lower soft sandy platform than a vegetated slope, at least until the former cliff line is exposed. In other respects, however, a rock berm will have some advantages over other forms of protection in the same way a rock revetment would, notably reducing wave reflections to limit the scouring effect of those waves on the beach in front and retaining flexibility into the future. But it will also have some of the same limitations as a rock revetment, in particular foreshore lowering occurring as a natural process will not be prevented, although any further sand eroded from the dunes would pass over the rock and could help to sustain a slightly better beach. In summary, a rock berm would help to limit and control erosion of the area behind, but not prevent some further loss of the dunes. Furthermore, if natural processes continue to result in foreshore recession and lowering, then the consequence may be a limited width of beach in front of the structure. This approach may, however, be a suitable form of defence in conjunction with other works (e.g. schemes to maintain a beach along the frontage) to limit the rate of erosion of the dune face or provide some temporary protection whilst a more permanent scheme is being developed. Depending upon the nature of any permanent scheme, the rock used for the berm could be recycled and incorporated into the new structure.	
OTHER CONSIDERATIONS: Armour rock is sometimes perceived to present a safety risk, due to people wishing to climb on them or even into the gaps where those are large, with a risk of becoming trapped. Consequently, this is sometimes an unpopular choice on recreational beaches, although they remain one of the most commonly used materials in such areas. Approaches to reduce this risk can be considered during the design and construction phase. Public access to the beach over rock works is an aspect to be addressed, although a variety of design solutions exist to accommodate this. Both these points do however appear to have been overcome at California to the south of Hemsby where this type of structure has been in place for approximately 20 years. Rock solutions retain the flexibility to accommodate future design modifications if necessary.	
TYPICAL COSTS:	The rock berm built in 1995/6 at California cost £1.4 Million, i.e. approximately £1,000 per metre length. Allowing for inflation those costs would be 50% higher today, but that was remarkably cheap even 20 years ago. More recently, the price for extending the same structure over 900 m along the Scratby frontage would have been £3.9 Million, i.e. approximately £4,300 per metre, which is more consistent with present day rates.

TYPE:	Other Revetment Systems

DESCRIPTION:

There is a variety of patented revetment block systems available, which include interlocking concrete blocks and interlinked concrete block mattresses (individual blocks linked with cables to form a flexible mattress). These are primarily used for facing embankments in rivers and estuaries, where wave conditions are less severe than on the open coast.

Other, more robust systems include Seabee blocks, which are hexagonal voided units underlain by rocks to dissipate the energy of waves running up the slope. These have been used in coastal situations. Similar wave energy dissipating armour units include the Cob and the SHED, more commonly seen on breakwaters although those have been used less in recent times with the more massive concrete armour units being more popular instead (see separate assessment).

These types of block all require a well-constructed base upon which to lay the units, together with fixing at the crest, toe, and ends, to maintain their stability. Without those, there is a risk of the system 'unravelling', exposing the protected surface, and failing.

Other systems include Open Stone Asphalt (OSA), a mixture of stone and asphalt laid on a slope to provide protection against scour. Although this can have a higher degree of flexibility in terms of toe, crest and end details, and is extendable, again it is necessary to have a well formed and compacted sub-layer upon which to construct.

EXAMPLES OF APPLICATION:

Seabees used on section of sea defences to north of Skegness along Lincolnshire coast.

Use of Open Stone Asphalt (OSA) in Thames Estuary near Southend.

LIKELY EFFECTIVENESS AT HEMSBY:	
None of these systems could be laid directly onto the dune face, even if it were regraded back to a more stable slope; they each need a firm and well-compacted base upon which to construct, which dune sand will not provide. Consequently, some form of bank/fill would need to be provided along the base of the dune, upon which the system could be laid. Furthermore, except for the Seabee units, wave conditions at this open coast location will be far too aggressive for most if not all such revetment systems, and these would be likely to eventually fail under severe storm conditions. Details to fix the toe and crest would also be hugely problematic. With the construction of a bank, Seabee units could provide an alternative form of revetment, to provide long-term protection, but will not halt the foreshore lowering occurring as a natural process, so will not prevent any loss of beach. Indeed, despite the energy dissipating qualities of such a system, to prevent undermining and movement that could lead to rapid displacement and unravelling, with wholesale failure, steel sheet piling at the toe would probably be required. Once exposed, that sheet piling would exacerbate such losses in the same way as a vertical seawall. In summary, most of these other revetment systems will not provide a suitable form of defence and although a Seabee revetment might resist erosion of the dune face it is unlikely to be a long-term solution as it will not address the foreshore erosion along the frontage.	
OTHER CONSIDERATIONS: None.	
TYPICAL COSTS:	None sourced as these are unlikely to be suitable. However, this would be considerably more expensive than an equivalent rock revetment structure.

TYPE:	Timber Wave Break

DESCRIPTION:

This form of structure comprises a sloping revetment constructed of timber planks, fixed to a timber frame and timber piles driven into the beach (much like the piles used on a timber groyne). Gaps are left between the timber planks, to make the revetment face permeable and help dissipate wave energy and reduce wave reflections. Frequently, these defences have also included a toe of steel sheet piling to add support to the structure and prevent sand from being drawn out from underneath the timbers.

Such structures provide a partial barrier to wave energy, and have been used to reduce and limit erosion of cliff/dunes behind, rather than completely stop it. Estimates from the North Norfolk coastline indicated they may limit erosion to around 30% of that of an undefended cliff. The structure temporarily traps that sand behind the timbers, adding to the cliff toe protection for a period of time.

This form of defence been used at a number of locations along the Norfolk and Suffolk coastlines in the past, but is not a form of defence that has (to best of knowledge) been constructed in over 40 years.

The longevity of these structures depends heavily upon the nature of coastal processes, i.e. whether foreshore/beach lowering is an ongoing process or not, and the ability of the structure to remain stable under such conditions, plus the type of timber used and its resistance to abrasion and decay.

EXAMPLES OF APPLICATION:

Examples of application include along the coast of North Norfolk at Trimingham, in front of Happisburgh village (where they eventually failed), and along stretches between Gorleston and Lowestoft.

The photos below from just below Gorleston shows this working well, but a short distance further south, the commencement of failure is evident. Beach levels have lowered to expose the piling, and wave reflections have led to scouring at the toe, which will ultimately lead to the onset of failure.

Just north of Corton in Suffolk, longer piles have left the heavily damaged timber revetment standing, but not prevented the erosion of the beach seaward, due to similar processes as being observed at Hemsby, leaving that stretch of shoreline unusable to the public due to the safety risks that now exist.

<table>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">LIKELY EFFECTIVENESS AT HEMSBY:

These offer a potential measure to limit erosion of the dunes at Hemsby, but the primary limiting factor is the continued lowering of the beach in-front. With high seasonal volatility of beach levels, there is a good probability that the sheet piled toe will become exposed and further exacerbate the scour and erosion, resulting in failure similar to that recently experienced on the Hopton frontage. Alternatively, if longer piles are used, this may result in a redundant structure remaining, posing an unsightly and public safety hazard and leaving an unusable foreshore, such as seen on the shoreline north of Corton.

Consequently, unless there are signs of longer term beach accretion here, where this might form a backstop to offer some additional protection to the cliff face during extreme surges, this will not be a suitable long-term option for Hemsby.</td></tr>
<tr><td colspan="2">OTHER CONSIDERATIONS:

None.</td></tr>
<tr><td>TYPICAL COSTS:</td><td>None sourced as these are unlikely to be suitable.</td></tr>
</table>

TYPE:	Concrete Armour Units

DESCRIPTION:

Concrete armour units are sometimes used in structures as an alternative to rock, generally in locations where rock of a suitable quality for the primary protective layer is difficult to obtain either due to the large size required, or in sufficient quantity. These armour units are generally unreinforced, relying on concrete strength to resist wave and settlement loads. Like rock armour, they work by dissipating the energy of the breaking waves in various directions through the spaces created between units by their shape.

There are a wide variety of shapes for these units, which have evolved over the past 60 years. The simplest type of unit is a cube or rectangular block, although modifications to those have been made over time, e.g. the Antifer which is tapered and grooved to improve interlock. Many types of concrete armour unit have been developed to give improved stability, with varying degrees of complexity such as the Tetrapod and the Dolos several decades ago. More recently a new generation of more robust/massive units including Accropode, Core-loc and X-Block amongst others were developed as some earlier slenderer units experienced issues with breakage and failure on a number of deep-water breakwaters.

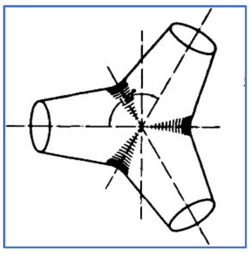
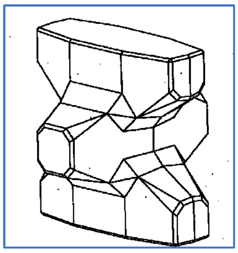
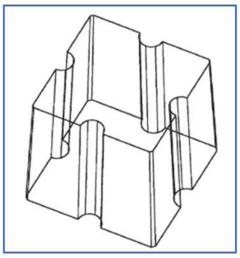
All these units have different characteristics and thus suited to different circumstances, but for the purposes of this assessment can be considered collectively to address some of the more general aspects regarding suitability.

It is rare for concrete armour units to be used for coastal revetments, they are more typically utilised on large breakwaters for ports and harbours where the steep slopes and height of the structures help to provide weight and downward forces to increase their stability. A few units have stability based almost purely on their mass, whilst others rely heavily upon a degree of interlock achieved through their shape and placing pattern, and for many it is a combination of the two.

Most of the older unit types would have been placed in two layers, although some of the newer designs have been created to be placed in a single layer to save on costs; but in both cases in a regular pattern to achieve the interlocking necessary for stability. Even in these situations, these units are almost always built over the top of a layer of large armour rock, which aids the dissipative qualities of the armouring and thus stability.

EXAMPLES OF APPLICATION:

Below are illustrations of some types of concrete armour unit (right to left: Tetrapod, Accropode, Antifer), together with a photograph of more typical application on a large breakwater.


Concrete armour units do also include much simpler shapes such as the Tripod, basically half a cube, which have been used for cliff protection at Southwold.

LIKELY EFFECTIVENESS AT HEMSBY:

To provide a coastal defence revetment at Hemsby, or even on relatively low-level structures such as groynes or shore parallel breakwaters, the interlocking characteristics that enable the highest stability to weight ratios, that certain units can provide, are going to be more difficult to achieve on these smaller structures. Consequently, there will be more reliance upon their mass and thus any choice on types of units that might be considered are likely to be those that are larger but simpler in terms of shape to construct, and are also going to be cheaper to manufacture than the complex units that might also be available.

If these were to be used as a protective barrier at the base of the dunes, they might be better placed and used in a pyramid formation to create a bund rather than a revetment on the dune face (see Fairlight example shown for rock bund). This is because (a) they are more porous than rock, so would need to be underlain by another material, such as a layer of armour rock, to provide protection to the dune face, and (b) as such this would be an extraordinarily thick protective layer which will be extremely expensive.

Like a rock structure, they would also need to be able to accommodate beach lowering and potential undermining, so being both trenched into the beach and also being able to move in position to accommodate lowering will be necessary. Therefore, units which are heavily reliant upon precise positioning for high interlock are not going to be as beneficial as those that can accommodate movement without losing overall structural integrity. One benefit of these units is their highly dissipative nature, so they do not exacerbate scouring. However, they will not prevent the ongoing foreshore lowering trend so the consequence may be a defended coastline with little beach in front of the structure. Also, these structures will take up more width on the beach than some of the other options.

Units such as Tripod are simple to produce and should offer similar or even better qualities in this setting to, say, the Tetrapod (which may even have a propensity to 'roll' if laid on the flat). Slender units (Dolos for example) are less likely to be suitable for this problem and are more difficult/expensive to produce, whilst more the recently developed units are mostly still covered by patent so will incur royalty payments if used, without perhaps offering considerable advantages in this particular setting.

In summary, the use of concrete armour units is a possible alternative to armour rock but may have less flexibility and higher costs, depending on the nature of structure into which they might

be incorporated. It is likely that if used as a linear defence only, they might be better used to build a bund to reduce erosion rather than constructing a traditional revetment.	
OTHER CONSIDERATIONS: There are similar perceptions as for the use of rock, with regard to safety risks, when built on recreational beaches. Whilst there may be better options than concrete armour units for providing a linear defence, another application of these might be in the deeper water construction of any headlands or nearshore breakwaters used to manage and control beach stability.	
TYPICAL COSTS:	Costs are going to be highly dependent upon the nature and size of any project, which will also determine their necessity and most appropriate type. However, a simple comparison between the relative material rates for rock and mass concrete armour blocks to fill the same area, indicate that concrete units are likely to be at least 30% more expensive.

TYPE:	Beach Nourishment

DESCRIPTION:

Beach nourishment (also known as recharge) involves adding a volume of sand (or shingle) to a beach, to raise its height and width and thus provide improved protection to the area behind. The imported sand would come from a remote source, sometimes another area of beach deposits further downdrift (with that process described as 'recycling'), onshore sources, or more commonly from dredging offshore deposits.

This approach is adopted where the beach can provide the primary form of defence, and some level of stability can be achieved. Efforts are usually made to import a similar material composition to that found at the host location, to avoid 'contamination' of adjacent beaches, although sometimes a coarser material might be imported if this would be more stable.

If dredged, the sand is usually hydraulically pumped or 'rainbowed' onto the beach area, with machines on the beach used to distribute the new material evenly across the areas required. If recycled, then this will usually be transported up the coast by trucks.

Typically, nourishment is placed directly onto the upper beach, although some schemes, for example in the Netherlands, have also placed the material seaward of low water, allowing natural wave action to bring the material ashore (this is called 'shoreface' nourishment).

Beach nourishment is sometimes a single operation, but for many schemes is an action that will need to be repeated on future occasions to replenish the material lost through natural working of the beach by waves and currents. Some locations also have an ongoing maintenance commitment, to regularly move sand and reprofile the beach within the confines of the scheme. In many instances, beach nourishment is one component of a scheme which also includes control structures (e.g. groynes).

EXAMPLES OF APPLICATION:

There are many examples of application around the UK. One of the largest has been on the Lincolnshire coast, where over 20 km of seawall has been protected by an annual renourishment operation since the mid 1990s. This scheme involves no control structures to restrict movement and the annual programme involves up to 500,000 m^3 of sand each year.

That is, however, the exception and in other locations, such as Bournemouth, the renourishment process may be required only once every several years.

On some other schemes, the nourishment has been a single operation only, although those are more commonly where there are also control structures in place and/or much lower quantities involved.

LIKELY EFFECTIVENESS AT HEMSBY:	
A beach provides a natural defence, and given sufficient supply of new sand from the north and sufficient space for the beach to develop to its full height and width, this would be a preferential choice. Recharge would then be required only if there were not sufficient supply. However, that is not the case here, which at the larger scale is a sediment-rich system as shown by the build-up further along this shoreline such as at Caister and Great Yarmouth to the south and accumulation at Winterton Ness to the north. An issue here is the reduction in width of the shore platform, due to the proximity of a nearshore channel which has migrated landward. Therefore, the addition of beach nourishment alone is not going to resolve the problem. Shoreface nourishment (just below low water) is unlikely to be a viable option here either. With a component of alongshore movement on sub-tidal bars it is uncertainty whether this recharge would have the chance to move onshore before the strong currents have transported the new material along the coast and away from the area required. In summary, the additional sand may provide a short term 'buffer' but is unlikely to remain stable given the driving forces acting to cause the erosion problems at Hemsby.	
OTHER CONSIDERATIONS:	
The beach would need to be closed to the public for a short period during recharge operations and beach maintenance works. Beach material grading and profiling needs careful specification and achieving these can be problematic. Although imported material would ideally be the same size and grading, the material obtained from licensed dredging areas is generally not identical and, depending upon the characteristics and placement, instances of cliffing can occur. This can temporarily be a safety hazard but can also be addressed through reprofiling, albeit that requires construction plant to be on the beach from time to time.	
TYPICAL COSTS:	Not applicable.

TYPE:	Groynes

DESCRIPTION:

A beach is one of the most effective forms of coastal defence, but instability of the beach can be an issue in many locations, therefore some form of control structures can be necessary to reduce transport of sand (or shingle). Those controls may be cross-shore, shore-parallel, or sometimes a combination of both depending upon prevailing sediment transport processes.

Groynes are cross-shore structures built at an angle to the shoreline (usually 90º) to trap sand and build a higher beach where greater protection is needed and are likely to be used where alongshore drift is the main sediment transport process. Typically, groynes should be designed to reduce alongshore transport, not prevent it altogether, and thus not be detrimental to sites further downdrift.

Traditional groynes were constructed of timber, and in some cases still are, although construction from armour rock has become more popular and widespread over the past 30 years. Wooden groynes usually comprise horizontal planks fixed to vertical timber piles. They have a shorter life expectancy, a higher maintenance commitment, and require replacing every 30 to 40 years. They are also more susceptible to large variations in beach levels; if levels drop, wave reflection can exacerbate scouring making them more prone to collapse.

Rock provides much longer-term durability and helps absorb some of the wave energy, reducing reflection and aiding beach stability. They are also simpler to construct, easier to adapt, and can accommodate extreme variations in beach levels.

Variations in rock groyne shape include Y-shape and T-shape (also sometime called a 'shore-connected breakwater'). These additions to the groyne ends are sometimes the outcome of designs to better retain the beach where there are more complex processes moving the sand around.

The length and spacing of groynes is determined by the height and width of beach that needs to be retained. Depending upon the nature of the site and processes, a groyne scheme may or may not include beach nourishment.

EXAMPLES OF APPLICATION:

Local examples of timber groynes can be seen very close by, along the frontage managed by the Environment Agency just north of Winterton (left) and at Southwold (right).

Examples of rock groynes can also be seen at these locations, with examples from north of Winterton shown below.


An example of Y-shape groynes can also be seen locally, at the northern end of Caister where these were introduced to help hold a beach that would extend northwards along the California frontage.

LIKELY EFFECTIVENESS AT HEMSBY:

A key contributing factor to the dune erosion occurring at Hemsby is the low beach levels and, under present conditions, the inability for it to naturally accumulate along this shoreline. Control structures at Hemsby could help intercept and retain beach material to provide better protection to the eroding dune face.

Whether those control structures should be groynes or nearshore breakwaters, or indeed some combination of both, depends entirely upon the dynamics of sediment movement along this section of shoreline. This is not an aesthetic choice and appraisal of this is beyond the capacity of this current initial high-level assessment. But even without the more detailed design to confirm the best option it is possible to conclude that one of these forms of control in front of Hemsby would be feasible to intercept sand being transported alongshore and thus encourage a higher beach here. This is a sediment rich system, with a lot of sand moving through it, so this should happen naturally and the addition of renourishing the beach as undertaken in some locations should not be necessary.

If groynes are used, then rock structures are likely to be the best choice as they are less reflective and have better sand retention capacity, and can also adapt better to the changing foreshore levels occurring at Hemsby compared to more rigid timber constructions. That may be especially important at their ends if the nearshore channel continues to migrate landward.

A further potential benefit of groynes would be to interrupt the development of runnels on the beach, which could also be a contributor to the dune erosion in places. Again, rock would lend

itself to addressing this, whereas timber groynes could actually become vulnerable to the lowering around those features. The configuration (i.e. length, spacing) and form of groyne (e.g. straight, Y-shape) would depend upon the detailed design. Those details would also consider the downdrift effects and the design made to allow sufficient bypassing to avoid detrimental impacts on other frontages such as Scratby and California. In summary, control structures (groynes or nearshore breakwaters, or a combination of both) would help intercept and retain beach material to provide better protection to the eroding dune face. This might also be part of broader scheme and/or one including some additional backshore protection.	
OTHER CONSIDERATIONS: Access along the coast can be constrained by groynes, but designs can incorporate pathways through the upper groyne for walking through without having to climb over them. Large rock is sometimes perceived to present a safety risk, due to people wishing to climb on them or even into the gaps where those are large, with a risk of becoming trapped. Consequently, this is sometimes an unpopular choice on recreational beaches, although they remain one of the most commonly used materials in such areas. Large height differences on either side of a timber groyne can result in a large drop and present a safety hazard. Rock solutions retain the flexibility to accommodate future design modifications if necessary. Geotextile sand containers have also been used as an alternative to form groynes.	
TYPICAL COSTS:	The costs would depend upon the length and spacing of groynes required along this beach. As a guide, information published by Defra on a small selection of schemes is quoted here, noting that the range depends upon both the length and cross section requirements which vary considerably between locations. Timber groynes on those schemes cost between £100,000 and £300,000 each, with the cost per metre length being in the range £ 1,000 and £3,000. Rock groynes were reported to cost between £2,500 and £4,500 per metre length. The two Y-shaped groynes at Caister, constructed in 1994, cost approximately £900,000. Allowing for inflation those costs would be 50% higher today.

TYPE:	Nearshore Breakwaters

DESCRIPTION:

A beach is one of the most effective forms of coastal defence, but instability of the beach can be an issue in many locations, therefore some form of control structures can be necessary to reduce transport of sand (or shingle). Those controls may be cross-shore, shore-parallel, or sometimes a combination of both depending upon prevailing sediment transport processes.

Nearshore breakwaters are structures built parallel to the shore to diffract incoming waves to alter their direction and sand movement in their lee as well as providing some sheltering to the shoreline, and thus build a more stable beach where greater protection is needed. The design of nearshore breakwaters can vary from those intended to completely stabilise the beach behind into a series of bays and salients (typically where the dominant sediment transport process is onshore-offshore), to those designed to only slow alongshore transport.

They do this by diffracting the waves as they pass between and through the structures, changing the direction of the wave fronts and spreading that energy at the same time. In this respect they are therefore distinct from sills or reefs (see separate assessment) in that they are not usually fully submerged and they are not continuous, having spaces between for water and sediment movement.

These structures are usually constructed from armour rock, although concrete armour units might also be used. The location of these structures depends on the size of beach to be held and the transport pathways. Consequently, they may sometimes be located around low water, in other cases a short distance offshore. The length and gaps between breakwaters is determined by shape and width of beach that needs to be retained. Depending upon the nature of the site and processes, a nearshore breakwater scheme may or may not include beach nourishment.

EXAMPLES OF APPLICATION:

Two geographically close applications of this approach can be found to the north at Sea Palling (to the right) and south at Caister (below).

These two examples illustrate the contrast in beach response. This is partly due to the difference in coastal setting and processes operating at each location, but also reflects the fact that the breakwaters have been also designed to have a different effect.

LIKELY EFFECTIVENESS AT HEMSBY:

A key contributing factor to the dune erosion occurring at Hemsby is the low beach levels and, under present conditions, the inability for sediment to naturally accumulate along this shoreline. Control structures at Hemsby could help intercept and retain beach material to provide better protection to the eroding dune face.

Whether those control structures should be groynes or nearshore breakwaters, or some combination of both, depends entirely upon the dynamics of sediment movement along this section of shoreline. This is not an aesthetic choice – appraisal of this is beyond the capacity of this current initial high-level assessment to be able to determine. But even without the more detailed design to confirm the best option it is possible to conclude that one of these forms of control in front of Hemsby would intercept sand being transported alongshore and thus encourage a higher beach here. This is a sediment-rich system, with a lot of sand moving through it, so this should happen naturally and the addition of renourishing the beach as undertaken in some locations should not be necessary.

If nearshore breakwaters are used then rock structures are a common choice, offering high stability and energy dissipation qualities. However, another option is concrete armour units, which may offer different opportunities to manage and control the wave transmission.

One consideration with respect to these structures may be the migration of the nearshore channel where shore parallel structures may be more vulnerable than those normal to the direction of strong flows, so deeper (and more expensive) structures could be needed to prevent instability. Another design consideration would be to establish whether these might have a negative effect by encouraging the runnels that already develop on the beach to stabilise or even deepen, by directing flows around the landward side of the breakwater structures.

The configuration (i.e. length, spacing), plus width and elevation which also affect the wave transmission, would depend upon the detailed design. Those details would also consider the downdrift effects and ensure sufficient bypassing to minimise impacts on downdrift frontages such as Scratby and California.

In summary, control structures (groynes or nearshore breakwaters, or a combination of both) would help intercept and retain beach material to provide better protection to the eroding dune face. This might also be part of broader scheme and/or one including some additional backshore protection.

OTHER CONSIDERATIONS:	
Nearshore breakwaters may provide new habitat and thereby lead to ecological enhancement, supporting more diverse marine life in an area where this may otherwise not be possible. Rock solutions retain the flexibility to accommodate future design modifications if necessary. Geotextile sand containers have also been used as an alternative to form submerged breakwaters.	
TYPICAL COSTS:	The four breakwaters at Caister, which cover a length of shoreline of 450m, cost approximately £750,000 in 1999. Allowing for inflation those costs would be 50% higher today, although that remains extremely cheap. Based upon present day unit cost rates, the equivalent structures would be expected to cost over £3 to £4 Million. It is also likely that larger structures would be required at Hemsby to accommodate the deeper water.

TYPE:	Sill/Submerged Reef (Perched Beach)

DESCRIPTION:

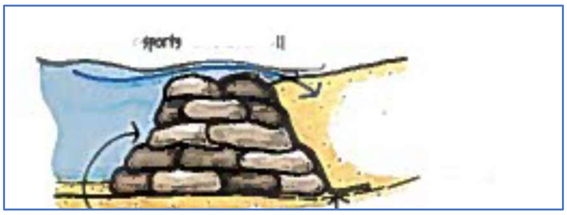
Another form of beach control is to 'perch' the beach where water offshore is too deep for a full natural beach width to be supported. This might be achieved by constructing a sill; a permanently submerged hard toe below the low water mark, behind which sand can retained at a higher elevation than would otherwise be possible. What is effectively an artificial reef, this may also act to break larger waves further from the top of the beach, so together with the higher beach provide better defence.

This would most likely be created by constructing a bund of suitably sized rock armour, although sand-filled geotubes are another option. The position would depend upon the sand transport pathways and the ability to work with those. Previous applications have been limited to locations in the Gulf (at least as far as known to the authors of this assessment), where artificial beaches have been created through nourishment in relatively deep water, and in sheltered environments with little if any alongshore sediment transport.

Alternative forms of reef have been advocated from time to time, including sunken vessels (such as old barges). That may have cost savings, but there are other issues to consider such as the stability of those vessels under extreme storm conditions, as well as safety concerns with old and deteriorating steel presenting a hazard to bathers and boats.

EXAMPLES OF APPLICATION:

Below is an illustration of the concept (reproduced from 'Low Cost Shore Protection, USACE, 1981).



No examples have been identified of an application to perch a beach in an environment that might be considered similar to Hemsby, although there are locations where geotubes have been used as submerged structures to help build beaches or reclaim land.

Below example of geotubes placed as a submerged structure (reproduced by permission of Tencate Geosythetics).

LIKELY EFFECTIVENESS AT HEMSBY:

The effectiveness of a reef would be dependent upon the sand transport mechanisms. If there is a strong onshore component to the movement of material, then this could potentially cut off some of the natural sediment supply, and thus deplete the beaches it is intended to help support.

Another consideration at Hemsby would be the nature of change of the nearshore channel which has been moving landward. Whether this might act as a training wall, and thus help limit further shoreward movement is questionable, and it may instead drop down as the channel undercuts it, in which case its effectiveness will be lost. It has been noted elsewhere (Scottish Natural Heritage, 2000) that reefs have limited effectiveness where currents, rather than waves, are the main erosive force.

Given that the currents here are a key component of the reasons for coastal change, then it is probably a high-risk strategy to consider this form of defence for Hemsby.

OTHER CONSIDERATIONS:

Reefs can also provide a positive ecological enhancement, potentially supporting more diverse marine life in an area where this may otherwise not be possible.

There may be safety concerns for beach users due to the sudden change in bed elevation between the beach and the seaward side of the reef.

TYPICAL COSTS:	Not applicable

TYPE:	Headland Structures

DESCRIPTION:

Headland is the term used here for long structures intended to act upon both waves and currents, with greater beach retention characteristics at the shoreline between these.

The offshore channels and banks, and the flows through them, have some similarities to a river system, and a technique that has been used in some of the world's largest rivers and estuaries has been to build structures with the purpose of deflecting tidal current flows and keeping the deeper water channel away from the eroding shoreline. These include a range of structures including spur dykes and bendway weirs amongst others, some of which modify the flow direction over them, others that divert flows altogether.

A coastal equivalent of these also exists, which is also able to diffract waves to modify the movement of sand and produce greater beach stability between these structures (so combining some of the attributes of both groynes and nearshore breakwaters). These structures, generally referred to as a 'fishtail groyne' (and not to be confused with the shorter and generally taller Y-shape groyne), will typically be built as a rock mound, or using concrete armour units in place of the armour rock.

Design at the seaward end of these structures requires careful design as some shapes may lead to pronounced eddies and increased scour. In some instances, slopes as flat as 1:5 or even 1:10 might be used on large structures. The crest elevation may slope down to follow beach slope as the primary function of those extended arms is to keep the current causing the sub-tidal scour of the nearshore channel away, not block sand transport altogether.

EXAMPLES OF APPLICATION:

The design and construction of coastal defences along the Wirral Coast (1972-1987), the Morecambe seafront (1983-2010), Llandudno (1990-1996) and Llanelli (1991-2000) all have strong tidal currents running parallel to the shoreline and these schemes all employed structures to hold the tidal currents at a fixed distance away from the shoreline to allow the location of the shoreline to become effectively fixed behind a stable beach.

Google Earth image showing the headland structure at LLandudno.

LIKELY EFFECTIVENESS AT HEMSBY:

A key contributing factor to the dune erosion occurring at Hemsby is the low beach level and, under present conditions, the inability for sediment to naturally accumulate along this shoreline. This is considered to be largely due to the landward movement of the nearshore channel, meaning stronger currents close to the shore removing sand, larger waves closer to the shore also moving sand, and insufficient space between the channel and the dune face for a sufficiently large beach to accumulate. Therefore, an approach to address the root cause of the problem might be appropriate.

Recent work studying the processes within the offshore bank and channel system here discusses how tidal currents influence the evolution of beaches and how such effects are often ignored. This is particularly the case on the west coast of the UK where the tidal range is large and tidal currents are strong and often run parallel to the coast. That study notes the coastal situation in the Great Yarmouth area exhibits striking similarities with that occurring on the west coast, with strong tidal currents running parallel to the shoreline and the offshore banks canalising the tidal flows. Whilst the tidal range at Hemsby is actually much smaller, the locally peculiar characteristics of a very large tidal differential over a very short distance between Winterton and Caister mean very strong tidal currents run close inshore.

Consequently, structures such as fishtail groynes, designed to restrict further inshore movement of the nearshore channel, could help to prevent further narrowing of the shore platform and the resultant erosion at the back of the beach. Also, through further modifying the wave fronts, slowing the alongshore transport and trapping sand, these should encourage beach growth.

In some respect these headlands might be seen as very long groynes, but unlike groynes the seaward lengths may be partially submerged, at least for a good portion of the tidal cycle, and the ends would be flatter broader structures. These structures would need to be carefully designed to hold back currents and create a wider shore platform without themselves becoming unstable, and act as groynes on the upper beach to intercept longshore transport and help prevent runnels from forming, without detrimental downdrift effects on frontages such as Scratby and California. Spacing is another factor that is critical, to prevent formation of strong eddies that could themselves result in erosion.

These could be designed as part of a system of self-contained ‘bays, or designed so that the embayments are prevented from becoming independent units by allowing some movement of wave and current induced transport over the top of the structures, in addition to the windblown component.

In summary, structures designed to keep strong currents away from the shore and restrict further landward movement of the nearshore channel, could enable a wider and higher beach to reform and therefore reinstate the natural protection to the dunes which previously existed.

OTHER CONSIDERATIONS:

Although the focus is on Hemsby, these might be suited when considering in a wider management approach that also includes the protection of the longer frontage including Scratby and California.

TYPICAL COSTS:	Costs could vary considerably depending upon length of structures and water depths, as well as unit rate for construction materials (rock or concrete units) which can also vary considerably.

TYPE:	Sand Motor

DESCRIPTION:

A sand motor (sometimes referred to as a sand engine or sandscaping) is a recently developed concept. A large volume of dredged sand is placed at a specific location on the coast, with the intention that waves, winds and tidal currents will spread that sand along the coast. The placed feature will therefore change in shape as this sand redistributes.

A main difference from traditional beach nourishment is that the dredged sand is pumped into shallow water (like shoreface nourishment), rather than placed and profiled directly on the beach, allowing natural processes to then move the sand onshore and alongshore. A much wider body of sand is initially placed in the area of concern, so offering more immediate protection, albeit that will gradually reduce as material is redistributed by natural processes.

This approach can also achieve a much-reduced price per cubic metre of sand compared with regular renourishment, as some elements of the operation are eliminated, plus as this will generally involve much larger quantities of sand, some efficiencies of scale can also be realised.

EXAMPLES OF APPLICATION:

Sandscaping has not yet been implemented in the UK but has been advocated by the Crown Estate as a method for coastal protection that also creates a new area of coastal land with a variety of uses.

Although sites for trialing this in the UK are still being investigated, there is currently only one example of an application which is in the Netherlands, shown below. This was itself a trial and is still the subject of many ongoing research projects to gain improved understanding from its behaviour.

Source: www.flickr.com (Zandmotor).

This work has been identified as being free of known restrictions under copyright law, including all related and neighboring rights

LIKELY EFFECTIVENESS AT HEMSBY: In many respects, the initial feature may look very similar to Winterton Ness. However, beyond that it should not be confused with the Ness, as the processes that control the location of the Ness will probably not apply at Hemsby. Changes in the behaviour of Winterton Ness remain unclear, therefore the movement of a similarly large sand feature may also be quite unpredictable. Consequently, whilst this might on one hand provide a wide expanse of sand at Hemsby for several years, equally there is a high risk that it could disperse rapidly and not achieve the desired outcome. There is another large promontory at Caister Ness, but the orientation of the shoreline, configuration of the banks, channels and tidal flows are quite different from Hemsby, so a direct comparison with there is also appropriate either and raises further uncertainty over predicting how this might behave. There are other considerations. • Firstly, a sand motor at Hemsby would have to extend some distance into deep water due to the proximity of the nearshore channel. There are strong current flows through that area (hence the channel), so the stability of this would be in question and there could be considerable and rapid loss of sand into the channel system rather than along the shoreline or mirror the recent infilling and cause scouring on the seaward Dock. That could have unpredicted effects on the local flow regime and therefore affect banks and channels, and therefore the shoreline over some distance north and south of here. • Secondly, it is recognised that the sand motor is only expected to be a temporary feature, with estimates of time before it would need to be repeated ranging between locations from 20 to 50 years. Furthermore, the issue at Hemsby is not that there is not enough sand passing through the area; it is part of a sediment-rich system. The problem is that it is not being retained at Hemsby, so although this approach would bolster the volume there, the mechanisms that move it away still exist. Consequently, the rate of movement here might be much faster and this could be only a short-term solution. In summary, it may be interesting to trial a sand motor at Hemsby, but the risks associated with complex and uncertain behaviour of tidal currents in the nearshore bank and channel system, and the potential for unforeseen consequences from the introduction of this sand mass, are probably not going to be acceptable.	
OTHER CONSIDERATIONS: The added sand volume may for some time provide additional beach space for recreational activities. The redistribution of the sand may also result in additional protection being provided to the Scratby and California frontages.	
TYPICAL COSTS:	The Dutch Sand Motor was reported to be in excess of 70 Million Euros for 21.5 Mm^3. A review of options for a sand motor near Aldeburgh on the Suffolk coast estimated costs in excess of £15 to 20 Million for 1.2 Mm^3 volume, based upon most recent dredging rates. An option proposed for Bacton in North Norfolk would reportedly cost in the order of £17 to £20 Million for 1.5 to 1.8 Mm^3

FINAL

Appendix C: Costs and Funding Review

Prepared for

Great Yarmouth Borough Council

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Contents

This appendix

This Appendix provides an estimate of potential costs for the different management approaches that might be considered at Hemsby presented, in the main study report, and the potential funding required to deliver those. It is based upon the assessments of option effectiveness outlined in Appendix B, and the projected erosion outlined in Appendix A.

This is not a full economic assessment, required as part of the business case for any scheme, which would require much more detailed information and go into more detailed calculation of both costs and benefits. It is instead designed to be a quick and simple identification of the broad level of flood defence grant aid that might be obtainable with these management approaches, and thus the level of additional funding that may be required to be found from alternative sources.

Commentary on potential funding mechanisms, provided by CPE, has been included to follow these calculations.

Costs

2.1 Background

This study has assessed a range of different options for coastal defence, identifying several as unsuitable or unlikely to be suitable for the Hemsby frontage.

Consideration has subsequently been given to how those options that may be technically feasible might be employed in providing a scheme, rationalising that down into a few management approaches:

- Providing a linear defence;
- Providing a short term or interim defence;
- Providing a beach;
- Providing a broader management approach (along an extended frontage);
- Realignment (not defending now, but potentially introducing defences at a later date).

The best means of achieving these from the assessment of the options, has been identified, and the costs for each are outlined in this section.

2.2 Cost information

Costs of providing the management approaches have been estimated using a range of information sources, but because of the high-level nature of this assessment and the exact nature of requirements at this location to deal with the dynamic and changing conditions, they must be treated as indicative only. Therefore, a contingency of 60% is applied to the costs of all potential approaches to account for a range of variable factors and uncertainties that may be encountered.

Those can include items that fall outside of the primary costs, such as lesser ancillary works (e.g. access roads), temporary works required during construction, uncertainties over actual volumes required, additional investigations and surveys, dealing with unsuitable ground conditions, on-costs such as design fees, modelling, other unforeseen or changeable factors such as increases in cost rates, material supply issues etc. This is standard practice and a requirement when planning funding needs, with this standard percentage value based upon analysis of a range of previous estimates and actual outturn costs from a large number of schemes.

2.3 Cost calculations

Costs for protection of Hemsby are based upon an assumption of 1300m of defence being required, to include a length of approximately 400m north of Hemsby Gap, through to 50m south of the Newport/Scratby boundary.

The distance north of Hemsby Gap is determined to protect against potential outflanking of the higher ground at the south end of the Valley, and protect the built assets that extend north of the Gap. The distance south of the Newport/Scratby border is to provide a buffer from potential outflanking, but is also based upon the assumption that some level of protection, at least in the immediate term, such as the gabions will continue to be provided along that stretch to the south of here.

The expected costs of delivering the different approaches and using various defence types are outlined in the tables below. These are then used to define the likely upper and lower bounds of the range of costs that might be required to implement any of the potential management approaches. Table 1 describes the basis for the cost estimates, and excludes the optimism bias. Table 2 summarises the potential cost range for each management approach, including optimism bias.

Table 1 Potential costs for various defence types

Option	*Costing Assumptions*	Unit Cost	Total Cost
Rock Revetment	• *Estimated based upon typical current rates for rock supply and placement.* • *Assumed 60m^3/m to include for full height, trenched toe, and additional falling toe to counter ongoing beach lowering.*	£9,000/linear metre	£11.7 Million
Rock Berm (permanent)	• *Based upon more recent costings for proposed berm at Scratby.* • *Added allowance for deeper toe and additional falling toe to counter ongoing beach lowering.*	£4,300/linear metre + £2,200/linear metre	£8.4 Million
Rock Berm (interim)	• *As above but without additional falling toe as not designed for long term lowering.*	£4,300/linear metre	£5.6 Million
Gabions	• *Based upon rates for recent Gabions at Scratby.* • *But assumed much wider and deeper structure to address beach volatility (increased by factor of 3).*	£2,100/linear metre	£2.8 Million
Geotextile Sand Container	• *Range based upon information from projects.* • *(i) Assuming wall or bund built at £40 per cubic metre.* • *(ii) 50% of rock berm.*	£1,900/linear metre to £2,200/linear metre	£2.5 – £2.9 Million
Beach Control Structures	• *Based upon rock groynes; assume upper end rate from published information +10% roundheads.* • *Added allowance at ends for falling toe around roundheads.* • *Assume 1:1 length to spacing ratio with 13 groynes to cover 1.3km.*	£6,000/m length (=£600,000/groyne) + £115,000/groyne	£9.3 Million
Control Structures plus Backstop Protection	• *Beach control structures as above.* • *Assume backstop protection as short-term measures.*	£9.3 million + £2.5 Million to £5.6 Million	£11.8 – £14.9 Million
Headland Structures	• *Based upon estimates for another strategy, factored to account for changes in length and rock rates.* • *Assume 4 structures to cover 1.3km.*	£4 to £5 Million each	£16.0 to £20.0 Million

Table 2 Total potential cash costs for each management approach

Approach	Base Cost Estimate (Range)	Total Cost (including Optimism Bias)
Dune Face Protection (Linear Defence)	£8.4 to £11.7 Million	£14 to £18 Million
Beach Retention	£11.8 to £20.0 Million	£20 to £30 Million
Interim Solution	£2.5 to £5.6 Million	£4 to £9 Million

The costs for delivering a broader management approach have not been calculated, as that would be subject to further investigation and the approach taken, but a simple pro-rata of the costs for the options at Hemsby would be indicative.

Costs for realignment through later interventions (i.e. not constructing defences today but in the future) would be similar to any of the above, but deferred for a number of years. Other adaptation costs have not been assessed as that would be subject to further investigations and the approach taken.

Funding

3.1 Flood and coastal defence grant

Flood and coastal risk management grant in aid (FCERM GiA) is sourced from central government and is administered through the Environment Agency. Flood Risk Management Authorities (RMAs) - the Environment Agency, English local authorities and Internal Drainage Boards (IDBs) can use it for a range of activities that help reduce the risk of flooding and coastal erosion but allocation is managed through the Regional Flood and Coastal Committees (RFCCs) based on a competitive partnership funding score. A Partnership Funding calculator is used to determine the level of government grant aid and any shortfall in funding that will need to be found from other sources.

This section presents the approach to the assessment of damages due to erosion and the build of costings for the short-listed options. A high-level Benefit Cost Assessment has been completed and the Partnership Funding Calculations undertaken to highlight the additional funding that may be required to be found from alternative sources to financially deliver the project. The economic assessment has been carried out in accordance with the guidance given by Defra and the Environment Agency in the Flood and Coastal Erosion Risk Management Appraisal Guidance (Environment Agency, 2010) (FCERM-AG) and the Middlesex University Multi-Coloured Manual (MCM Handbook 2010).

This assessment is very preliminary to establish order of magnitude funding levels; however, it would be necessary to undertake a more detailed review of benefits and costs should it be decided to proceed with a formal application for FCERM GiA funding.

3.2 Benefit calculation

3.2.1 Erosion Risk

The benefit area is the area of land which is estimated to be at risk of erosion within the next fifty years which will therefore benefit from any works being carried out. The annual average erosion rate was based upon the past 10 years of the topographic beach profile data, (2008 onward) to represent the recent trend in erosion (Table 3). The rate was based on observed changes at the toe of the dune cliff for Profile N098, which sits centrally along the Hemsby frontage, and for Profile N097, which sits just north of the Gap.

Table 3 Indicative erosion in the next 50 years for profile lines N097 and N098

Profile	Annual Average Erosion Rate (m/year)	Indicative Erosion Rate (m)		
		10 years	20 years	50 years
N097	-2.1	-21.2	-42.3	-105.8
N098	-3.0	-30.1	-60.2	-150.6

The most recent cliff line (as seen in the 2018 post-storm aerial photography) was digitised to extrapolate future erosion for 10, 20 and 50 years hence. The rate was applied for up to 500m north and south of these profile lines.

An old cliff line extends through the frontage (which runs from Scratby cliffs to Winterton) which may erode at a slower rate, although no such data is available to provide an actual rate as the cliff here is not yet exposed. To account for this potentially reduced rate in later years, a lower limit of erosion which considers reducing the predicted erosion rate to something similar to that observed on other similar cliff lines along the Norfolk and Suffolk coasts, approximately 1 metre per year, has also been considered as an economic sensitivity test in the 20 – 50 year epoch.

3.2.2 Flood risk

There were concerns that as the sand dunes north of Hemsby Gap are considered to provide some flood protection, that the loss of the sand dunes would result in an increased flood risk. A review of ground levels behind the sand dunes indicated ground levels are generally above 5m OD which is above the levels recorded in the most extreme storm surge events (below 4m OD). Therefore, no further consideration of flood damages has been undertaken.

3.2.3 Assessment of damages

The predicted erosion extents were mapped against the National Receptor Database (NRD) data for the benefit area and the properties affected in each epoch were determined. A review of the NRD data using Google, OS maps and geotagged photos was undertaken to confirm the number of residential properties, chalets and static caravans. The number and type of properties affected in each epoch are summarised in Table 4. No chalet or static caravans were noted to be at risk until after 20 years.

Table 4 Property count based on erosion rates given

	Years 0 – 10	Years 10 – 20	Years 20 – 50	Total
Residential	24	59	80	163
Non-residential properties (NRPs)	0	9	26	35
Static Caravans	0	0	79	79
Chalets	0	0	27	27

Residential Losses

The most up to date market value (March 2018) of the average house price for the Great Yarmouth region were taken from the Land Registry (http://www.landregistry.gov.uk/public/house-prices-and-sales/search-the-index). This is the latest available (as of June 2018). The average house price assigned to each residential property is £170,684. This was taken as the write off value for all residential properties in the benefit area.

For the chalet buildings the local average price was established by searching the Land Registry's Price Paid Data (https://www.gov.uk/government/collections/price-paid-data). Prices below £60,000 were searched for, as these are considered to be relevant to chalet type structures, and those properties within Holiday parks extracted and split into their respective sites. The similarity of the sites to Hemsby were then considered and an average price was established from an average of the similar sites

The Multi-Coloured Manual guidance (Section 4.4) states that "in assessing economic damages, consider…mobile homes, chalets or other temporary buildings or structures as depreciating assets worth, on average, only half their replacement costs", and that "the benefit figures that should generally be used therefore are the total loss figures, being half the replacement costs".

Therefore, the write off and capping costs for chalets at Hemsby have been taken as £8,710.

Non-Residential Property Damages

Non-Residential Properties were identified from the National Receptor Dataset (NRD). Non-residential properties include properties such as shops, self-catering holiday units, public conveniences, car parks, amusements and the entertainment facility. Market values were estimated from rateable values derived from (https://www.gov.uk/government/statistics/non-domestic-rating-business-floorspace) and a yield factor as described in the MCM. The non-residential property market values have been updated using GDP deflator indices to 2017 Q4 from (https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/l8gg/qna). This is the most up to date GDP deflator index available (June 2018). The capped rateable values used are shown in Table 5.

Table 5 Capped rateable value per m²

Type	Capped m² value (£)
Retail	990
Offices	690
Industrial	300
Other	670

Static caravan/mobile home benefits

In accordance with Environment Agency (2008) guidance the “Economic evaluation of damages for Flood Risk Management projects, Environment Agency, Bristol”, the economic impacts to class 513 (caravan mobile) and 514 (caravan static) assets in the risk area were calculated to be equivalent to the cost of moving the dwelling and establishing it on a new site. The cost of the unit itself is not valued.

A relocation cost of £5,250 per unit was estimated, given that the current park is large with substantial infrastructure (EA economic evaluation guidance suggests between £4,500 to £6,000/unit). This relocation cost includes land purchase, infrastructure, legal and planning fees and the moving cost. This price was then updated to 2017 Q4 prices using the GPD deflator index to give a current relocation cost of £6,136.

There are 79 static caravans within the 20 to 50 year erosion band. A complete relocation of the caravan and infrastructure would therefore have an estimated cost of £484,770.

3.2.4 Calculation of damages and benefits

For economics assessments, ‘Present Value’ (PV) damages are calculated, taking account of the timing of the losses and using standard discounting factors to calculate the PV. Based upon the above figures, the Do-Nothing PV Damages total approximately £16.6 Million.

Benefits are the damages averted. Therefore, management approaches that would reduce the risk of erosion along the frontage for the entire 50-year appraisal period (including the ‘dune face protection’ and ‘beach retention’ approaches) would avert most of those losses, and would consequently be a direct benefit of those approaches. Approaches that reduce the risk of erosion for less than 50 years would avert some of the damages and therefore generate some benefits but there would remain some damages.

It is assumed for the benefits of calculation that interim solutions would delay the onset of erosion from between 10 and 20 years, depending on the level on investment. With those approaches, the PV Damages are reduced to between approximately £8.3 Million and £11.7 Million.

For the potential realignment approaches, the assumption has been that no scheme is built for 10 years. With erosion up to that point, the PV Damages are calculated to be approximately £3.5 Million.

Sensitivity test

These calculations have been repeated assuming the lower erosion rate from year 20 onwards, to test the economic viability of the potential management approaches should the erosion rate be overpredicted. With this change, the total Do Nothing PV Damages reduce to approximately £12.6 Million.

Summary damages and benefits

Table 6 below summarise the order of magnitude damages and benefits of each approach.

It should be noted that the Benefit Cost Ratio (BCR) of any of the above approaches would be marginal at best with a BCR of unity or higher, i.e. the costs will be higher than these benefits alone.

Table 6 Damages and benefits

Approach	**Base case**		***Sensitivity***	
	PV Damages	**PV Benefits**	***PV Damages***	***PV Benefits***
Do Nothing	£16.6 Million	£0	*£12.6 Million*	*£0*
Dune Face Protection (Linear Defence)	£0	£16.6 Million	*£0*	*£12.6 Million*
Beach Retention	£0	£16.6 Million	*£0*	*£12.6 Million*
Interim Solution	£8.3 to £11.7 Million	£4.9 to £8.3 Million	*£6.4 to £9.0 Million*	*£3.6 to £6.2 Million*
Realignment (defer until Year 10)	£3.5 Million	£13.1 Million	*£3.5 Million*	*£9.1 Million*

3.3 Partnership Funding calculation

For each proposed management approach, a partnership funding calculation has been produced. This provides an indicator of a) the viability of the management options for FCERM GiA and b) the amount of additional partnership contribution required to achieve the required threshold for FCERM GiA funding.

Table 7 presents a summary of the calculation for each of the approaches. It is important to note that the extent of FCERM GiA funding will change in relation to changes in whole life benefits (£) provided by the scheme and number of properties protected by the proposed scheme.

Some slight differences in some costs in this table and those in earlier tables result from the calculation of Present Value (PV) costs and benefits, which takes account of the timing of investments and losses. For the purpose of calculation, it has been assumed that steps likely to be required before a full scheme could not be constructed would defer the costs until year 2. For the realignment calculation, it has been assumed that a scheme around the upper end of the 'dune face protection'/lower end of the 'beach retention' approaches might be implemented.

Table 7 Present Value Costs and potential available funding/required contributions

Option	PV Cost	BCR	Raw PF Score	Potential FCERM GiA (PV)	Partnership Contribution Required (PV)
Dune Face Protection (Linear Defence)	£12.5 to £17.5 Million	0.95 to 1.33	17% to 24%	£ 3.0 Million	£9.5 to £14.5 Million
Beach Retention	£17.6 to £29.9 Million	0.56 to 0.94	10% to 17%	£ 3.0 Million	£14.6 to £26.9 Million
Interim Solution	£3.7 to £8.4 Million	1.00 to 1.32	19% to 47%	£1.6 to £1.7 Million	£2.0 to £6.7 Million
Re-alignment (defer until Year 10)	£13.3 Million	1.00	18%	£2.4 Million	£10.9 Million

Partnership Funding

One factor determining the most appropriate approach to be taken at Hemsby is going to be that of affordability and funding. In England, flood and coastal erosion projects are funded by a range of sources based on the benefits they deliver to people, the wider community and businesses. This is called the 'Partnership Funding' model.

For smaller, less densely populated coastal communities where the cost of addressing the risk is high, the percentage of funding available from FCERM GiA is relatively low. This is presented in section 3. This is low percentage is due to a combination of: low numbers of properties protected (compared to towns and cities); sometimes lower values of properties; erosion spread over a number of years affecting homes at different times; and limited infrastructure that will be lost if no defence works take place.

Therefore, a typical coastal erosion project will secure funding from a range of other sources. This report highlights that under all approaches there is a gap in funding that would need to be met.

There are many funding options available when flood and coastal projects can deliver a range of benefits. These can include reducing risk and creating new opportunities for individual private businesses and providing wider benefits to the local / regional economy, such as regeneration, business growth and employment opportunities. In East Anglia, a number of coastal schemes have been completed recently or will be shortly, that have secured funding from multiple sources and have delivered a range of benefits to businesses and the wider community. These include:

1. The **East Wash Community Interest Company (CIC)** which is set up and operated by members of the community and operates in partnership with businesses, the Local Authority and Environment Agency. The CIC received a contribution from local caravan parks and landowners (£50 per caravan or £1 per hectare annually). It then combines this with holiday home donations and local and national government funding to maintain a shingle ridge that protects homes and holiday parks from flooding and erosion, plus natural beach for people to enjoy. More information: www.west-norfolk.gov.uk/info/20098/water_management_and_flooding/175/local_sea_defences_funding

2. In **Mundesley, North Norfolk**, a coastal resilience project will commence construction in early 2019 to address erosion and maintain the beach. It will pool funding from central government (FCERM GiA), the Regional Flood & Coastal Committee (RFCC – 'Local Levy' funding collected from by Council Tax), the Parish Council and local landowners. A funding application has also been submitted to Anglian Water, which has been positively received. More information: www.north-norfolk.gov.uk/tasks/coastal-management/mundesley-coastal-management-scheme/

3. In **Essex**, local tourism businesses are contributing to a project that will enhance beaches in front of a seawall. Although a basic scheme could be delivered to repair the wall using mainly public money, the beach could be lost. By pooling public and private funding, a higher cost scheme that delivers many more benefits for communities and tourism businesses over a longer period could be delivered.

4. In **Hopton, Great Yarmouth Borough**, the owners of two holiday parks have wholly funded two phases of a coastal defence scheme where their sites were at risk of erosion and beaches could be lost. A commercial decision was made based on protecting their assets and revenue, but in addition it has also reduced the risk to the village and created beaches to be enjoyed by visitors and the wider community.

5. For the **Gorleston (Norfolk) to Lowestoft (Suffolk)** stretch of rapidly eroding coastline, a strategy has been developed. The strategy recognises the strong economic advantage in investing to maintain and even create beaches plus reduce erosion to protect jobs and commercial interests. Waveney District Council have established that maintaining interests in those locations fits with their wider economic regeneration and communities' plans.

   Like the Winterton to California frontage, these projects can apply for a relatively low percentage of project costs to be funded by FCERM GiA, but by working in partnership with the community, businesses (particularly holiday park owners and landowners) and the Local Authorities a series of coastal resilience schemes will begin to be delivered in the near future and over coming years. More information: https://www.coasteast.org.uk/media/1351/gorleston-to-lowestoft-main-strategy_final.pdf

Importantly in these examples, by working in partnership, a number of wider benefits have been or will be delivered which have also attracted a number of sources of funding. For example, if businesses require a beach to attract visitors, then they have been able to invest in an option that also delivers this. It also allows for additional enhancements and features to the scheme that are desired by other investors, where they are technically and environmentally acceptable.

Some of these examples may also be of interest to Great Yarmouth Borough Council. If a large proportion of the holidaymakers coming to the area base themselves in Hemsby, Scratby and California, but then spend their money across the wider area, any strategy to maintain this base as an attractive visitor destination may have borough-wide or county-wide benefits, and also attract investment through those channels. There is clear evidence that income from parking, rental of land and holiday accommodation / facilities and business rates can also be protected and improved by coastal schemes that deliver multiple outcomes.

A practical first step that has proven to be successful in the case studies above, plus a number of other local and national projects, is to conduct an initial map of beneficiaries and benefits that would be delivered by potential scheme options. Additional studies can then also be commissioned that quantify:

- The contribution to the local economy of the area benefitting from a coastal scheme
- Which local plans and strategies are supported and even enabled by the potential schemes
- What commercial development and employment will be both supported and enabled, plus what new business opportunities can be created

By working in partnership with the range of organisations with an interest in the area, and by using the findings of the studies above to inform discussions, a range of viable options from a funding perspective can be identified.

FINAL

Appendix D: Winterton erosion issue

Prepared for

Great Yarmouth Borough Council

June 2018

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Contents

This appendix

This Appendix looks at the technical viability of defending Winterton car park. Based upon the understanding of coastal change (presented in Appendix A), it briefly summarises whether options for Winterton Beach Road are likely to be effective or not.

Shoreline change at Winterton Ness

2.1 Recent Change

2.1.1 Analysis of mean sea level position/aerial photography 1992 - 2018

Beach profile data have been collected along Winterton Ness by Anglian Coastal Monitoring since 1992: Annex 1 includes a map showing the locations of all profile lines around Winterton Ness. GPS is used to capture the position and elevation of a point along a profile line. The surveyor records these points at 5 m intervals or where there is a notable change in beach level, whichever is smaller.

The following analysis uses these data to plot the position of the Mean Sea Level (MSL) mark, onto the corresponding aerial maps to illustrate the changes in shoreline over time. The position (co-ordinates) of MSL[1] was extracted from 25 years of topographic beach profile (Figure 1), for all spring surveys between 1997 and 2018. This extracted data was plotted using mapping software, ArcMap (Figure 1). A line was then drawn between the points to give the position and shape of the shoreline for each beach profile survey. This line was checked against the aerial photography (also held within the mapping software) to ensure that the line followed the shape of the shoreline.

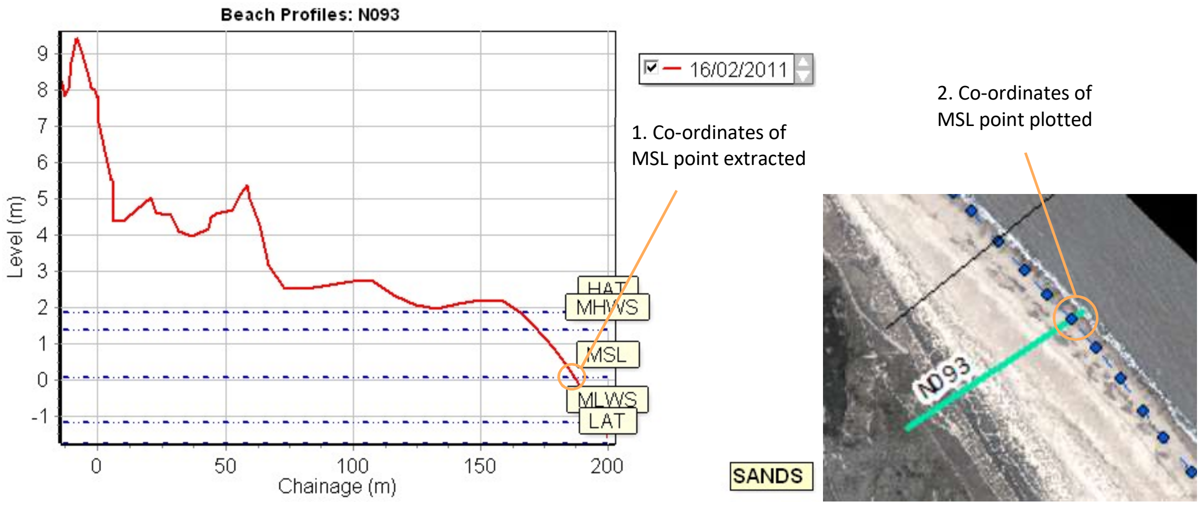

Figure 1 Extraction of the geographical co-ordinates from Jacob's inhouse SANDS database to be plotted within a Geographical Information System.

Due to changes in the frequency that individual profiles were recorded, there are only 3 years in which all profiles were surveyed, 2011, 2012 and 2017. The remaining years have fewer profiles and this did not entirely capture the shape of the ness, so during these years, using the aerial photography as a guide, an additional point was added to reflect the actual shape of the ness.

The shoreline position for the 1992 data could not be extracted from the profiles because the survey data did not consistently cover the correct area. So, to give an indicative MSL position, a line was drawn based on the aerial photography – this is thought to be acceptable as a visual guide however should not be used to calculate rates of change. Furthermore, in the 2018 post storm survey only profiles N093, N094, N095 and N096 had been surveyed. These points were joined together with the aid of both the aerial photography and (particularly about the apex) the interpolated line from the previous survey.Both extracted points and interpolated lines are shown, alongside the oldest aerial photography within Figure 2 to Figure 7. The number of years shown within each diagram was chosen to represent observed trends which are summarised within Figure 18.

[1] For the purpose of this exercise a level of +0.55mAOND was taken as this point was above that of the ridge which extends along part of the Winterton frontage. The aim of this was not to give a false, i.e. narrower, representation of the shoreline, rather to avoid the algorithm which extracted the points to consistently choose one. This would prevent the shoreline appearing to 'jump around' when no actual change had occurred.

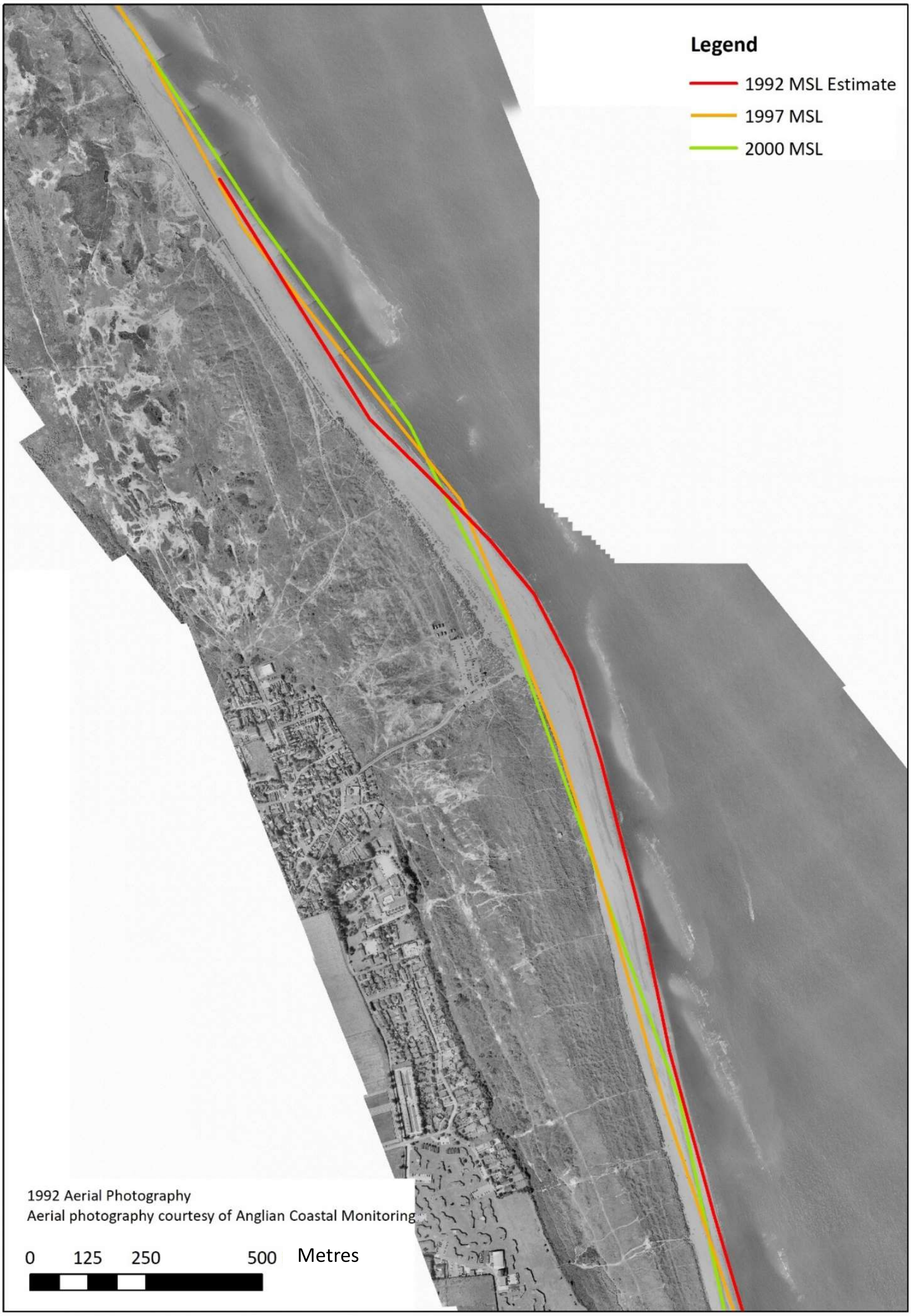

Figure 2 Extracted MSL points and interpolated lines for years 1997 – 2000. N.B. the 1992 line is based upon the aerial photography and whilst this gives a good indication of the shape may not truly reflect the MSL position.

Figure 3 Extracted MSL points and interpolated lines for years 2000 – 2005.

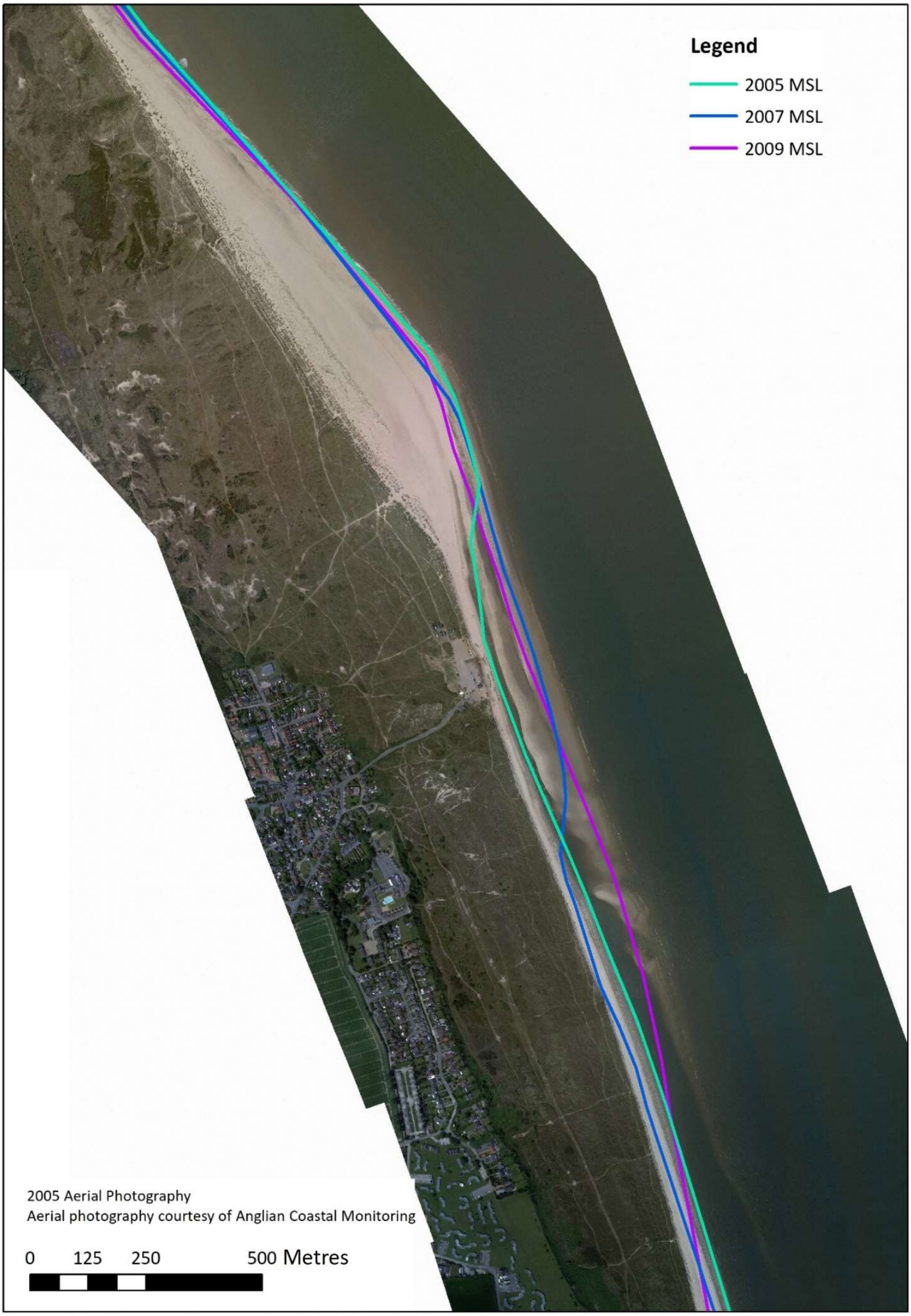

Figure 4 Extracted MSL points and interpolated lines for years 2005 – 2009.

Figure 5 Extracted MSL points and interpolated lines for years 2009 – 2014.

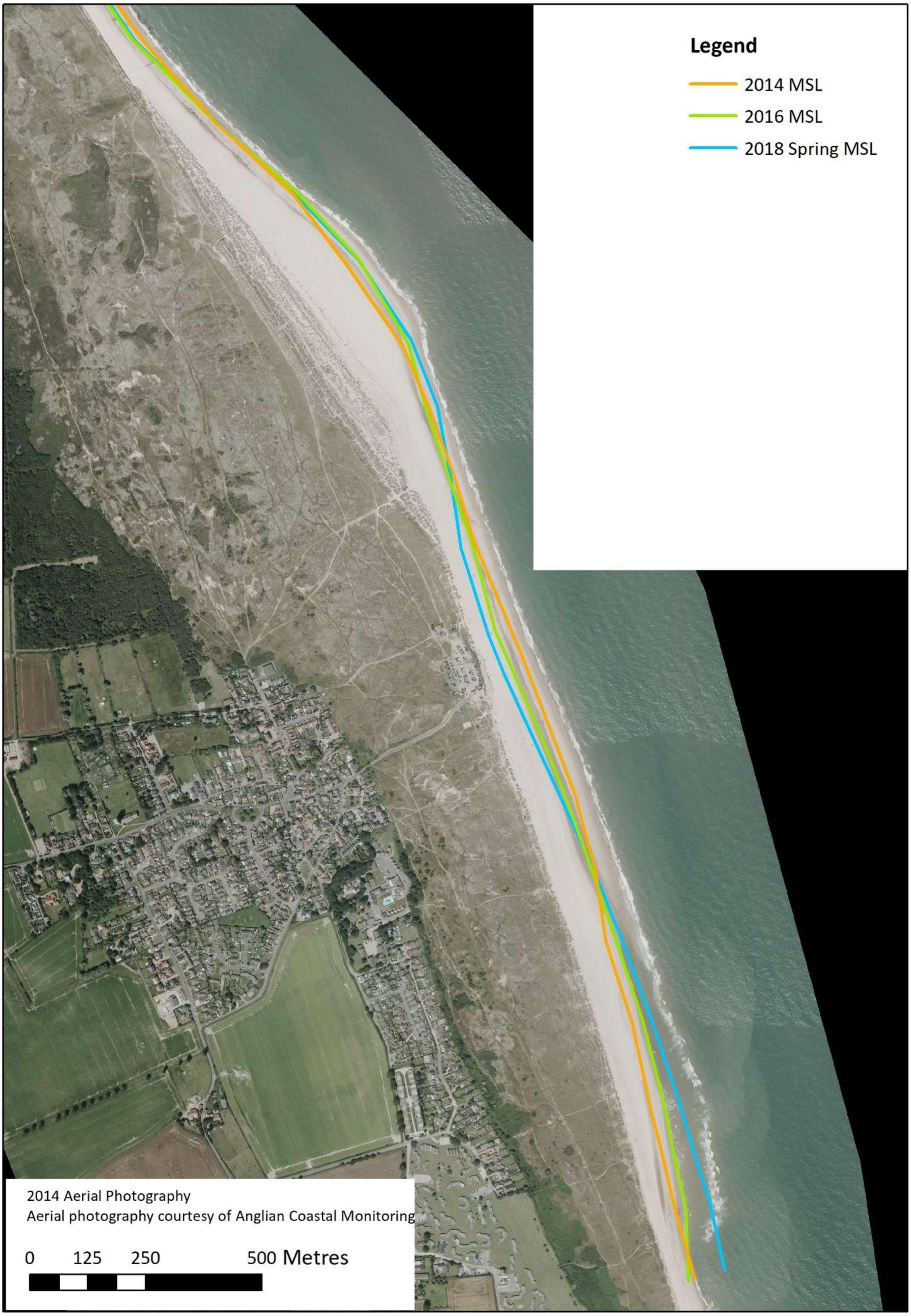

Figure 6 Extracted MSL points and interpolated lines for years 2014 – 2018.

Figure 7 – Extracted MSL points and interpolated lines for Spring 2018 – 2018 Post Storm.

From the graphs above and the aerial photography, which is available for most years between 1992 and 2018 it is possible to observe some key changes in the ness shape, movement and size. The limitations of this analysis include the fact that the photographs are not always taken at the same tidal level and as discussed above additional data was added in some of the lines to represent the shape of the ness. Key changes observed are as follows:

- Between 1992 and 1998, all along the frontage between Winterton café and the start of Scratby there was erosion of the frontal dunes. This coincides within northward movement of the apex of the ness, moving approximately 600 m over 5 years. At the beginning of this period the apex was located directly opposite the café, which meant that the café was over 100 m from the seaward edge of the dune vegetation. As the ness moved north, the café was no longer fronted by this mass of sand; by 2001 there was less than 50 m of dune vegetation in front of the café.
- Between 1998 and 2001 the apex of the ness moved north a further 250 m. There was some seaward/landward movement of the MSL; but no clear directional trend.
- Between 2001 and 2005 there was significant growth to the ness to the north of the apex. This is the largest amount of growth observed in recent times, with the ness effectively doubling in size. This was coupled with erosion to the south of the apex, in the area fronting the car park.
- In 2005, the apex reached the largest and most pronounced point. The accretion to the north and growth about the ness coincided with erosion to the south of the apex, meaning that, for the first time, an S-shaped coastline was observed. This could be due to the protruding apex either interrupting tidal flows or starving the lower area of sediment as the angle become too oblique for material to be transported around.
- Between 2006 and 2011, there was a period of 'recovery', whereby material was pushed around and down (southwards) past the apex, creating a wider beach. This is possibly due to a nearshore ridge becoming 'welded' to the coast. The apex does not move north or south during this period. Despite this 'straightening-out' of the coastline, where the beach had not recovered erosion continued between Winterton café and Hemsby Gap.
- In 2012 and 2013 there was some accretion to the north of the apex and erosion to the south, extending along the Valleys in 2012 and along the entire length in 2013.
- Between 2014 and 2018 there was a relatively stable period, when the position of the apex remained unchanged and although there was some year to year variation in the position of the MSL mark, there were no consistent trends, unlike previous years. The erosion that had previously occurred had 'straightened-out' the coastline here and this shape appeared to be more stable than the s-shaped beach of 2005.
- The 2018 post storm topographic beach survey showed that since the spring there had been erosion around the car park, however there had been little/not change to the north of the ness (at profile N093). Erosion occurred along the car park frontage with tank traps exposed along the base of the dune cliffs. It should be noted that although there is no 2018 Post Storm beach data between Profile lines N093 and N094, the aerial photography provides reasonable confidence that the position of the apex did not significantly change during 2017 and 2018.

The shape of the beach in 2005 is similar to that of the 2018 post-storm survey (Figure 8). Notably in 2005 the balance between erosion and accretion was favoured towards accretion north of the apex, whilst in 2018 there was more erosion. For example, in 2005 Profile HW351 prograded by 90 m, in comparison to the previous year, whilst in 2018 this profile only gained 21 m. At Profile N094, erosion between 2004-2005 was in the order of 20 m whilst in 2017-2018 the losses were around 40 m; nearly double that of the change in 2005. A key observation is that in 2005 the position of the MSL mark/line is practically the same as that shown in the 2018 post storm data.

From the 1992 aerial photography, it appears that there is a wet patch of sand to the area north of the ness, which may potentially be an area of scour. This may be a similar feature to that observed in 2005 and 2018, but possibly the result of south easterly waves rather than north easterly.

Figure 8 Similarities and differences between the shape of Winterton ness in 2005 and 2018. Orange arrows indicate the re-orientation of shoreline as the area to the south of the ness eroded.

2.1.2 Relating MSL Position and CSA Analysis

Cross Sectional Area (CSA) analysis, using the area between an arbitrary datum (set at -1.0 mOD for the purpose of this report) and the beach profile (in cross section), provides a measure of the size of the beach. Profiles N093, N094 and N095 have data for the years 1992 to 2018 and therefore provide a good long-term record of the changes at this site.

Profile N093 is located to the north of the apex. The CSA graph (Figure 9) shows that this profile has been accreting for the past 25 years. Figure 9 also shows that this growth has not been consistent over time and we are now in a period of (relatively) slow but steady growth (2005 to present). In contrast there was a period of accelerated growth between 1996 and 2005 which was much higher than present. These two periods roughly correspond with the northward movement of the ness (1992 – 2001), the rapid growth of the ness in (2004-2005) and a more stable period where the apex has not moved but there has been some accretion north of the apex.

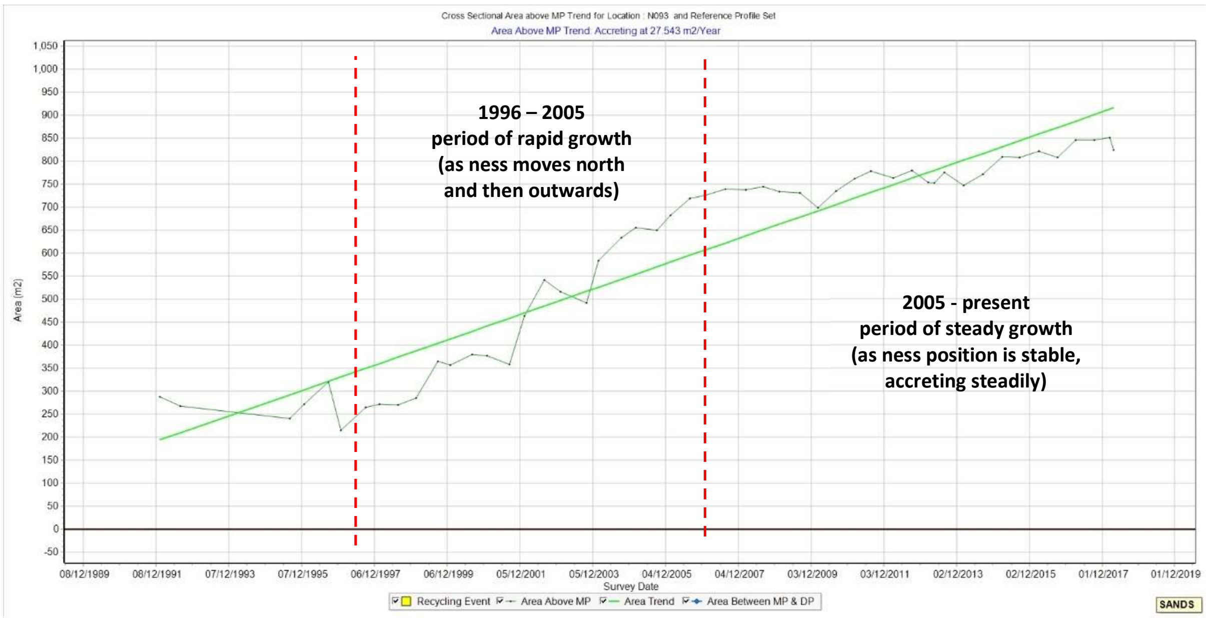

Figure 9 Profile N093 - Cross sectional area over time (1992 - 2018)

To the south of the apex, profiles N094 and N095 show a long term erosive trend. It could also be interpreted that at these profiles there was a short term highly erosive period, followed by a recovery period within 2001 and 2005. As with Profile N093, this trend roughly correlates with the trends observed in the MSL analysis discussed in the section above.

The northward movement of the ness (1992 – 2001) has resulted in a decrease in CSA as the size of the beach has reduced. The rapid growth of the ness in (leading up to 2005) corresponded with erosion to the south of the apex, which can be observed in Figure 3. Subsequently, there was a period of recovery (Figure 4), when material built back up (in the intertidal area rather than in the dunes) and the CSA in front of the car park recovered (Figure 10, Figure 11).

Figures 11 and 12 show that there is a long term erosive trend along this frontage. To understand the drivers for change in this area, the nearshore area needs to be considered.

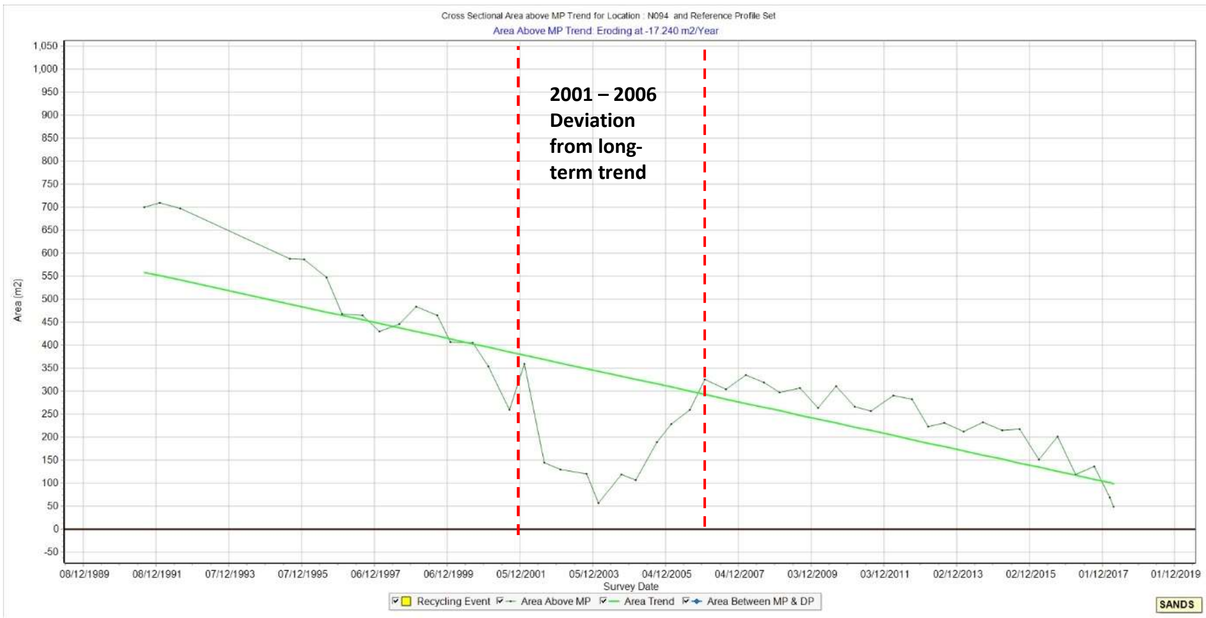

Figure 10 Profile N094 - Cross Sectional Area over time (1992 - 2018)

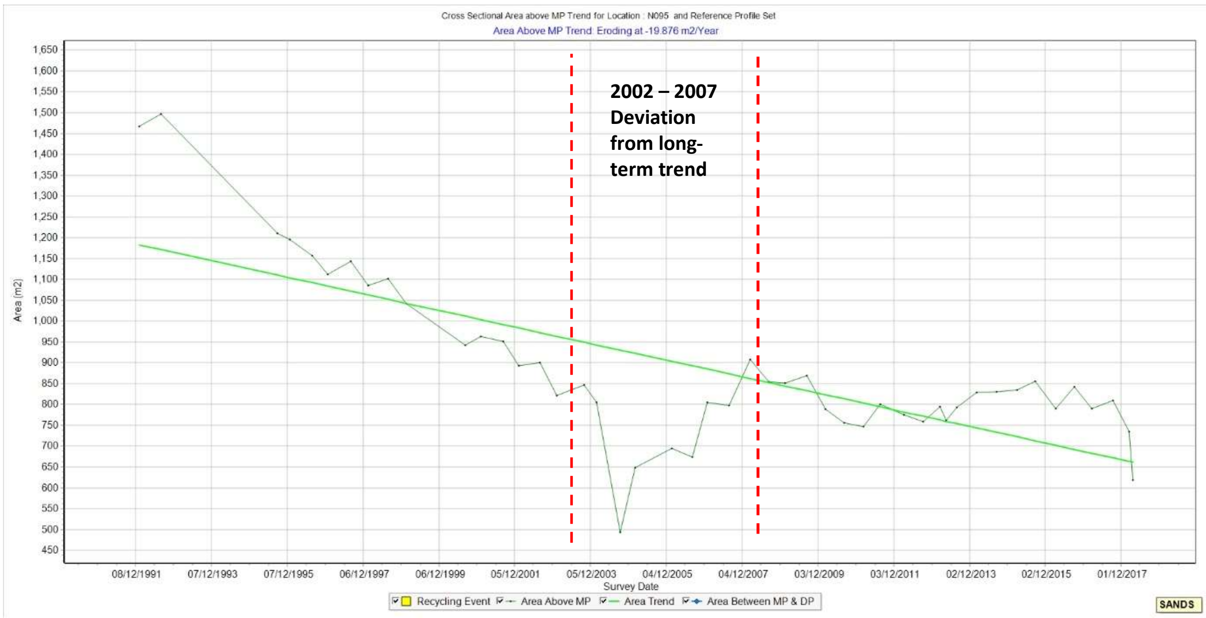

Figure 11 Profile N095 - Cross Sectional Area over time (1992 - 2018)

2.1.3 Nearshore bathymetry

Figure 13 shows the change in morphology over the past 70 years as observed from Admiralty Charts.

The key changes along Winterton has been the development of the channel and the movement of this channel inshore. This has also been observed within the more recent bathymetry surveys.

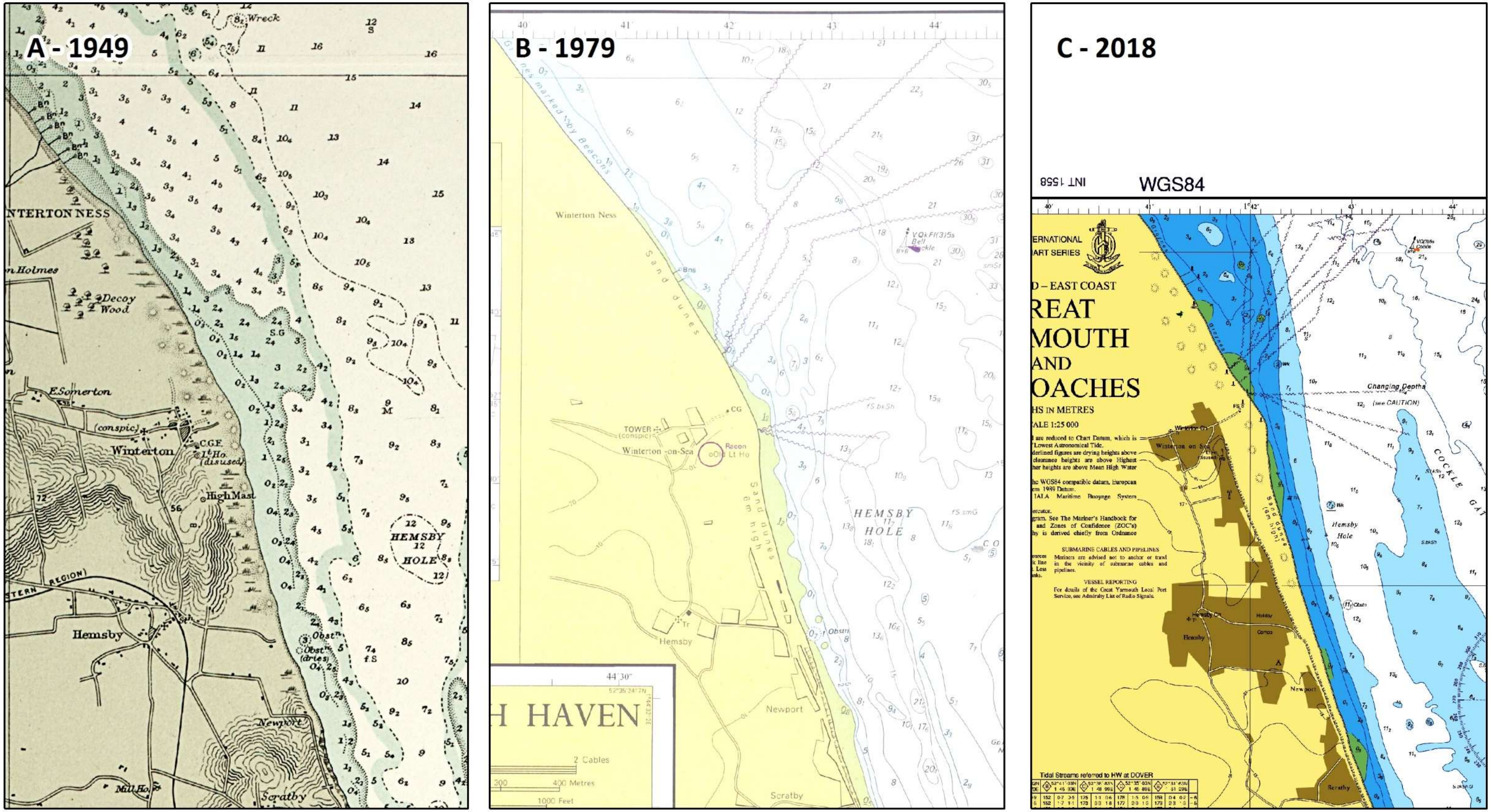

Figure 12 Winterton Ness Admiralty Charts © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.GOV.uk/UKHO).

Figures 13 – 15 show the topographic beach profiles with additional bathymetry extracted from Maritime Coastal Agency surveys. It should be noted that although surveyed in the same year, the exact date of the surveys may not overlap – therefore there may be seasonal differences between the beach and seafloor data. It is also important to bear in mind that the bathymetry data is less accurate than the beach profile data. However, over the scales given here (hundreds of metres) it is still possible to interpret indicative trends from the bathymetry surveys.

There is a gap between the topographic and bathymetric data where surveys do not cover: within this zone it is too shallow for a survey boat and too dangerous for a surveyor. The bathymetry data is also highly subject to error in the surf zone (i.e. where waves shoal and break) so data in this area should be used with caution.

Profile N093 is to the north of the apex and crosses 'Winterton Ness Shoal' a shallow area that lies to the north of the ness (not formally recognised as a feature on the UKHO charts). Here in the past 17 years there has been a movement of this shoal inshore and the development of a V-shaped channel.

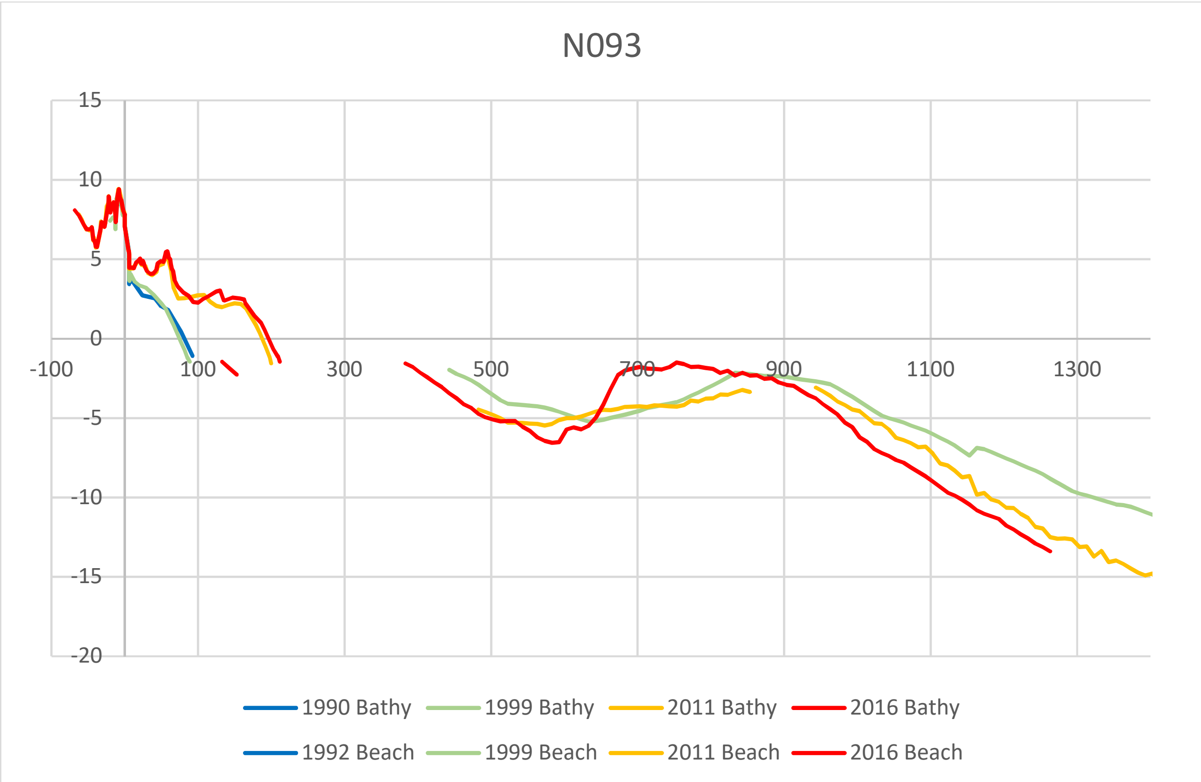

Figure 13 Beach profile data Profile N093 with additional bathymetry (sea floor) data extracted from MCA surveys. Note: the vertical axis is in metres above Ordnance Datum.

Profiles N094 and N095 (see Figure 10 and Figure 11 respectively) lie either side of the café at Winterton (approximately 250 m apart). There was little net change between 2011 and 2016; however, between 1999 and 2016, there appears to have been lowering of the nearshore channel.

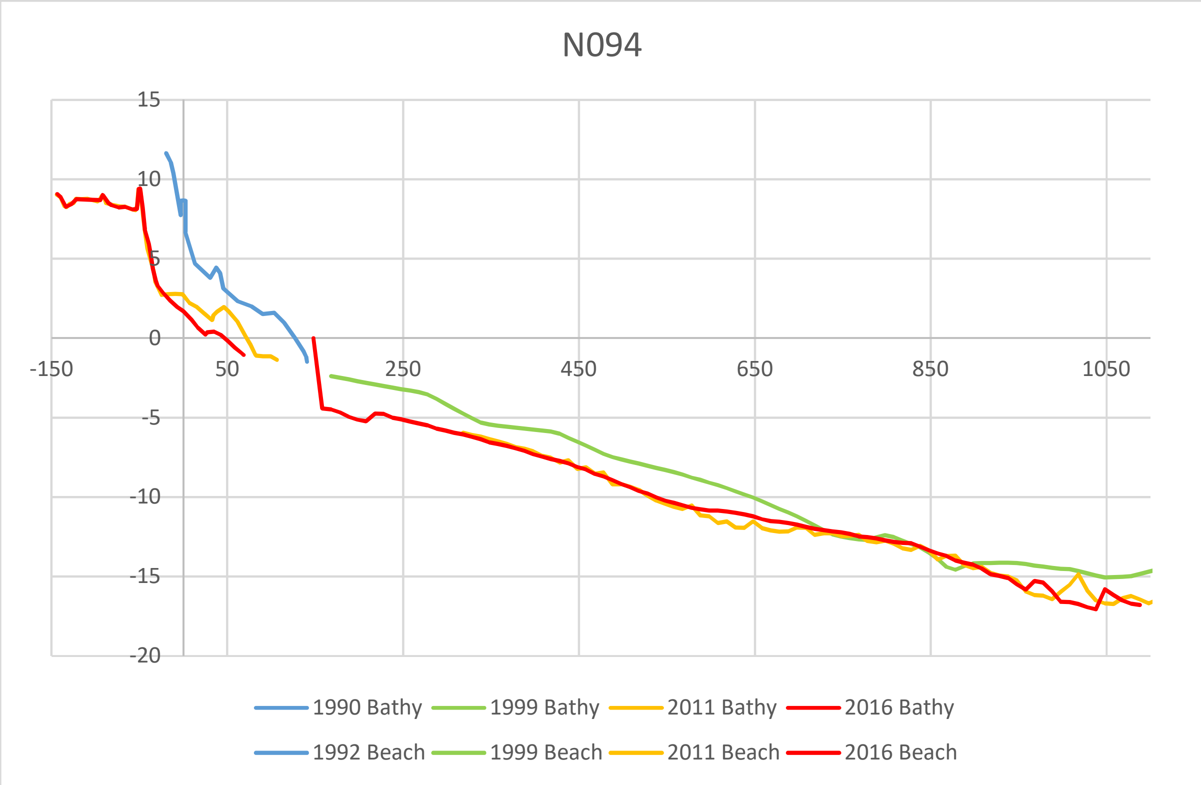

Figure 14 Beach profile data Profile N094 with additional bathymetry (sea floor) data extracted from MCA surveys. Note: the vertical axis is in metres above Ordnance Datum.

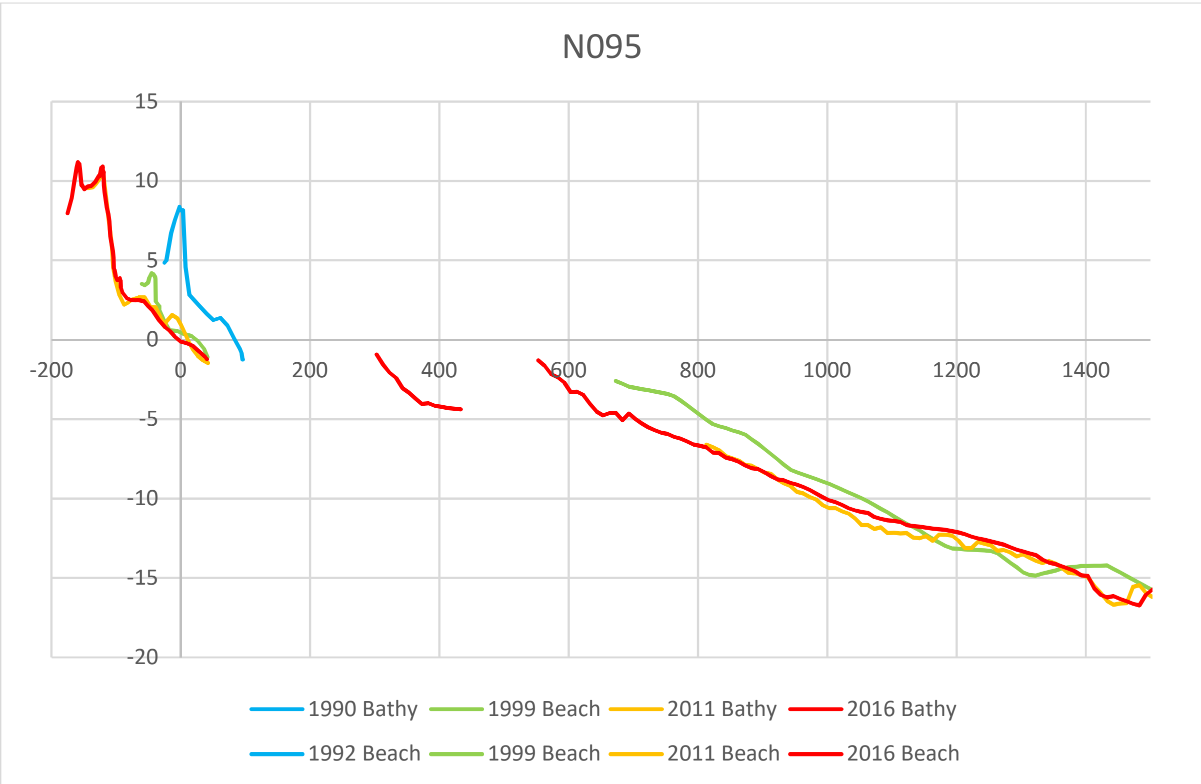

Figure 15 Beach profile data Profile N095 with additional bathymetry (sea floor) data extracted from MCA surveys. Note: the vertical axis is in metres above Ordnance Datum.

2.1.4 Rates of change 1992, 2013 & 2018

Rates of change were calculated for 6 profiles in the vicinity of the ness and the car park. This was undertaken by extracting the chainage of Mean High Water Springs (MHWS) and MSL[2] for each spring survey for the oldest available record, 1992 for profiles N093, N094 and N095) and 1997 for all other profiles, Spring 2013 and Spring 2018. The post storm data was not included due to data limitations[3]. It was not possible to extract any data below MLS as the survey data did not consistently extend far enough offshore.

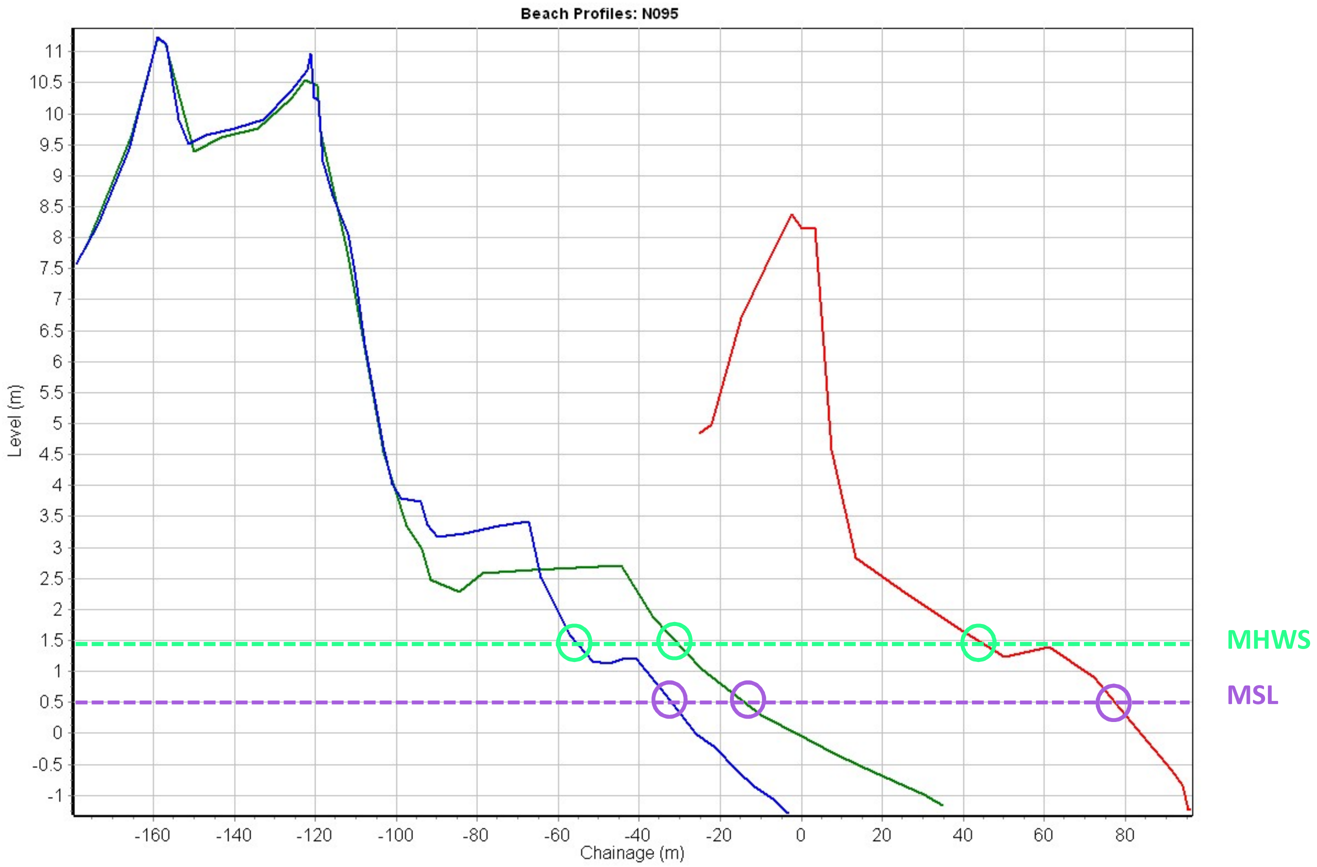

Figure 16 Extraction of chainage point at Mean Sea Level (purple points) and Mean High Water Springs (green points) from beach profile data. Chainages were extracted for the 1992/1997 (red), 2013 (dark green) and 2018 (blue).

The baseline rate covers the entire data record, which spans 25 years for Profiles N093, N094 and N095 and 20 years for Profile HW351. A baseline rate was not calculated for Profiles HW333 and 348 as their oldest records were not comparable to the older records. The recent rate was calculated for all profiles over five years. The difference was calculated and an average rate per year was derived from the total change. Results are presented in the Table 1 below.

The *recent average annual rates* show that Profile N094 has been retreating (on average) by - 9.3 m/year. Further south, Profile N095 has shown a *recent annual average rate* of -4.6 m/year. This corresponds to growth to the north of the apex (recent annual average rate of +3.0 m/year at HW348 (at apex) and +3.3 m/year at N093.

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[2] As with the MSL analysis previously reported, a level of +0.55 mODN was taken as this point was above that of the ridge which extends along part of the Winterton frontage. The aim of this was not to give a false, i.e. narrower, representation of the shoreline, rather to avoid the algorithm which extracted the points to consistently choose one. This would prevent the shoreline appearing to 'jump around' when no actual change had occurred.

[3] If the period was extended to the post storm survey in 2018, two storm periods would have been captured which may have given an exaggerated rate.

The *baseline average annual change* typically shows accretion to the north and erosion in the south of around ±4.0 m/year. Although this is indicative of overall shoreline change, these rates cannot be used to predict future change as they represent several different periods of change, as discussed in Section 2.1.1 above.

Table 1 Average Annual Rates generated for the Recent (2013-2018) and Baseline (1992/1997 - 2018)

Profile	Recent Average Annual Rate (m/year)	Baseline Average Annual Rate (m/year)
	MHWS	
HW333	2.6	N/A
N093	5.2	4.3
HW348 (Apex)	5.6	N/A
HW351	5	4.2
N094	-6	-4.4
N095	-4.8	-4.5
	MSL	
HW333	0.8	N/A
N093	3.3	4.0
HW348 (Apex)	3	N/A
HW351	2.4	4.2
N094	-9.3	-4.6
N095	-4.6	-4.2

Figure 17 shows the recent changes in the position of MSL and MHWS. At Profile N094, between Spring 2013 to Spring 2018 (pre-storm), there has been a seaward advance in MHWS of approximately 25 metres, and a seaward advance at MSL of approximately 15 metres. This indicates that the foreshore has become steeper (at least between these two points) during this time. shallower.

To the north of the ness there has been some profile steepening and to the south of the ness the profile has become shallower. This may correspond to the development of an accretive convex profile north of the apex and an erosive concave profile to the south of the apex. Alternatively, the change at the south of the ness may relate to the development of the sand ridge.

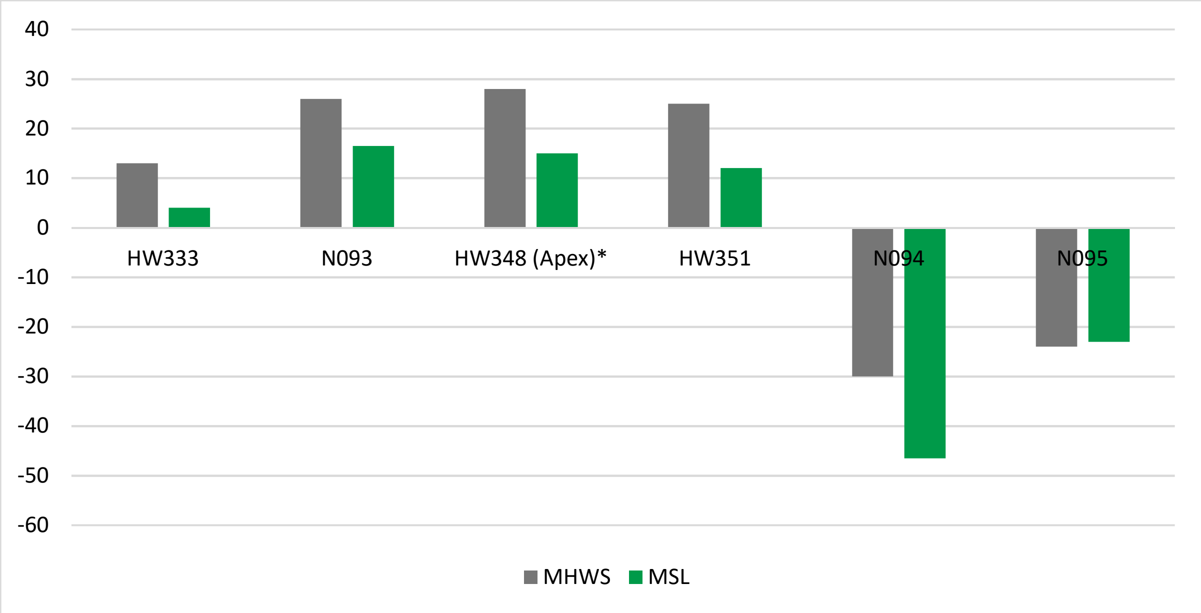

Figure 17 Recent change in position of MSL and MHWS at specific profile locations.

2.2 Discussion

The ness has been shown to be a semi-permanent feature, whose position is linked to the nearshore banks system (see Appendix A for further discussion). Historic mapping has shown the ness at different positions along the coast over time and the analysis of more recent data, presented within this report, concurs with this conclusion. Since coastal monitoring began (1992) there have been four key periods of change, summarised within Figure 18.

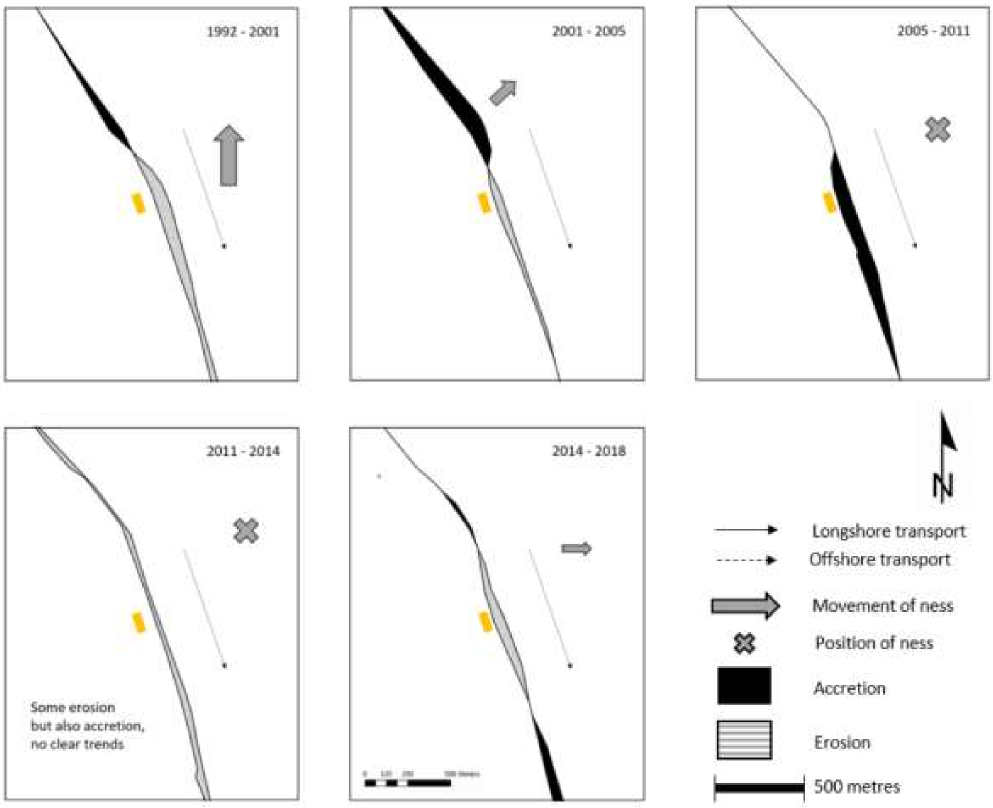

Figure 18 Conceptual summary of changes at Winterton Ness during the period 1992 – 2018. The yellow rectangle indicates the position of the car park for reference.

It has been observed that there was a period of recovery to the south of the ness between 2005 to 2011, but although the foreshore i.e. the intertidal area recovered, the dunes at the back of the beach did not recover. Comparing this area to the area north of the apex provides a good comparison/explanation why the dunes have not grown back in this area. Dune development to the north of the apex has been observed since 2005. For dunes to form, a wide expanse of dry sand is required. The large deposition of sediment between 2004 and 2005 was largely above mean high water which was possible due to the sheltered shallow water environment fronting the beach here, i.e. Winterton Ness Shoal.

In contrast the build-up of beach material to the south of the ness was unlikely to be wide or dry enough to enable a supply of wind-blown sand to the backshore, as accretion here was in the form of a shore parallel ridge. In accordance with current trends, it is unlikely that new sand dune growth will occur here in the near future.

Despite the fact that the dunes have not recovered, the ridge of sand that development post 2005 has provided the beach with an improved level of protection. From the site inspection in April 2018, it appeared that the sand ridge was underlain with shingle and could therefore provide more resistance to longshore transport and dissipation of wave energy. Post storm 2018, this bar may have migrated southwards, exposing the car park area and providing some protection to the area fronting the valleys.

2.3 Future change

It is not possible to say with any certainty what will happen to Winterton Ness in the future and there are a large number of different configurations of ness migration, shape and size; however there are likely scenarios which we can consider.

Three potential scenarios are outlined below:

Scenario 1 – The ness moves northwards

Scenario 2 – The ness stays put and rates continue as at present

Scenario 3 – The ness moves southwards (considered unlikely)

Figure 19 shows the potential northward migration of the ness, Scenario 1. It is not thought that the ness itself would be transported northwards as the predominant drift direction is southerly. Rather, the shape and size presented within Figure 19 represents what has currently been stable for the past ten years and may develop again, albeit northwards of its current position.

Figure 20 shows Scenario 2, based on an extrapolation of current rates, i.e. growth at the apex and to the north of the apex, and scour around the car park area. The outcome of this extrapolation seems unnatural, and we could therefore expect some change in rates to gain a more natural shoreline configuration.

Should Scenario 3 occur, which is considered unlikely based on information to date, there would be accretion to the south of the ness and the car park and café will become protected by the beach again, although erosion of dunes to the north of the apex could be expected. No figure has been produced to illustrate this scenario.

Importantly under both Scenarios 1 and 2, the village is not at risk of erosion within the next 20 years, although it is most likely that the car park and café will be lost.

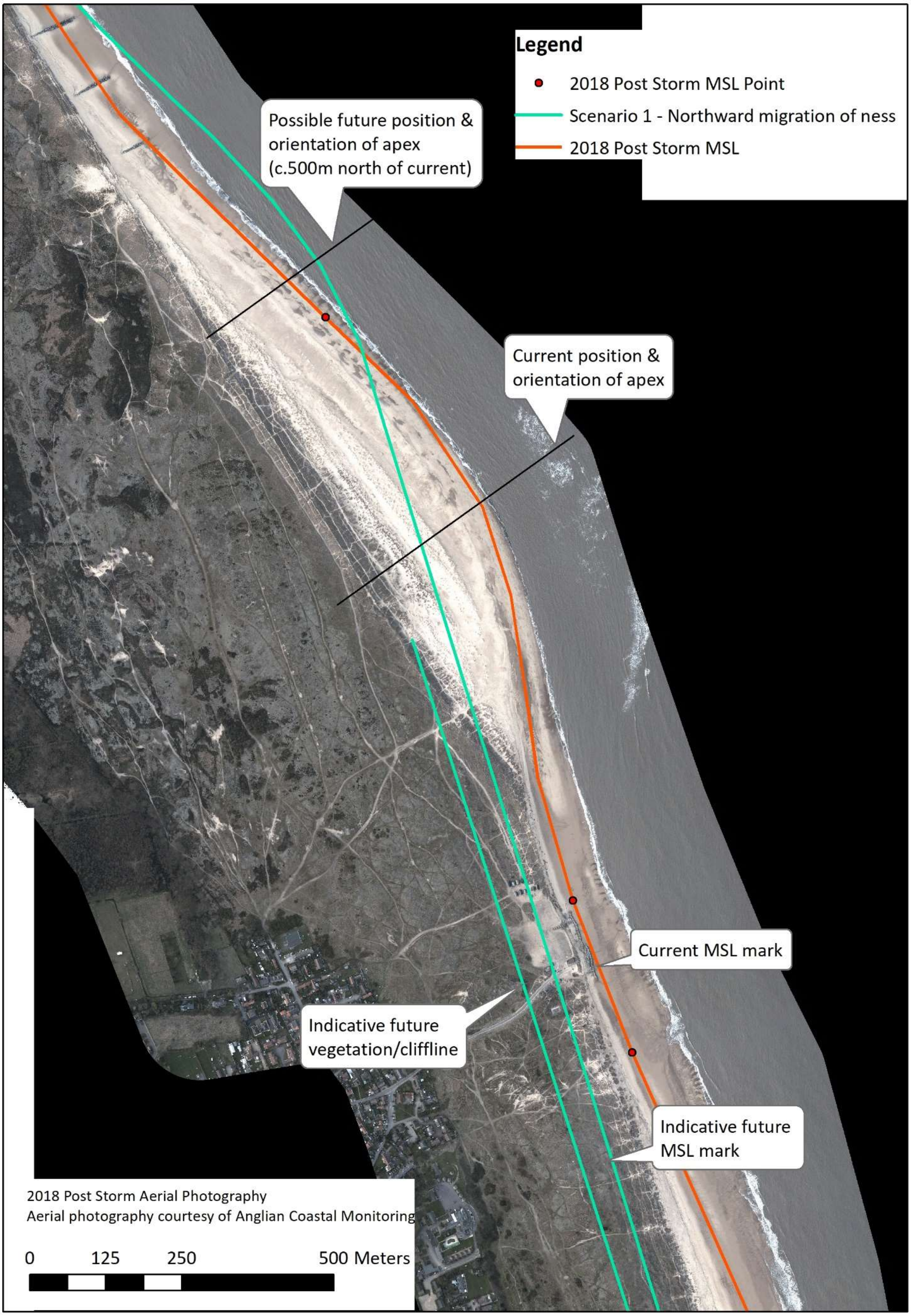

Figure 19 Scenario 1 – Northward migration of the ness (20 year projection).

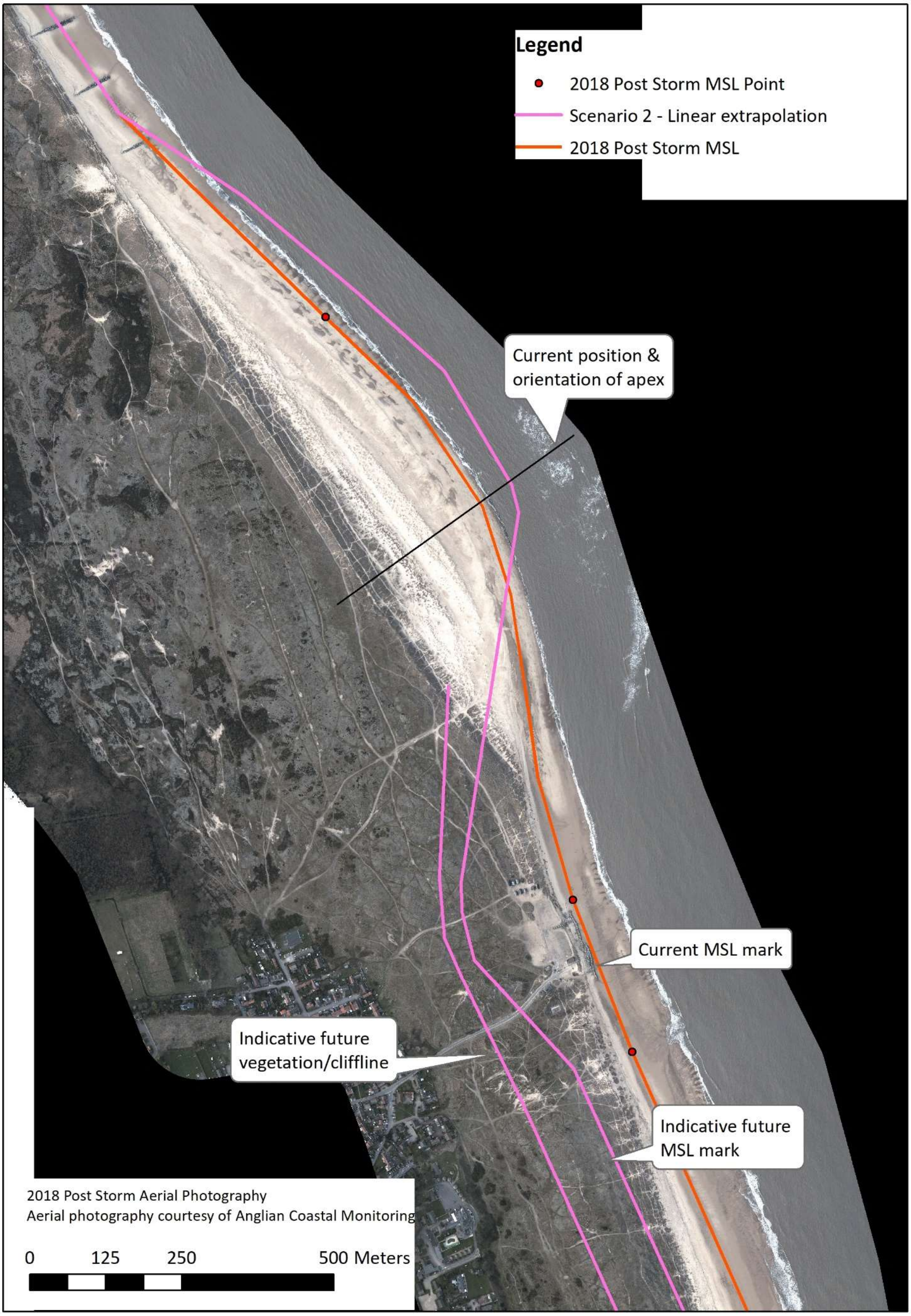

Figure 20 Scenario 2 - linear extrapolation of current trends alongside current MSL mark (20 year projection).

Coastal defence assessment

This section assesses the likely effectiveness of coastal defence options along the Winterton car park and beach access frontage.

3.1 The consequence of coastal change for defences

To understand whether any coastal defence options might be effective at Winterton, it is necessary to understand the nature of the problem and how the shoreline is changing. This has been set out in the preceding section, establishing two key points:

1. Some of the issues to be overcome are similar to Hemsby, i.e. as the dune face retreats, so does the beach, meaning that the level at any one point is lowering over time.
2. Unlike Hemsby, where the channel appears to be a driving force, the key behavioural change at Winterton is the movement and reshaping of the ness feature.

The latter point further complicates the situation with respect to the provision of any coastal defences, as explained in 3.1.2 below.

3.1.1 Beach lowering

As the position of the dune line and the beach position has changed, the depth of water over the place that beach previous occupied has increased, as illustrated in Figure 3.1 of the main study report. This is an extremely important point when considering options and understanding why some approaches may be less suitable than others. As the figure below illustrates (taken from Figure 3.2 of the main report), although dune face erosion might be prevented by construction of a defence, the beach changes seaward of that would continue as a consequence of the changes taking place to the ness. That translates to an ongoing lowering at the point where the defences were installed, which would lead to them being undermined and failing if not bedded deep enough into the beach.

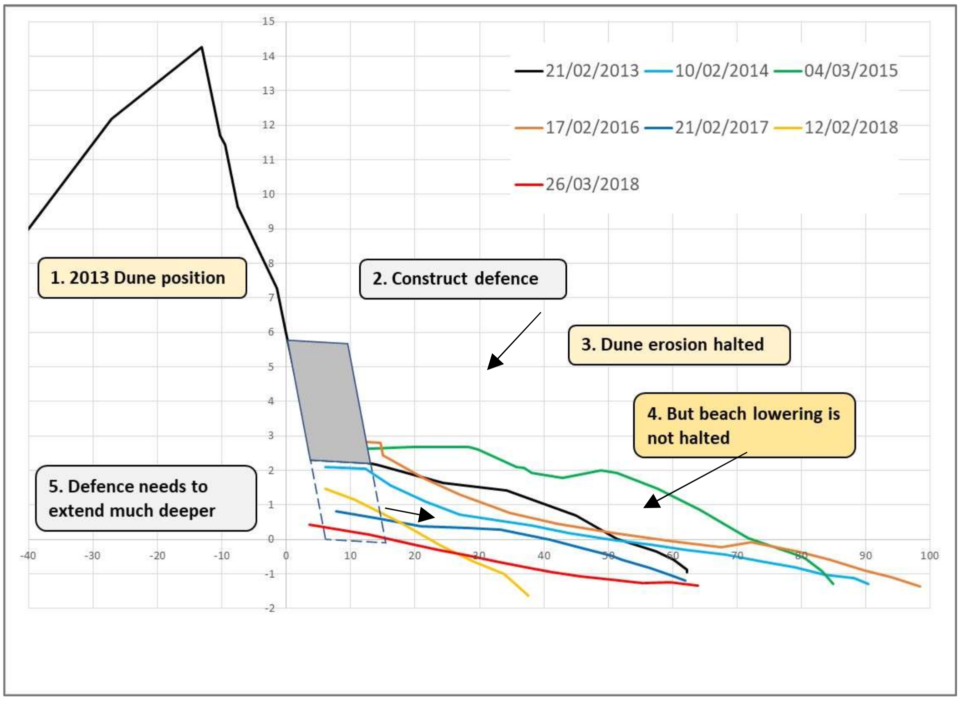

Figure 22 Impact of defence construction

3.1.2 Shoreline movement

The movement of, and changes to, the ness are not a localised issue, but part of a much larger scale coastal system behaviour that is both complex and largely unpredictable, particularly as it is not fully understood. It is clear that there are relationships between the movement of Winterton Ness (and Benacre Ness to the south), the configuration of the offshore banks and channels, and the effects of waves and tidal currents; but which of these are triggers and which are responses is unknown.

However, it is clear is that changes at the behaviour of the ness are controlled by significant natural forces. Consequently, we would expect the major shifts in the landmass that is Winterton Ness to continue, with that remaining the dominant mechanism with regard to shoreline change.

Section 2 has presented the changes that have been observed in the ness position in recent years, and how the shoreline will evolve if those continue. The key point to draw from that is the shoreline orientation is altering over a large area, which is manifesting as a recession of the beach and dune line at the car park, but also altering the shoreline shape and position to north and south. Therefore, the additional issue that any defence of the car park area needs to take into account is the recession predicted to occur to north and south, and thus the outflanking of any defence measures put in place here. The introduction of structures are themselves not going to alter the movement of this landmass due to the scale of the changes taking place.

This limited ability to control such movement is starkly illustrated from observations of Benacre Ness at the southern end of this coastal system. Groynes built in front of Kessingland a few decades ago had no discernible effect on the movement of the ness, being swamped and overrun by it to the point that they are now buried a considerable distance landward of the water line. South of those, a 200 m long outfall structure to Benacre pumping station, which should have effectively acted like a groyne, had no effect upon reducing the movement of the ness, which simply moved through and past this structure, to the point this now the tail end of this ness with the sea now back to the pumping station.

A similar situation is noted on the north side of Winterton Ness, where groynes originally built to manage alongshore sediment movements are now completely redundant, having been overrun by the movement of this feature, emphasising that the large-scale behaviour of this feature has outstripped the influence of man’s interventions.

3.2 Review of defence options

The potential effectiveness of the coastal defence types presented in Appendix B has been considered with respect to reducing erosion risk at Winterton car park, and summarised below. The option numbering used for the Hemsby assessment has been retained for ease of reference.

3.2.1 Unsuitable techniques

Several options considered unsuitable at Hemsby are also clearly unsuitable here too.

OPTION		ASSESSMENT
1	Dune/Cliff Stabilisation	None of these approaches is going to prevent erosion of dunes at this location.
4	Rubber Tyres	An approach not proven in a dynamic beach environment, and considered to be vulnerable to instability under aggressive wave conditions and beach changes.
5	Intermittent Blocks	An open array of blocks will not prevent erosion at this location (as the tank traps that have fallen onto the beach here already demonstrate).

3.2.2 Walls and rigid defence structures

A primary issue with each of these options is that of beach lowering and the requirements for a design that can accommodate that, which will generally lead to an expensive option. Each of these will also require counter-walls to prevent the sea from reaching the back of these structures and undermining them from the rear.

None of these options are considered suitable for providing protection at Winterton Ness.

OPTION		ASSESSMENT
6	Concrete Seawall	A seawall will lack long term sustainability; it will not prevent foreshore lowering and would exacerbate beach scouring. A deep piled toe would be required and rock or similar in front. This will also be highly vulnerable to outflanking due to the larger scale shoreline movement through this area, so will need counter-walls to be constructed back towards land as the shoreline recedes. It will also be the most expensive of all hard defence options.
7	Blockwork Wall	This will suffer from exactly the same limitations as other forms of seawall, described above.
8	HexiBlocks	As at Hemsby, this needs further development to be effective. Notwithstanding that, like other options listed here there will be stability issues due to underlying processes causing loss of the beach, and any structure will be susceptible to outflanking.
11	Other Revetment Systems	Most types of revetment system would be inadequate for this aggressive coastal environment, or require 'seawall' type toe protection, which could increase scour. Similar issues of outflanking apply.
12	Timber Wave Break	As for other options, a primary issue is the foreshore lowering, which the sheet piled toe will only exacerbate, with resultant instability issues. Again, unless some counter-walls extending landward are introduced, this will also fail due to the sea coming in behind this structure.

3.2.3 Flexible defence structures

Options that can accommodate some change in the beach without losing their integrity offer advantages on a highly mobile shoreline. However, these too will have limitations at this location, in particular because of the nature of change occurring here and the outflanking problem.

Structures built against the dune face (e.g. revetment or berm) are going to be vulnerable to the outflanking too, so would need to have works to the rear face to prevent collapse. Indeed, unless counter-walls are built, these are not going to remain stable, and the more appropriate alternative would be to construct a bund directly in front of the dune face, rather than against it.

One additional consideration at Winterton, is the higher proportion of shingle that appears to exist here below the surface. Although not confirmed through investigations and sampling, observations from the site visit were that the bar forming the tail end of the ness appeared to have a very high shingle content, possibly indicating a larger shingle deposit beneath the ness itself. This could have implications for the suitability of certain options, due to the highly abrasive nature of this material.

OPTION		ASSESSMENT
2	Gabions/Stone-Filled Mattresses	These can provide some protection to an eroding dune face, and do have an advantage in that counter-walls could be built by extending these relatively easily. But these remain susceptible to undermining and failure, so a structure built of gabions will have limited life expectancy. A further disadvantage here is the much lower durability in a shingle environment, with abrasion a key failure mechanism which will limit their effective life.
3	Geotextile Sand Containers	Again, these could provide some protection to the eroding dune and have an advantage in that counter-walls could be built by extending these relatively easily. They also have the same limitations as gabions however; these will not prevent

		the loss of beach, and depending on the product they may be less durable in an abrasive shingle environment.
9	Rock Revetment	Although this may be a successful approach to deal with erosion issues elsewhere, and better able to accommodate beach lowering than many alternatives, the main issue here is outflanking due to shoreline reorientation. It would actually be more appropriate to build a rock bund just in front of the dune, rather than a revetment against the face (see below), as the revetment would be undermined from behind unless counter-walls are also constructed.
10	Rock Berm (or Bund)	A berm would have the same issues with respect to outflanking as a revetment. Constructing a bund away from the dune face might however be effective, as this will be stable in its own right with a constructed rear slope. This would not halt erosion but might be can be effective to limit it, by locally reducing direct wave attack and helping to trap some material behind during more benign conditions.
13	Concrete Armour Units (Bund)	Could be an alternative to armour rock for a bund option. Simple units (e.g. Tripod) are probably most appropriate.

3.2.4 Beach retention options

Options that seek to retain a beach in front of the car park are considered unlikely to be effective at this location, due primarily to the underlying forces controlling behaviour of the ness and the much wider geographic risks of disrupting this highly dynamic coastal system. Observations of the lack of effect that control structures have had upon the movement of Benacre Ness (south of this frontage) only serve to illustrate that the forces controlling movements of this large landmass are not going to be significantly influenced by what are by comparison small scale structures.

None of these options are considered suitable for providing protection at Winterton Ness.

OPTION		ASSESSMENT
14	Beach Nourishment	This is not a sand-starved system, but one that is highly dynamic. It is unlikely that importing additional sand is required and any placed there will be subject to the same erosive processes already ongoing there and unlikely to remain.
15	Groynes	Although many circumstances control structures would help retain beach material and provide better protection to the eroding dune face. However, the underlying natural forces here are driving changes in the shoreline that are not going to be significantly affected by localised interventions. It is considered highly probable that control structures are going to be ineffective here.
16	Nearshore Breakwaters	As with groynes, it is considered highly probable that control structures are not going to be effective in stabilising a beach here.
17	Sill/Submerged Reef (Perched Beach)	Again, these are expected to be ineffective at controlling the movement of the shoreline and beach at this location due to the underlying large-scale movement of the ness feature.
18	Headland Structures	These are designed to keep strong currents and deep-water channels away from the shore, but the nature of the tidal flows around the ness itself are potentially critical to the wider bank and channel system behaviour, so intervention such as this could have significant unforeseen consequence.
19	Sand Motor	Given some of the physical similarities with the ness, and the observed relatively rapid changes in behaviour of that, this is unlikely to offer any benefit. As discussed elsewhere, the issue is not an absence of sand, but the processes determining how that landmass moves. Adding to that would be a high-risk approach that would most likely not work here, but could have wider unforeseen consequences through disrupting the dynamic equilibrium of the system through changing the flow of tidal currents around this important feature.

3.3 Conclusions

It is clear is that the movement of sediment in this area and the behaviour of the shoreline at this point is not consistent with that normally observed on many coastlines. Therefore, traditional coastal defence options are not necessarily going to be effective here in the same way as they might be elsewhere.

Due to the nature of changes at this location, any structures that might be able to offer a solution will need to have been founded at some considerable depth to accommodate beach changes and to remain stable. Any scheme would also probably need to extend along a distance of at least 400 m, i.e. the length of the car park plus 100 m to north and south, to provide a buffer against potential outflanking as a result of the shoreline reorientation to north and south, and/or would require counter-walls to prevent that outflanking and destabilisation of any defences from behind.

If stable defences could be built, then defending this area will most likely result in a hard promontory into the sea, lined by a continuous coastal defence structure, or a shore parallel barrier.

A shore parallel barrier, in the form of a bund constructed from armour rock or concrete armour units, is probably the only option that might be considered to offer some level of structural stability here and accommodate the various issues at least cost. Based upon the estimates for Hemsby it is still likely this will be in the order of £4 to £6 Million (including optimism bias). However, this option will not completely prevent erosion, only limit it, and then only if constructed over such a distance to limit the extent of outflanking that might occur. Rock or concrete armour units do offer flexibility in that their design can be adapted at a later time and the materials can be reused, if required, to rebuild and reshape future defences.

Cheaper alternatives, gabions or geo-containers, would be a very temporary option only.

It should be noted that one further scenario is that the presently observed changes in the ness shape and behaviour might actually see some fresh accumulations of sand in the area south of apex. This occurred previously post-2005, when the shoreline position here was also close to the current line, and ness shape change was also taking place. Under those circumstances an investment in defences may be unnecessary. However, the exact nature of change is not predictable, and it is still probable that at least some further erosion of the car park area and beach access will occur, even if this scenario does result. Consequently, adaptation approaches, including rolling back the assets (e.g. relocating the café) should also be considered.

As with all schemes, any approach to intervene would need to be assessed further in line with environmental impacts, noting that there are designated areas that may be affected.

Annex 1: profile locations

Profile Locations around Winterton Ness