# Appendix F

# Shoreline interactions and response

## Appendix F
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# F1 Introduction

This appendix reports on a number of tasks from the early stages of the SMP: assessment of coastal defences, development of baseline scenarios and the assessments of flood risk and erosion risk.

# F2 Assessment of defences

## F2.1 Introduction

The aim of this task is to review coastal behaviour and dynamics. Understanding these processes underpins the sound development of the SMP. This will include assessment of natural features as well as considering the existing defences. The results from this task will be used to develop the baseline scenarios, identify risks and test the response and implications of different management policy scenarios over three separate timescales (present day to 2025, 2026 to 2055 and 2056 to 2105).

This task is divided into two explicit tasks. This section deals with the second part of this task, which consists of assessing, in broad terms, every coastal defence in the SMP study area. It has been split down further into two stages:

- theoretical approach based on condition, according to the SMP guidance
- validation by asset managers.

This appendix has been produced after validation by the asset managers.

Section F2.9 reports on additional work, undertaken after the public consultation, to estimate the residual life of the flood defences if current levels of maintenance were continued.

## F2.2 Step 1: Residual life based on condition grade

### F2.2.1 Method

<u>SMP guidance</u>
The SMP guidance provides residual life numbers based on the existing defence condition grades for a number of defence types (table F2.1). This information has been derived from previous NADNAC (National Appraisal of Defence Needs and Costs) deterioration profiles.

**Table F2.1: Estimate of deterioration for assessment of residual life (from SMP guidance)**

| Defence description | | Estimate of residual life (years) | | | | |
|---|---|---|---|---|---|---|
| | | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
| Sea wall (concrete/masonry) | Fastest | 25 | 15 | 10 | 5 | 0 |
| | Slowest | 35 | 25 | 15 | 7 | 0 |
| Revetment (concrete/rock) | Fastest | 25 | 15 | 10 | 5 | 7 |
| | Slowest | 35 | 25 | 15 | 7 | 0 |
| Timber groynes/ timber structures | Fastest | 15 | 10 | 8 | 2 | 0 |
| | Slowest | 25 | 20 | 12 | 7 | 0 |
| Gabion | Fastest | 10 | 6 | 4 | 1 | 0 |
| | Slowest | 25 | 10 | 7 | 3 | 0 |

<u>Additional method for grassed embankments</u>
The SMP guidance does not contain residual life estimates for grassed earth embankments, which make up a high proportion of the flood defences along the north Norfolk coast. We have therefore developed a residual life profile for this asset type. In discussion with the Environment Agency and Defra, we have decided to use the latest knowledge about asset deterioration. This was improved in 2007 from the NADNAC information for using in the Environment Agency's System Asset Management Plans (SAMPs), adapting this so it is in the same format as the SMP guidance.

Defence class number 45 (type 2) from NADNAC, described as a wide earth embankment with turf revetment, most closely matches the grassed earth embankments characteristic of the Wash area. The SAMP (2007) deterioration profile for this defence type is shown in table F2.2. This information differs from the SMP guidance as the SAMP numbers indicate the number of years to reach a condition from new. The SMP numbers indicate the number of years from a condition to failure.

**Table F2.2: NADNAC deterioration profile for a wide earth embankment with turf revetment**

| Number | Type | | Time (years) to reach condition from new | | | | |
|---|---|---|---|---|---|---|---|
| | | | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
| 45 | Type 2, W, FP, Turf | Best estimate | 0 | 13 | 20 | 28 | 33 |
| | | Fastest | 0 | 10 | 15 | 22 | 25 |
| | | Slowest | 0 | 15 | 25 | 35 | 40 |

After consulting the Environment Agency and Defra, it was decided to convert the deterioration profiles from SAMP (2007) directly to residual life profiles. Grade 5 is assumed to signify failure. The difference in years between a certain grade and grade 5 is assumed to be the residual life of a defence of that grade. This approach is comparable to the one used to establish the residual life profiles in the SMP guidance. Technically, this assumes that the assigned condition is always at the 'top' of the condition, but this is acceptable given the uncertainties in the scientific background of the deterioration rates. Table F2.3 defines the final residual life assessments used for the grassed earth embankments (sea banks) of north Norfolk. This approach is consistent with that taken for the Wash SMP2.

**Table F2.3: Estimate of deterioration for assessment of residual life adopted for grassed earth embankments (sea banks)**

| Defence description | | Estimate of residual life (years) | | | | |
|---|---|---|---|---|---|---|
| | | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
| Sea bank | Fastest | 25 | 15 | 10 | 3 | 0 |
| | Slowest | 40 | 25 | 15 | 5 | 0 |

Also, the guidance does not contain residual life numbers for ‘natural defences’ such as sand dunes. These occur widely along the north Norfolk coastline. In some cases they are natural, undisturbed features. In others, they have a variety of man-made toe protection elements, such as gabions and revetments. However, as human intervention on these defences is minimal, and the weakest element of the defence is the sand dune itself, the dunes have been classed as natural features for this assessment so there has been no estimate made of residual life and defence failure.

Further assumptions

A number of other assumptions were made about the defence type. In some cases, the descriptions of the individual defences are not clear so we have had to make certain assumptions to assign a defence to a specific SMP category. These assumptions are listed in table F2.4.

**Table F2.4: Assumptions about SMP defence types**

| Specific NFCDD description | Assumed SMP category |
|---|---|
| Any sand dune with toe protection | Sand dune |
| Concrete revetment on vegetated earth flood bank | Sea bank |
| Timber sea wall protecting earth bank | Sea bank |
| Gabion groyne constructed from 1m x 1m gabion baskets | Gabion |

### F2.2.2 Data availability

Data about specific elements of each defence were provided by the defences’ asset managers from the National Flood and Coastal Defence Database (NFCDD). The download date for these data was 17 December 2007. NFCDD includes a description of each defence and an ‘overall condition grade’ that was assigned to the defence during the last inspection. In some cases, an overall condition is not available so we have used the manual override condition from NFCDD instead. This override grade was assigned by the asset manager to certain defences based on the condition of the asset elements and their weightings. In cases where both the overall condition grade and the manual override condition were available, the manual override condition was used as this provides the best overview of the condition of a particular defence.

It is also worth mentioning that the received NFCDD data contain an estimate of residual life but, as specified in the SMP guidance, these have not been used for the defence assessment. Instead, the residual life for each defence has been derived using the method discussed in section F2.1.

The NFCDD database also contained a number of defences that were either outside the boundaries of the study area, were secondary defences or had a condition grade of 5 and so have already failed. These defences were subsequently removed from the final output.

The NFCDD database does not always provide accurate, up-to-date information for defences that are owned privately or by local authorities. As a result the following sources were also consulted to gain a complete record of coastal defences in this SMP area:

- North Norfolk District Council - quay wall in Wells-next-the-Sea
- "RSPB Titchwell Reserve EIA: Assessment of Condition and Standard of Defence" (Royal Haskoning 2005) and consultation with RSPB staff - defences protecting the Titchwell RSPB nature reserve
- Royal West Norfolk golf club staff - defences protecting the golf clubhouse and golf links.

### F2.2.3 Results

Referencing the defences
A unique 'SMP2 reference' has been assigned to all relevant defences within the SMP boundary. For this assessment only, the frontline defences have been identified and assessed so the format of the unique 'SMP2 reference' reflects this (DEF_1_defence number). Defences were numbered in numerical order starting at the western boundary of the study area (immediately to the north east of Old Hunstanton) to the eastern boundary (Kelling Hard).

Assessment for 'no active Intervention'
The results of this task are shown in table F2.6. This table provides a summary of the defences within the study area and includes an individual defence's location, description and who maintains it. This information comes directly from NFCDD. The table also summarises the assumptions used for the condition assessment, the defence category (see section F2.2.1) and the fastest and slowest estimates of residual life under the 'no active intervention' (NAI) policy. The defence category column relates to the 'with present management' scenario (see section F2.2.3).

The residual life for each defence has also been used to define the epoch during which the defence is likely to fail. The three epochs are defined under the SMP guidance:

- epoch 1 - present day to 2025
- epoch 2 - 2026 to 2055
- epoch 3 - 2056 to 2105.

This is not necessarily an essential part of this task, but it will provide vital information for completing the baseline scenarios task.

Table F2.6 also identifies the areas where data needed to complete the assessment have been assumed (red text). There are many defences that have the potential to fail during epoch 1, but may not fail until epoch 2. This provides uncertainty to the assessment of defence failure and will need to be taken into account in subsequent tasks.

The condition grades for each defence are presented diagrammatically in section F2.6 and the estimate of the residual life for each defence is presented in section F2.7. Section F2.8 illustrates an expected failure plan for the three epochs.

Assessment for with present management

In order to prepare the defence assessment output for the 'with present management (WPM)' scenario to be analysed, it was necessary to define the functions of the defence 'practice' rather than simply the specifics of the structure itself. As a result, an extra column has been inserted into the output table (table F2.6) to this section (labelled 'defence category') to determine how the present management and practices in the study area affect shoreline processes and behaviour. Defences have been categorised using the guidance from table D2 in appendix D of the SMP guidance. A summary of the categories and the assumptions for each are included in table F2.5.

**Table F2.5: Categories and assumptions for the with present management baseline assessment**

| Defence type category | Example structure | Brief assumptions |
|---|---|---|
| Linear stoppers | Sea wall, grassed embankments | Minimise breach, structural integrity remains and wall is rebuilt at a similar standard of effectiveness |
| Linear reducers | Maintained shingle barrier | Continues to reduce erosion, although level of effectiveness may change so rate of erosion may change |
| Cross-shore interrupters | Groynes, breakwaters | Continues to interrupt drift but not necessarily the same amount |
| Changers | Recharge/recycling | Continues to recharge with same amount, sediment type and timing |

Note that we have assumed that maintained grassed embankments will act as linear stoppers, just like sea walls.

### F2.2.4 Discussion

Just over 50 per cent of the north Norfolk defences are classed as sea banks and just under 15 per cent are classed as natural defences (shingle ridge/ sand dune). Due to their classification as 'natural defences', they do not have a calculated residual life. However, many of the sand dunes have some degree of hard/soft engineered toe protection structures but they have been classed as sand dunes in the assessment as the sand dune is the weakest element.

The north Norfolk coastline provides a varied selection of condition grades for the study area. Condition grades range from 1 to 5, but for this task those with a condition grade of 5 are assumed to have failed so have been removed from the table in section F2.6. Most of the defences have a condition grade of 2 or 3 (34 per cent and 43 per cent respectively). Of the remaining defences, 20 per cent have a condition grade of 4 and only two per cent have a condition grade of 1 (best condition).

Sections F2.7 and F2.8, the assessment of residual life for a scenario of no active intervention and the resulting epoch of defence failure, indicate that the strongest sea defences along the north Norfolk coast are those that protect the villages of Burnham Deepdale, Burnham Norton and Burnham Overy Staithe. The weakest location along the coast is highlighted with the gabion defences at Old Hunstanton with most residual life estimates ranging from four to seven years. A few have shorter life estimates of one to three years. There are also a number of weak locations at Titchwell, Brancaster Staithe and Morston.

In summary, most of the sea defences along the north Norfolk coast are expected to fail during epoch 1 (60 per cent) under a policy of NAI. There is also a large proportion of defences (24 per cent) that have the potential to fail during epoch 1 or may not fail until epoch 2.

## F2.3 Step 2: Validation by the defence asset managers

This appendix has been completed using the information provided by the asset managers and following consultation with local authorities and a number of private organisations.

## F2.4 Coastal defence management schemes

As well as providing a basic inventory of all frontline coastal defences in this SMP area, and undertaking an assessment of each defence's condition grade and predicted failure, it is also necessary to obtain background knowledge of the specific management strategies that have been carried out. This section provides a brief overview of the various known management strategies. This will also be useful when carrying out the assessment of baseline scenarios task.

### F2.4.1 River Glaven realignment

The natural rollback of Blakeney Spit has been seen to block the tidal River Glaven channel. As a result, the natural channel was cut back in 1924 by about 75 metres due to the threat of a permanent blockage occurring. In addition, management of the tidal River Glaven involved dredging the shingle material from the channel and replacing it on the back-face of the shingle ridge.

Despite these management attempts, the natural rollback caused the channel to block in 1996 and there were other similar blockages in 1953, 1978 and 1991. It was therefore decided that this management strategy was unsustainable.

If a blockage does occur in the tidal River Glaven channel, drainage from both the Cley and Salthouse marshes (a SPA and cSAC), and from the fluvial River Glaven, is impeded. This causes damage to the marsh and river flooding upstream of the River Glaven tidal sluice (in Cley-next-the-Sea and Wiveton). It is known that occasional saline inundation of freshwater marshes, such as the Cley and Salthouse marshes, is environmentally acceptable provided the saline flood waters are quickly evacuated from the marshes within five to seven days. The Cley-Salthouse Flood Management Scheme was put in place to allow effective discharge of saline flood waters into the upper Glaven estuary (downstream of the tidal outfall sluice). However, in 1996 the blockage of the tidal River Glaven in the upper Glaven estuary compromised the success of this scheme and meant that saline flood waters did not effectively drain from the marsh for between three and four weeks. This caused significant environmental damage to freshwater habitats and saline lagoon features.

Because of these events, and the acknowledgement that continued dredging of the channel was unsustainable, a number of options were considered and a preferred option was chosen. The details of all options, and of the preferred options, can be found in the Blakeney Project Appraisal Report (Halcrow 2002). The preferred option involved building a new tidal channel in Blakeney Freshes about 200 metres inland of its old position. The flood defence embankment, located on the landward edge of the old channel, was also realigned to the landward edge of the new channel. This option is the minimum needed to ensure compliance with the Conservation Regulations (1994). It will provide continued impeded drainage for around 200 years, so is not considered to be a long term option. The preferred option does not prejudice the success of a longer-term plan for managed realignment of the Blakeney Freshes site.

### F2.4.2 Titchwell RSPB reserve

There is currently a managed realignment project underway in the RSPB reserve at Titchwell. This involves building a new defence line (the Parrinder Wall, to be completed in autumn 2011), strengthening the west wall to increase flood protection and allow continued access to the bird hides and beach (to be completed in autumn 2010) and finally breaching the existing northern bank in autumn 2011. The RSPB has designed the planned realignment for a 50-year period, after which they expect further inland realignment will be needed in response to coastal processes.

## F2.5 References


Halcrow, 2005, Salthouse and Cley Marshes – Drainage Improvement Scheme Project Appraisal Report

Royal Haskoning, 2005, RSPB Titchwell Reserve EIA: Assessment of Condition and Standard of Defence

**Table F2.6: Assumptions for the with present management baseline assessment**

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_001 | 054CANNNS1001C01 | TF6791542445 | From Old Hunstanton lifeboat station TF6817542647 to TF6833542802. | Sea defence (man-made) | Stepped gabion basket toe wall backed by sand dune. | 532.9 | Environment Agency | high | 10 | 6-10 | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_002 | 054CANNNS1001C02 | TF6851242903 | About 200 metres from lifeboat house in Old Hunstanton. In front of Hunstanton golf course. | Sea defence (man-made) | Gabion basket toe wall with stub groynes/ dunes. | 218.4 | Environment Agency | high | 10 | 1-5 | 4 | | Sand dune | 4 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_003 | 054CANNNS1001C03 | TF6925143717 | In front of Hunstanton golf course. | Sea defence (man-made) | Natural sand dune with gabion basket protection at toe of dune. Gabion groynes extending from gabion to toe wall. | 1100.3 | Environment Agency | high | 10 | 6-10 | 4 | | Sand dune | 4 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_004 | 054CANNNS1001C04 | TF6952644066 | North east end of golf course near Holme village from TF6919643703 to TF6950044000. | Sea defence (natural) | Vegetated sand dunes. | 444.7 | Environment Agency | high | 10 | | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_005 | 054CANNNS1001C08 | TF6830742769 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.2 | Environment Agency | high | 10 | 6-10 | 2 | 1 | Gabion | 1 | 10 | 2017 | 25 | 2032 | Cross-shore interrupter | 1/2 |
| DEF_1_006 | 054CANNNS1001C09 | TF6832442781 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.1 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_007 | 054CANNNS1001C10 | TF6834142794 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.1 | Environment Agency | high | 10 | 6-10 | 2 | 3 | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_008 | 054CANNNS1001C11 | TF6835742806 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.1 | Environment Agency | high | 10 | 6-10 | 4 | 3 | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_009 | 054CANNNS1001C12 | TF6837342819 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.0 | Environment Agency | high | 10 | 6-10 | 4 | 3 | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_010 | 054CANNNS1001C13 | TF6839042831 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.0 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_011 | 054CANNNS1001C14 | TF6840642843 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.0 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_012 | 054CANNNS1001C15 | TF6842342856 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.0 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_013 | 054CANNNS1001C16 | TF6843942867 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.4 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_014 | 054CANNNS1001C17 | TF6845042887 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 8.5 | Environment Agency | high | 10 | 6-10 | 4 | 3 | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_015 | 054CANNNS1001C18 | TF6847342894 | Old Hunstanton | Sea defence (man-made) | Eight metre long gabion groyne built with 1m x 1m gabion baskets. | 7.9 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_016 | 054CANNNS1001C19 | TF6847042932 | Old Hunstanton, seaward of Hunstanton golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.4 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_017 | 054CANNNS1001C20 | TF6853142943 | Old Hunstanton seaward of Hunstanton golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.1 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_018 | 054CANNNS1001C21 | TF6855043003 | Old Hunstanton seaward of Hunstanton golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.3 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_019 | 054CANNNS1001C22 | TF6861543017 | Old Hunstanton in front of Hunstanton golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.3 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_020 | 054CANNNS1001C23 | TF6865543052 | Old Hunstanton seaward of Hunstanton golf club | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 33.3 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_021 | 054CANNNS1001C24 | TF6869643087 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 33.7 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_022 | 054CANNNS1001C25 | TF6873043118 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 33.5 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 1 |
| DEF_1_023 | 054CANNNS1001C26 | TF6875443171 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 34.3 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 2 |
| DEF_1_024 | 054CANNNS1001C27 | TF6878843206 | Old Hunstanton seaward of Hunstanton golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 33.9 | Environment Agency | high | 10 | 6-10 | 2 | | Gabion | 2 | 6 | 2013 | 10 | 2017 | Cross-shore interrupter | 2 |
| DEF_1_025 | 054CANNNS1001C28 | TF6882243242 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 33.1 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_026 | 054CANNNS1001C29 | TF6885843279 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.9 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_027 | 054CANNNS1001C30 | TF6889243315 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.5 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_028 | 054CANNNS1001C31 | TF6892743351 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 32.2 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_029 | 054CANNNS1001C32 | TF6896243388 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 31.7 | Environment Agency | high | 10 | 1-5 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_030 | 054CANNNS1001C33 | TF6899443421 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 32 metre long gabion groyne built with 1m x 1m gabion baskets. | 31.5 | Environment Agency | high | 10 | 1-5 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_033 | 054CANNNS1001C36 | TF6906543523 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 24.2 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_034 | 054CANNNS1001C37 | TF6908143542 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 24.7 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_035 | 054CANNNS1001C38 | TF6909843561 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 25.7 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_036 | 054CANNNS1001C39 | TF6911243580 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 24.5 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_037 | 054CANNNS1001C40 | TF6912743599 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 24.0 | Environment Agency | high | 10 | 6-10 | 3 | | Gabion | 3 | 4 | 2011 | 7 | 2014 | Cross-shore interrupter | 1 |
| DEF_1_038 | 054CANNNS1001C41 | TF6914443618 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 24.2 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_039 | 054CANNNS1001C42 | TF6915843636 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | 24 metre long gabion groyne built with 1m x 1m gabion baskets. | 23.4 | Environment Agency | high | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_040 | 054CANNNS1001C43 | TF6918043656 | Old Hunstanton seaward of golf club. | Sea defence (man-made) | Stone-filled gabion groyne 24 metres long. | 20.5 | Environment Agency | - | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_041 | 054CANNNS1001C44 | TF6919143677 | Old Hunstanton seaward of golf course. | Sea defence (man-made) | Stone-filled gabion groyne 24 metres long. | 19.2 | Environment Agency | - | 10 | 6-10 | 4 | | Gabion | 4 | 1 | 2008 | 3 | 2010 | Cross-shore interrupter | 1 |
| DEF_1_042 | 054CANNNS0901C01 | TF6985044330 | Near Holme village. | Sea defence (natural) | Vegetated sand dunes. | 419.2 | Environment Agency | high | 10 | 6-10 | 3 | 3 | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_043 | 054CANNNS0901C02 | TF7040044600 | Near Holme village. | Sea defence (natural) | Sand dunes separated by marshland. | 611.0 | Environment Agency | high | 10 | 11-20 | 2 | | Sand dune | 2 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_044 | 054CANNNS0901C03 | TF7051044550 | Near Holme village and Gore Point. | Sea defence (natural) | Low-lying first line of sand dunes/ marshland. Inlet to saltmarsh. | 120.5 | Environment Agency | high | 10 | 6-10 | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_045 | 054CANNNS0901C04 | TF7113045030 | Holme Dunes Nature Reserve near Gore Point. | Sea defence (natural) | Vegetated sand dunes. | 847.1 | Environment Agency | high | 10 | 6-10 | 4 | | Sand dune | 4 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_046 | 054CANNNS0901C05 | TF7155045070 | Holme Dunes Nature Reserve near The Firs. | Sea defence (natural) | Natural sand dunes with dragon tooth soft sea defences. | 420.6 | Environment Agency | high | 10 | 6-10 | 3 | 1 | Sand dune | 1 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_047 | 054CANNNS0901C06 | TF7194444960 | In front of Broadwater Reserve. | Sea defence (natural) | Vegetated sand dunes. | 430.9 | Environment Agency | high | 10 | 6-10 | 4 | | Sand dune | 4 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_048 | 054CANNNS0902C01 | TF7202944811 | From Broadwater 'The Firs' running inland TF7196044970 to TF7204344788. | Sea defence (man-made) | Well-vegetated earth flood bank. | 173.4 | Environment Agency | high | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_049 | 054CANNNS0902C02 | TF7208844686 | From around 150 metres north of Hun outfall sluice to Hun outfall sluice TF7204344788 to TF7209244681. | Sea defence (man-made) | Concrete revetment on vegetated earth flood bank. | 138.0 | Environment Agency | high | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_050 | 054CANNNS0902C03 | TF7222344401 | From Hun outfall sluice to eastward turn in bank. | Sea defence (man-made) | Well-vegetated earth flood bank. | 314.6 | Environment Agency | high | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_051 | 054CANNNS0902C04 | TF7222344401 | West to east run on flood bank TF7222244413 to TF7266444335. | Sea defence (man-made) | Vegetated, revetted earth flood bank. | 443.8 | Environment Agency | - | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_052 | 054CANNNS0902C05 | TF7266244332 | Corner of flood bank to first access gate on flood bank (Staithe Lane) TF7266444335 to TF7280343918. | Sea defence (man-made) | Vegetated earth flood bank. | 491.3 | Environment Agency | - | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_053 | 054CANNNS0902C06 | TF7280243907 | From the first access on flood bank (Staithe Lane) to higher ground TF7280343918 to TF7282043810. | Sea defence (man-made) | Vegetated earth flood bank. | 97.1 | Environment Agency | - | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_0 54 | 054CANNNS0801C01 | TF7325043730 | Thornham marsh bank TF7281043810 to TF7325043730. | Sea defence (man-made) | Small earth flood bank used as footpath. | 500.1 | Environment Agency | high | 10 | 1-5 | 4 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_05 5 | 054CANNNS0802C01 | TF7322043810 | From seaward side of Marsh House, Thornham TF7325043730 to TF7321743812. | Sea defence (man-made) | Well-vegetated earth flood bank. | 85.5 | Environment Agency | high | 10 | 1-5 | 4 | | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_0 56 | 054CANNNS0802C02 | TF7322043810 | Adjacent to Marsh House, Thornham TF7321743812 to TF7331644007. | Sea defence (man-made) | Vegetated coastal flood bank. | 251.9 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear Stopper | 1 |
| DEF_1_057 | 054CANNNS0802C03 | TF7333044001 | North east section of bank, Thornham. | Sea defence (man-made) | Marshlands ring bank, Thornham. Coastal vegetated bank. | 245.6 | Environment Agency | - | - | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_0 58 | 054CANNNS0802C04 | TF7357044019 | Eastern section of bank, Thornham TF7331644007 to TF7375843989. | Sea defence (man-made) | Vegetated earth bank. | 199.2 | Environment Agency | - | - | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_059 | 054CANNNS0802C05 | TF7375743978 | East section of bank, runs into higher ground TF7375843989 to TF7375043800. | Sea defence (man-made) | Thornham ring bank. Vegetated earth bank. | 178.5 | Environment Agency | - | - | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_059a** | N/A | TF7557744262 | Titchwell RSPB reserve east wall TF7557744262 to TF7557444742. | Sea defence (man-made) | Stable and well-vegetated earth embankment. | 500.0 | RSPB | | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_059b** | N/A | TF7557444742 | Titchwell RSPB reserve north wall TF7557444742 to TF7501744682. | Sea defence (man-made) | Embankment. Pronounced erosion on north east corner. | 600.0 | RSPB | | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_059c** | N/A | TF7501744682 | Titchwell RSPB reserve west wall TF7501744682 to TF7495943867. | Sea defence (man-made) | Narrow embankment with variable crest level. | 1150.0 | RSPB | | | | 4 | | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_059d** | N/A | TF7501244487 | Titchwell RSPB reserve Parrinder wall TF7501244487 to TF7549744535. | Sea defence (man-made) | Earth embankment, not suitable for flood defence. | 500.0 | RSPB | | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_059e** | N/A | TF74984344182 | Titchwell RSPB reserve boundary between freshwater marsh and reedbed TF74984344182 TF7557744262. | Sea defence (man-made) | Earth embankment formed from local material. Improvements have been undertaken recently. | 600.0 | RSPB | | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_059f** | N/A | TF7557744262 | Titchwell RSPB reserve south east corner TF7557744262 to TF7578444190. | Sea defence (man-made) | Earth embankment with a stable and vegetated bank slope. Does not tie in with higher ground to south or east bank to the east. | 270.0 | RSPB | | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_060 | 054CANNNS0804C01 | TF7661844758 | From Gypsy Lane (track) to sand dunes. | Sea defence (natural) | Well-vegetated earth flood bank. | 678.6 | Environment Agency | high | 10 | 11-20 | 2 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_061 | 054CANNNS0804C05 | TF7662044767 | Runs east to west about 300 metres back from now-redundant sand dune. | Sea defence (man-made) | New compacted earth embankment. Geotextile grass reinforcement on seaward face and crest. | 469.7 | Environment Agency | - | 20 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_062*** | N/A | TF7700144813 | Runs north to south from golf club embankment to EA embankment TF7700144813 to TF7692345112. | Sea defence (man-made) | Well-vegetated earth embankment, protecting practice green to the east. | 310.0 | Royal West Norfolk golf club | - | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_063*** | N/A | TF7692345112 | Runs east to west from now-redundant sand dune to revetment protecting clubhouse TF7692345112 to TF7702945130. | Sea defence (man-made) | Well-vegetated earth embankment, protecting practice green to the east. | 100.0 | Royal West Norfolk golf club | - | | | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_064*** | N/A | TF7702945130 | Rock revetment protecting clubhouse promontory TF7702945130 to TF7714245176. | Sea defence (man-made) | Rock revetment. | 150.0 | Royal West Norfolk golf club | - | | | 2 | | Revetment | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_064a*** | N/A | TF7716745169 | Rock revetment protecting western extent of golf course TF7716745169 to TF7727145197. | Sea defence (man-made) | Rock revetment. | 55.0 | Royal West Norfolk golf club | - | | | 2 | | Revetment | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_064b*** | N/A | TF7727145197 | Protects western extent of golf course TF7727145197 to TF7750045264. | Sea defence (man-made) | Geotextile bags protecting sand dunes. Constructed about 1995. | 200.0 | Royal West Norfolk golf club | - | | | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_065 | 054CANNNS0701C01 | TF7706544289 | From golf clubhouse to flood bank fork TF7703045130 to TF7706444282. | Sea defence (natural) | Well-vegetated earth flood bank. | 908.7 | Environment Agency | high | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_066 | 054CANNNS0702C01 | TF7706444204 | Brancaster closure bank TF7705044330 to TF7706044250. | Sea defence (natural) | Well-vegetated earth flood bank. | 84.3 | Environment Agency | low | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_067 | 054CANNNS0701C02 | TF7716044259 | Where bank turns east along Beach Road, Brancaster TF7706444282 to TF7716544260. | Sea defence (man-made) | Well-vegetated earth flood bank. | 95.0 | Environment Agency | high | 10 | 11-20 | 4 | | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_068 | 054CANNNS0701C03 | TF7719344216 | Flood bank runs adjacent to properties and ties into higher ground at Broad Lane, Brancaster TF7716544260 to TF7719444215. | Sea defence (man-made) | Vegetated earth flood bank. | 54.2 | Environment Agency | high | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_069 | 054CANNNS0703C01 | TF7920044310 | From Brancaster to Brancaster Staithe. | Sea defence (natural) | Erratic earth flood bank. | 1988.6 | Environment Agency | high | 10 | - | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_070 | 054CANNNS0601C01 | TF7938044420 | Brancaster Staithe. | Sea defence (natural) | Staithe area - miscellaneous defences. | 211.0 | Private | high | 10 | - | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_071 | 054CANNNS0602C01 | TF8020044390 | Brancaster Staithe. | Sea defence (natural) | Well-vegetated earth flood bank. | 818.0 | Environment Agency | high | 10 | 1-5 | 3 | 4 | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_072 | 054CANNNS0603C01 | TF8033544463 | Property Burnham Deepdale. | Sea defence (man-made) | Well-vegetated earth ring flood bank. | 210.7 | Private | high | 10 | 11-20 | 2 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_073 | 054CANNNS0604C01 | TF8349145198 | Burnham Deepdale sea bank. | Sea defence (natural) | Well-vegetated earth flood bank. | 3460.7 | Environment Agency | high | 10 | 11-20 | 2 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_074 | 054CANNNS0605C01 | TF8339243956 | Burnham Deepdale east bank. | Sea defence (natural) | Well-vegetated earth flood bank. | 1424.4 | Environment Agency | high | 10 | 11-20 | 2 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_075 | 054CANNNS0606C01 | TF8357143848 | From end of sub-reach 5 going east. Burnham Norton bank. | Sea defence (man-made) | Well-vegetated earth flood bank. | 209.2 | Environment Agency | high | 10 | 6-10 | 2 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_076 | 054CANNNS0606C02 | TF8300844003 | From end of sub-reach 5 going west from Burnham Norton bank to Burnham Norton village. | Sea defence (natural) | Well-vegetated low level earth flood bank. | 406.2 | Environment Agency | high | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_077 | 054CANNNS0607C01 | TF8418344257 | North of Burnham Overy mill. | Sea defence (natural) | Vegetated earth flood bank. | 767.2 | Environment Agency | high | 10 | - | 3 | | Sea bank | 3 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_078 | 054CANNNS0607C02 | TF8431044310 | Burnham Overy Staithe. | Sea defence (natural) | Private masonry walls protecting residential area. | 143.2 | Private | high | 10 | - | 3 | | Seawall | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_079 | 054CANNNS0607C03 | TF8458344364 | Burnham Overy Staithe. | Sea defence (man-made) | Timber sea wall protecting earth bank. | 281.6 | Private | high | 10 | - | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_080 | 054CANNNS0608C01 | TF8532244905 | Extends northwards about one kilometre from Burnham Overy Staithe. | Sea defence (man-made) | Well-vegetated flood bank with concrete revetment. | 1036.2 | Environment Agency | high | 10 | 11-20 | 3 | 2 | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_081 | 054CANNNS0610C01 | TF8530044870 | Access track to east of Burnham Overy Staithe village TF8530044870. | Sea defence (man-made) | Raised access track contributing secondary defence. | 356.8 | Environment Agency | low | 10 | 6-10 | 3 | 3 | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_081a | 054CANNNS0608C02 | TF8577045648 | Northern one kilometre of flood bank between access track and Gun Hill. | Sea defence (natural) | Well-vegetated earth flood bank. | 966.2 | Environment Agency | high | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_082 | 054CANNNS0501C01 | TF8687645729 | First one kilometre east of Gun Hill TF8576945648 to TF8687645729. | Sea defence (natural) | Very bulbous, well-vegetated sand dunes. | 1339.2 | Environment Agency | high | 10 | 6-10 | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_083 | 054CANNNS0501C02 | TF8909044800 | Lady Ann's Drive, Holkham towards Gun Hill TF8687645728 to TF8908944800. | Sea defence (natural) | Well-vegetated sand dunes extending into fir trees. | 2527.1 | Environment Agency | high | 10 | 11-20 | 3 | | Sand dune | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_084 | 054CANNNS0504C01 | TF8841645353 | From Holkham Meals bird hide going southwards TF8841645353 to TF8825344849. | Sea defence (natural) | Holkham cross bank. Well-vegetated but poorly defined undulating flood bank. | 530.8 | Environment Agency | med | 10 | 6-10 | 4 | | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_085a | 054CANNNS0504C03 | TF8793044140 | Southernmost 50 metres of sub-reach TF8794044200 to TF8793044140. | Sea defence (natural) | Holkham cross bank. Well-vegetated flood bank. | 60.8 | Environment Agency | med | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_086 | 054CANNNS0502C01 | TF9083245805 | Lady Ann's Drive towards Wells TF8908944800 to TF9083245805. | Sea defence (natural) | Well-vegetated sand dunes extending into fir trees. | 2376.7 | Environment Agency | high | 10 | 11-20 | 3 | 2 | Sand dune | 2 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_087 | 054CANNNS0502C02 | TF9147345590 | From start of beach huts on west sands TF9083245805 to TF9147345589. | Sea defence (natural) | Well-vegetated, fenced-off sand dunes with groynes. | 698.7 | Environment Agency | high | 10 | 11-20 | 2 | | Sand dune | 2 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_088 | 054CANNNS0502C03 | TF9157445543 | Between coastguard look-out and RNLI lifeboat station TF9147345589 to TF9157345542. | Sea defence (natural) | Sand dunes protected by gabion revetment and groynes. | 114.3 | Environment Agency | high | 10 | 6-10 | 2 | | Sand dune | 2 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_089 | 054CANNNS0401C01 | TF9147345590 | Wells-next-the-Sea TF9148245562 to TF9154943915. | Sea defence (man-made) | Wells west bank: sea defence embankment with integral road and light railway. Built from sand and clay with top-soil covering revetment to seaward face. | 1658.2 | Environment Agency | | 10 | 11-20 | 1 | | Sea bank | 1 | 25 | 2032 | 40 | 2047 | Linear stopper | 2 |
| DEF_1_090 | 054CANNNS0401C02 | TF9154743932 | Beach Road, Wells-next-the-Sea TF9154943915 to TF9158943858. | Sea defence (man-made) | Wells west bank closure: steel piled flood wall with masonry facings and concrete capping. | 83.6 | Environment Agency | | 10 | 11-20 | 2 | | Sea wall | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_091 | 054CANNNS0401C03 | TF9158943859 | Beach Road, Wells-next-the-Sea TF9154943915 to TF9158943858. | Sea defence (man-made) | Wells west bank closure: steel piled flood wall with masonry facings and concrete capping. Timber flood boards installed October to April brings wall to full flood defence standard of 6.0 metres AOD. | 45.2 | Environment Agency | | 10 | 6-10 | 3 | | Sea wall | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_091a* | N/A | TF9158843814 | Wells-next-the-Sea quay wall. | Sea defence (man-made) | Wall running along the footpath/ roadside with boards inserted to complete the defence when required. | 150.0 | North Norfolk District Council | | | | 3 | | Sea wall | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_092 | 054CANNNS0403C01 | TF9229243779 | East of Wells-next-the-Sea TF9219644248 to TF9305143622. | Sea defence (man-made) | Wells east bank: clay embankment partly revetted with 12,500 concrete revetment blocks. | 896.5 | Environment Agency | med | 10 | 6-10 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_093 | 054CANNNS0404C01 | TF9252943749 | Wells-next-the-Sea TF9252943748 to TF9255543571. | Sea defence (man-made) | Wells east bank closure. Running southwards from Wells east bank to Wells allotments. | 179.1 | Environment Agency | | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

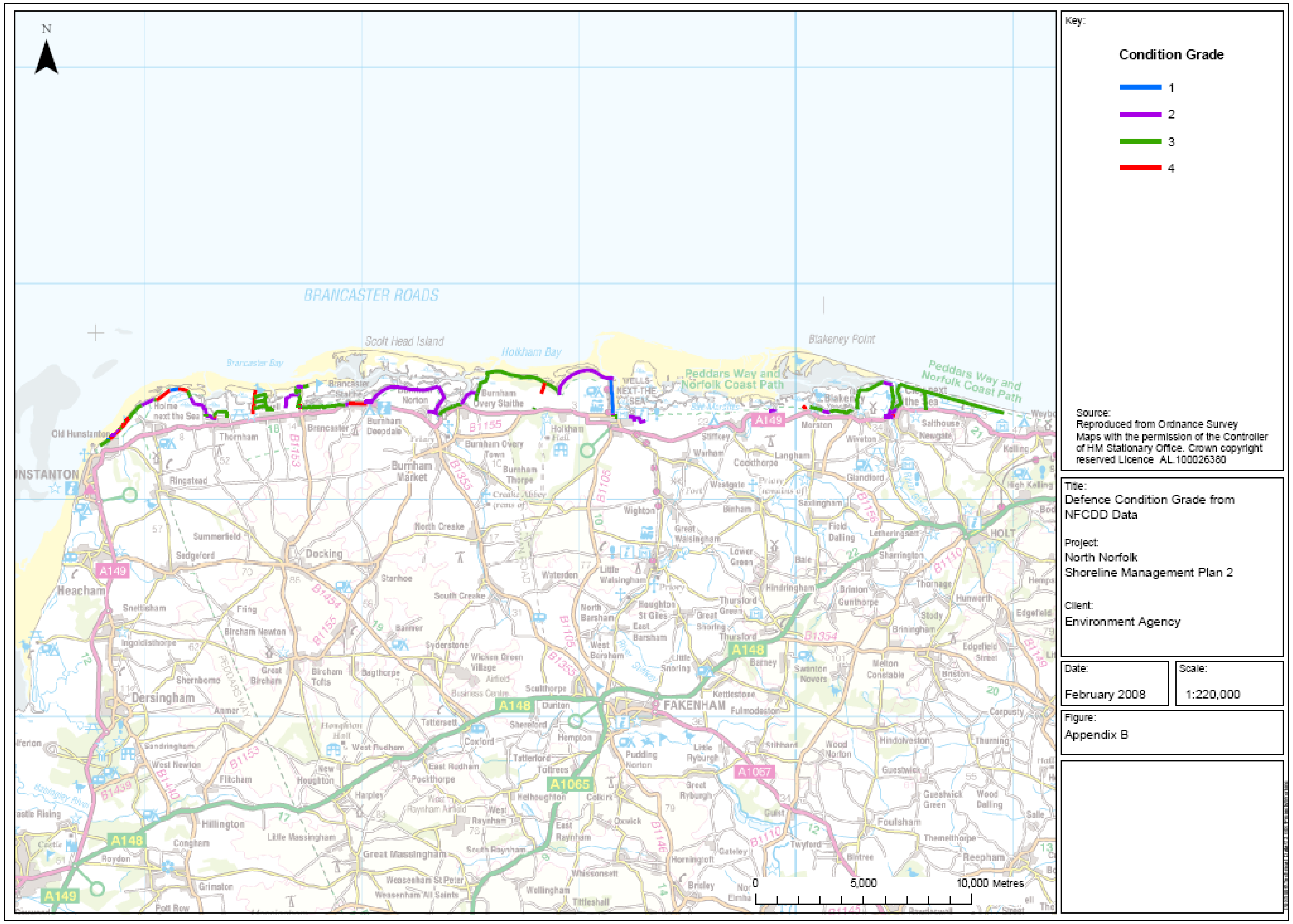
| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_094 | 054CANNNS0301C01 | TF9904044129 | Stiffkey outfall bank TF9903944128 to TF9874444049. | Sea defence (man-made) | Well-vegetated earth flood bank. | 322.6 | Environment Agency | high | 10 | 6-10 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_095 | 054CANNNS0303C01 | TG0042944134 | North west of Morston village TF9874544050 to TF9904044100. | Sea defence (man-made) | Poorly-defined and overgrown earth flood bank. | 191.0 | Environment Agency | high | 10 | 1-5 | 4 | | Sea bank | 4 | 3 | 2010 | 5 | 2012 | Linear stopper | 1 |
| DEF_1_096 | 054CANNNS0305C01 | TG0067044060 | Between Morston and Blakeney TG0067044060 to TG0125244060. | Sea defence (man-made) | Well-vegetated earth flood bank. | 627.1 | Environment Agency | high | 10 | 1-5 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_097 | 054CANNNS0305C02 | TG0161043980 | Between Morston and Blakeney TG0161043980 to TG0125244060. | Sea defence (man-made) | Vegetated earth embankment. | 384.8 | Environment Agency | high | 10 | 6-10 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_098 | 054CANNNS0306C01 | TG0256644090 | West of Blakeney TG0164044030 to TG0257044080. | Sea defence (man-made) | Earth flood bank. | 1088.8 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_099 | 054CANNNS0308C01 | TG0281144271 | Blakeney sea front car park TG0281144270 to TG0283944131. | Sea defence (man-made) | Earth flood bank with concrete revetment. | 143.2 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_100 | 054CANNNS0308C02 | TG0282044370 | Blakeney boatyard TG0282144384 to TG0281144270. | Sea defence (man-made) | Boatyard in front of earth flood bank. | 99.8 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_101 | 054CANNNS0308C03 | TG0287444840 | Blakeney to Blakeney Eye TG0287444840 to TG0282144384. | Sea defence (man-made) | Vegetated earth flood bank. | 485.0 | Environment Agency | high | 10 | 1-5 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_1_02 | 054CANNNS0308C04 | TG0402345380 | Between Blakeney and Blakeney Eye TG0402245380 to TG0287444840. | Sea defence (man-made) | Well-vegetated but poorly-defined earth flood bank. | 1356.2 | Environment Agency | high | 10 | 1-5 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_1_03 | 054CANNNS0308C05 | TG0441445281 | North of Blakeney Eye TG0441445281 to TG0402245380. | Sea defence (man-made) | Wide crested but poorly-defined earth flood bank. | 403.5 | Environment Agency | high | 10 | 1-5 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_104 | 054CANNNS0308C06 | TG0440745182 | Blakeney Eye TG0444045170 to TG0441445281. | Sea defence (natural) | Natural higher ground at Blakeney Eye features the remains of a hermit's chapel. | 100.1 | Environment Agency | high | 10 | 6-10 | 2 | | Sea bank | 2 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_1_05 | 054CANNNS0308C07 | TG0439344108 | Cley to Blakeney earth bank TG0439244107 to TG0444045170. | Sea defence (man-made) | Well-vegetated earth bank. | 1112.7 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_106 | 054CANNNS0308C08 | TG0427343824 | Coast Road, Cley to new bank/Cley Blakeney bank junction TG0427243824 to TG0439244107. | Sea defence (man-made) | Well-vegetated earth bank with access track to landward face. | 317.8 | Environment Agency | high | 10 | 6-10 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_1_07 | 054CANNNS0312C02 | TG0427343824 | Between Marsh Lane and Cley closure bank TG0427243823 to TG408543817. | Sea defence (man-made) | Vegetated clay flood bank. | 186.6 | Environment Agency | low | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_1_08 | 054CANNNS0312C01 | TG0447843768 | Cley-next-the-Sea TG0447743767 to TG0427243823. | Sea defence (man-made) | Clay flood bank adjacent A149 coast road. | 219.5 | Environment Agency | high | 10 | 11-20 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |

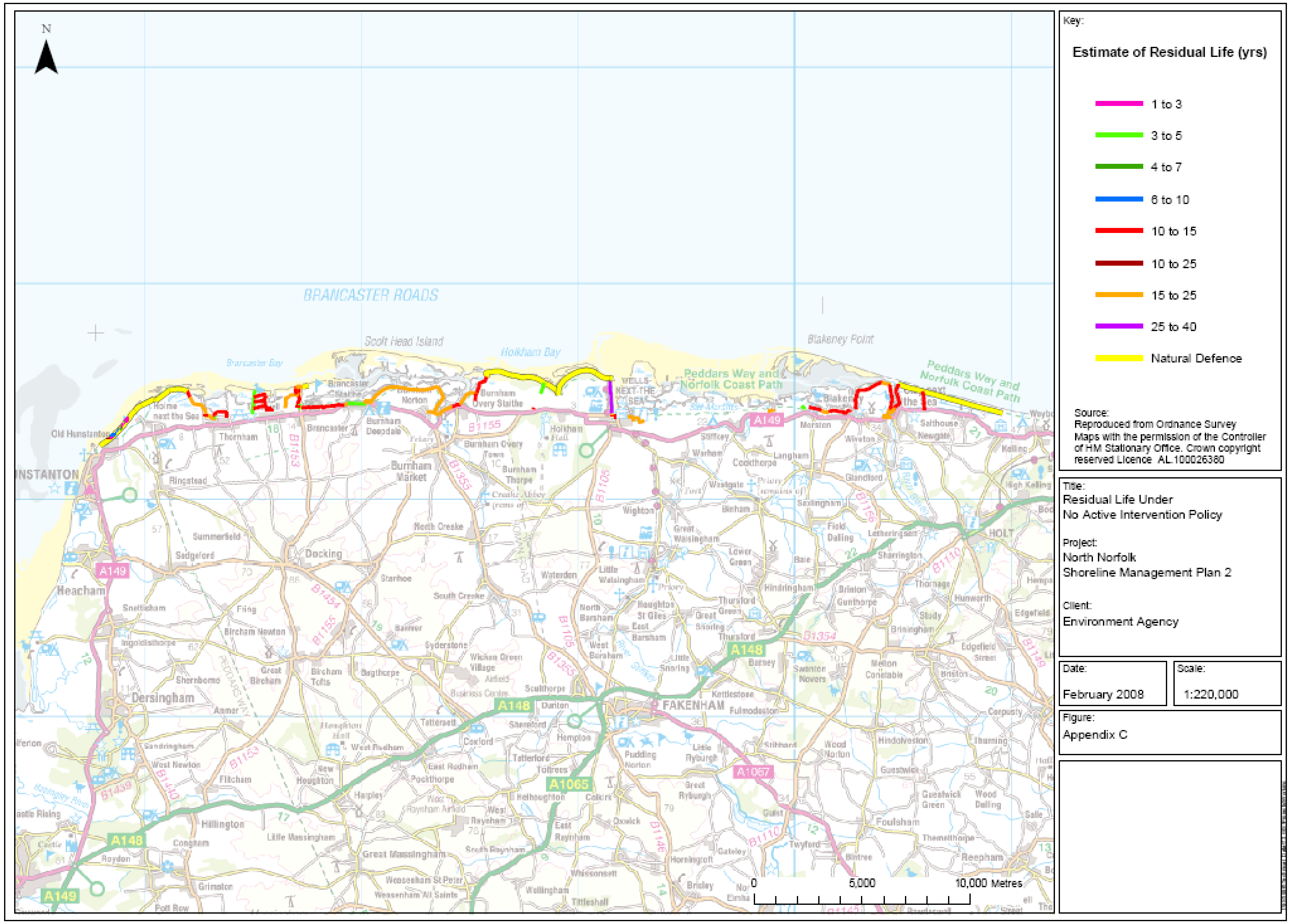
| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_109 | 054CANNNS0311C01 | TG0443043938 | West of Cley village from clay bank to access steps at 'Beau Rivage' TG0447743767 to TG0442943937. | Sea defence (man-made) | Concrete flood wall: steel sheet piles with poured concrete outer skin. | 185.4 | Environment Agency | high | 10 | 6-10 | 4 | | Sea wall | 4 | 5 | 2012 | 7 | 2014 | Linear stopper | 1 |
| DEF_1_110 | 054CANNNS0311C02 | TG0447443987 | 'Beau Rivage' access steps to Cley quay access ramp TG0442943937 to TG0447343987. | Sea defence (man-made) | R.C. flood wall – Promenade. | 85.6 | Environment Agency | high | 10 | 6-10 | 2 | | Sea wall | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_111 | 054CANNNS0311C03 | TG0453844048 | From Cley quay access ramp to timber steps TG0447343987 to TG0453744048. | Sea defence (man-made) | Rock and mortar, reinforced concrete flood wall. | 96.0 | Environment Agency | high | 10 | 6-10 | 2 | | Sea wall | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_112 | 054CANNNS0311C04 | TG0457044157 | Timber access steps to junction of three banks TG0453744048 to TG0457044156. | Sea defence (man-made) | Well maintained clay flood bank. | 138.6 | Environment Agency | high | 10 | 6-10 | 2 | | Sea bank | 2 | 15 | 2022 | 25 | 2032 | Linear stopper | 1/2 |
| DEF_1_113 | 054CANNNS0309C01 | TG0457044157 | North of Cley village TG0417044306 to TG0448544603. | Sea defence (man-made) | Well-vegetated sea defence bank with access track on western perimeter. | 183.8 | Environment Agency | high | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_114 | 054CANNNS0310C01 | TG0470444869 | TG0 From Cley village (Three Banks) towards Cley New Cut outfall TG0457044156 to TG0470344869. | Sea defence (man-made) | Cley beach road flood bank. Vegetated earth flood bank with intermittent low spots. | 855.2 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |
| DEF_1_115 | 054CANNNS0310C02 | TG0478545287 | From Cley New Cut outfall to coastguard look-out TG0470344869 to TG0479045290. | Sea defence (man-made) | Well-vegetated earth flood bank. | 446.9 | Environment Agency | high | 10 | 6-10 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

| SMP2 reference | NFCDD reference | Grid reference | Location | Defence type | Description | Length (m) | Maintainer | Degree of exposure | Design standard | NFCDD residual life | Overall condition | Manual override condition | Category for condition assessment | Condition used for assessment | Estimate of residual life (yrs) under NAI policy - fastest | Estimated year of failure - fastest | Estimate of residual life (yrs) under NAI policy - slowest | Estimated year of failure - slowest | Defence category | Defence failure (epoch) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEF_1_116 | 054CANNNS0201C01 | TG0427343824 | Kelling Hard to Cley coastguard look-out TG0959844012 to TG0468645759. | Sea defence (natural) | Shingle bank graded by bulldozers. From winter 2005 re-profiling of shingle ridge has stopped. Shingle ridge to form natural profile. | 4981.4 | Private | high | 10 | 6-10 | 3 | | Shingle ridge | 3 | Natural defence | Natural defence | Natural defence | Natural defence | Linear reducer/ changer | Natural defence |
| DEF_1_117 | 054CANNNS0202C01 | TG0598044110 | Cley east bank closure TG0591144218 to TG0579543439. | Sea defence (man-made) | Vegetated earth cross bank running for 866 metres northwards dividing Cley / Salthouse marsh into two compartments. | 861.9 | Environment Agency | low | 10 | 11-20 | 3 | | Sea bank | 3 | 10 | 2017 | 15 | 2022 | Linear stopper | 1 |

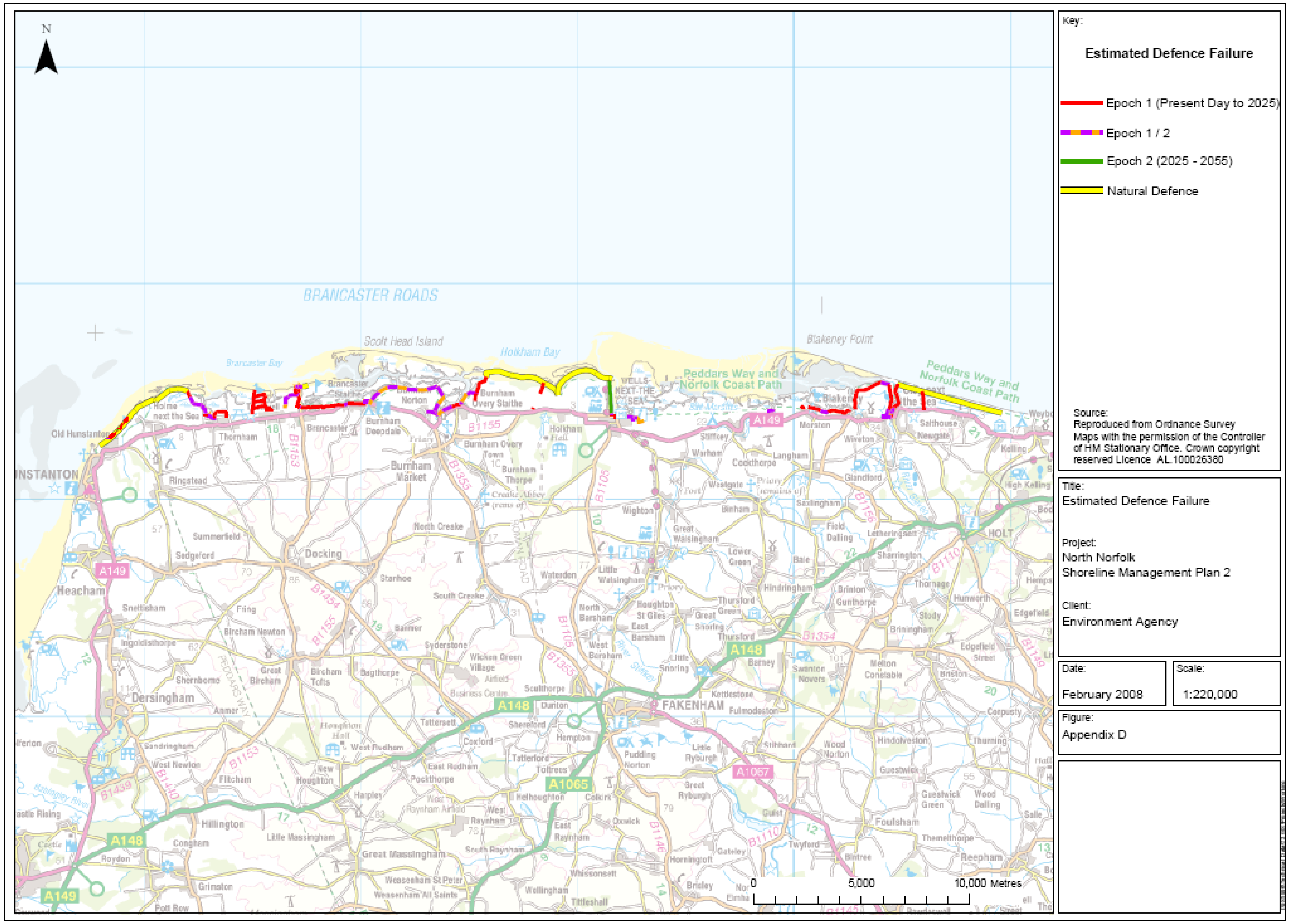
## F 2.1 Defence condition assessment



## F 2.2 Defence residual life assessment



## F 2.3 Estimated defence failure assessment



## F2.6 Residual life under continued maintenance

This section provides an assessment to determine the residual life with maintenance for nine of the coastal embankments. Two assessments have taken place for each embankment:

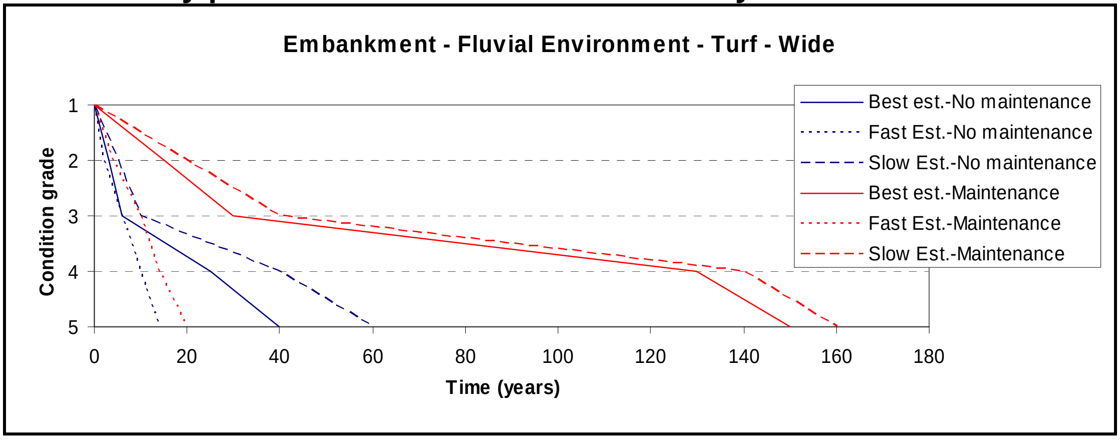
- when the condition grade of the embankment reaches 5 (that is, very poor condition) in a 'with maintenance' scenario and
- when the standard of protection reaches once a year due to sea level rise.

The analysis is based on limited available data and broad-scale methods. It has been validated by the Environment Agency's asset management team's local knowledge and judgement.

### F2.6.1 Method 1 - assessment when condition grade reaches 5

Table F2.7 shows each relevant policy development zone (PDZ) and the condition of each embankment in the specified zone. The standard of protection for each embankment has been given along with the condition used for assessment. An estimated range (years) until each embankment reaches condition 5 is provided. 1 refers to an embankment that is in very good condition and 5 refers to an embankment in very poor condition.

**Figure F2.4: Condition grade against time for embankments-fluvial environment-turf-wide. The condition grade of each embankment reaches very poor as time increases from 0-180 years.**




This graph was taken from Science Report SC060078/SR: Guidance on determining asset deterioration and the use of condition grade deterioration curves (Environment Agency, 2009). This is the same source for the analysis of no active intervention residual lives (see section F2.1), but for this analysis we have used the deterioration curves for the 'with maintenance' scenarios. The approach is based on the same assumptions used for assessing residual life under no active intervention:

- We have assumed the defences are halfway between two condition grades (that is, if the current CG is 3, we've assumed it is halfway through the period that it takes to deteriorate to CG4 according to the tables).
- CG5 means failure.

**Table F2.7: Time for embankment to reach very poor condition (CG5)**

| Policy development zone | Condition used for assessment | Range (fastest to slowest estimate) |
|---|---|---|
| PDZ1C | 3 | (8 to 70 years) |
| PDZ2D | 2 | (10 to 125 years) |
| PDZ2G.1 | 2 | (10 to 125 years) |
| PDZ2G.3 | 2 | (10 to 125 years) |
| PDZ2J | 1 | (15 to 146 years) |
| PDZ2L | 2 | (10 to 125 years) |
| PDZ3A.2 | 3 | (8 to 70 years) |
| PDZ3A.3 | 2 | (10 to 125 years) |
| PDZ3A.5 | 3 | (8 to 70 years) |

Data used in table F2.7 can be found in table F2.6.

For policy development zones 1C, 3A.2 and 3A.5, table F2.7 shows the embankments all have a condition grade of 3 with an estimated range of eight to 70 years before the embankment reaches grade 5. Embankments in PDZs 2D, 2G.1, 2G.3, 2L and 3A.3 all have a condition grade of 2 with an estimated range of 10 to 125 years before grade 5 is reached. The embankment in PDZ2J has a condition grade of 1 with an estimated range of 15 to 146 years until grade 5 is reached. See section 3 for conclusions.

### F2.6.2 Method 2 - assessment when the standard of protection (SoP) becomes 1:1 year

Table F2.8 has used the extreme water levels table (table C3.2 appendix C - baseline processes, June 2009) and the Defra (2006) sea level rise guidance (table 2.1 in the main SMP document) to calculate how long it will take for the embankment to get to the 1:1 year standard of protection (SoP). The sea level rise guidance has been used over the period 1990 to 2105.

We currently do not have defence crest levels. There is information in the Environment Agency's National Flood and Coastal Defence Database (NFCDD) about their existing standard of protection, which is 1:10 a year for all assets. However, the asset management team has indicated that this is uncertain and has asked this analysis to be done for a 1:25 a year SoP as well to test the sensitivity.

We have used the SoP as a basis for the analysis as follows. We have assumed the water level is the dominant factor in the SoP (not waves). We can then calculate how long it takes sea level rise to reduce the SoP from its current standard to 1:1. We have used that to indicate when a defence could fail.

**Table F2.8: Time for SoP to reduce from 1:10 a year to 1:1 a year**

| PDZ | Standard of protection | Water level for SoP return period (m) | Water level for 1:1 return period (m) | Level difference(m) | Year of failure |
|---|---|---|---|---|---|
| PDZ1C | 1:10 | 4.99 | 4.46 | 0.53 | 2072 |
| PDZ2D | 1:10 | 4.7 | 4.16 | 0.54 | 2073 |
| PDZG.1 | 1:10 | 4.52 | 3.96 | 0.56 | 2074 |
| PDZG.3 | 1:10 | 4.52 | 3.96 | 0.56 | 2074 |
| PDZ2J | 1:10 | 4.47 | 3.87 | 0.6 | 2078 |
| PDZ2L | 1:10 | 4.47 | 3.87 | 0.6 | 2078 |
| PDZ3A.2 | 1:10 | 4.24 | 3.67 | 0.57 | 2075 |
| PDZ3A.3 | 1:10 | 4.24 | 3.67 | 0.57 | 2075 |
| PDZ3A.5 | 1:10 | 4.24 | 3.67 | 0.57 | 2075 |

Table F2.8 shows that the residual life is very similar for all these defences - between 2070 and 2075, some way into epoch 3. The only difference is caused by the fact that the difference between the 1:1 and 1:10 for water levels varies along the shoreline. Given the uncertainty in the various datasets, the calculated residual life values can be assumed to be the same.

**Table F2.9: Time for SoP to reduce from 1:25 a year to 1:1 a year**

| PDZ | Standard of protection | Water level for SoP return period (m) | Water level for 1:1 return period (m) | Level difference(m) | Year of failure |
|---|---|---|---|---|---|
| PDZ1C | 1:25 | 5.20 | 4.46 | 0.74 | 2088 |
| PDZ2D | 1:25 | 5.92 | 4.16 | 1.76 | 2105 |
| PDZG.1 | 1:25 | 4.75 | 3.96 | 0.79 | 2092 |
| PDZG.3 | 1:25 | 4.75 | 3.96 | 0.79 | 2092 |
| PDZ2J | 1:25 | 4.70 | 3.87 | 0.83 | 2094 |
| PDZ2L | 1:25 | 4.70 | 3.87 | 0.83 | 2094 |
| PDZ3A.2 | 1:25 | 4.47 | 3.67 | 0.8 | 2092 |
| PDZ3A.3 | 1:25 | 4.47 | 3.67 | 0.8 | 2092 |
| PDZ3A.5 | 1:25 | 4.47 | 3.67 | 0.8 | 2092 |

Table F2.9 shows the 1:25 year standard of protection for each of the defences in the given PDZ. Compared to table 2, the residual life is generally about 15 to 20 years longer - up to the end of epoch 3.

### F2.6.3 Conclusions and recommendations

The results of the two assessments lead to the following conclusions:

Method 1: the application of generic deterioration curves to determine the residual life until the condition grade reaches very poor, produces a very wide range of results. In line with the guidance report (EA, 2009), local judgement is needed to assess how the asset fits within this wide range, based on structural characteristics and exposure. Based on the broad-scale SMP level overview, an initial assessment would be as follows:

- The deterioration curves were actually developed for fluvial conditions (there are no curves for grassed coastal embankments). In principle, the presence of waves and the saline coastal environment are likely to lead to more rapid deterioration.
- The banks are relatively wide and are very rarely exposed to waves or currents.

This would suggest that the deterioration rates are in the middle of the spectrum, suggesting a residual life of 40 to 60 years.

Method 2: the application of sea level rise rates to determine when the standard of protection would reach 1:1 also produces a range of outcomes because the crest level/current standard of protection of the defences is uncertain. The resulting residual life is 60 to 80 years.

The content of this section can inform the SMP's policy statements. The SMP's action plan contains an action to provide more certainty about the residual life of these sea banks to inform shoreline management, as this is likely to be an important factor in the timing of the medium- and long-term policies.

# F3 Baseline scenarios

## F3.1 Introduction

### F3.1.1 Aim

The aim of this section is to provide an appreciation of how the shoreline is behaving and the influence that coastal management has on this behaviour. This will provide the basis on which flood and coastal erosion risks are determined. This analysis will then be used to develop and appraise policy scenarios.

This is divided into three components:

- A description of the baseline response assessments for the 'no active intervention' (NAI) scenario. This assumes that defences are no longer maintained and will fail over time.
- A description of the baseline response assessment for a 'with present management' (WPM) scenario. This assumes that all defences are maintained to provide a similar level of protection to that provided at present.
- Maps to illustrate predicted shoreline change.

Both the NAI and WPM scenarios will discuss coastal evolution in three epochs: present day to 2025, 2026 to 2055 and 2056 to 2105.

### F3.1.2 Geographical units

The north Norfolk coastline has been sub-divided into eight frontages. These were derived mainly using the natural geomorphological breaks found along this coastline. However, these boundaries are often blurred and are subsequently hard to define. As a result, volumetric analysis of recent Environment Agency profile monitoring data was used to define these boundaries more clearly. The method and results of this analysis are detailed in appendix C. The eight frontages are described below and illustrated in figure F3.1.

- Frontage A (Old Hunstanton) – start of dunes at Old Hunstanton (western boundary of SMP study area) to Gore Point.
- Frontage B (Holme-next-the-Sea and Thornham) – north eastern boundary of Old Hunstanton golf course to western limit of Brancaster bay (just to the east of Thornham).
- Frontage C (Titchwell and Brancaster) – western limit of Brancaster bay to western limit of Scolt Head Island.
- Frontage D (Scolt Head Island) – western limit of Brancaster to Norton Hills.
- Frontage E (Holkham Bay) – Norton Hills to Bob Hall's Sands.
- Frontage F (Stiffkey and Warham marshes) – Bob Hall's Sands to western limit of Blakeney Spit.
- Frontage G (Blakeney Spit) – western limit of Blakeney Spit to Blakeney Eye.
- Frontage H (Cley and Salthouse) – Blakeney Eye to Kelling Hard (eastern boundary of SMP study area).

This part of the appendix also assesses the longshore interactions between these frontages. This has been completed by further dividing the coast into three 'super-frontages'. A 'super-frontage' for the purpose of this appendix consists of an unspecified number of frontages (as described in section F3.1.2). There will be geomorphological interactions between the frontages within a particular 'super-frontage', but these interactions are generally limited to that particular 'super-frontage'. This definition is intended to aid the definition of policy units undertaken in stage 3, as it determines how much external coastal processes interact between different areas of the north Norfolk coast.

The ‘super-frontages’ are as follows (from west to east along the north Norfolk coast):

- Super-frontage 1 - start of dunes at Old Hunstanton to western limit of Brancaster bay (frontages A and B).
- Super-frontage 2 - western limit of Brancaster bay to western limit of Blakeney Spit (frontages C, D, E and F).
- Super-frontage 3 - western limit of Blakeney Spit to Kelling Hard (frontages G and H).

**Figure F3.1 Frontages used for developing baseline scenarios**


### F3.1.3 Task method

The first stage in completing this task was to collate all relevant baseline information for each frontage. These baseline data were originally collected as part of the assessment of coastal processes. For this report, however, it was necessary to highlight the relevant information for each frontage and assemble it into a useful format. A table was therefore designed to present this information that included a section for the baseline scenario predictions. This table is based on the presentation of results suggested for this task in the SMP guidance (Defra 2006). This has effectively allowed a quick reference guide to be created for each frontage.

The table is divided into four main sections, with the first three summarising the baseline conditions and the final one outlining the baseline scenario assessment outcomes. The individual sections are:

- Section 1 – **Description**. Includes information about the physical characteristics of the frontage and the existing coastal defences and management practices.

- Section 2 – **Baseline information**. Includes data on water levels, extreme water levels, currents, tides, wave climate, patterns of erosion and accretion and sediment sources and transport.
- Section 3 – **Geomorphology**. Includes data about processes, patterns of change and geomorphological controls, sensitivities and influences.
- Section 4 – **Baseline management scenarios**. This section describes the results of the scenario assessment for both the WPM and NAI scenarios and outlines the thought process behind the scenario results.

It is useful to mention here that, if the individual sections in the tables are blank, specific information for the relevant frontage was not available when this report was completed. In some cases where this information was not available, it was felt there was enough information relevant in other sections to provide an accurate assessment of the baseline scenarios.

The tables are provided in section F3.6. These tables will also be referred to individually in the text in section F3.3.

After collating the baseline data, the actual scenario assessment began. The geomorphology of the frontage was studied, leading to an in-depth knowledge of the main processes that occur to shape the frontage and the importance of longshore interactions between the frontages. In some cases there were conflicting ideas about the formation of certain landforms and in these situations expert judgement was needed to choose the most likely mechanism involved. This information was then compared to the future evolution predictions discussed in both the North Norfolk Coastal Habitat Management Plan (CHaMP 2003) and Futurecoast (Halcrow 2002). Finally, a description of future evolution was completed using a combination of these sources and geomorphological knowledge gained. This description was also broken down into the three epochs for both scenarios. The results were written up into the table discussed earlier.

The future shoreline development was then mapped and two figures were produced for each frontage (NAI and WPM). Where possible, the rates recorded during the recent Environment Agency monitoring programme were applied to the future prediction of shoreline evolution. In most cases one rate was applied to the entire frontage. This rate was calculated from an average of the rates for each individual profile for that particular frontage. In some cases specific profiles showed highly variable trends and only the rate at high water was available. In these cases, the profile was excluded from calculations of an average rate for the specific frontage. The average rates used are in table F3.1.

Finally, the technical description of the processes under the baseline scenarios was described in a more accessible format, focusing on an overall understanding of coastal behaviour within the frontages and their interactions. This description is included in section F3.2. The tables and figures relating to each frontage are in section F3.6.

## Table F3.1 Environment Agency monitoring rates (metres a year) 1996 to 2006

| | EA PROFILE NO. | MHWS | MLWN/S | MEAN |
|---|---|---|---|---|
| A | N1D4 | 0.87 | 1.02 | 2.20 |
| | N1D5 | 4.73 | 0.98 | 1.41 |
| | Average | **2.80** | **1.00** | **1.81** |
| B | N1D7 | -0.95 | -3.46 | -3.37 |
| | N1C1 | -1.64 | -2.58 | -2.69 |
| | N1C2 | -4.33 | -2.26 | -2.07 |
| | N1C3 | 0.58 | 0.73 | 0.67 |
| | Average | **-1.59** | **-1.89** | **-1.87** |
| C | N1C4 | -0.87 | 0.18 | -0.04 |
| | N1C5 | -0.15 | 6.55 | 2.66 |
| | N1C6 | 0.02 | -3.17 | -0.10 |
| | Average | **-0.33** | **1.19** | **0.84** |
| D | N1B1 | 3.57 | -1.97 | -0.04 |
| | N1B2 | -1.02 | -4.11 | -1.88 |
| | N1B3 | -0.51 | -2.33 | -1.15 |
| | N1B4 | -1.02 | -1.20 | -1.26 |
| | N1B5 | -0.62 | 1.93 | 0.19 |
| | N1B6A | -0.73 | -0.66 | 0.13 |
| | Average | **-0.06** | **-1.39** | **-0.67** |
| E | N1A1 | -3.49 | -3.49 | -4.49 |
| | N1A2 | -3.02 | 5.10 | -0.27 |
| | N1A3 | -0.98 | -0.18 | 0.50 |
| | N1A4 | 7.64 | -1.46 | 1.50 |
| | N1A5 | -1.24 | -2.11 | -1.82 |
| | N1A6 | -2.37 | -1.20 | -1.74 |
| | Average | **-0.58** | **-0.56** | **-1.05** |
| F | N2D1 | 6.22 | -0.04 | 2.50 |
| | N2D2 | -1.06 | -2.07 | -0.01 |
| | N2D3 | -2.22 | -3.06 | -2.01 |
| | N2D4 | 0.51 | -0.98 | 0.70 |
| | N2D5 | -1.16 | -6.73 | -0.19 |
| | N2D6 | -1.93 | -4.33 | 1.59 |
| | Average | **0.06** | **-2.87** | **0.43** |
| G | N2C2 | -2.29 | -15.80 | -7.67 |
| | N2C3 | -0.11 | -1.49 | -0.61 |
| | N2C4 | -1.53 | -1.35 | -1.46 |
| | Average | **-1.31** | **-6.21** | **-3.25** |
| H | Frontage H - modified due to shingle ridge recycling | | | |

The EA profile number is the number allocated to the profile by the Environment Agency.

### F3.1.4 Sea level rise

For the purpose of assessing baseline scenarios, the rate of sea level rise will need to be taken into account. The following summarises the current guidance relating to sea level rise.

Defra's sea level rise guidance for the East of England, East Midlands, London and south east England (south of Flamborough Head) is summarised in table F3.2 (FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities – Climate Change Impacts October 2006). All values are rounded to the nearest 0.5 millimetres a year ($mmyr^{-1}$).

**Table F3.2 Sea level rise guidance (Defra 2006)**

| Time period | Net rate of sea level rise ($mmyr^{-1}$) | Total sea level rise (mm) |
|---|---|---|
| 1990 to 2025 | 4.0 | 140 |
| 2025 to 2055 | 8.5 | 255 |
| 2055 to 2085 | 12.0 | 360 |
| 2085 to 2115 | 15.0 | 450 |

### F3.1.5 Assumptions and general notes

The following assumptions have been applied when assessing shoreline evolution for the north Norfolk frontages.

- The predicted year that a defence is expected to fail in is assumed to signify total defence failure. It has therefore been assumed that, once a defence has "failed", it will have no residual effect as a defence.
- All accretion/erosion rates quoted are an average for the entire frontage length (unless stated) and can mask local trends of erosion and accretion.
- All rates and predictions of future morphological development in the WPM scenario assume that WPM will continue in the adjoining SMP areas (particularly SMPs 4, 6, 7 and 8), as well as the adjoining lengths of coast.

The following notes summarise sources of individual erosion/accretion rates as well as a number of points that need to be considered when reading the main text.

- Vertical and horizontal accretion/erosion rates have been taken from the Environment Agency's Shoreline Management Group's Coastal Trends Analysis report (2007). In some cases, these are an average of those experienced throughout the entire frontage between 1991 and 2006.
- Although increased storminess is predicted in the future as an effect of climate change, a quantitative assessment of these effects has not been included in any of the scenarios above. Currently there are no long-term datasets available to identify specific trends in the occurrence of storms. However, the coastline development discussed in each scenario may

actually occur earlier than predicted if the frequency and strength of storms increases.
- The Defra rates of sea level rise quoted are intended as conservative estimates so the scenarios represent the worst case scenario.

### F3.1.6 Lay-out

Section F3.2 will provide a brief overview of the coastal processes and geomorphological interactions along the north Norfolk coast. This is a summary of the assessment of coastal processes report and provides the knowledge used to assess the baseline scenarios.

Section F3.3 will discuss the large-scale interactions along the north Norfolk SMP frontage. Each section presents an overview of the geomorphological characteristics and predicted shoreline evolution under the two baseline scenarios for each individual frontage. It then assesses the longshore interactions between each frontage in a 'super-frontage'.

The final sections of this report will provide a broad summary of the north Norfolk area as a whole and the main conclusions drawn from the assessment, as well as the references used in the analysis itself.

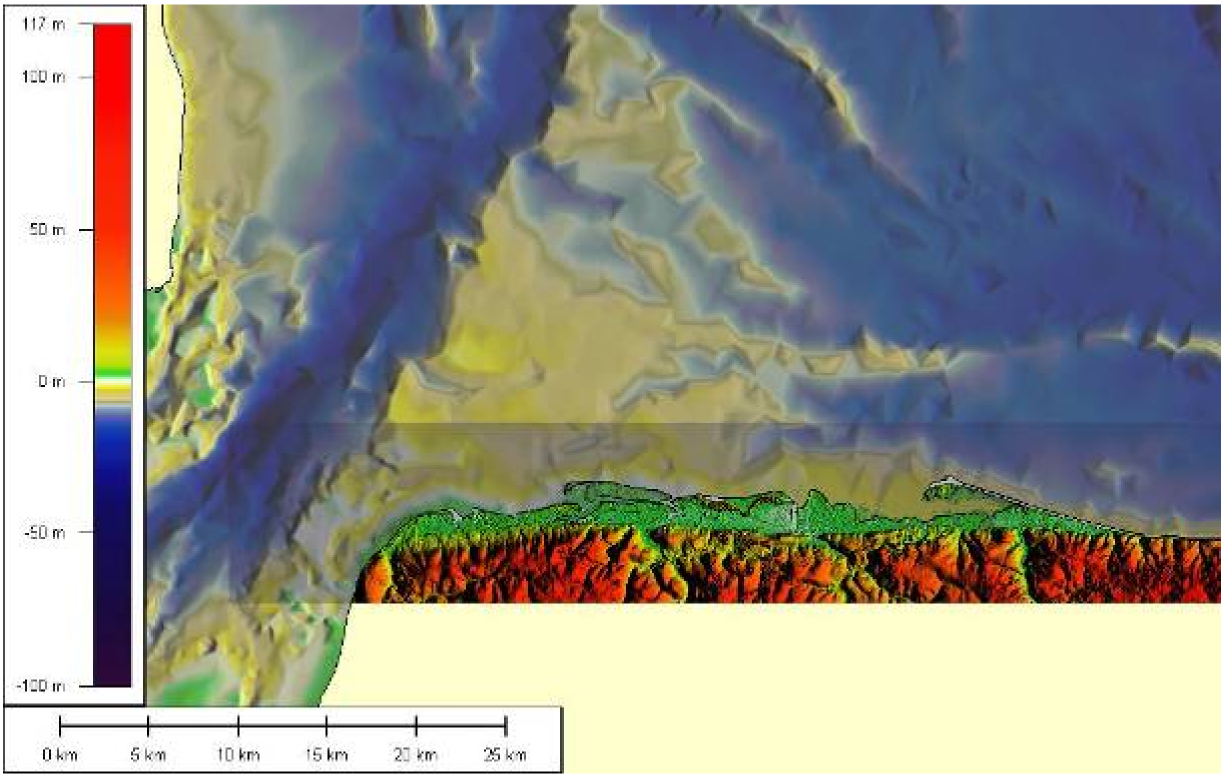
## F3.2 SMP-wide overview of north Norfolk coastal processes

Before discussing the predicted development of each individual frontage, it is useful to give an overview of the north Norfolk coast as a whole. Figure F3.2 presents a combined bathymetry and Synthetic Aperture Radar (SAR – a form of radar commonly used in remote sensing and mapping) data plot for the entire north Norfolk coast. This figure identifies a number of important features that shape the evolution of this coast:

- There is a clear definition between the higher ground and the lower coastal plain. This 'ridge' runs west to east, starting at the northern edge of the cliffs at Old Hunstanton and finishing near Weybourne.
- There is a large expanse of sediment overlying harder geology known as the Burnham Flats.
- Under 'normal' conditions (that is, non-storm conditions) sediment is exchanged between the offshore banks and the coast.
- The 'coastline' as we know it provides the interface between the offshore bank and the coast so the coastline is constantly changing.
- It is a sediment-rich coastline, so it is dominated by depositional features, such as barrier islands and spits with recurved distal ends.
- The alignment of the spit features suggests a movement of sediment to the west. However, the estimates presented in the Southern North Sea Sediment Transport report (2002) for a westward drift are relatively small and cannot be compared with present day accretion rates, or indeed with long-term rates.

- It is likely that there is a westward sediment transport pathway during low magnitude, high frequency events ('normal' conditions). This involves relatively small volumes of sediment and the redistribution of sediment already present in the north Norfolk system. There is therefore no major source from the east.
- In high-magnitude, low-frequency events, there is a strong north to south movement across the Burnham Flats and Docking Shoal. This moves large volumes of sediment onshore.
- During extreme events, nearshore movement is west to east and accretion occurs as material moves into the tidal deltas.
- The main sources of sediment are:
    - o fine sand deposits within Burnham Flats and Docking Shoal
    - o secondary source – sand deposits within the Wash embayment
    - o internal sources of sediment moving between neighbouring frontages.

**Figure F3.2 Combined SAR/bathymetry plot of the north Norfolk coastline**

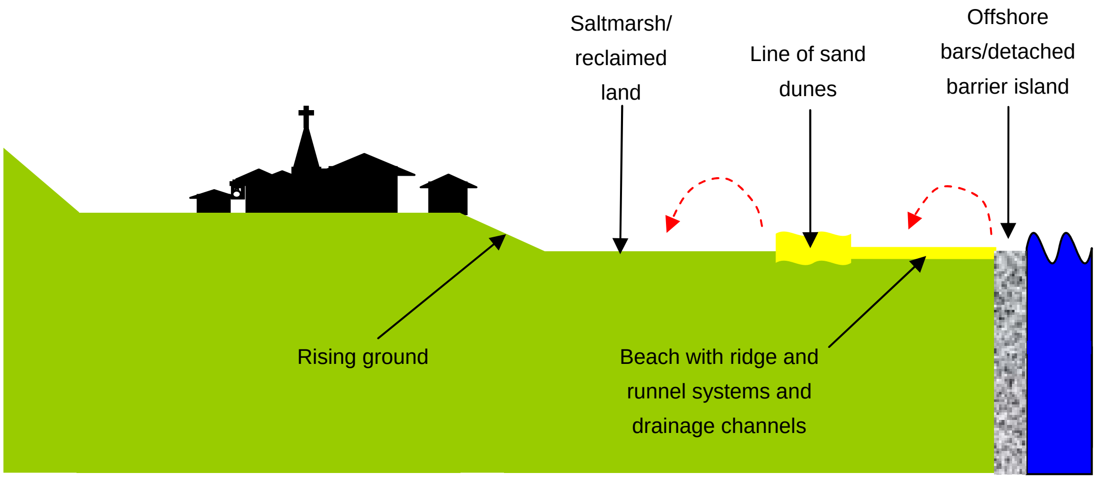



Despite the apparent complexity of the coastline, there are two types of geomorphological system that can be used to classify each frontage defined in section F3.1.2.

The first system is the barrier island feature shown in figure F3.3. This system consists of a number of offshore bar features at its seaward edge, progressing to a beach system with various drainage channels and ridge and runnel features. The beach is usually backed by a line of sand dunes, with natural saltmarsh and/or reclaimed land inland of this. If the land is reclaimed, it is usually lower than the natural saltmarsh. Examples of this type of system can be found at Gore Point and Blakeney Point.

In terms of the evolution of this type of frontage, due to sea level rise the whole frontage will move towards land until the sand dunes reach a natural or man-made constraint, such as higher ground or a fixed hard defence.

**Figure F3.3 Barrier system**

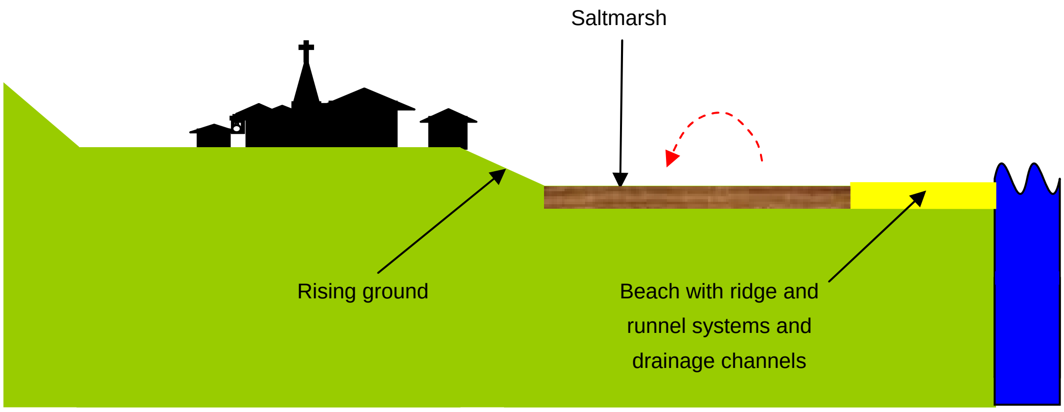



The second system is the open coast system (see figure F3.4). This system consists of a number of offshore bar features or a detached barrier island at its seaward edge, progressing to a beach system with various drainage channels and ridge and runnel features. Rather than the beach being backed by sand dunes as in the barrier system, the beach in the open coast system naturally transgresses into saltmarsh. This saltmarsh is bounded at its inland edge by higher ground. Examples of this type of system can be found in Brancaster bay, Holkham bay and at Stiffkey marshes. In some cases, such as at Holkham bay, these frontages have been modified by reclamation so the progression does not necessarily take the form described here.

In terms of the evolution of this type of frontage, due to sea level rise the whole frontage will also move towards land, gradually squeezing the saltmarsh between the rising sea levels and the higher ground. This process will occur until there is no saltmarsh left.

The following assessment of baseline scenarios will be carried out on the basis of the wide-scale interactions and processes occurring along the north Norfolk coast. At the policy development stage it will also be necessary to consider the small-scale interactions at frontage level, as provided for each frontage in detail in section F3.5.

**Figure F3.4 Open coast system**




## F3.3 Description of each frontage and interactions

This section of the appendix provides a brief summary of the geomorphological characteristics and outcome of the baseline scenarios assessment for each frontage. It then explains the longshore interactions between the individual frontages at a super-frontage scale. The report is divided into three sub-sections, with each sub-section dealing with a separate 'super-frontage' (as defined in section F3.1.2). Further details of the baseline scenarios assessment and the figures representing the shoreline evolution of each frontage are in section F3.5 and are referred to specifically in the text.

### F3.3.1 Super-frontage 1 (frontages A and B)

Old Hunstanton (frontage A)

This frontage is characterised by a stable bay that has an overall tendency to move towards land. The frontage itself is relatively natural and the beach is a highly active zone. Waves generally approach the frontage from a northerly direction and are then refracted around to a more north westerly direction. On most of the other frontages along the north Norfolk coast, the waves generally approach normal to the frontage. The dominant wave direction across this frontage generates a southward movement of sediment along the frontage towards the cliffs at Old Hunstanton and subsequently into the Wash.

Gore Point provides some shelter from north easterly waves at the north eastern edge of this frontage. Gore Point can therefore be described as a control point.

Under a scenario of WPM, into epochs 2 and 3 the dune line would need replacing with a harder defence line to protect the low-lying area behind. For a scenario of NAI, the dunes would naturally roll inland. There would be some risk of flooding following overtopping events but this is likely to be short-lived as there is enough sediment to re-seal the gaps in the dunes created during such events.

Detailed assessment tables and figures for frontage A are provided in section F3.6.1.

In terms of interactions with neighbouring frontages, this frontage is not strongly affected by the management practices in frontage B on the wider scale. However, there is the potential for local effects towards the north-eastern edge in the lee of Gore Point.

<u>Holme-next-the-Sea and Thornham (frontage B)</u>

This frontage consists of a barrier system attached to the coast, constrained by a tidal inlet to the east and the natural Wash coastline to the west. The eastern edge of the frontage is flood-dominated, causing any spit-like features to be recurved (or pulled) towards the coast.

WPM for this frontage means controlling flooding in the areas behind the present dune line and sea bank. This scenario therefore assumes that the sea bank remains and that the current natural defence (dune line) is maintained as a viable defence. Under this scenario, the tidal delta to the east would move towards land and towards the west. The eastern ‘shoulder’ of the frontage would come under increasing pressure. This would eventually lead to the need to continue the hard defences along the frontage towards the west (that is, continuing westward from the current sea banks). This would create a new headland (control point) and would, in turn, increase the need for more defences. The shoreline directly in front of Thornham is not likely to experience any significant changes.

Under a scenario of NAI, the dune ridge along Gore Point would continue to move onshore. The outfall of the River Hun to the north west of Thornham would no longer be maintained and so would take a more natural, meandering, route towards the sea. Failure of this outfall would also cause the harbour channel directly in front of Thornham to silt up. The saltmarsh in front of Thornham would also continue to accrete. The spit-like features that mark the eastern edge of Gore Point would continue to move towards land and would have a tendency to recurve. Following failure of the sea bank to the north west of Thornham during epoch 2, the reclaimed area behind would be opened up and this would tend to reinforce the harbour channel (except for the stretch in front of Thornham which would silt up as discussed earlier). The former reclaimed area would become the River Hun’s estuary and would be characterised by a number of small drainage creeks.

Detailed assessment tables and figures for frontage B are provided in section F3.6.2.

Frontage B has been separated from frontage C as it would not be affected by the management options that are available for frontage C. Choice of management in this frontage would have a local effect on the north-eastern edge of frontage A, namely in the lee of Gore Point.

### F3.3.2 Super-frontage 2 (frontages C, D, E and F)

Scolt Head Island (frontage D)

This frontage is discussed first within super-frontage 2 because its future evolution, under both scenarios, is largely independent of other frontages. As a result, decisions about management in frontages C and E will not affect how this frontage evolves. However, the future evolution of this frontage will have an effect on how neighbouring frontages evolve, as discussed in the sections below.

Scolt Head Island (frontage D) is the dominating feature in this super-frontage. Scolt is a detached barrier island separated from the 'mainland' by Norton Creek, which empties completely at low tide. The seaward face of the island is characterised by an established dune line.

Currently there are two main processes occurring: rollback of the entire barrier system (including the barrier island and the creek system in its lee) and siltation of Brancaster harbour channel. Sea level rise will bring some uncertainty about the processes occurring and the extent to which these processes will continue to occur in future epochs.

Under a scenario of WPM, in the first two epochs it is predicted that current processes would continue. As a result, the western end of Scolt Head Island would move towards the west and it would continue to have a tendency to move towards land. The eastern edge of the island would continue to try to close the Burnham harbour channel to merge with Gun Hill, but it is unlikely to achieve this. There would also be continued vertical accretion across the saltmarshes in the first two epochs. During epoch 3, there would be increased uncertainty so evolution is likely to follow one of two scenarios. The first potential scenario under WPM is that the Brancaster harbour channel would close up as the western end of Scolt Head moves onshore (so sedimentation increases with sea level rise). Alternatively, there could be more water entering behind the island (as sea level rise outpaces sedimentation) and this would cause a loss of saltmarsh.

Under a scenario of NAI, defence failure in epoch 1 would lead to an increase in tidal prism (the total amount of water that flows in or out of a coastal inlet with the rise and fall of the tide, excluding any freshwater discharges), which will gradually reduce into epoch 2. It is likely that, during this epoch, saltmarsh development (vertical accretion) would continue as with WPM. There would also be continued rollback of Scolt Head and siltation of Brancaster harbour channel as with the WPM scenario. During epoch 2, pressure from tidal flows and sea level rise would cause the western end of Scolt Head to recurve. As with the WPM scenario, the level of uncertainty increases into epoch 3 under the NAI scenario to such an extent that there are two potential scenarios. The main uncertainty is whether the western end attaches itself to the ‘mainland’ and this in turn depends on the tidal volume behind Scolt. In an ebb-dominated situation, characterised by an increase in prism and a decrease in saltmarsh, there would be a breakdown of the dune line across the seaward edge of the island, leading to the possibility of a breach and movement of the dune line towards land. Alternatively, under a flood-dominated scenario, there would be continued growth of Scolt Head Island as in epoch 2, leading to the possibility of the western end attaching itself to the ‘mainland’. Regardless of which scenario would dominate in epoch 3, the main outcomes under NAI would be movement of the western end of the island towards land and to the west.

Detailed assessment tables and figures for frontage D are provided in section F3.6.4.

Brancaster bay (frontage C)

To the west of Scolt Head Island is Brancaster bay (frontage C). Brancaster bay is a large sweeping sandy bay backed by saltmarsh. The shape of the bay is constrained by a tidal delta at both the western and eastern ends. These tidal deltas act as natural headlands (control points). The eastern tidal delta depends greatly on how frontage D develops. The distinct sweeping shape of the frontage is caused by a combination of these natural headlands and the tidal inlet in the middle of the frontage (to the east of Titchwell RSPB reserve). There are a number of artificial control points, namely at the RSPB reserve at Titchwell and at the Royal West Norfolk golf course.

Currently at the Titchwell RSPB reserve, a scheme of managed realignment is being undertaken to provide more protection to the designated freshwater lagoon behind the frontline defence. This realignment is attempting to move the current defences away from interactions with the tidal inlet in the middle of Brancaster bay. Under a scenario of WPM, the new north-eastern corner of the reserve (where the east wall ties in with the Parrinder wall) is likely to start interacting with the natural processes occurring in the tidal delta by epoch 3. This would mean significant work to the defence to maintain the standard of protection. The Royal West Norfolk clubhouse would also become a promontory under a WPM scenario, but as it does, it may become a more ‘natural’ feature within the realigned coast. In summary, the general bay shape of this frontage would be maintained under a scenario of WPM, with artificial control points being created at the north-eastern corner of the Titchwell RSPB reserve and at the Royal West Norfolk clubhouse.

Under a scenario of NAI, the Royal West Norfolk golf course would become a potential natural control point as it interacts with the western end of Scolt Head Island. This is obviously linked to whether a flood- or ebb-dominated situation occurs. The general bay shape of the frontage would also be maintained, but it is uncertain exactly how it might develop under NAI.

There are detailed assessment tables and figures for frontage C in section F3.6.3**.**

The management of this frontage depends greatly on the decisions made about managing Scolt Head Island (frontage D). In the ‘worst case’ long-term scenario, an ebb-dominated system (that is, increase in tidal prism and decrease in saltmarsh) in frontage D under the NAI scenario would mean that the Brancaster harbour channel would be pushed towards land, exposing the Royal West Norfolk golf course to increased pressure from tidal flow. The ‘best-case’ long-term scenario would be if the management policy in frontage D was NAI. This would either be caused by the western end of the island attaching itself to the ‘mainland’ or by accretion of the saltmarsh behind the island increasing so much that the Brancaster harbour channel weakens, causing extensive growth of saltmarsh. This could be brought about by a NAI scenario that would lead to a flood-dominated system. So, although a policy of NAI in frontage D would benefit frontage C, it could lead to an ebb-dominated system and so cause increased exposure of the golf course.

The management of this frontage itself does not affect the neighbouring frontage (frontage B to the west). This is why there is a significant management ‘break’ to the west of Brancaster bay, meaning that both frontages A and B form a separate ‘super-frontage’.

<u>Holkham bay (frontage E)</u>

To the eastern side of Scolt Head Island is Holkham bay. As with Brancaster bay (to the west of Scolt Head), this frontage is characterised by a stable bay that is constrained both to the west and the east by a tidal delta. There is also a former tidal delta, roughly in the middle of this frontage, known as Holkham Gap. The frontage is an open coast frontage, with a line of healthy dunes stretching along its entire length. Behind the dune line is an area of low-lying land that ties in with higher ground roughly along the line of the A149. The dunes along the frontage have a natural tendency to roll back but they are currently constrained by heavy vegetation (fir trees). This line of fir trees, known locally as the Holkham Meols, still allows erosion of the front face of the dunes but does not allow dune development at the back face. The result of this is that rollback is constrained. Presently there seems to be a significant volume of sediment along this frontage, but recent Environment Agency profiles have shown erosion of the front face of the dunes at some locations. Holkham Gap, the tidal delta in the middle of the frontage, has a natural tendency to silt up and therefore seal and subsequently roll inland.

The evolution of this frontage is closely linked to frontage D so is best described in relation to possible management practices and their consequences in this neighbouring frontage.

Under the WPM scenario in frontage D, there is likely to be increased erosion of the western edge of the bay in epoch 2. Along the open coast (most of this frontage) however, there are likely to be limited effects.

Under a scenario of NAI in frontages D and E, the defences at the western edge of frontage E would fail first (in epoch 1). There would be a general increase in tidal prism behind Scolt Head Island and to the west of frontage E, near Gun Hill, by epoch 3. It is likely that the tidal delta at Gun Hill would also move towards the west. To the east of the frontage, following defence failure in epoch 2, the Wells harbour channel would take a more natural course and would meander out to sea. Both consequences of defence failure would, however, only be expected to cause local effects. Defence failure would also cause flooding behind the dune line in the areas of reclaimed land (Overy marshes for example).

Detailed assessment tables and figures for frontage E are provided in section F3.6.5.

The management of frontage D is key to how this frontage develops. There is, however, great uncertainty as to how this frontage is likely to react in line with the uncertainty over the development of frontage D itself.

Warham and Stiffkey marshes (frontage F)

This frontage is typically open coast with mudflat turning into established saltmarsh, which ties in with higher ground. There are typically no complex interactions with neighbouring frontages (E and G). As a result, this frontage could be treated as an independent 'super-frontage' at a later stage. Under both NAI and WPM scenarios in this frontage, there would be continued saltmarsh and mudflat accretion (both vertically and horizontally) during epoch 1. Into epoch 2, sediment accretion is likely to be outpaced by sea level rise and the trend of accretion could switch to erosion. This would cause erosion of the saltmarsh/mudflat boundary, leading to an overall decrease in the total area of saltmarsh.

Detailed assessment tables and figures for frontage F are provided in section F3.6.6.

### F3.3.3 Super-frontage 3 (frontages G and H)

Blakeney Point (frontage G)

Blakeney Point is a spit, orientated towards the west north west. It is attached to the mainland at Blakeney Eye (eastern edge of the frontage). Generally, the active section of the spit is within this frontage. The spit's distal end (the end of the spit that is furthest from the point of attachment) is characterised by a number of recurves, indicating the former extent of the spit.

The future development of Blakeney Spit depends to some degree on management actions in frontage H. Under a scenario of WPM, the flushing of the Blakeney and Cley fresh marshes (increasing in later epochs) on the ebb tide (following overtopping of the shingle ridge during a storm event) in frontage H would tend to reinforce the low water channel. As a result, the channel would become ebb-dominant. This ebb-dominated situation would tend to cause saltmarsh erosion. Into later epochs, with the same WPM approach in frontage H, water would tend to drain directly seaward back over the failed shingle barrier, instead of draining out through the River Glaven and Blakeney channel on the ebb tide. Actions would be needed in frontage H to ensure that the current fresh marshes are kept free of significant saline intrusion. However, the type and extent of 'with present management' is not clear at this stage.

The spit would continue to grow towards the west during epochs 1 and 2. Into epoch 3 it is likely to start showing significant signs of recurving and retreat as the saltmarshes experience continued sedimentation and eventually close the Blakeney harbour channel. This will only happen if the River Glaven is allowed to take a natural course directly through the shingle ridge. This provides an uncertainty and depends on the continued management of the fresh marshes. Alternatively, Stiffkey marshes could become more exposed into epoch 3 with sea level rise.

Under a scenario of NAI, there would be reinforced tidal flow behind the spit following failure of the sea banks, causing the marshes to become saline as opposed to freshwater habitats. The increased tidal prism would move the spit in a westward direction and the entire system would continue to move towards land. This would affect the development of the marshes in the lee of the spit. There is also more uncertainty about the spit itself. If siltation does not keep pace with sea level rise, it may not continue to grow. It may instead thin out with breaches occurring along the length of the spit.

Detailed assessment tables and figures for frontage G are provided in section F3.6.7.

<u>Cley to Salthouse shingle ridge (frontage H)</u>

As discussed in the previous section, WPM along this frontage assumes NAI along the ridge to keep it as a Natura 2000 site, but with management of the freshwater marshes (that is, continued pumping). It has also been assumed that the current freshwater marshes will be kept as they are now for all epochs.

Under a scenario of WPM, the shingle ridge would have a tendency to flatten and, due to lack of sediment supply, its previous height and profile would not be reinstated. This would lead to regular flooding and to a situation where the freshwater marshes would be permanently inundated. In this situation, saline water would be exchanged across the failed shingle ridge line on the flood and ebb tide. This would create an overwash system. It is likely, in this situation, that the current sea banks and pumping facilities would be abandoned as they would no longer be effective.

Under a scenario of NAI (assuming NAI in frontage G), water would preferentially drain out behind the spit, reinforcing Blakeney channel.

Because of uncertainties about how both frontages (G and H) may develop, it is vital they are considered as one when deciding future management options. The preferred management policy for both frontages is likely to depend greatly on decisions made about the maintenance of the fresh marshes.

Detailed assessment tables and figures for frontage H are provided in section F3.6.8.

### F3.3.4 Summary

The following sections provide a simplified overview of the geomorphological interactions within each super-frontage.

- Super-frontage 1 (frontages A and B):
  - Local interactions only between the north-eastern edge of frontage A and the south-western edge of frontage B (near Gore Point)

- Super-frontage 2 (frontages C, D, E and F):
  - Scolt Head Island is the dominant feature
  - Management of Scolt Head Island (frontage D) will have a large effect on decisions about managing frontages C and E
  - Frontage F (Warham and Stiffkey marshes) is a typical open coast and is not greatly affected how the neighbouring frontage (E) is managed. Frontage F could therefore be classed as a separate 'super-frontage'

- Super-frontage 3 (frontage G and H):
  - The intent and extent of continued management of the fresh marshes in frontage H will have a large effect on management of both frontages G and H
  - The sustainability of the fresh marshes needs to be assessed before making decisions about managing frontages G and H

## F3.4 Overall conclusions

### F3.4.1 No active intervention

Under a scenario of NAI, it is likely that the main process that would occur along the north Norfolk coastline is the restoration of the large expanses of reclaimed saltmarsh back to their natural state. This is not likely to occur until the end of epoch 1 in most cases because of the predicted timing of defence failure discussed in section F2. Following initial inundation of these former reclaimed areas, there would be a considerable increase in tidal exchange there and this would significantly change the sediment transport patterns of each individual unit. There is unlikely to be any widespread flooding of individual towns and villages, with damages being confined to water-edge development and some agricultural land (grades 2 to 4). The main effect of a scenario of NAI would be that a number of the small harbours may silt up (due to lack of maintenance) or water depths and flows may become too strong to allow safe mooring of boats. In this situation the effect on the town/village and surrounding area would be large, due to the loss of revenue provided by tourism and the potential that the area is no longer desirable for second home owners.

### F3.4.2 With present management

Under the WPM scenario, there is still likely to be more water entering the sheltered areas behind the various spit/barrier features as a result of sea level rise, but this will be constrained by the defences, gradually creating a form of coastal squeeze. There would also be increased pressure on the defences due to rising sea levels, which would increase the need for regular maintenance and inspections of the structures. This process will also change the geomorphological processes involved in forming the various depositional features.

## F3.5 References

Defra, 2006, Flood and Coastal Defence Appraisal Guidance FCDPAG3 Economic Appraisal – Supplementary note to operating authorities – climate change impacts

EA SMG (Environment Agency Shoreline Management Group), 2007, Anglian Coastal Monitoring Programme: Coastal Trends Analysis – North Norfolk

HR Wallingford, 2002, Cromer Coastal Strategy Study Final Report (Report EX 4363)

HR Wallingford and Royal Haskoning, 2002, Southern North Sea Longshore Sediment Transport Study

Royal Haskoning, 2003, North Norfolk Coast Coastal Habitat Management Plan Final Report

Mouchel, 1996, North Norfolk Shoreline Management Plan 1

## F3.6 Frontage tables

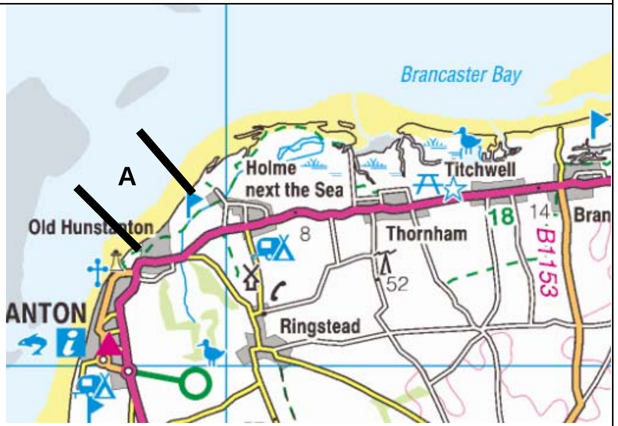
Frontage tables are provided below.

### F3.6.1 Frontage A – Old Hunstanton

| **Frontage A – Old Hunstanton** | **Chainage 0km 2.2km** |
|---|---|
| Start of dunes at Old Hunstanton (western boundary of SMP study area) to Gore Point | |

**Section 1 – Description**

| | |
|---|---|
| General | This frontage contains the village of Old Hunstanton, which is separated from the town of Hunstanton by a cliff-top car park and small pitch and putt golf course. To the north east of Old Hunstanton is the Hunstanton golf course, with the Peddars Way and Norfolk coast path running through it. |
| Physical | This frontage is characterised by successive lines of shingle and sand ridges, running in a south west to north east direction. The oldest dune ridges are at the landward edge and the newest at the seaward edge. The older dune ridges form the Hunstanton golf course. The newest dunes are generally protected by gabion basket groynes.<br><br>To the south west of the frontage are Hunstanton cliffs, which gradually diminish inland in a north-easterly direction up to the beginning of this frontage, where they are no longer visible.<br><br>At low water there is a significant width of sandy beach exposed (about 500 metres). At high water this beach is covered up to the seaward end of the groynes.<br><br>Offshore there is a large sand bank, consisting of Sunk Sand and Silver Sand, located around 3.5 kilometres from the frontage. The bank is generally exposed at low water. |



| Frontage A – Old Hunstanton | Chainage 0km 2.2km |
|---|---|
| Defences and man-made features | The whole frontage is protected by lines of natural vegetated sand dunes. There are around 35 gabion groynes that stabilise the beach in front of the newest dune line. |

**Section 2 – Baseline information (current data relevant to the frontage)**

Tide and water levels (MODN)

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hunstanton** | N/A | -2.85 | -1.25 | N/A | 1.85 | 3.65 | N/A | 6.50m | 3.10m | CD is 3.75 metres below OD |

Extremes (MODN)

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Hunstanton** | Royal Haskoning 2007 | 4.73 | 5.24 | 5.45 | 5.60 | 5.76 | 5.91 | 6.11 | 6.27 |

Notes:

Currents

| | | Notes |
|---|---|---|
| Av. flood | North | Current data deduced from tidal diamond Q on Admiralty chart no. 108. |
| Av. ebb | South | The flow pattern over much of the rising tide is relatively weak over mid-tide and towards the south, changing to a weak flow over high water towards the north. On the ebb, the flow is generally towards the north, but reverses to a strong flow towards the south over low water, flowing into the ebb tide from the Wash. |
| Net residual | West | |

Wave

The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the

## Section 2 – Baseline information (current data relevant to the frontage)

| | |
|---|---|
| climate | coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between 1.0 and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988). |
| Accretion/ erosion | Notes: Erosion has been a problem along this entire frontage, with the sand dunes being protected by gabions and groynes to try to slow the loss of material southwards and to stabilise the position of the shoreline. |

| **Average rates (myr$^{-1}$ unless stated)[1]** | Cliff/backshore feature | | | | Intertidal | | | | Nearshore | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | general | crest | face | toe | backshore | Mean | MHWS | MLWS | Trend | Source |
| Average of EA profiles N1D4 and N1D5 | | | | | | 1.81 | 2.80 | 1.00 | Accretion | EA Coastal Trends Analysis (2007) |

Sediment

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system. General movement along this frontage is into the Wash.

| | | | | |
|---|---|---|---|---|
| **Material** | Coarse-grained sand and gravel (outer sand flats, barrier beaches and sand dunes).<br>Fine-grained silt and clay (inner saltmarshes and associated mudflats). | | | |
| **Sources** | External: | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal: | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| **Movement:** Sediment transport is towards the west during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals in this direction (Evans | **Location** | **Net drift ($m^3$/yr x 1000)** | **Source** |
|---|---|---|---|
| | Wash entrance | 14.00 (south westward) | Ke et al. (1996) |
| | Wash | 12.44 (southward) | HR Wallingford |

**Section 2 – Baseline information (current data relevant to the frontage)**

| | | | | | |
|---|---|---|---|---|---|
| | et al 1998). During high energy surge conditions there may be a sudden change in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to changes in normal sediment pathways and delivery and moves signficant amounts of sediment during single events (HR Wallingford 2002). | entrance | | | (1998) |
| | | | | | |
| | | | | | |

[1] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| Frontage A – Old Hunstanton | Chainage 0km 2.2km |
|---|---|
| **Section 3 - Geomorphology** | |
| Process description: Overall description of current processes: sources, transport and sinks | It has been suggested that the north eastward orientation of the shingle and sand ridges is related to their position in the mouth of the Wash. The past erosion has been more significant than over the neighbouring frontage (frontage B) to the north east. The frontage therefore tends to form a slowly eroding embayment. The greater resilience of the frontage to the north east has not been examined in previous reports but seems to be associated with local nearshore features, namely the Norfolk Banks and the Burnham Flats. These features consist of sand and may provide limited sediment during low-frequency high-magnitude events. |
| Patterns of change | **Past development:**<br>In the past, there has been erosion along this frontage. As a result the upper beach has been stabilised using gabion groynes.<br>**Recent trends:**<br>Recent EA monitoring data suggest that the groynes are acting to stabilise the upper beach profile. This frontage is now, therefore, experiencing accretion at average rates of 1.81 metres a year.<br>**Future evolution (unconstrained):**<br>Removing the defences along this frontage is likely to lead to the onset of erosion, as noted in the past. This would release some sediment to the Hunstanton-Heacham frontage, which may provide some increased protection there. However, most is likely to be moved offshore where it will be stored as a sediment sink. This process would have a detrimental effect on the sand dunes in front of Old Hunstanton and the Hunstanton golf course. |

## Frontage A – Old Hunstanton    Chainage 0km    2.2km

**Dependency: Factors affecting the evolution of the frontage both internally and externally**

| Control and sensitivities | Control features | Significance | Dependence | Chainage |
|---|---|---|---|---|
| The slight embayment is anchored by the cliffs to the south but, in a potentially more transient manner, by the dunes to the north east. The behaviour of frontage B is critcial to that of frontage A. The frontage is very sensitive to continued sediment supply. The groynes act at present to hold the shore. | Gabion groynes | Secondary | Human intervention | 0 to 2.2km |
| | Hunstanton cliffs | Primary | Fixed | Outside study area |

| Internal interaction | External interaction |
|---|---|
| | Continued use of defences along this frontage acts to pin the shoreline in position, while the neighbouring frontage (B) around Gore Point is free to realign. |

**Sea level / climate change**

For recent Defra (2006) guidance on sea level rise due to climate change - see section 1.4 in the main report.

**Influence: Factors that may influence evolution of other areas**

If management of this frontage is abandoned, there would be a minor release of sediment. Alternatively, if management continues, this would hold the shoreline in a relatively unnatural position, with the neighbouring frontage (B) being free to realign. This could lead to an increased potential for catastrophic failure of the sand dunes at the north eastern edge of the frontage, particularly during extreme events.

| Frontage A – Old Hunstanton | Chainage: 0km | 2.2km |
|---|---|---|

## Section 4 – Baseline management scenarios[2,3]

| | |
|---|---|
| No active intervention (NAI) | **Scenario description**<br>This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced, but an epoch of failure can be determined, as shown in the ' Assessment of coastal defences' report.<br>**Shoreline response**<br>Under a scenario of NAI, over 90 per cent of the groynes along this frontage are expected to fail by the end of epoch 1, with the remaining groynes failing by the end of epoch 2.<br><br>Initially, while the defences remain intact, they will continue to hold the shoreline where it is now. There is likely to be continued accretion across the whole profile at rates of around 1.81 metres a year. Following failure of most of the groynes towards the end of epoch 1 and beginning of epoch 2, there is likely to be quite rapid rollback and realignment of the shoreline. The shoreline would take on a more natural position and would form a slight embayment as it is anchored to the south by the slowly-eroding cliffs and to the north by Gore Point. However, if NAI was applied to frontage B, anchoring of the northern end of frontage A is unlikely to be as significant. As the dunes roll back they would react to the rising sea level by forming increased crest heights and wider profiles. These natural dunes would obviously be susceptible to overtopping during extreme events.<br><br>For epochs 1, 2 and 3, pressure for erosion is likely to be in terms of rollback with sea level rise, with continued supply from frontage B. Rates of erosion might be expected to be directly associated with the rate of sea level rise and beach slope. The following table calculates the erosion rate by multiplying the rate of sea level rise by the |

[2] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, within this assessment of baseline scenarios, it has not been considered relevant to quantify these effects due to the uncertainty surrounding this issue.

[3] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

beach slope (a simplification of the Brunn rule):

| Epoch | Sea level rise (myr$^{-1}$) | Beach slope | Erosion rate (myr$^{-1}$) |
|---|---|---|---|
| 1 (2008 to 2025) | 0.004 | 1:20 | 0.08 |
| 2 (2025 to 2055) | 0.0085 | 1:20 | 0.17 |
| 3 (2055 to 2085) | 0.012 | 1:20 | 0.24 |
| 3 (2085 to 2105) | 0.015 | 1:20 | 0.30 |

If at any time during epochs 2 and 3 there is any constraint (natural or man-made) on the natural progression of the dune line towards land, there would be oversteepening of the seaward face of the dune and a risk of breakdown of the dune function as a natural defence. In this situation there would be flooding of the backshore area and it is likely that it would gradually make the progression to natural saltmarsh.

| Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Failure of over 90 per cent of the groynes. | The natural coast would remain in the same "unnatural" position, but the upper foreshore is likely to continue to accrete. | Complete defence failure. The natural dune line will provide some protection. | Wide-scale realignment of the dune line with breach/ overtopping during extreme events. Frontage will begin to shape into a slight embayment, fixed to the south by the cliffs. | Complete defence failure. The natural dune line will continue to provide some protection. | Same as epoch 2. Dune line will become in balance with the natural processes. Continued flooding of the backshore during extreme events. |

With present management (WPM)

**Scenario description**

This scenario assumes that the current policy of hold the line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

**Shoreline response**

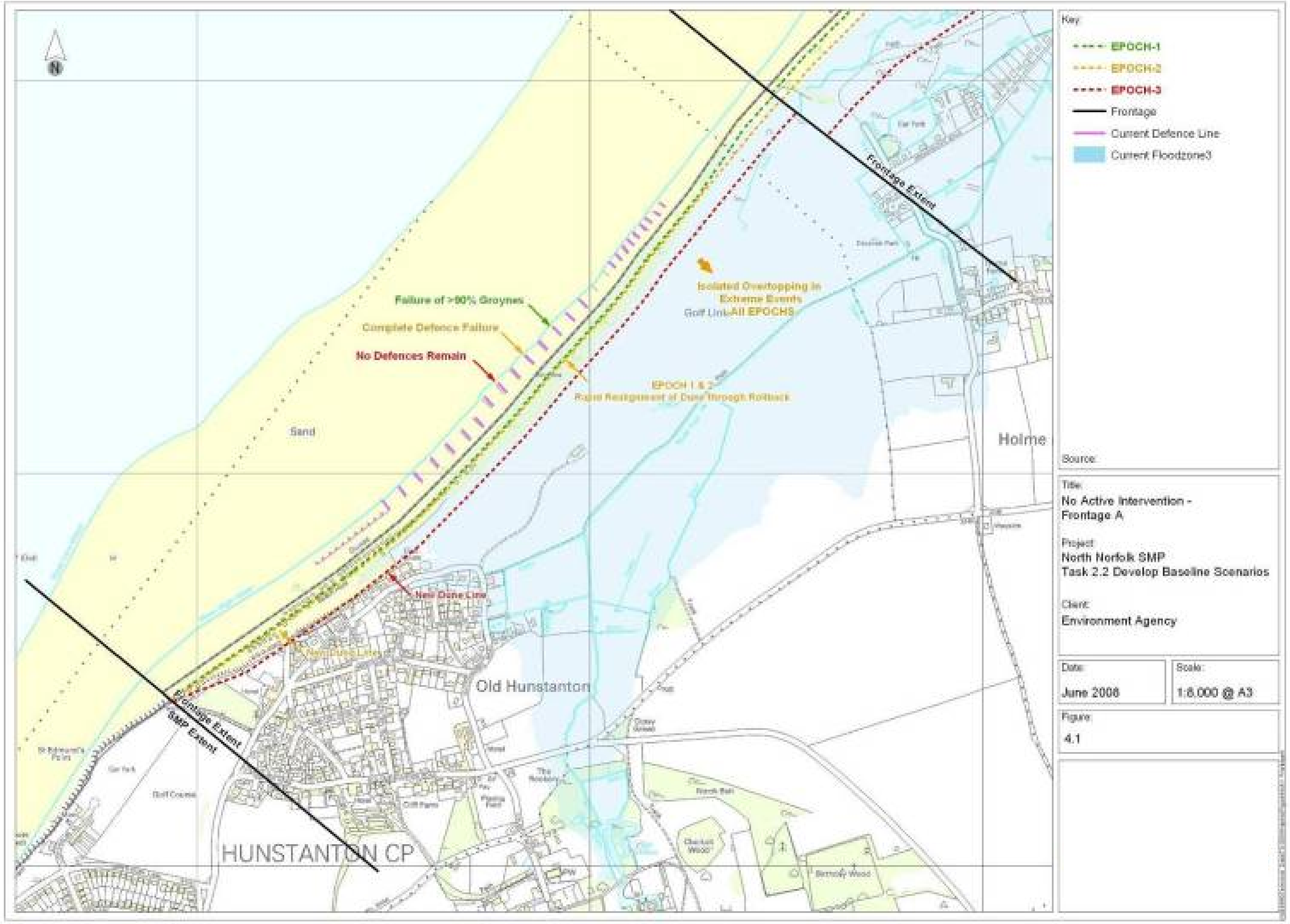
Under a scenario of WPM, during epoch 1 the gabion basket groynes would effectively continue to pin this part of the shoreline in position. In contrast, the neighbouring frontage (frontage B) would be free to realign. As a result, the shoreline across this frontage would become increasingly out of line with neighbouring frontages. This will increase pressure on the northern end of the frontage with a need for more protection and management. This is despite accretion trends being recorded recently from EA monitoring results. In epoch 1 accretion is still likely to occur.

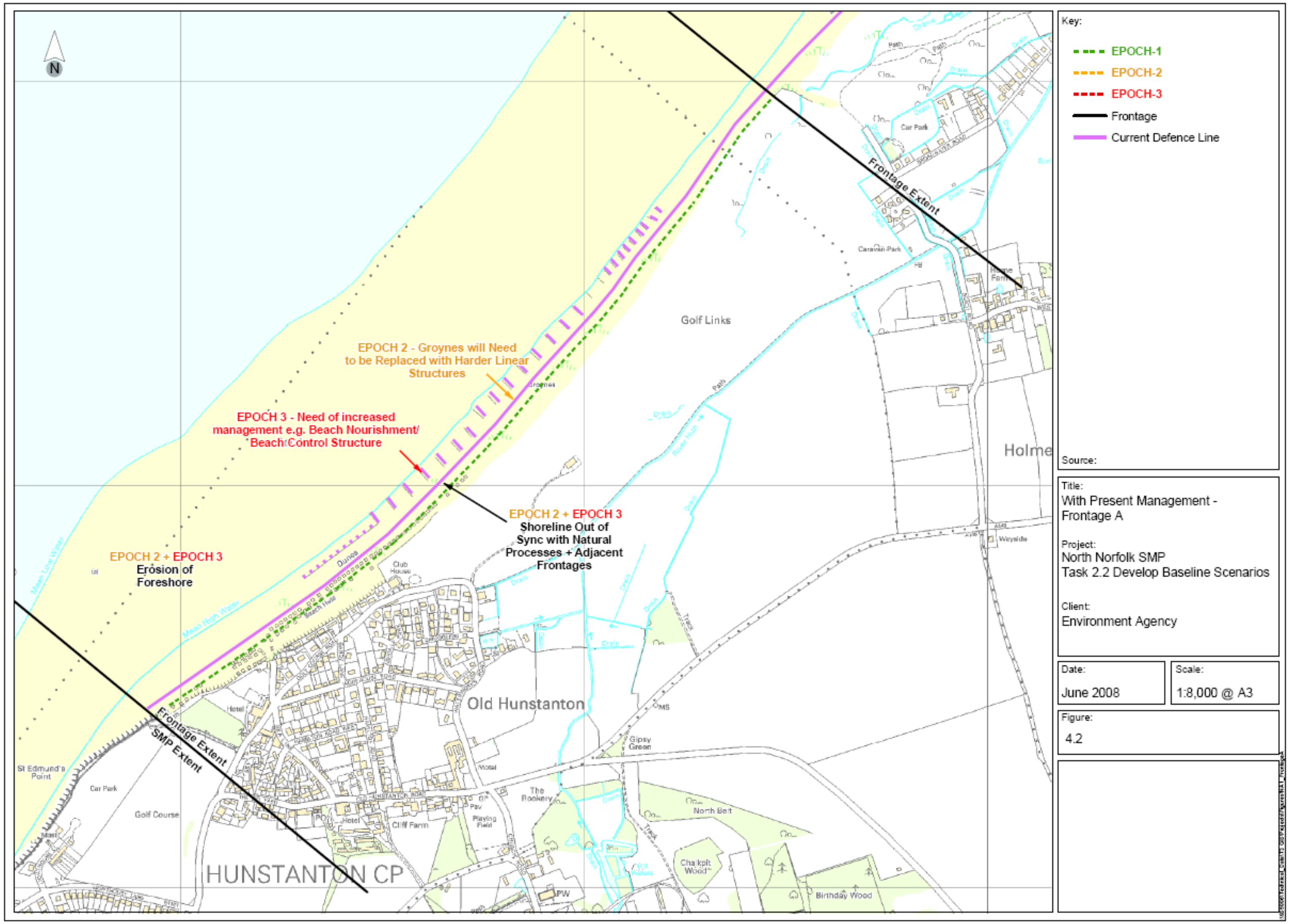
In epoch 2 there would potentially be a change from accretion to erosion along the foreshore. There would also be the increasing need for groynes to be replaced with harder beach control structures, such as linear defences, to reduce the risk of flooding to the backshore areas. However, if this defence replacement was undertaken, the shoreline would be increasingly out of balance with the natural behaviour and it is likely that there would be some erosion in front of the defences, with the possibility of lowering beach levels and undermining of the defences.

Into epoch 3, the new hard linear defences would need to be continually maintained and improved to provide an increased standard of protection. There may be the need for other management options, such as beach renourishment with associated beach control structures.

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences will remain. | Same as epoch 1 NAI: The natural coast would remain in the same “unnatural” position, but the upper foreshore is likely to | Defences will remain, but gabion groynes are likely to be replaced with hard linear | Erosion, as opposed to accretion, would be experienced along the foreshore. Shoreline would be increasingly out of line with neighbouring | Hard linear defences may need to be accompanied by other beach management options such as beach nourishment and beach control | Increased erosion of the foreshore and lowering of beach levels. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | continue to accrete. | defences. | frontages. | structures. | |


Failure of >90% Groynes
Complete Defence Failure
No Defences Remain
Isolated Overtopping in Extreme Events All EPOCHS
EPOCH 1 & 2
Rapid Realignment of Dune through Rollback
New Dune Line
Sand
Old Hunstanton
Holme
HUNSTANTON CP
Frontage Extent
SMP Extent
Key
EPOCH-1
EPOCH-2
EPOCH-3
Frontage
Current Defence Line
Current Floodzone3
Source:
Title:
No Active Intervention -
Frontage A
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:8,000 @ A3
Figure:
4.1


N
Key:
EPOCH-1
EPOCH-2
EPOCH-3
Frontage
Current Defence Line
Source:
Title:
With Present Management - Frontage A
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:8,000 @ A3
Figure:
4.2
EPOCH 2 - Groynes will Need to be Replaced with Harder Linear Structures
EPOCH 3 - Need of increased management e.g. Beach Nourishment/ Beach Control Structure
EPOCH 2 + EPOCH 3
Shoreline Out of Sync with Natural Processes + Adjacent Frontages
EPOCH 2 + EPOCH 3
Erosion of Foreshore
Frontage Extent
Frontage Extent
SMP Extent
Golf Links
Holme
Old Hunstanton
HUNSTANTON CP
Golf Course
Car Park
Birthday Wood
Chalkpit Wood
North Belt
Cliff Farm
The Rookery
Gipsy Green

### F3.6.2 Frontage B – Holme-next-the-Sea and Thornham

**Frontage B – Holme-next-the-Sea and Thornham** **Chainage 2.2km 8.2km**

North-eastern limit of Hunstanton golf course to western end of Brancaster bay (just to the east of Thornham).

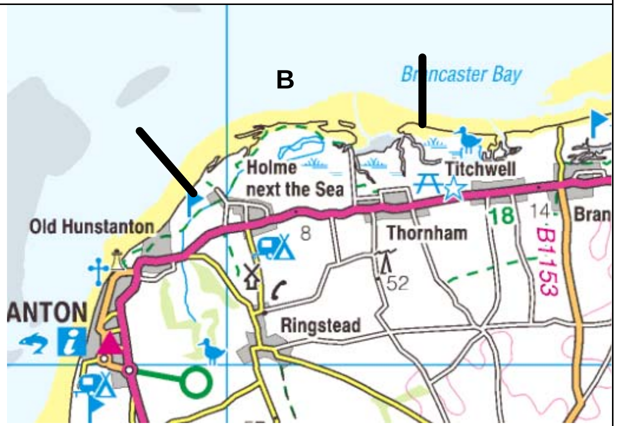
**Section 1 – Description**

**General**

This frontage contains the villages of Holme-next-the-Sea and Thornham connected by the main coast road (A149). Near Holme there is a dune ridge system similar to that found along frontage A. Towards the east around Thornham there are extensive saltmarshes separated from the reclaimed Holme marshes by an embankment along Thornham harbour channel.

**Physical**

The extensive (around 250 hectares) saltmarshes of the Thornham area are separated from the reclaimed Holme marshes by an embankment along the Thornham harbour channel. The tidal discharge from the harbour channel (not constrained by training walls) has resulted in a large tidal delta whose ramparts form a dune ridge enclosing Thornham marshes (to the east of the frontage) and Holme dunes (to the west).




This tidal delta forms Gore Point, which acts as a barrier island similar to Scolt Head Island but more closely attached to the shore. There is a smaller tidal inlet at the western side of Gore Point. This cuts through the dune ridge, forming a slight discontinuity in the dunes. This small inlet tends to hold the western end of Gore Point slightly out to sea. Although still within the overall low-lying area of the River Hun, there appears to be a slight ridge of higher ground running north from Holme. The barrier dunes are recurved only at the eastern end, giving some shelter to the embankment and fixed outfall of the River Hun. The River Hun discharges into the saltmarsh along this frontage through a tidal outfall sluice on the eastern side of Gore Point.

| Frontage B – Holme-next-the-Sea and Thornham | Chainage 2.2km 8.2km |
|---|---|
| Defences and man-made features | Near Holme and across Gore Point there are no formal man-made defences, only vegetated sand dunes. In front of Holme Dunes Nature Reserve the dunes have limited soft protection on their seaward face. This soft protection consists of timber boards and brushwood fencing (faggotting). To the east of Gore Point the natural line of sand dunes is replaced by a vegetated sea bank that protects Thornham from flooding. |

## Frontage B – Holme-next-the-Sea and Thornham    Chainage 2.2km    8.2km

### Section 2 – Baseline information (current data relevant to the frontage)

**Tide and water levels (mODN)**

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hunstanton** | N/A | -2.85 | -1.25 | N/A | 1.85 | 3.65 | N/A | 6.50m | 3.10m | CD is 3.75 metres below OD |

**Extremes (mODN)**

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Holme-next-the-Sea** | Royal Haskoning 2007 | 4.46 | 4.99 | 5.20 | 5.36 | 5.52 | 5.68 | 5.89 | 6.04 |

Notes:

**Currents**

| | | **Notes** |
|---|---|---|
| Av. flood | South | Current data deduced from tidal diamond K on Admiralty chart no.108 – note significantly offshore.<br>The flow pattern over much of the rising tide is relatively strong over mid-tide and towards the south, changing to a weak flow over high water towards the north. On the ebb, the flow is generally strong and towards the north. |
| Av. ebb | North east | |
| Net residual | North | |

**Wave climate**

The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988).

| Frontage B – Holme-next-the-Sea and Thornham | Chainage 2.2km 8.2km |
|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

**Accretion/ erosion**

Notes: In the area known locally as the Firs, recession rates of up to eight metres were recorded between 1988 and 1993. Accretion in Thornham harbour has also been noted between 1966 and 1994 aerial photographs. Between 1992 and 2001, EA data show that around 100,000$m^3$ a year of sediment was lost from this frontage. Between Holme and Blakeney, Futurecoast (Halcrow 2002) notes that the coastline is typically accreting.

| **Average rates ($myr^{-1}$ unless stated)**[4] | Cliff/backshore feature | | | | Intertidal | | | | Nearshore | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | general | crest | face | toe | backshore | mean | MHWS | MLWS | trend | Source |
| Average of EA profiles N1D7 to N1C3 | | | | | | **-1.87** | -1.59 | -1.89 | Erosion | EA Coastal Trends Analysis (2007) |

**Sediment**

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system.

**Material** Coarse-grained sand and gravel (outer sand flats, barrier beaches and sand dunes).
Fine-grained silt and clay (inner saltmarshes and associated mudflats).

**Sources**

External: Erosion of Holderness cliffs (fine). Erosion of cliffs along north Norfolk coast (fine).

Internal: Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse). Offshore banks (during high magnitude, low frequency events).

**Movement:** There is a westward sediment transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment.

| **Location** | **Net drift ($m^3$/yr x 1000)** | **Source** |
|---|---|---|

[4] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| Frontage B – Holme-next-the-Sea and Thornham | Chainage 2.2km | 8.2km |
|---|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

| | |
|---|---|
| | There are seasonal reversals in this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from Burnham Flats being transported. This leads to changes in normal sediment pathways and delivery and acts to move large amounts of sediment during single events (HR Wallingford 2002). |

| Frontage B – Holme-next-the-Sea and Thornham | Chainage 2.2km 8.2km |
|---|---|

**Section 3 - Geomorphology**

| | |
|---|---|
| Process description: Overall description of current processes: sources, transport and sinks | The area between Thornham and Hunstanton golf course is very similar to the features between Wells harbour and Scolt Head Island (frontage E). However, the features indicate a less fully-developed stage compared to the Wells-Scolt Head Island unit. This frontage is mainly fronted by natural dunes set out in parallel ridges up to 100 metres back from the shoreline. Waves from the west play a role as this area is exposed to locally-generated waves from the Wash as well as the north east-south west orientated tidal system.<br><br>There is a wave-modified ebb tidal delta caused by discharge from Thornham harbour channel. This is accreting north of the tidal inlet at Thornham. This tidal delta acts as a sediment sink where local sediment convergence and circulation occurs to form offshore bars and dune ridges. These enclose Thornham marshes on the east and Holme dunes on the west. Tidal deltas occur where discharges from tidal inlets cause the longshore pathway of sediment to be pushed seaward and become intermittent. This creates a pronounced lobe in the lower intertidal that causes a decrease in energy at the upper shore and formation of sand dunes. There is also a smaller tidal delta at Gore Point, towards the west of the frontage. Gore Point is thought to be a relatively stable feature (Leggett et al 1998; Schong et al 2001).<br><br>Between Holme-next-the-Sea and the outfall of Thornham harbour channel there is about 84 hectares of reclaimed marsh. These 'grazing marshes' are very susceptible and fragile habitats. There are a couple of significant offshore features along this frontage, the Norfolk Banks and the Burnham Flats, consisting of sand. These will act as a significant source of sediment during high energy surge conditions. |
| Patterns of change | **Past development:**<br>The saltmarshes have accreted vertically in pace with sea level rise since the mid-Holocene. Erosion is a problem in the area known as the Firs where, between 1988 and 1993, recession rates of up to eight metres were recorded. Gore Point has also eroded from the eastern end near the drainage channels for Holme marsh. This is balanced to an extent by accretion in the Thornham harbour area noted in comparisons between 1966 and 1994. |

## Frontage B – Holme-next-the-Sea and Thornham  Chainage 2.2km 8.2km

**Recent trends:**
The sand dunes in front of the Holme Dunes National Nature Reserve are subject to enhanced erosion, with the released sand carried eastwards (Futurecoast 2002). The EA has noted this erosion during recent monitoring.

**Future evolution (unconstrained):**
To the west of Thornham harbour the immature sand bars are likely to continue to try to move to the swash alignment, but the lack of mobile material is expected to hinder this process. The area around Gore Point and the Firs is likely to continue to erode at the present rate as there is very little protection for the area. Under an unconstrained scenario, the tidal delta formed by the discharge of the River Hun will probably progress towards the west.

Dependency: Factors affecting the evolution of the frontage both internally and externally

| Control and sensitivities | Control features | Significance | Dependence | Chainage |
|---|---|---|---|---|
| Locally-generated waves from the Wash.<br>Sea level rise – will tend to cause rollback of the frontage.<br>Existence of tidal inlet discharge. | Holme marsh tidal inlet | Secondary | Transient | |
| | Thornham/Hun tidal channels | Secondary | Subject to change with sea level rise and enclosure | |
| | Burham Flats | Primary | Change due SLR | |
| | | | | |

| Internal interaction | External interaction |
|---|---|
| Continued sea level rise will cause an increase in the depth of water over the Burnham Flats, which could mean that the focus of wave energy changes.<br><br>The tidal prism of the various inlets, | There is a feed of sediment from the frontage to the east. The frontage depends on feed from the offshore areas. |

<table>
<tr><td colspan="3">Frontage B – Holme-next-the-Sea and Thornham      Chainage 2.2km 8.2km</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Influence: Factors that may influence evolution of other areas</td><td>and particularly as a result of inundation of the Hun river flood area, would significantly alter the control this imposes on the coast.</td><td></td></tr>
<tr><td colspan="2">Sea level / climate change<br>For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.</td></tr>
<tr><td colspan="2">Rollback of Gore Point may cause a change in control along frontage A to the east. Strong control imposed on the frontage may weaken the supply to the east, with Gore Point acting as a barrier to drift.</td></tr>
</table>

## Section 4 – Baseline management scenarios[5,6]

| | |
|---|---|
| No active intervention (NAI) | **Scenario description**<br>This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced, but an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.<br>**Shoreline response**<br>Under a scenario of NAI there would be continued erosion along the frontage at rates of about 1.87 metres a year. Dunes parallel to the barriers on the open coast are likely roll back with the potential for overwash fans moving residual beach sediment over the reclaimed marshes. In the long term, these could provide the foundation for new dunes, depending on the availability of sediment. If formed, these new dunes are likely to be big enough to act as a natural coastal defence in the future. The whole system would roll back and there would be continued vertical accretion across the natural saltmarsh areas within the barrier of the dunes. Most of the defences are likely to have failed by the end of epoch 1, at which point there would be some realignment of the previously-fixed coastline and flooding of the areas behind the defences on high tides. This would eventually lead to a reinstatement of the reclaimed saltmarsh back to natural saltmarsh, as they are at a lower level and would promote ponding. This rapid realignment would tend to have a major effect on the system as it re-establishes itself to an initial increase in tidal volume. The saltmarsh area would tend to act as a sediment sink initially. The general retreat would have an effect on frontage A as this frontage would provide less of an anchor to the north of it.<br><br>Under this scenario there would be a failure of the River Hun tidal outfall sluice. In this situation, the river outfall would take a more natural route over the saltmarsh and it is likely to move towards the west. |

[5] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, in this assessment of baseline scenarios it has not been considered relevant to quantify these effects due to the uncertainty surrounding this issue.

[6] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

| Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Most of the earth embankments and the tidal outfall of the River Hun would fail by the end of epoch 1. | Continued erosion along the frontage with overwashing of the dunes and subsequent rollback. Following defence failure, the previously-fixed coastline would realign, with flooding of the previously-reclaimed areas. Defence failure would have a major effect on the geomorphological system. | Complete defence failure. | Tidal delta would move towards the west as it is unconstrained. Backshore areas would begin to develop into natural saltmarsh. There would be continued rollback of the natural dune line. | Complete defence failure. | Same as epoch 2. Continued westward movement of the tidal delta. Saltmarsh would continue to develop. |

With present management (WPM)

**Scenario description**

This scenario assumes that defences are maintained and improved to provide a similar level of protection to that provided now. This management is aimed at defending the area behind (reclaimed land) from flooding. This will involve regularly inspecting and maintaining defences. The natural dune frontages are assumed to roll back with no intervention.

**Shoreline response**

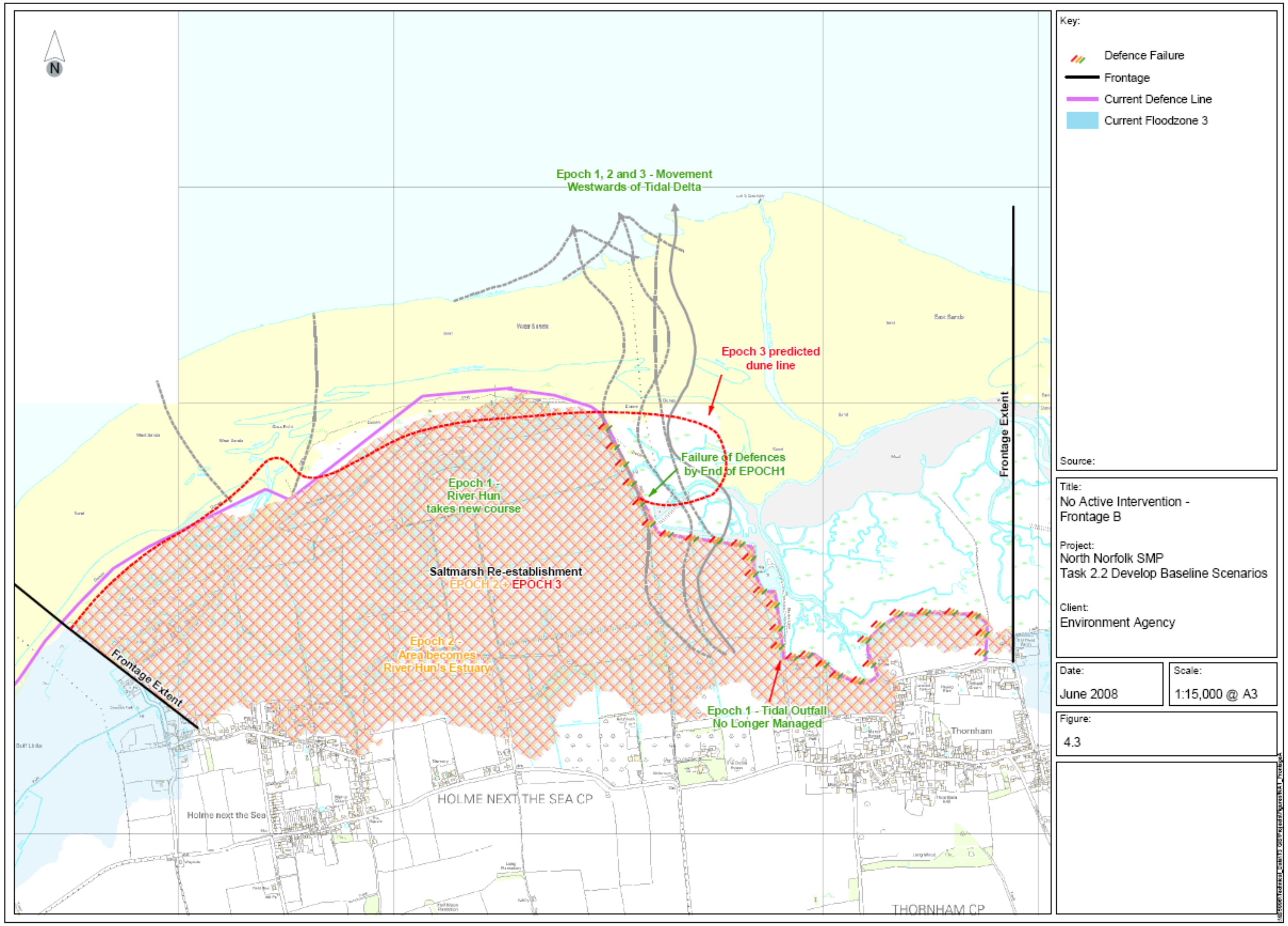
In epoch 1 under a scenario of WPM, there would be similar shore development to that described in epoch 1 under the NAI scenario. As a result, erosion would continue along the foreshore at rates of around 1.87 metres a year. Dunes parallel to the barriers on the open coast are likely to roll back with the potential for overwash fans to move residual beach sediment over the reclaimed marshes. The whole system would roll back and vertical accretion is likely to continue across the natural saltmarsh areas within the barrier of the dunes.

Into epoch 2, the continued rollback of the dunes parallel to the barriers on the open coast would create a greater interaction between the dunes and the fixed earth embankments. At this interface there is likely to be a weakness in the natural interface with increased risk of failure. In epoch 2 there would therefore be a need to extend the current earth embankment towards the west following the current dune line. In epoch 2 it is also likely that vertical accretion of the saltmarsh areas may reduce or even change to erosion. As a result, in front of the fixed earth embankments there would be a squeeze of the current tidal delta between the rising sea level and the fixed earth embankment. This squeeze would in turn increase the likelihood of overtopping and cause ponding of water on the lower reclaimed marshes. This would lead to the need for higher earth embankments in these areas.

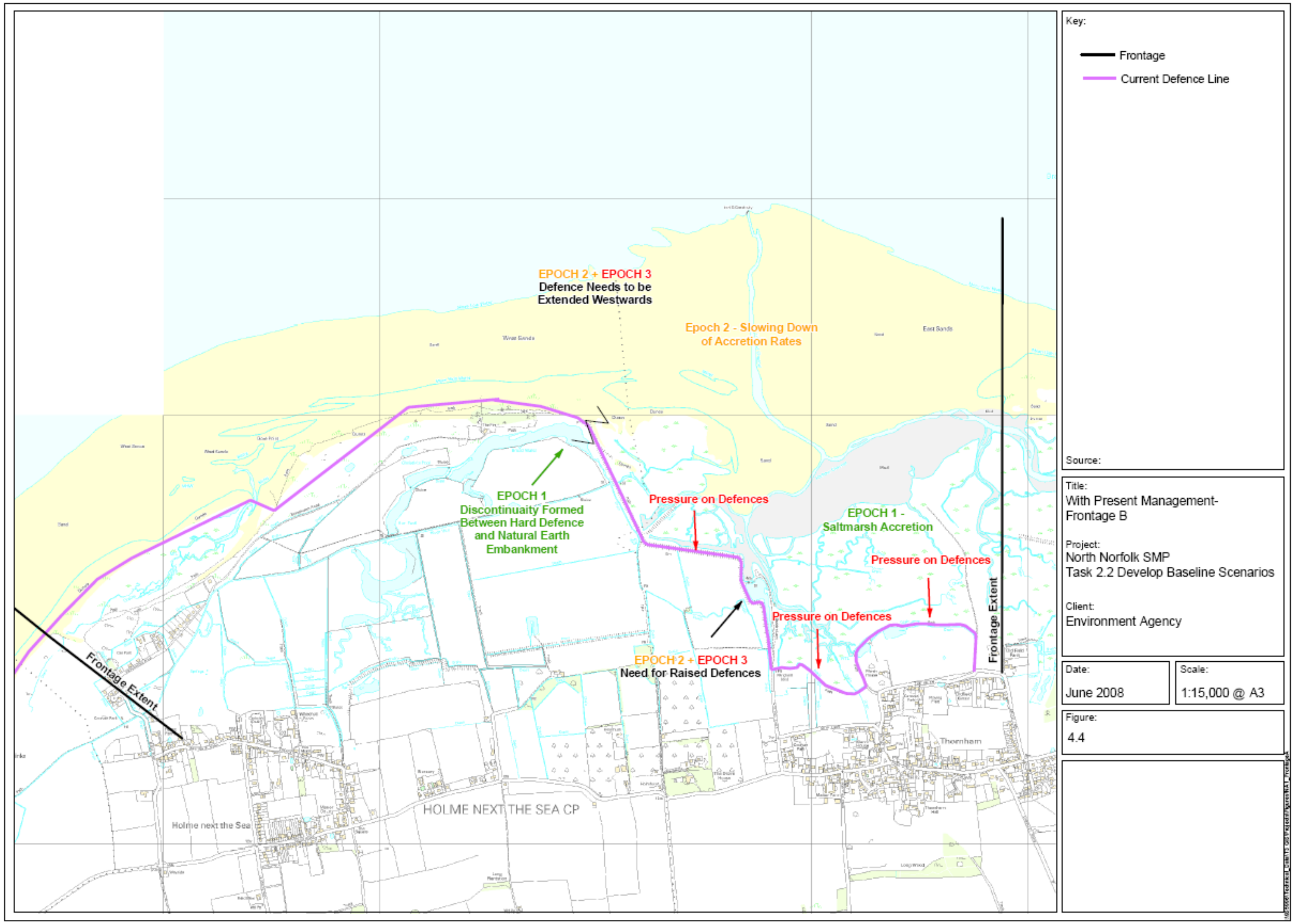
In epoch 3, the shoreline development noted in epoch 2 would continue. There would be a continued need to extend the earth embankments towards the west, gradually replacing the natural dune line. The earth embankments in the eastern half of the frontage would also need to be increased in height as coastal squeeze in front of the defences increases the risk of overtopping of the defences. Into epoch 3, associated with the increased discontinuity in coastal alignment, it is possible that a new outfall of the River Hun would open up. This behaviour would need closer monitoring and examination.

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences would remain. | Continued erosion along the frontage with overwashing of the dunes and subsequent rollback. | Defences would remain. | Continued dune rollback with discontinuity forming between the fixed earth embankment and the dunes. Need for defence line to be extended westward to halt this discontinuity. Coastal squeeze in front of earth embankments due to sea level rise. Need for higher earth embankments to reduce | Defences would remain. | Same as epoch 2, with increased need for defences to be extended westwards and standard of protection provided by existing earth embankments to be increased. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | threat of overtopping. | | | |



N
Epoch 1, 2 and 3 - Movement Westwards of Tidal Delta
Epoch 3 predicted dune line
Failure of Defences by End of EPOCH1
Epoch 1 - River Hun takes new course
Saltmarsh Re-establishment
EPOCH 2 - EPOCH 3
Epoch 2 - Area becomes River Hun's Estuary
Epoch 1 - Tidal Outfall No Longer Managed
Frontage Extent
Frontage Extent
HOLME NEXT THE SEA CP
Holme next the Sea
Thornham
THORNHAM CP
Key:
Defence Failure
Frontage
Current Defence Line
Current Floodzone 3
Source:
Title:
No Active Intervention - Frontage B
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:15,000 @ A3
Figure:
4.3


EPOCH 2 + EPOCH 3
Defence Needs to be Extended Westwards
Epoch 2 - Slowing Down of Accretion Rates
EPOCH 1
Discontinuaity Formed Between Hard Defence and Natural Earth Embankment
Pressure on Defences
EPOCH 1 - Saltmarsh Accretion
Pressure on Defences
Pressure on Defences
EPOCH 2 + EPOCH 3
Need for Raised Defences
Frontage Extent
Frontage Extent
HOLME NEXT THE SEA CP
Holme next the Sea
Thornham
Key:
Frontage
Current Defence Line
Source:
Title:
With Present Management-Frontage B
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:15,000 @ A3
Figure:
4.4

### F3.6.3 Frontage C – Titchwell and Brancaster

| **Frontage C – Titchwell and Brancaster** | **Chainage 8.2km** | **13.9km** |
|---|---|---|

Western limit of Brancaster bay to western end of Scolt Head Island.

**Section 1 – Description**

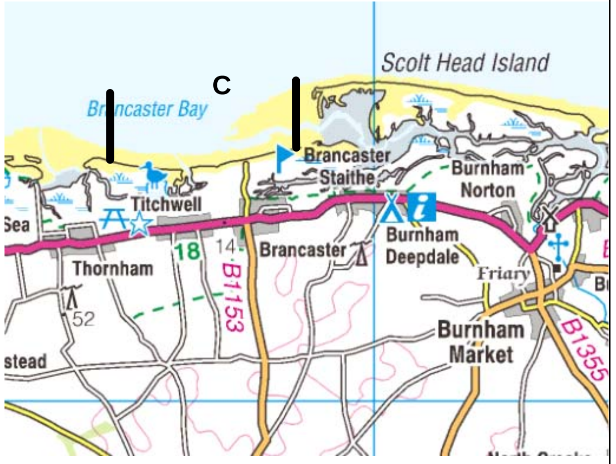
| | |
|---|---|
| General | This frontage, encompassing Brancaster bay, contains the small hamlet of Titchwell and the large village of Brancaster, both connected by the A149 coast road. There is a RSPB nature reserve seaward of Titchwell and a Roman fort at Brancaster (Branodunum). The Royal West Norfolk golf course starts south of the dunes, seaward of Brancaster. |

Physical

This frontage is split into two by a vegetated earth flood bank that runs north to south and starts to the west of Brancaster village. This sea bank separates the Titchwell RSPB reserve from Brancaster marsh and the Royal West Norfolk golf course.

In general, the physical characteristics of both sections of this frontage are the same. There is a line of sand dunes at the seaward edge, backed by saltmarsh (over one kilometre wide) and then the villages of Titchwell and Brancaster at the landward edge.

Brancaster bay itself has a number of spit-like features at its western and eastern ends, potentially indicating a divergence of transport paths along the beach.



| Frontage C – Titchwell and Brancaster | Chainage 8.2km 13.9km |
|---|---|
| Defences and man-made features | There are raised earth sea banks along the front, and around the edge, of Titchwell marsh that currently protect the brackish areas of the reserve. Managed realignment at Titchwell is currently taking place. The plans involve breaching the east wall along its northern section and strengthening the Parrinder wall which would then become the main defence protecting the reserve. As a result, the section of the reserve to the north of the Parrinder wall would develop into natural saltmarsh. The Royal West Norfolk golf club is protected by a combination of sea banks (to the north, south and west of the practice green), rock revetment in front of the clubhouse and western edge of the course itself and sand-filled geotextile bags (also in front of the western edge of the golf course). The dunes that run west to east at the seaward edge of the golf course are not formally managed, although the groundsman does place tree cuttings etc on the front face of the dunes to stabilise them. There are also a number of Environment Agency-managed defences to the south of the golf course. An 'erratic' earth sea bank also protects the eastern edge of this frontage from Brancaster to Staithe Cottage. This is really a secondary defence, as the dunes to the north of the golf course provide the main protection. However, if these dunes disappeared, the saltmarsh behind would suffer from increased erosion, which would, in turn, expose Brancaster to direct wave action. |

**Frontage C – Titchwell and Brancaster** **Chainage 8.2km 13.9km**

**Section 2 – Baseline information (current data relevant to the frontage)**

Tide and water levels (mOD N)

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Burnham Overy Staithe** | | | | | 1.50 | 2.90 | | | | |

Extremes (mOD N)

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Brancaster** | Royal Haskoning 2007 | 4.16 | 4.70 | 4.92 | 5.08 | 5.24 | 5.41 | 5.62 | 5.79 |

Notes:

Currents

| | | Notes |
|---|---|---|
| Av. flood | North west | Current data deduced from tidal diamond L on Admiralty chart no. 108 – note significantly offshore.<br>The flow pattern over much of the rising tide is relatively weak over mid-tide and towards the west, increasing to a strong flow towards the east over high water. On the ebb, the flow is towards the east, reversing to a strong flow towards the west at low water, flowing into the ebb tide from the Wash. |
| Av. ebb | South east | |
| Net residual | North west | |

Wave

The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988).

Notes: Coastal retreat around the eastern end of Brancaster bay may be part of a general re-orientation of the shoreline rather than erosional loss. EA profiles for the Thornham area between 1992 and 2001 indicate slight erosion of the upper intertidal and dune face, but significant accretion of the lower intertidal zone. This is a response to sea level rise. Between Holme and Blakeney, Futurecoast (Halcrow 2002) notes that the coastline is typically accreting.

## Frontage C – Titchwell and Brancaster    Chainage 8.2km    13.9km

**Section 2 – Baseline information (current data relevant to the frontage)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| climate | **Average rates (myr$^{-1}$ unless stated)**[7] | Cliff/backshore feature | | | | | Intertidal | | | Nearshore | | |
| | Location | general | crest | face | toe | backshore | mean | MHWS | MLWS | trend | | Source |
| Accretion/ erosion | Average of EA profiles | | | | | | **0.84** | -0.33 | 1.19 | Accretion | | EA Coastal Trends Analysis (2007) |

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system.

| | | | | |
|---|---|---|---|---|
| **Material** | Coarse-grained sand and gravel (outer sand flats, barrier beaches and sand dunes).<br>Fine-grained silt and clay (inner saltmarshes and associated mudflats). | | | |
| **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine).<br>Supply from Scolt Head Island. | Internal | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

Sediment

| **Movement:** A westward sediment transport pathway develops along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals in this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from Burnham Flats being transported. This | **Location** | **Net drift ($m^3$/yr x 1000)** | **Source** |
|---|---|---|---|
| | Golf course (577050E 345150N) | 0 | Observation by HR Wallingford |
| | | | |

[7] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| Frontage C – Titchwell and Brancaster | | Chainage 8.2km | | 13.9km |
|---|---|---|---|---|
| **Section 2 – Baseline information (current data relevant to the frontage)** | | | | |
| | leads to changes in normal sediment pathways and delivery and moves signficant amounts of sediment during single events (HR Wallingford 2002). | | | |

| Frontage C – Titchwell and Brancaster | Chainage 8.2km 13.9km |
|---|---|
| **Section 3 - Geomorphology** | |
| Process description: Overall description of current processes: sources, transport and sinks | Brancaster bay has spit-like features at either end (Brancaster Staithe and Thornham), possibly indicating a divergence of transport paths along the beach. The shape of the beach is mirrored in the offshore contours which suggests the control is probably wave refraction (coupled with the wave shadow effect of Scolt Head Island). As a result, the large-scale process occurring along this frontage is sediment being carried onto the frontage and focused over a large area along the Titchwell and golf club frontages. Sediment is then transported towards the east and particularly to the west where it is deposited in the sediment sink close to the tidal delta. In this area local sediment convergence and circulation occurs to form offshore bars. There are also large-scale, but more local, interactions to the east of the frontage near the distal end of Scolt Head Island. Here, the frequent re-shaping of the distal end acts to shelter small sections of the frontage from wave attack and allows this small area to form a promontory in the natural line of the coast. This natural promontory is likely to change position in line with the position of the distal end.<br>There are are a couple of significant offshore features along this frontage, namely the Norfolk Banks and the Burnham Flats, consisting of sand.<br>There is a significant amount of reclaimed marsh along this frontage (around 54 hectares). These are lower than the natural saltmarshes and are therefore vulnerable to flooding and ponding. |
| Patterns of change | **Past development:**<br>Historically there has been a build-up of material at either end of Brancaster bay in the form of spits. The bay is therefore still adjusting to the wave refraction pattern. There has been retreat of the shoreline in the area where there is no protection and the golf clubhouse has formed a small promontory. This is therefore likely to be the rough location of the drift divide. The dunes on Brancaster beach have experienced episodes of both advance and retreat over recent timescales (Futurecoast 2002). The natural saltmarshes have accreted vertically in pace with sea level rise since the mid-Holocene.<br>The breaching of the Titchwell flood embankment in 1949 shows an interesting example of restoration of such areas. The areas inundated were colonised with saltmarsh vegetation, although the density of the vegetation cover was less than other saltmarshes along the north Norfolk coast. The development of a small tidal delta, and |

## Frontage C – Titchwell and Brancaster        Chainage 8.2km    13.9km

the emergence of a stable tidal entrance to the marsh, are also important as examples of the potential restoration process.

**Recent trends:**
Some World War two tank trap defence structures are now exposed on the seaward face of the dunes on Brancaster beach, but were originally installed seaward of the dunes. This implies post-war dune growth, followed by erosion (Futurecoast 2002). This dune erosion appears to have been balanced by foreshore accretion (CHaMP 2003).

**Future evolution (unconstrained):**
In an unconstrained scenario, natural rollback of the entire system would continue. This rollback would occur at greater rates around the tidal delta (in the centre of the cell), causing the shoreline to move further seaward at both the western and eastern frontages and gradually retreating landwards towards the centre. Under an unconstrained scenario the current promontory at the golf club would experience rapid erosion as the shoreline adjusts back to the natural line. The dunes parallel to the barriers on the open coast are likely to disappear, to be replaced by some overwash fans moving residual beach sediment over the marshes. They may provide the foundation for new dunes, depending on the availablility of new sediment. It is unlikely, however, that any new formations would be large enough to act as a major natural coastal defence in the future. The natural saltmarshes are well supplied with fine-grained sediment, enabling them to accrete vertically as sea levels continue to rise. However, the reclaimed marshes are lower than the natural marsh and would be particularly prone to flooding, leading to the creation of coastal dunes if ponding of water occurred. (Futurecoast 2002).

| Dependency: Factors affecting the evolution of the frontage both | Control and sensitivities | Control features | Significance | Dependence | Chainage |
|---|---|---|---|---|---|
| | Wave refraction and the wave shadow effect caused by Scolt Head Island. | Influence of the tidal delta | Secondary | Transient | |
| | Sea level rise.<br>Position of the sediment divide. | Position of distal end of Scolt Head Island | Primary | Transient | |
| | **Internal interaction** | **External Interaction** | | | |

| Frontage C – Titchwell and Brancaster | | Chainage 8.2km 13.9km |
|---|---|---|
| internally and externally | Sediment supply from the centre of the unit, feeding towards the western and eastern limits of the frontage.<br><br>**Sea level / climate change**<br>For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report. | Position of Scolt Head Island affects the amount of wave refraction and so the angle at which the waves approach this frontage. |
| Influence: Factors that may influence evolution of other areas | No influences on other areas identified. | |

## Section 4 – Baseline management scenarios[8,9]

**No active intervention (NAI)**

**Scenario description**

This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.

**Shoreline response**

In epoch 1, sedimentation would continue behind Scolt Head Island, as discussed in the NAI scenario for frontage D. This would cause a reduction in the influence of the tidal delta of Brancaster harbour channel and would therefore reduce the amount of sediment pulsing to the distal end of Scolt Head Island. As a result, the interactions between the distal end of the island and eastern edge of the golf course in the lee of the distal end would remain similar to that seen recently. As a result, there would continue to be a small promontory at this location that would move around locally in line with the movements of the distal end. Most of the defences along this frontage are likely to have failed by the end of epoch 1 under a scenario of NAI, but until this failure is likely to behave the same. This would result in continued rollback of the dune system, but accretion across the foreshore areas. The current promontory around the golf clubhouse would remain.

By the end of epoch 2 all the defences are likely to have failed. This would allow the frontage to regain its natural position. The predicted increased rate of sea level rise would allow more water to enter behind the golf course through Mow Creek. Sedimentation across the saltmarsh should keep pace with the rising sea level and there would therefore be continued vertical accretion. The former brackish areas of the nature reserve would gradually develop into saltmarsh due to frequent inundation. There would be some local changes around the small

[8] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, within this assessment of baseline scenarios, it was not considered relevant to quantify these effects due to the uncertainty surrounding this issue.

[9] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

promontory that has developed in the lee of Scolt Head Island's distal end, but these changes would be relatively small-scale and should not affect the general functioning of the frontage.

In epoch 3, the whole system would continue to roll back, squeezing the saltmarsh area and causing an overall reduction in the total area of saltmarsh. As larger volumes of water enter behind the dune line through Mow Creek and the other drainage channels, the dunes could initially become detached from the mainland and would then either cease to exist or move onshore and merge with the existing saltmarsh. There would be some inundation of the whole saltmarsh area right back to higher ground. However, this is not likely to cause flooding to a large number of properties.

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences remain, but towards the end of the epoch there is likely to be increased defence failure. | Rollback of dune system and accretion across foreshore. | By the end of this epoch, all defences would have failed. | Frontage would realign to natural position. Increased tidal prism behind golf course. Titchwell nature reserve would develop into saltmarsh. | No defences would remain. | Continued rollback of system and squeeze of saltmarsh. Some inundation of saltmarsh area back to higher ground. |

With present management (WPM)

**Scenario description**

This scenario assumes that defences are maintained to provide a similar level of protection to that provided at present. This will involve regularly inspecting and maintaining defences. It is assumed under this scenario that the defence at the golf course is maintained and that planned realignment in front of Titchwell RSPB reserve happens.

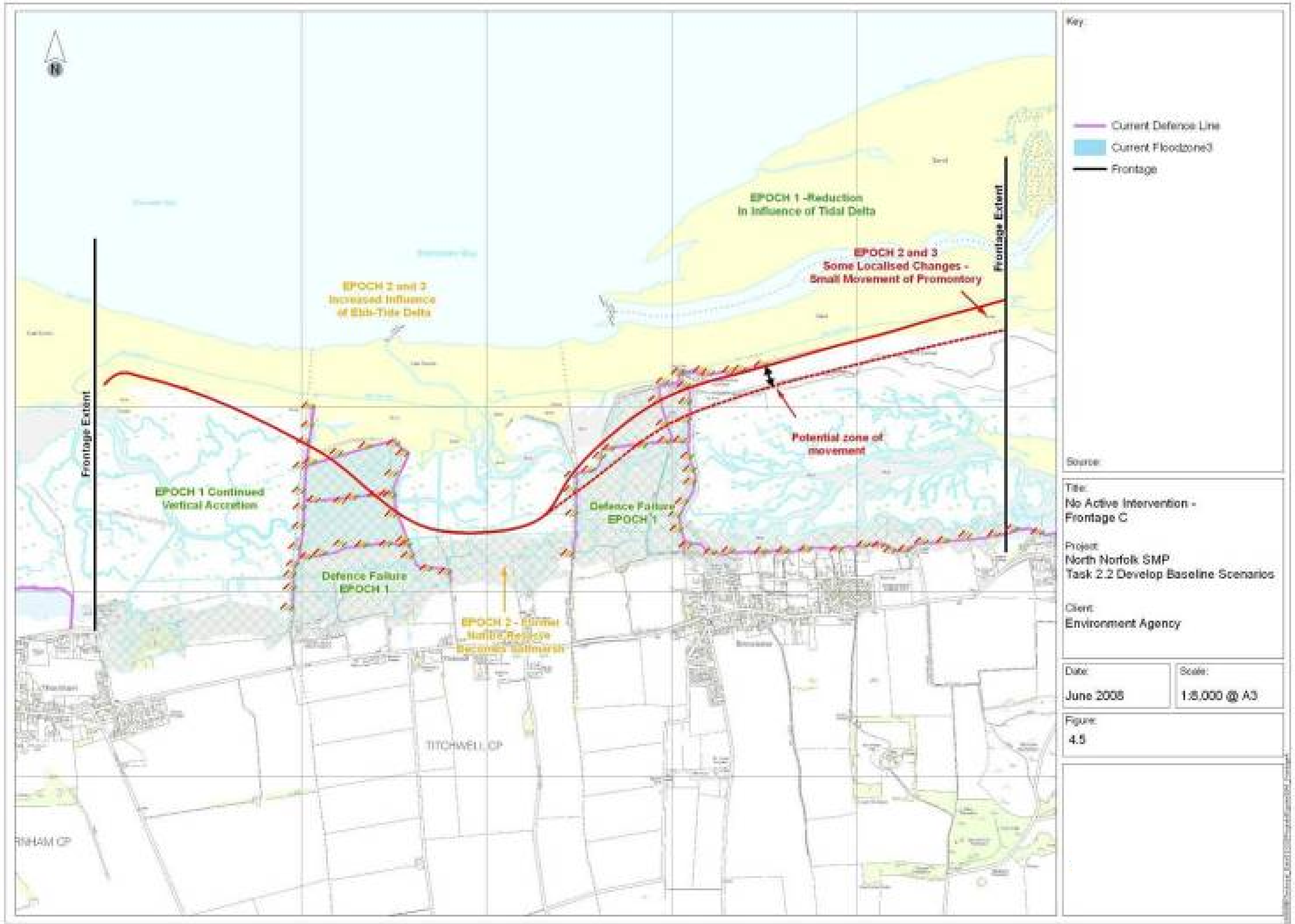
**Shoreline response**

In epoch 1 there are likely to be the same developments as under the NAI scenario. Sedimentation would continue behind Scolt Head Island, as discussed in the WPM scenario for frontage D. This would cause a reduction in the influence of the tidal delta of Brancaster harbour channel and would therefore reduce the degree of sediment pulsing to the distal end of Scolt Head Island. As a result, the interactions between the distal end of the island and eastern edge of the golf course in the lee of the distal end should remain similar to that seen recently. There would continue to be a small promontory at this location that would move around locally with the movements of the distal end. The sedimentation behind Scolt Head Island should also provide increased protection to the frontage to the east of the golf clubhouse. The current promontory around the golf clubhouse would remain and the defences here would continue to provide the required standard of protection. There would also be continued natural rollback of the dunes but accretion across the foreshore.

Into epoch 2, some of the defences would come under increased pressure. The current line of geotextile bags that protects the western edge of the golf links is likely to need extending in an easterly direction to protect the golf course from inundation during storm events or high tides. It is likely that, during this epoch, the rock revetment protecting the golf clubhouse would provide the required standard of protection.

By epoch 3, all the defences protecting the golf course would need to be strengthened. The eastern corner of the Titchwell reserve (where the north wall meets the east wall) would become a ‘pressure point’, as would the area around the golf clubhouse. As a result, they would suffer increased erosion and need greater protection. Elsewhere along the frontage, there would be continued rollback of the dune system, but accretion of the foreshore with erosion focused towards the middle of the frontage. Due to the predicted rate of sea level rise the natural dunes are likely to experience more frequent overtopping. There is therefore the potential for them to become swamped and no longer exist. The natural areas of this frontage would therefore have sand/mudflat at the seaward edge and saltmarsh at the landward edge.

| | Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|---|
| | **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| | Defences would remain. | Rollback of dune system and accretion across foreshore. | Defences would remain. Need to extend geotextile bags towards the east. | Certain areas of the current defences would come under increased pressure as other sections of the coast continue to roll back and realign. | Defences would remain, but need for increased protection along the eastern corner of the Titchwell reserve and around the golf clubhouse. | Two 'pressure points' develop as they become misaligned with the natural coastline. Potential for loss of sand dunes. |



Key:
Current Defence Line
Current Floodzone3
Frontage
Source:
Title:
No Active Intervention -
Frontage C
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:8,000 @ A3
Figure:
4.5
Frontage Extent
Frontage Extent
EPOCH 1 -Reduction
in Influence of Tidal Delta
EPOCH 2 and 3
Some Localised Changes -
Small Movement of Promontory
EPOCH 2 and 3
Increased Influence
of Ebb-Tide Delta
Potential zone of
movement
EPOCH 1 Continued
Vertical Accretion
Defence Failure
EPOCH 1
Defence Failure
EPOCH 1
EPOCH 2 - Former
Nature Reserve
Becomes Saltmarsh
TITCHWELL CP
RNHAM CP

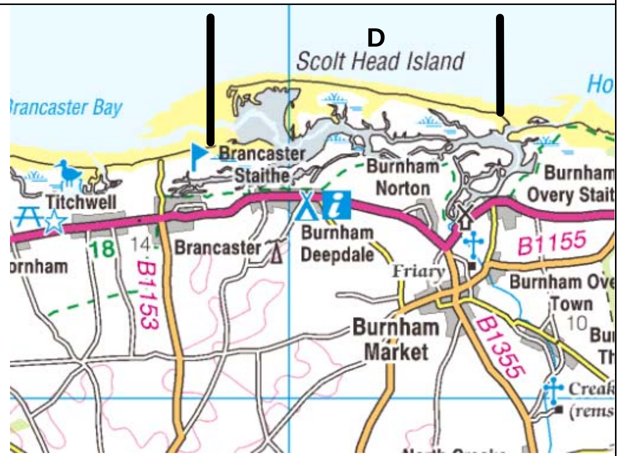
EPOCH 1,2 + 3 - Rollback of Dune System (0.33m/yr)
EPOCH 3
Need to Strengthen Pressure Point
EPOCH 3
Increased Protection Around Club House
Potential zone of movement
EPOCH 2 - Need for Increased Protection
Frontage Extent
Frontage Extent
TITCHWELL CP
Key:
Current Defence Line
Current Floodzone3
Frontage
Source:
Title:
With Present Management - Frontage C
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:17,500 @ A3
Figure:
4.6

### F3.6.4 Frontage D – Scolt Head Island

**Frontage D – Scolt Head Island** **Chainage 13.9km 23.4km**

Western extent of Brancaster to Norton Hills.

**Section 1 – Description**

| | |
|---|---|
| General | This frontage, encompassing Scolt Head Island, contains the almost-combined villages of Brancaster Staithe and Burnham Deepdale, located on the A149. It also includes Burnham Norton, located just north of the coast road to the east of Brancaster Staithe and Burnham Deepdale. Scolt Head Island is a National Nature Reserve. |
| Physical | Scolt Head Island is about 6.5 kilometres long and is irregular in shape. It consists of a main shingle beach with dunes running parallel to the incident wave crests. The island is separated from the mainland by Norton Creek which runs through extensive marsh areas. Both the western and eastern ends of Scolt Head are marked by tidal deltas: to the west the tidal delta is formed by the combined tidal discharge from Norton Creek and Brancaster marsh. To the east it is formed by the discharge from the Burnham harbour channel.  <br><br>Near Burnham Norton there is a section of reclaimed marsh that extends into the Scolt Head Island National Nature Reserve. This is separated from the natural marsh by a well-vegetated earth flood bank.<br><br>The River Burn discharges onto the saltmarsh to the east of Burnham Norton through a tidal outfall. |
| Defences and man- | There are currently no coastal defences on Scolt Head Island. A well-vegetated earth flood bank runs along the whole of this frontage at the seaward edge of the saltmarsh. Between Burnham Deepdale and Burnham Norton it pushes further seaward reflecting reclamation of a former area of saltmarsh. The outfall of the River Burn is also managed by a tidal sluice between Burnham Norton and Burnham Overy Staithe. |

| Frontage D – Scolt Head Island | Chainage 13.9km 23.4km |
|---|---|
| made features | |

**Frontage D – Scolt Head Island** **Chainage 13.9km 23.4km**

## Section 2 – Baseline information (current data relevant to the frontage)

**Tide and water levels (mODN)**

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Burnham Overy Staithe** | | | | | 1.50 | 2.90 | | | | |

**Extremes (mODN)**

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Burnham Overy Staithe** | Royal Haskoning 2007 | 3.96 | 4.52 | 4.75 | 4.92 | 5.09 | 5.26 | 5.48 | 5.65 |

Notes:

**Currents**

| | **Notes** |
|---|---|
| Av. flood<br>Av. ebb<br>Net residual | Current data deduced from tidal diamond L on Admiralty chart no. 108 – note significantly offshore. The flow pattern over much of the rising tide is relatively weak over mid-tide and towards the west, increasing to a strong flow towards the east over high water. On the ebb, the flow is towards the east, reversing to a strong flow towards the west at low water, flowing into the ebb tide from the Wash. |

The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (from north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Fututrecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988).

Notes: It is generally accepted that the barrier island of Scolt Head is moving towards the west and is also rolling back.

**Wave**

| **Frontage D – Scolt Head Island** | **Chainage** | **13.9km** | **23.4km** |
|---|---|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

| | **Average rates ($myr^{-1}$ unless stated)**[10] | Cliff/backshore feature | | | | | Intertidal | | | Nearshore | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| climate: | Location | general | crest | face | toe | backshore | general | MHWS | MLWS | Trend | Source |
| Accretion/ erosion: | Scolt ridge | | | | | | -1.00 | | | Landward migration | North Norfolk CHaMP (2003) |
| | Scolt ridge (western end) | | | | | | 3.50 | | | Westward migration | North Norfolk CHaMP (2003) |
| | Average of EA profiles N1B1 to N1B6A | | | | | | **-0.67** | -0.06 | -1.39 | Landward migration | EA Coastal Trends Analysis (2007) |
| | Western end of Scolt ridge (EA profile N1B1) | | | | | | -0.04 | **3.57** | -1.97 | Westward migration | EA Coastal Trends Analysis (2007) |
| | Scolt saltmarshes | **4.86 $mmyr^{-1}$** | | | | | | | | Vertical accretion | Andrews et al (1999) |
| | **Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system. | | | | | | | | | | |

| | | | | |
|---|---|---|---|---|
| **Material** | Sand dominates the outer beach of Scolt Head Island.<br>Gravel concentrated at Far Point and on the quite regularly spaced laterals. | | | |
| **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal | Erosion of Scolt Head island.<br>Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| **Frontage D – Scolt Head Island** | | **Chainage** | **13.9km** | **23.4km** | |
|---|---|---|---|---|---|
| **Section 2 – Baseline information (current data relevant to the frontage)** | | | | | |
| Sediment | **Movement:** There is a westward sediment transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals of this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to changes in normal sediment pathways and delivery and moving of signficant amounts of sediment during single events (HR Wallingford 2002). | **Location** | **Net drift ($m^3$/yr x 1000)** | | **Source** |
| | | Scolt Head Island (584500E 346700N) | 190 (westward) | | Vincent (1977) |
| | | | | | |

[10] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| Frontage D – Scolt Head Island | Chainage 13.9km 23.4km |
|---|---|

## Section 3 - Geomorphology

| | |
|---|---|
| Process description: Overall description of current processes: sources, transport and sinks | Scolt Head Island grows by the development of the lateral ridges, with each new ridge lengthening the island towards the west. The formation of the lateral ridges is very similar to the formation of the recurves of Blakeney Point - wave action from the north west, combined with a pulsing of sediment from the west. When a new lateral ridge forms, it starves the sheltered ridge of sediment and the feature becomes essentially relict (no longer interacts with coastal processes). The area between the ridges has been filled with saltmarsh with younger, lower marshes to the west. Norton Creek separates the island from the natural and reclaimed saltmarsh that extends up to the relict cliff line. Norton Creek empties entirely at low tide.<br><br>Alternatively, it has been suggested that the Burnham harbour channel can be thought of as a storm breach in a continuous ridge stretching from Holkham to Brancaster Staithe. In this theory, tidal scouring keeps the channel open and the sheltered, tidally-dominated waters allowed the Great Aster Marsh to develop. However, it is now thought that, if a breach did occur, it was probably at an early stage in development before mud was deposited and the saltmarsh vegetation established.<br><br>There are a couple of significant offshore features along this frontage, namely the Norfolk Banks and the Burnham Flats, consisting of sand. There are about 121 hectares of reclaimed marshes near Burnham Norton. |
| Patterns of change | **Past development:**<br>Scolt Head Island seems to be moving south and extending west (Andrews et al 2000; Bridges 1989). It appears that the eastern end has moved south faster than the western end (Bridges 1989). The shingle needed to extend the spit westward originated from the central section of the coastline and it was potentially being supplied to some degree from the offshore area. This movement of the spit seems to suggest that Scolt Head Island is realigning itself to face the incident wave direction from the north east. The development of the island has provided shelter for the saltmarsh to grow in the back-barrier area. This now acts as a sink for fine sediment, as it is transported into the harbour, up into Mow Creek (inland of the golf course) and into Norton Creek, which is now very shallow in places (Futurecoast 2002). As the barrier island continues to grow west, the width of the Brancaster harbour inlet |

has been reduced.
The dunes along Scolt Head Island are also experiencing erosion as the barriers roll towards land. These dunes are not fully reforming by rollover processes and instead are progressively narrowing as the barriers move towards land (CHaMP 2003).

**Recent trends:**

Current trends would appear to be similar to those described in the above section (past development).

**Future evolution (unconstrained):**

The formation of the lateral recurves may become frequent and they may reduce in size as the pulsed nature of the bar feed from the west decreases in period and volume due to the reducing size of the inlet. Under the unconstrained scenario, the reclaimed area behind Scolt Head Island would be opened, increasing the tidal prism of the Brancaster channel and potentially increasing flow to the east. This increased prism would, to a degree, balance the current siltation of the Brancaster channel, tending to force Scolt Head Island to develop further to the east.

| Dependency: Factors affecting the evolution of the frontage both internally and externally | **Control and sensitivities** | **Control features** | **Significance** | **Dependence** | **Chainage** |
|---|---|---|---|---|---|
| | The main constraint to the development of Scolt Head Island is the location of the Brancaster and Burnham harbour channels. | Scolt Head barrier | Primary | Long term development | |
| | | Brancaster channel | Primary | Variable | |
| | | Burnham harbour channel | Secondary | Variable | |
| | | | | | |
| | **Internal interaction** | **External interaction** | | | |
| | The supply of sediment from the front face of Scolt Head Island feeds east and west conflicting with the development of the channels.<br>The tidal prism of both channels influences the development of the eastern and western ends of Scolt Head | The supply of sediment from the nearshore area. | | | |

| Frontage D – Scolt Head Island | | Chainage 13.9km 23.4km |
|---|---|---|
| | | |
| | Island. | |
| | **Sea level / climate change** | |
| | For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report . | |
| Influence: Factors that may influence evolution of other areas | Scolt Head Island, particularly at its western end, influences the Titchwell frontage (frontage C). It supplies this frontage with sediment and influences the behaviour of Brancaster harbour channel. This in turn acts to shelter the frontage and modified wave action influences the frontage. | |

**Frontage D – Scolt Head Island** **Chainage: 13.9km 23.4km**

## Section 4 – Baseline management scenarios[11,12]

No active intervention (NAI)

**Scenario description**

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences'.

**Shoreline response**

In epoch 1, earth embankments at the landward edge of the saltmarsh should remain intact. As a result, the processes occurring would be similar to those seen today: movement of Scolt Head Island towards the west and south (rates of 3.57 and 0.67 metres a year respectively), retreat towards land of the eastern edge of the island and sedimentation behind the barrier island (with associated siltation of Norton Creek). Towards the end of epoch 1, there could be more frequent overtopping of the central part of the island near the 1953 and 1978 storm surge breakthroughs. This would cause sand and gravel to be washed onto the low marshes and flats behind the barrier island. The back-barrier marshes would continue to accrete vertically at rates similar to those noted recently (4.86 millimetres a year). The sustained movement of the barrier island towards land and to the west would continue to squeeze the back-barrier areas due to the long-term under-supply of coarse-grained sediment to the barrier island. This would cause changes in the configuration of the two tidal inlets and ebb-tidal deltas to the west and east of the barrier. This in turn would affect the sites of erosion and accretion. The back-barrier marshes would continue to accrete vertically at the rates discussed above. The formation of the lateral recurves could become less frequent and they could reduce in size as the pulsed nature of the bar feed from the west reduces in period and volume due to the decreasing size of the inlet.

[11] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, in this assessment of baseline scenarios, it was not considered relevant to quantify these effects due to the uncertainty surrounding this issue.

[12] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

Into epoch 2 there would be a higher likelihood of defence failure. By the end of epoch 2, all the defences would have failed. This would initially increase the tidal prism, which would reinforce the Brancaster harbour and Burnham harbour channels, starting a reversal of the trend discussed above. During this initial inundation of the former reclaimed areas, the saltmarsh is unlikely to experience significant accretion. Also in epoch 2, it is assumed that the outfall of the River Burn would no longer be managed under this scenario. It is therefore likely that it would take a more natural course out across the marshes. This would increase the influence of the Burnham harbour channel and also cause flooding upstream in Burnham Norton and Burnham Market.

By epoch 3, the back-barrier areas are likely to have adjusted to the increase in tidal prism. As a result, there would be accretion in these areas, with saltmarsh becoming re-established.

**NAI scenario summary**

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences remain, but towards the end of the epoch more defences would fail. | Westward and southward movement of Scolt Head Island, with retreat towards land focused at the eastern end. Continued vertical accretion of the back-barrier areas (including saltmarsh). | By the end of this epoch all the defences would have failed. | Large increase in tidal prism behind the barrier island, with associated strengthening of the ebb-tide deltas. Some tidal flooding upstream may occur in Burnham Norton and Burnham Market. | Complete defence failure. | Saltmarsh would re-establish and barrier island re-starts trend of rollback. |

With present management (WPM)

**Scenario description**

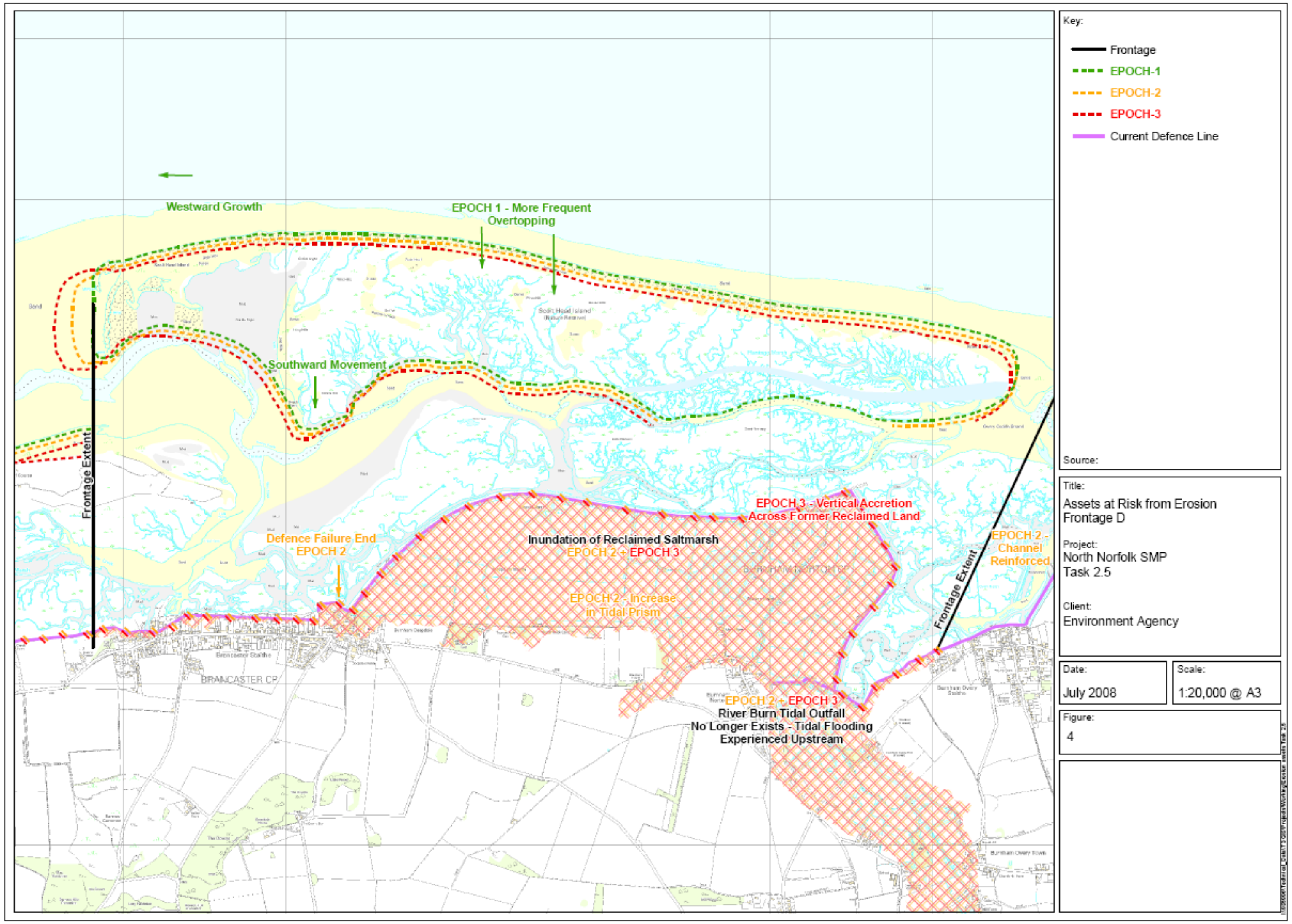
This scenario assumes that the current policy for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

**Shoreline response**

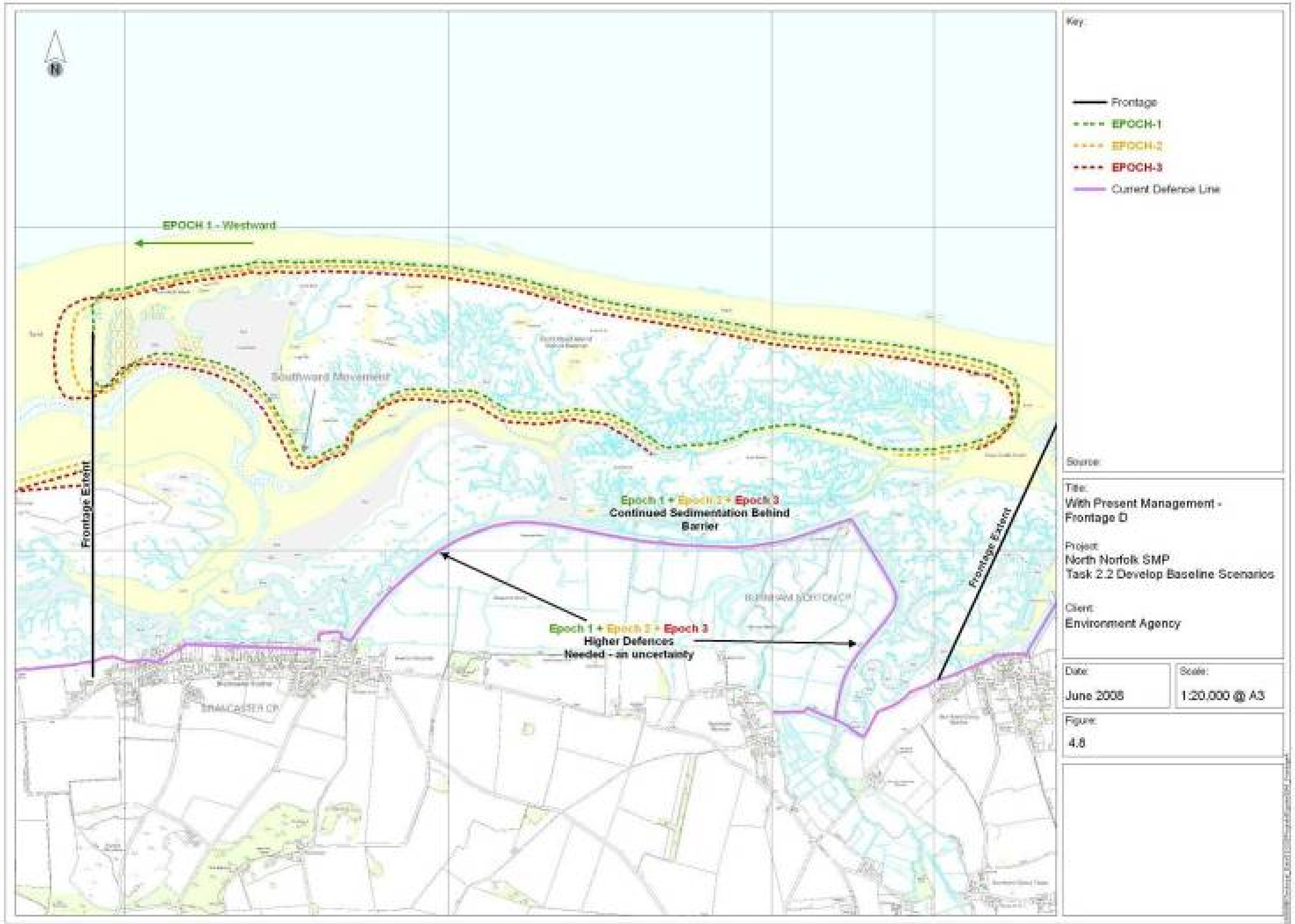
The WPM scenario response would initially be the same as in the unconstrained situation for epoch 1: movement of Scolt Head Island towards the west and south (rates of 3.57 and 0.67 metres a year respectively), retreat towards land of the eastern edge of the island and sedimentation behind the barrier island (with associated siltation of Norton Creek). Towards the end of epoch 1, there is likely to be more frequent overtopping of the central part of the island near the 1953 and 1978 storm surge breakthroughs. This would cause sand and gravel to be washed onto the low marshes and flats behind the barrier island. The back-barrier marshes would continue to accrete vertically at rates similar to those noted recently (4.86 millimetres a year). The continued landward and westward movement of the barrier island would continue to squeeze the back-barrier areas due to the long-term under-supply of coarse-grained sediment to the barrier island. This would cause changes in the configuration of the two tidal inlet and ebb-tidal deltas to the west and east of the barrier and in turn affect the sites of erosion and accretion. The back-barrier marshes would continue to accrete vertically at rates discussed above. The formation of the lateral recurves may become less frequent and they may become smaller as the pulsed nature of the bar feed from the west decreases in period and volume due to the reducing size of the inlet.

As the barrier continues to move towards land, it would also gradually squeeze the back-barrier areas and cause Norton Creek to silt up completely. Into epochs 2 and 3, the pressures from sea level rise would increase erosion and reduce the width of the shingle bank. Overtopping would become more frequent and water has the potential to pond on the reclaimed areas inland of the existing earth embankments. To prevent this, increasingly higher defences would probably be needed or the natural dune line on the seaward edge of Scolt Head Island replaced with hard defences. By the end of epoch 3, it is likely there would not be a detached barrier island. The frontage would effectively become an open coast frontage, with beach at the seaward edge transgressing to saltmarsh, with the landward edge being marked by higher ground. In epoch 3, the costs of maintaining and improving the earth embankments would be substantial.

| | Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|---|
| | **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| | Defences would remain. | Movement of Scolt Head Island towards the west and south, with retreat towards land focused at the eastern end. Continued vertical accretion of the back-barrier areas (including saltmarsh). | Defences would remain. Increasing need for higher defences and/or replacement of natural defences with raised earth embankments. | Squeeze of back-barrier areas due to sea level rise with Norton Creek silting up. More frequent overtopping and ponding on reclaimed marsh unless managed by higher defences. | Defences would remain. Further squeeze of back-barrier areas with ever-increasing need for harder, higher defences. | Escalation of epoch 2. |



Westward Growth
EPOCH 1 - More Frequent Overtopping
Southward Movement
Frontage Extent
Defence Failure End EPOCH 2
Inundation of Reclaimed Saltmarsh
EPOCH 2 + EPOCH 3
EPOCH 3 - Vertical Accretion Across Former Reclaimed Land
EPOCH 2 - Increase in Tidal Prism
EPOCH 2 - Channel Reinforced
EPOCH 2 + EPOCH 3
River Burn Tidal Outfall No Longer Exists - Tidal Flooding Experienced Upstream
BRANCASTER CP
Frontage Extent
Key:
Frontage
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Source:
Title:
Assets at Risk from Erosion
Frontage D
Project:
North Norfolk SMP
Task 2.5
Client:
Environment Agency
Date:
July 2008
Scale:
1:20,000 @ A3
Figure:
4


Key:
Frontage
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
EPOCH 1 - Westward
Southward Movement
Frontage Extent
Epoch 1 + Epoch 2 + Epoch 3
Continued Sedimentation Behind Barrier
Epoch 1 + Epoch 2 + Epoch 3
Higher Defences Needed - an uncertainty
Frontage Extent
Source:
Title:
With Present Management - Frontage D
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:20,000 @ A3
Figure:
4.8

### F3.6.5 Frontage E – Holkham bay

**Frontage E – Holkham bay** **Chainage 23.4km 34.4km**

Norton Hills to Bob Hall's Sands.

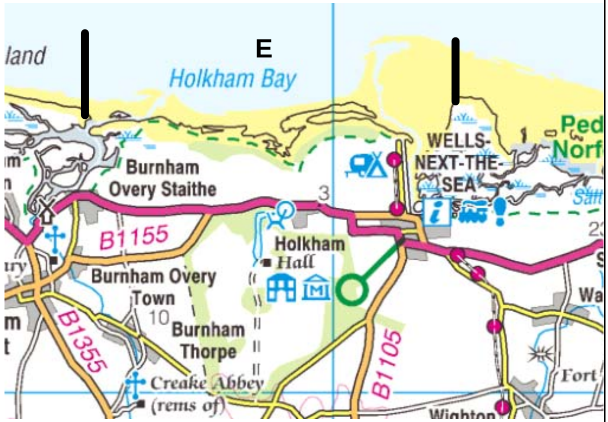
**Section 1 – Description**

**General**

This frontage covers the villages of Burnham Overy Staithe and Wells-next-the-Sea, as well as the small hamlet of Holkham and the beach access point at Holkham Gap. Between Burnham Overy Staithe and Holkham, the Holkham National Nature Reserve is inland of the line of sand dunes.

**Physical**

This frontage is characterised by an extensive area of reclaimed saltmarsh and has an artificial appearance. Reclamation began in 1660 and continued until 1860, by which time 800 hectares of former saltmarsh had been enclosed. This reclaimed area is used for arable production in some places. A line of sand dunes (Holkham Meals/Meols) marks the seaward edge of the reclaimed area. This dune line was planted with conifers along most of its length between 1853 and 1891.




Before it was reclaimed, it has been suggested that this frontage would have resembled that of Scolt Head Island, with the present day Holkham Meals being sand islands or offshore bars.

Lodge marsh (in frontage F) forms the ramparts of the Wells harbour tidal delta, which is the largest of five deltas along the north Norfolk coast. This tidal delta forms the extensive sand waves and sand flats apparent between Lodge marsh and Holkham Gap.

**Defences and man-made features**

Burnham Overy Staithe is protected by both private walls and well-vegetated earth flood banks maintained by the Environment Agency. These defences stop about 900 metres north east of Burnham Overy Staithe and are replaced with the natural dune line (see above). This extends up to Holkham Gap, after which the dune line continues around to the lifeboat station and is fenced off in some places. Behind this dune line there is a well-vegetated clay sea bank ("Old Sea Wall") that runs directly from Holkham Gap to Wells in a south-easterly direction. This now offers secondary protection to Wells and Holkham. A clay/sand bank with a revetment along the seaward face runs directly north to south alongside the miniature railway. Along the quay in Wells there is a low wall with boards that can be inserted to

| Frontage E – Holkham bay | Chainage 23.4km 34.4km |
|---|---|
| complete the defence. | |

**Section 2 – Baseline information (current data relevant to the frontage)**

Tide and water levels (mODN)

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Wells** | | | | | 1.25 | 2.75 | | | | CD is 0.75 metres below OD |

Extremes (mODN)

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Wells** | Royal Haskoning 2007 | 3.87 | 4.47 | 4.70 | 4.88 | 5.06 | 5.24 | 5.48 | 5.66 |

Notes:

Currents

| | | **Notes** |
|---|---|---|
| Av. flood | - | Current data deduced from tidal diamond N on Admiralty chart no. 108.<br>The flow pattern over much of the rising tide is relatively strong over mid-tide and towards the west, changing to a weak flow towards the east over high water. On the ebb, the flow is strong and towards the east, reversing to a weaker flow towards the west at low water, flowing into the ebb tide from the Wash. |
| Av. ebb | - | |
| Net residual | - | |

Wave climate

The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988).

Notes: Environment Agency profiles have shown annual accretion rates of 300,000$m^3$ a year over the past decade. Although the lower intertidal area has been accreting, the upper shore, and particularly the dune face, has been retreating. This is a typical response to climate change.

**Frontage E – Holkham bay** | **Chainage 23.4km 34.4km**

**Section 2 – Baseline information (current data relevant to the frontage)**

| | **Average rates (myr$^{-1}$ unless stated)**[13] | **Cliff/backshore feature** | | | | **Intertidal** | | | | **Nearshore** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Accretion/ erosion | Location | general | crest | face | toe | backshore | general | MHWS | MLWS | Trend | Source |
| | Average of EA profiles N1A1 to N1A6 | | | | | | **-1.05** | **-0.58** | **-0.56** | Erosion | EA Coastal Trends Analysis (2007) |

**Sediment**

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system.

| | | | | |
|---|---|---|---|---|
| **Material** | Coarse-grained sand and gravel (outer sand flats, barrier beaches and sand dunes).<br>Fine-grained silt and clay (inner saltmarshes and associated mudflats). | | | |
| **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| **Movement:** There is a westward sediment transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals in this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to changes in normal sediment pathways | **Location** | **Net drift (m$^3$/yr x 1000)** | **Source** |
|---|---|---|---|
| | | | |

[13] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| Frontage E – Holkham bay | | Chainage 23.4km | 34.4km | |
|---|---|---|---|---|
| **Section 2 – Baseline information (current data relevant to the frontage)** | | | | |
| | and delivery and moving of significant amounts of sediment during single events (HR Wallingford 2002). | | | |

| Frontage E – Holkham bay | Chainage 23.4km 34.4km |
|---|---|
| **Section 3 - Geomorphology** | |
| Process description: Overall description of current processes: sources, transport and sinks | The geomorphology in this frontage is complex. It represents a series of regressive overlap (depositional) features that have built further seaward over the past 6,000 to 7,000 years. This regressive sequence can be seen in the present shape of the coast. A series of beach bars develops on the lower shore face during storm events. These migrate towards land, increasing in height and grain size. Around the high water mark they stabilise and become colonised by pioneer species. This stable ridge can then develop into a sand dune if there is enough sand available, such as north of Holkham Gap (Holkham Meals/Meols) or may persist as low gravel ridges such as those embedded in the Stiffkey saltmarshes. Saltmarsh colonisation occurs in the shelter of the dune or gravel ridges, such as at Holkham Gap where saltmarsh development began in 1985. The inner saltmarsh line is marked by the old cliff line in the form of a gravel bank. As well as 'natural' saltmarsh development, there is also just under 300 hectares of reclaimed marshes at Holkham.<br><br>Offshore of this frontage, there are are a couple of significant features, namely the Norfolk Banks and the Burnham Flats, consisting of sand. These offshore sand banks, as well as the wide surf zone and small sand bars, act to dissipate wave energy along this stretch of coastline.<br><br>To the east of this frontage, there is a tidal delta at Wells-next-the-Sea. To the west of this frontage there is also a tidal delta at Burnham harbour. Both act to cause the longshore pathway of sediment to be pushed seaward and its movement to become intermittent. This leads to the formation of a pronounced lobe in the lower intertidal leading to reduced energy in the upper shore. These conditions therefore promote the growth of sand dunes. |
| Patterns of change | **Past development:**<br>There has been significant accretion near Holkham over the last century. The wave energy in the area seems to be reducing as shown by the deposition of material and by the increasingly fine material silting Wells harbour. This decrease has been caused by the build-up of a bar in front of Holkham, causing vegetation colonising the flats and reducing sediment mobility. Also, reclaiming the saltmarsh and losing the tidal inlet at Holkham has excluded tidal waters from wide areas, significantly reducing the tidal prism and the influence of tidal exchange on shoreline |

evolution (Futurecoast 2002).

**Recent trends:**
As a result of these developments, there has been a trend of accretion along the frontage, with a general seaward progradation of the sand flats. However, recent EA monitoring data have clearly shown that this frontage is no longer accreting but is effectively starting to erode. This trend has been seen throughout both the upper and lower profiles. The colonisation of the front ridge by fir trees constrains the natural ability of the dunes to roll back.

**Future evolution (unconstrained):**
Continued dredging of the Burnham channel will be needed if the present width is to be maintained.
Major changes could occur at Holkham if the marshes behind the defences were opened up. This could mean that sand would move offshore instead of acting as a sink. This could lead to the westward movement of Holkham Meals until no barrier remains, only back-barrier marsh remnants and an offshore remnant of the old ebb-delta, such as is now found at Stiffkey.

Dependency: Factors affecting the evolution of the frontage both internally and externally

| Control and sensitivities | Control features | Significance | Dependence | Chainage |
|---|---|---|---|---|
| This frontage is greatly influenced by the two tidal deltas at the western and eastern edges of the frontage (Burnham harbour channel and Wells harbour channel). These channels effectively contain the reclaimed saltmarsh and dune system between them. An offshore bar controls the development of the cell by providing sheltered conditions. | Offshore bank/bar | Primary | Variable | - |
| | Burham harbour channel | Primary | Variable with tidal prism | - |
| | Wells harbour channel | Primary | Variable with tidal prism | - |

| Internal interaction | External interaction |
|---|---|
| Currently the tidal prism around Holkham is reducing which has caused the effect of tidal exchange on shoreline evolution to reduce. If the marshes were opened up, sand may move offshore instead of | Following the previously reclaimed marshes being opened up under an unconstrained scenario, there would be changes in the Burnham harbour channel. This has the potential to influence the position of the channel behind |

| Frontage E – Holkham bay | | Chainage 23.4km 34.4km |
|---|---|---|
| | | |
| | acting as a sink. This would effectively build up the offshore bank. | Scolt Head Island and so the location of its eastern end. |
| | **Sea level / climate change** | |
| | For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report. | |
| Influence: Factors that may influence evolution of other areas. | Changes in the tidal prisms of the Burnham or Wells harbour channels will influence neighbouring frontages. | |

## Section 4 – Baseline management scenarios[14,15]

| | |
|---|---|
| No active intervention (NAI) | **Scenario description**<br>This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.<br>**Shoreline response**<br>In epoch 1 there would be a sustained supply of sediment to this frontage. However, it would continue to react to rising sea levels by exhibiting erosion along the entire profile. As a result, both the lower and upper beach profiles would show signs of erosion at rates similar to those experienced recently (a general retreat of 1.05 metres a year). There is unlikely to be any significant beach steepening due to the wide foreshore. Throughout this epoch the dunes would remain anchored in position because of the fir trees that currently follow the line of the sand dunes. There are a number of defences that would fail in epoch 1, potentially causing some inundation onto the reclaimed saltmarsh during high tide events.<br><br>Into epochs 2 and 3, when most of the defences towards the west and east of the frontage would have failed and the marshes opened up, there could be major changes. Initially, Holkham Meals/Meols would become a detached barrier island as tidal exchange occurs behind the line of stabilised dunes. The Burnham channel would no longer be constrained and would therefore take a more natural meandering course out to sea. This would cause the tidal delta to move gradually towards the west. Opening up the marshes behind the dunes would also substantially increase the tidal prism acting on the Wells and Burnham harbour channels. As a result, the influence of the tidal delta would increase. This would provide increased wave protection to Holkham Meals/Meols sand dunes, located |

[14] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, in this assessment of baseline scenarios, it was not considered relevant to quantify these effects due to the uncertainty surrounding this issue.
[15] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

between the two deltas. As a result, the sand dunes are likely to remain and would experience limited rollback.

| Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Failure of defences to the west of frontage. Defences near Wells would remain. | Erosion of entire profile, but little beach steepening. Some inundation of the reclaimed marshes. | Total defence failure. | Reclaimed marshes would be opened up. Detached barrier island would form. Wells harbour channel changes course, moving tidal delta westwards. Tidal deltas of Wells and Burnham harbour channels increase, protecting sand dunes. | No defences would remain. | Potential for Holkham Meals/ Meols to disappear. Some sedimentation behind the old dune line with associated saltmarsh formation. |

With present management (WPM)

**Scenario description**
This scenario assumes that the current policy for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

**Shoreline response**
During epoch 1 under the WPM scenario, the reclaimed saltmarsh would remain protected by the earth embankments and the geomorphological functioning of the frontage would remain the same. The dune line (Holkham Meals/Meols) would also remain where it is now, anchored in place by the line of fir trees. There would be continued seaward movement of the offshore bars and erosion of the entire beach profile.

During epoch 2, when sea level rise accelerates significantly, there would be much more pressure on the frontage. As a result, there would need to be increasingly hard defences along the dune line to prevent natural rollback and the earth embankments would probably need to be improved. If the standard of protection provided by the man-made and natural defences was not increased, there would be a greater likelihood of overtopping of the defences and therefore ponding on the reclaimed saltmarsh. This would lead to a need for more regular maintenance of the defences to repair and re-seal damage caused during high tide/extreme events. Seaward of the hard earth embankments, coastal squeeze would occur between rising sea levels and the fixed defence line, resulting in an overall loss of saltmarsh area. There is also the possibility that Wells harbour channel would need some works to maintain navigability.

The same shoreline responses would also be seen throughout epoch 3. During epoch 3, the cost of maintaining the existing defences and providing harder defences in place of the natural dune line is likely to be significant.

| **Years 0 to 20 (2025)** | | **Years 20 to 50 (2055)** | | **Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences would remain. | Similar geomorphological functioning to that of the NAI scenario. Erosion of entire beach profile, with seaward movement of offshore bars. | Defences would remain. Increasing need for hard defences in place of natural sand dunes and a higher standard of protection provided by the existing earth embankments. | Significant pressure on frontage from sea level rise. Need for hard defences instead of natural sand dunes and higher defences where there are now earth embankments. Coastal squeeze in front of earth embankments. Maintenance needed to sustain navigability of Wells harbour channel. | Defences would remain, but maintenance and cost of building new defences would be significant. | Same as epoch 2. |

Key:
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Frontage
Current Floodzone3
Source:
Title:
No Active Intervention -
Frontage E
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:30,000 @ A3
Figure:
4.9
EPOCH 2 - Increased Influence of Tidal Delta
EPOCH 2 - Tidal Delta Moves Westwards and has an Increased Influence
EPOCH 2 - Wells Harbour Channel Changes Course
Holkham Bay
EPOCH 3 - Dune Line Disappears
Frontage Extent
Defence Failure End EPOCH 1
More Regular Inundation of Marsh EPOCH 2 - EPOCH 3
Saltmarsh Will Begin to Develop
EPOCH 2 - Increased Protection of Dune from Tidal Delta
EPOCH 1 - Some Inundation
Defence Failure EPOCH 2
Burnham Channel Begins to Silt Up
Frontage Extent
WELLS-NEXT-THE-SEA


Key:
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Frontage
Source:
Title:
With Present Management - Frontage E
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:30,000 @ A3
Figure:
4.10
Frontage Extent
Epoch 2 + Epoch 3
Need for Higher Defences
Epoch 2 + Epoch 3
Need for Higher Defences
Frontage Extent
WELLS-NEXT-THE-SEA
BURNHAM OVERY CP
HOLKHAM CP

### F3.6.6 Frontage F – Stiffkey and Warham marshes

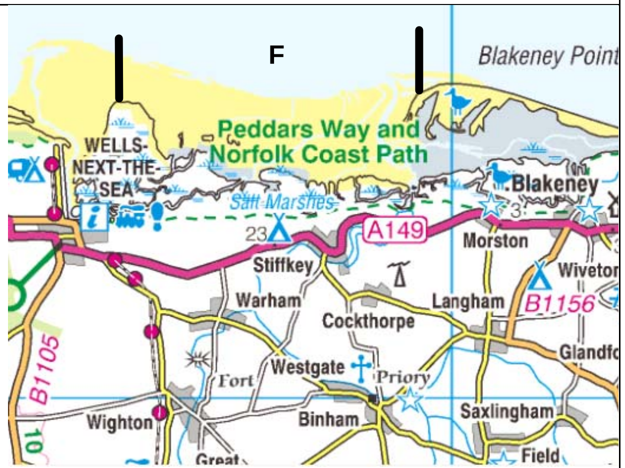
**Frontage F – Stiffkey (and Warham) marshes** | **Chainage** | **34.4km** | **42.3km**

Bob Hall's Sands to western end of Blakeney Spit.

**Section 1 – Description**

**General** This frontage covers the village of Stiffkey and includes a continuation of the Holkham National Nature Reserve. The frontage is characterised by an extensive saltmarsh/sand dune system with over one kilometre of foreshore being exposed at low water.

**Physical** This frontage is a typical open coast dominated by a large dissipative sand beach that transgresses naturally into saltmarsh and then into higher ground behind. The marshes (Stiffkey and Warham) make up one of the most extensive and important intertidal marsh areas in the country. One of the most important attributes is that they merge with the rising ground along the Stiffkey and Warham Greens forming a transitional habitat that, elsewhere, has been lost to reclamation. The marshes are generally protected from severe wave action by the large beach, which has a shallow slope.




At the western end of the frontage Lodge marsh, formerly reclaimed, has now largely been restored to saltmarsh.

The shape of the eastern end of this frontage is dominated by the River Stiffkey outfall. This protects Stiffkey and the surrounding areas from tidal flooding during extreme events. Once the river has flowed out onto the saltmarsh it joins the River Glaven in the Blakeney harbour channels and flows out to sea around the distal end of the spit. There is therefore a clear and important interaction between this frontage and frontage G.

**Defences and man-** As discussed above, a large dissipative sand beach and established saltmarsh provides natural coastal protection along this frontage. The only man-made coastal defence is a short section of well-vegetated earth flood bank (just over 300 metres long) at the outfall of the River Stiffkey. There is also the short section of embankment to the east of Wells-next-the Sea, known as Wells east bank, that protects a significant area of arable land and about 60 properties.

| Frontage F – Stiffkey (and Warham) marshes | Chainage 34.4km | 42.3km |
|---|---|---|
| made features | | |

**Frontage F – Stiffkey (and Warham) marshes** **Chainage 34.4km 42.3km**

**Section 2 – Baseline information (current data relevant to the frontage)**

| | | | Notes |
|---|---|---|---|
| Currents | Av. flood | West | Current data deduced from tidal diamond N on Admiralty chart no. 108. |
| | Av. ebb | East | The flow pattern over much of the rising tide is relatively strong over mid-tide and towards the west, changing to a weak flow towards the east over high water. On the ebb, the flow is strong and towards the east, reversing to a weaker flow towards the west at low water, flowing into the ebb tide from the Wash. |
| | Net residual | North | |
| Wave climate | Relatively low wave energy has been noted in this unit. The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988). | | |
| Accretion/ erosion | Notes: Between 1992 and 2000 there was accretion in the upper shore (higher saltmarshes) and also significant erosion of the lower intertidal (sand flats) which appears to be in response to sea level rise (Environment Agency). Between Holme and Blakeney, Futurecoast (Halcrow 2002) notes that the coastline is typically accreting. | | |

**Frontage F – Stiffkey (and Warham) marshes** **Chainage 34.4km 42.3km**

**Section 2 – Baseline information (current data relevant to the frontage)**

| | **Average rates ($myr^{-1}$ unless stated)**[16] | Cliff/backshore feature | | | | Intertidal | | | | Nearshore | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | general | crest | face | toe | back shore | general | MHWS | MLWN/S | Trend | |
| | Average of EA profiles N2D1 to N2D6 | | | | | | **0.43** | **0.06** | **-2.87** | Erosion of lower sand flats, accretion on upper saltmarsh | EA Coastal Trends Analysis (2007) |
| Sediment | Stiffkey saltmarshes | **4.03 $mmyr^{-1}$** | | | | | | | | Vertical accretion | Andrews et al (1999) |

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system.

| | | | | |
|---|---|---|---|---|
| **Material** | Coarse-grained sand and gravel (outer sand flats, barrier beaches and sand dunes).<br>Fine-grained silt and clay (inner saltmarshes and associated mudflats). | | | |
| **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| **Movement:** There is a westward sediment | **Location** | **Net drift ($m^3/yr$ x** | **Source** |
|---|---|---|---|

[16] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

| | | | | |
|---|---|---|---|---|
| | transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals of this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to changes in normal sediment pathways and delivery and moves significant amounts of sediment during single events (HR Wallingford 2002). | | **1000)** | |
| | | Stiffkey (597000E 346400N) | 290 (westward) | Vincent (1979) |

| **Frontage F – Stiffkey (and Warham) marshes** | **Chainage 34.4km 42.3km** |
|---|---|

**Section 3 - Geomorphology**

| | |
|---|---|
| Process description: Overall description of current processes: sources, transport and sinks | A large dissipative sand beach protects Stiffkey marshes by effectively dissipating wave energy along this frontage. This means that the waves break and lose energy over a wide surf zone. The beach has a wide and shallow slope, with multiple bars that further dissipate energy by 'tripping' waves. Around the low water mark there are a series of low bars of irregular shape that are relatively stable and are destroyed in extreme events. Stiffkey Meals (or Meols), located further inshore, are a more developed form of offshore bar and separate the beach from the older and more mature marshes of Stiffkey. The saltmarshes are drained by a number of permanent channels that cross the outer sand flats (for example, Cabbage Creek). The inland limit of the marshes is generally marked by a relict cliff line (or raised beach deposit) in the form of a gravel bank running between Cley and Hunstanton. The headland of Wells harbour (Lodge marsh, western edge of frontage), is a complex feature of shingle and sand ridges topped by dunes. This is a normal offshore bar that has been 'bent' due to littoral drift in both south east and south west directions. |
| Patterns of change | **Past development:**<br>The outer marshes at Stiffkey have undergone episodes of advance in the 1950s and 1960s, but erosion and retreat since the 1970s as a result of sea level rise.<br><br>**Recent trends:**<br>There has been no recent signficant evidence of erosion of the Stiffkey Meals/Meols, indicating that the supply of sediment is sufficient to maintain the existing shoreline. There has also been no evidence of accretion, indicating that there is not enough sediment to allow the shoreline to prograde or that sea level rise is now allowing accretion to occur. More recent EA monitoring results suggest that the sand flats are eroding as a result of rising sea level and the saltmarshes are continuing to experience vertical erosion. This would lead to a steeper profile overall.<br>**Future evolution (unconstrained):**<br>The whole profile would probably continue to steepen due to sea level rise. In the future there may be erosion of the saltmarsh edge due to squeeze of the saltmarsh area between the rising sea level and the higher ground inland. Under these circumstances the whole profile would shift towards land, including the offshore bars and the sand beach. The upper saltmarshes are likely to continue to accrete until the rate of sea level rise overtakes the |

| Frontage F – Stiffkey (and Warham) marshes | | Chainage 34.4km 42.3km | | | |
|---|---|---|---|---|---|
| | rate of accretion. | | | | |
| Dependency: Factors affecting the evolution of the frontage both internally and externally | **Control and sensitivities** | **Control features** | **Significance** | **Dependence** | **Chainage** |
| | Sea level rise | Relict cliff line | Primary | Permanent | - |
| | **Internal interaction** | **External interaction** | | | |
| | | If the outfall of the River Stiffkey was no longer maintained and left to form a natural meandering course, there could be effects on the neighbouring frontage (frontage G) as the new course of the river is likely to interact differently with the Blakeney harbour channel. | | | |
| | **Sea level / climate change** | | | | |
| | For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report. | | | | |
| Influence: Factors that may influence evolution of other areas | | | | | |

## Section 4 – Baseline management scenarios[17,18]

No active intervention (NAI)

**Scenario description**

This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.

**Shoreline response**

Initially, shoreline response is likely to be similar to that seen recently. There would be a continued trend of erosion of the lower sandflats, but vertical accretion of the upper saltmarsh in response to increasing sea levels. The whole system would continue to roll back towards land.

Into epoch 2, the small number of defences near the River Stiffkey outfall and to the east of Wells-next-the-Sea would have failed. This would cause local inundation of some back-shore areas to the east of Wells. The River Stiffkey outfall would also follow a more meandering course and there would be some local flooding upstream of the failed outfall during high tides and surge events. The new course of the outfall may enhance the effects of the Blakeney harbour channel on the development of the distal end of the spit. During epoch 2 there would be a similar trend as in epoch 1, with erosion of the lower sandflats, but continued vertical accretion along the upper saltmarsh. The whole system would also continue to retreat towards land. By the end of epoch 2, the reduction in total saltmarsh area would be increasingly apparent.

By epoch 3, the predicted rate of sea level rise is likely to outpace sedimentation along the saltmarsh and the saltmarshes would effectively be swamped during a normal high tide. The whole system would continue to move

[17] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, in this assessment of baseline scenarios, it was not considered relevant to quantify these effects due to the uncertainty surrounding this issue.

[18] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

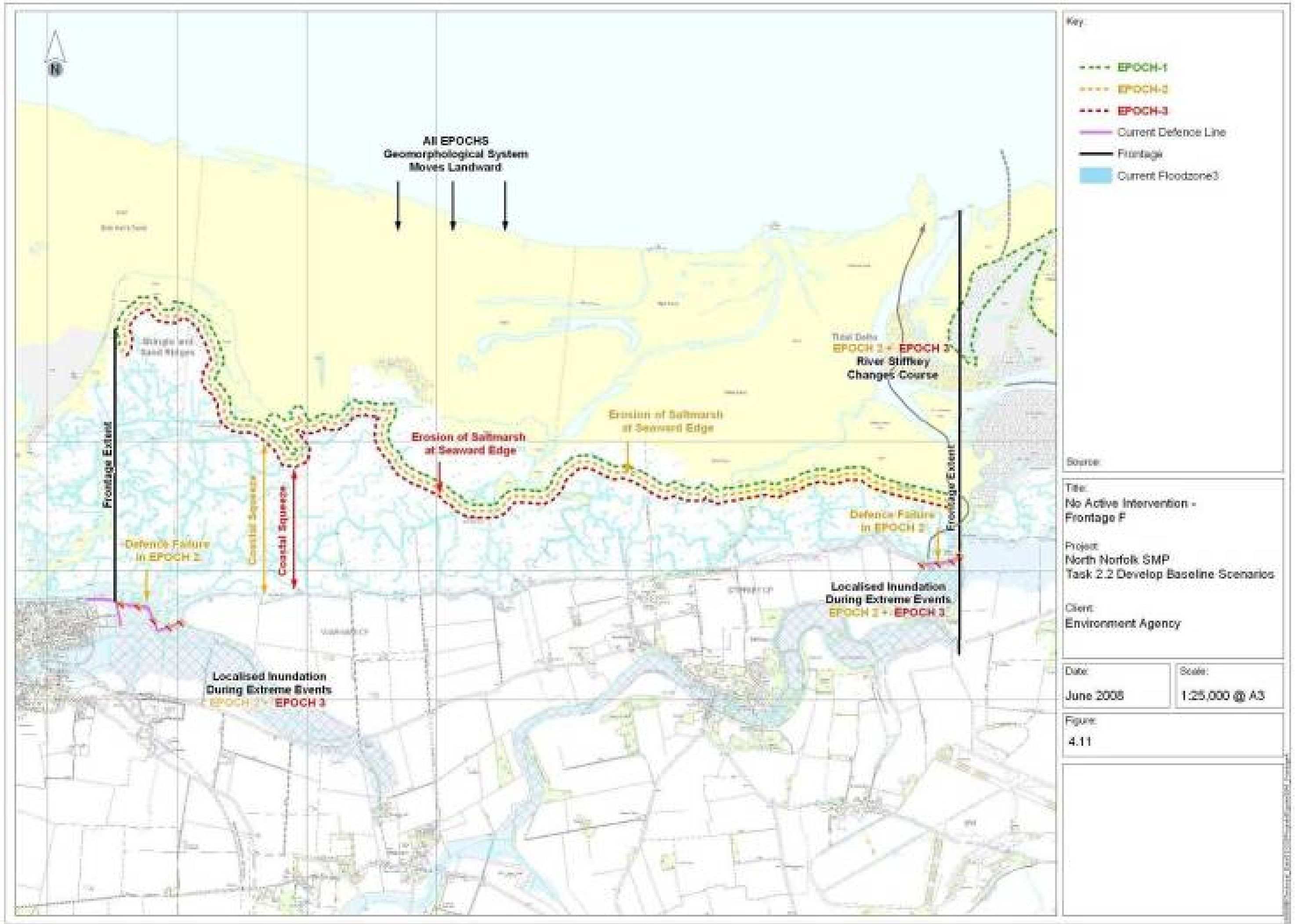
towards land, with coastal squeeze continuing between the rising sea levels and the relict cliff line.

Rates of erosion for all epochs might be expected to be directly associated with rate of sea level rise and beach slope. The following table calculates the erosion rate by multiplying the rate of sea level rise by the beach slope (a simplification of the Brunn rule):

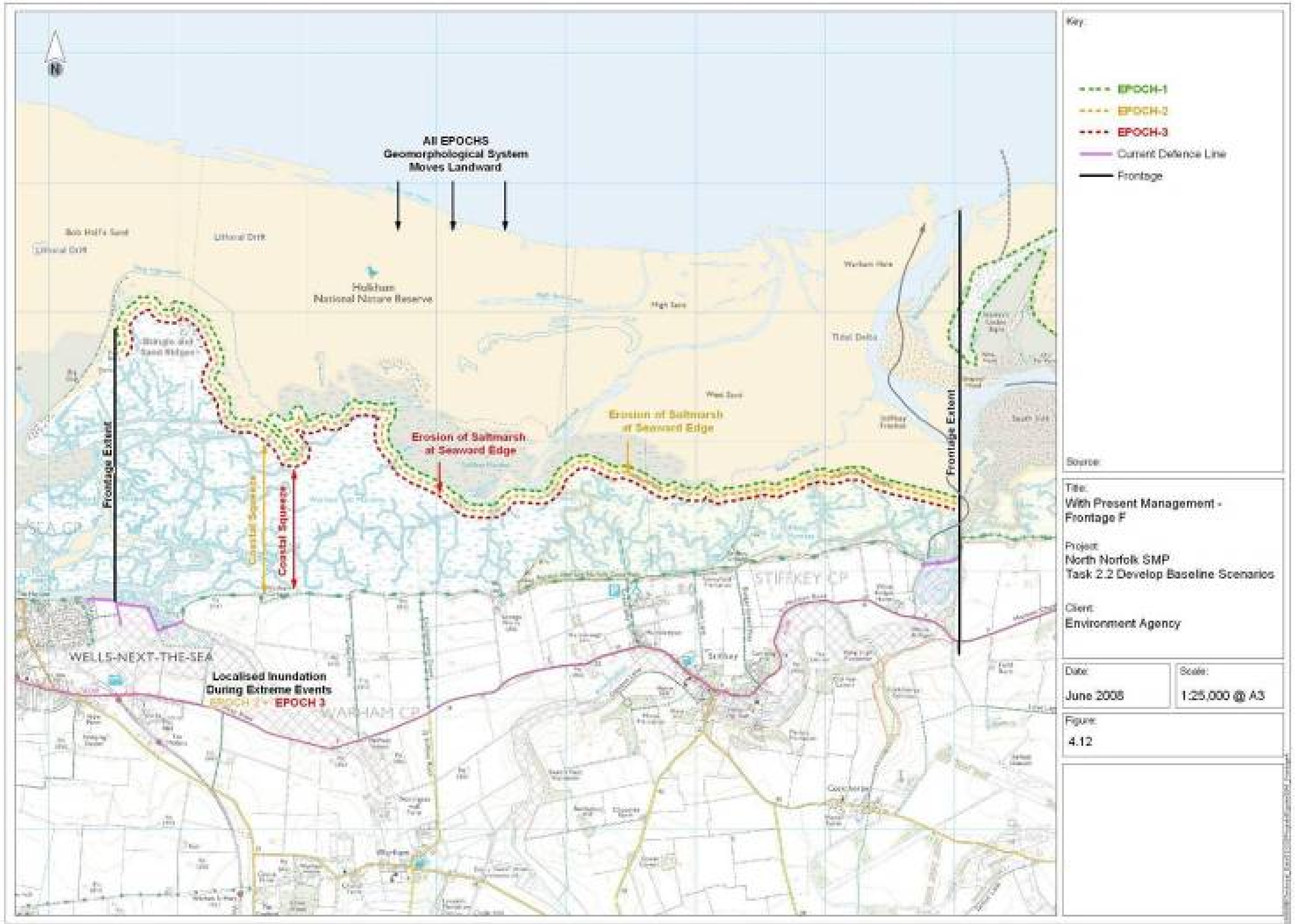
| **Epoch** | **Sea level rise ($myr^{-1}$)** | **Beach slope** | **Erosion rate ($myr^{-1}$)** |
|---|---|---|---|
| 1 (2008 to 2025) | 0.004 | 1:20 | 0.08 |
| 2 (2025 to 2055) | 0.0085 | 1:20 | 0.17 |
| 3 (2055 to 2085) | 0.012 | 1:20 | 0.24 |
| 3 (2085 to 2105) | 0.015 | 1:20 | 0.30 |

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences would remain. | Continued erosion of the lower sandflats, but vertical accretion across the upper saltmarsh due to sea level rise. The entire geomorphological system will roll back towards land. | Defences would have failed. | Continued rollback of the system similar to epoch 1. Change in course of River Stiffkey outfall, with local flooding upstream. Also some local flooding behind Wells east bank. | No defences would remain. | Sea level rise would outpace sedimentation, halting accretion over the saltmarsh. The whole system would continue to move towards land and coastal squeeze would occur. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| With present management (WPM) | **Scenario description**<br>This scenario assumes that the current policy for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.<br><br>**Shoreline response**<br>This scenario would effectively be the same as for the NAI scenario. However, the small number of defences would be maintained. This is not likely to affect the overall evolution of the shoreline along this frontage.<br><br>Rates of erosion for all epochs will be as with the NAI scenario. | | | | | | |
| | **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | | |
| | **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** | |
| | Defences would remain. | Continued erosion of the lower sandflats, but vertical accretion across the upper saltmarsh due to sea level rise. The entire geomorphological system would roll back towards land. | Defences would remain. | Continued rollback of the system similar to epoch 1. | Defences would remain. | Sea level rise would outpace sedimentation, halting accretion over the saltmarsh. The whole system would continue to move towards land and coastal squeeze would occur. | |



Key:
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Frontage
Current Floodzone3
All EPOCHS
Geomorphological System
Moves Landward
Shingle and
Sand Ridges
Frontage Extent
Defence Failure
in EPOCH 2
Coastal Squeeze
Coastal Squeeze
Erosion of Saltmarsh
at Seaward Edge
Erosion of Saltmarsh
at Seaward Edge
Tidal Delta
EPOCH 2 + EPOCH 3
River Stiffkey
Changes Course
Defence Failure
in EPOCH 2
Frontage Extent
Localised Inundation
During Extreme Events
EPOCH 2 + EPOCH 3
Localised Inundation
During Extreme Events
EPOCH 2 + EPOCH 3
Source:
Title:
No Active Intervention -
Frontage F
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:25,000 @ A3
Figure:
4.11


All EPOCHS
Geomorphological System
Moves Landward
Holkham
National Nature Reserve
Erosion of Saltmarsh
at Seaward Edge
Erosion of Saltmarsh
at Seaward Edge
Frontage Extent
Frontage Extent
Coastal Squeeze
Coastal Squeeze
WELLS-NEXT-THE-SEA
Localised Inundation
During Extreme Events
EPOCH 2 - EPOCH 3
WARHAM CP
STIFFKEY CP
Key:
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Frontage
Source:
Title:
With Present Management -
Frontage F
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:25,000 @ A3
Figure:
4.12

### F3.6.7 Frontage G – Blakeney Spit

| Frontage G – Blakeney Spit | Chainage 42.3km 49.5km |
|---|---|

Western extent of Blakeney Spit to Blakeney Eye.

**Section 1 – Description**

| | |
|---|---|
| General | This frontage covers the hamlet of Morston and the large village of Blakeney. Most of this frontage consists of a large spit that is also a National Nature Reserve. There are a large number of saltmarsh drainage channels in this frontage that are highly sought after for recreational purposes (canoeing, sailing etc). |
| Physical | The general orientation of Blakeney Point is towards the west north west. The currently active part of Blakeney is within this frontage and does not extend significantly into frontage H. The spit itself consists of a number of recurved features that indicate the former extent of the spit, namely the Marrams, the Hood and the Headland. Between the limbs of the recurves and inland of the spit itself, saltmarshes are developing in the shelter afforded by the ridges and spit. This frontage also contains Blakeney Fresh marshes. These freshwater marshes were formed in the 17th century and consist of around 170 hectares of freshwater grazing marshes, with small areas of reedbed and numerous drainage ditches. The freshwater marshes are protected from tidal inundation to the west, north and east by earth embankments and to the south by higher ground.  <br><br>The lower tidal River Glaven flows out onto the saltmarsh behind the spit to the east of this frontage. The course of this river has gradually been pushed southwards by the natural rollback of Blakeney Point. The River Glaven meanders its way out from behind the spit along the Cley channel, which then joins the Blakeney channel. |

| Frontage G – Blakeney Spit | Chainage 42.3km 49.5km |
|---|---|
| Defences and man-made features | There is a man-made defence line running in a west to east direction at the inland limit of the saltmarsh up to Blakeney. This then runs north and then north east around to Blakeney Eye. This defence line consists of a well-vegetated earth flood bank. These raised earth embankments protect the freshwater marsh at Blakeney Freshes from tidal inundation. Apart from this, there are no other formal man-made defence lines, although the shingle spit and ridge system running north west to south east acts as a natural defence. The ridge itself was re-profiled up to 2005 by bulldozers, but has since been left to regain its natural profile. Realignment of the tidal River Glaven was also carried out in 2005 as a result of repeated blockages occurring at the downstream end of the channel due to the rollback of the spit. This was causing damage to the fresh marshes as saline flood water could not be rapidly evacuated, as well as river flooding upstream of the tidal sluice in Cley and Wiveton. The previous method of management, which involved regular dredging of the channel, was also considered unsustainable. The recent realignment will provide continued drainage for around 200 years, at which time rollback of the spit is likely to infill the channel again. |

| Frontage G – Blakeney Spit | Chainage 42.3km 49.5km |
|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

Tide and water levels (mOD N)

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Blakeney** | N/A | N/A | N/A | N/A | 1.20 | 2.60 | N/A | | | |

Extremes (mOD N)

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Blakeney** | Royal Haskoning (2007) | 3.67 | 4.24 | 4.47 | 4.64 | 4.82 | 4.99 | 5.22 | 5.39 |

Notes:

Currents

| | | Notes |
|---|---|---|
| Av. flood | West | Current data deduced from tidal diamond N on Admiralty chart no. 108. |
| Av. ebb | East | The flow pattern over much of the rising tide is relatively strong over mid-tide and towards the west, changing to a weak flow towards the east over high water. On the ebb, the flow is strong and towards the east, reversing to a weaker flow towards the west at low water, flowing into the ebb tide from the Wash. |
| Net residual | North | Inshore the residual tidal current runs to the east (SMP1 1996). |

Wave climat

The dominant incident wave direction is from the north east. The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height offshore is between six and eight metres (Anglian Water 1988).

Notes:

## Frontage G – Blakeney Spit | Chainage 42.3km 49.5km

**Section 2 – Baseline information (current data relevant to the frontage)**

| | **Average rates (myr$^{-1}$) unless stated)**[19] | Cliff/backshore feature | | | | | Intertidal | | | Nearshore | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | general | crest | face | toe | backshore | general | MHWS | MLWS | Trend | Source |
| Accretion/erosion | Spit (distal end) 1586 to 1698 | | | | | | 18.00 | | | Advance | Cozens Hardy (1929) |
| | Spit (distal end) | | | | | | **3.50** | | | Accretion westwards | CHaMP (2003) |
| | Spit | | | | | | **-1.00** | | | Landward movement | Hardy (1964) |
| | Average of EA profiles N2C2 to N2C4 | | | | | | -3.25 | | | Erosion | EA Coastal Trends Analysis (2007) |

**Overview:** The north Norfolk sediment budget is positive and sediment is currently available to the coastal system.

| | | | | |
|---|---|---|---|---|
| **Material** | Blakeney Spit is made up of sand, with the size of gravel reducing from east to west. There is a higher sand content west of Cley coastguard station. Sand forms the distal end of the spit, indicating a long-term under-supply of coarse-grained sediment to the headland. | | | |
| **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| Frontage G – Blakeney Spit | Chainage 42.3km 49.5km |
|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

| | | | | |
|---|---|---|---|---|
| Sediment | **Movement:** There is a westward sediment transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals in this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to changes in normal sediment pathways and delivery and moves signficant amounts of sediment during single events (HR Wallingford 2002). There is a strong onshore-offshore sediment transport from the gravel ridge under the action of storm waves from the north east. This makes it possible for sand to be carried more than one kilometre offshore to the east-west orientated sand belts covered by sand waves known as Blakeney Overfalls and the Pollard. The saltmarshes behind the spit are important sinks for fine sediment. | **Location** | **Net drift ($m^3$/yr x 1000)** | **Source** |
| | | Blakeney Point | 40 to 60 (westward) | Potential sand transport (Vincent 1979) |
| | | Blakeney Point | 20 to 40 (westward) | Shingle longshore transport (Vincent 1979) |
| | | Blakeney (600000E 347000N) | 350 (westward) | Onyett & Simmonds (1983) |
| | | Blakeney (602500E 346300N) | 600 (westward) | Vincent (1979) |

[19] The rates highlighted in bold are the ones used when determining NAI and WPM baseline scenarios (section 4). In this case, despite the rate of -1.00myr$^{-1}$ being stated in 1964, it is the generally accepted rate of shingle ridge rollback along this frontage. The more recent EA monitoring data are also likely to be skewed by the re-profiling activities that occurred up to 2006.

| Frontage G – Blakeney Spit | Chainage | 42.3km | 49.5km |
|---|---|---|---|

## Section 3 - Geomorphology

| | |
|---|---|
| Process description: Overall description of current processes: sources, transport and sinks | The general orientation of the spit is towards the dominant incident wave direction (from the north east). Its shape suggests it is a traditional spit feature growing towards the west. This is also reinforced by the fact that the course of the River Glaven has been diverted due to the apparent movement of the spit towards the west. The distal end of the spit has also been rolling back over the saltmarshes. The spit is essentially a relict feature constructed from material deposited during the last glaciation. The distal end of the spit appears to develop as a result of large sand bars that move eastwards from Stiffkey across Blakeney channel and then weld themselves to the distal end. As a result, Blakeney Point grows towards the west but is fed by an eastward transport of material. The recurves may therefore reflect this pulsing of sediment feed and shaping of wave refraction along the Blakeney channel. The seaward side of the spit has a steep sloping beach that means it is subject to greater wave energy than the extensive gently-inclined intertidal flats further to the west. |
| Patterns of change | **Past development:**<br>Westward spit growth was in response to the prevailing storm waves that approach the spit obliquely from the north east. Bulldozing activities to protect Cley (eastern end of the frontage), and a reduced sediment supply brought about by cliff stabilisation measures in the next SMP area, has meant that the alignment of the spit has been artificially altered. The distal end of the spit has also been rolling back over the saltmarshes. Sediment has been added to the distal end by pulses of sand supplied from the west supplementing a persistent, but probably reducing, westward movement of sand by littoral drift along the seaward limb of the spit. As only the spit itself was free to move, it had the potential to become misaligned with the shingle ridge over time.<br>**Recent trends:**<br>Now that bulldozing activities have stopped, it is unlikely that the ridge will become misaligned with the spit. Continued rollback of the distal end of the spit has occurred, causing a reduction in the tidal prism of the River Glaven. The dunes of Blakeney are experiencing erosion as the barriers roll towards land. Unlike gravel barriers, the dunes do not reform by rollover processes and the dune ridges are progressively narrowing as the barriers |

<table>
<tr><td></td><td colspan="5">move towards land (CHaMP 2003).<br><br>Future evolution (unconstrained):<br>There are unlikely to be significant changes in longshore shape due to drift effects in frontage H. Continued rollback of the distal end of the spit may cause a greater reduction in the tidal prism, leading to a narrowing of the mouth of the River Glaven and Blakeney channel due to increased sedimentation. This could cause a change in sediment transport patterns in the area, causing a decrease in the pulse feed. Vertical accretion would continue across the saltmarshes in line with sea level rise due to the good supply of fine-grained sediment.</td></tr>
<tr><td rowspan="7">Dependency: Factors affecting the evolution of the frontage both internally and externally</td><td>Control and sensitivities</td><td>Control features</td><td>Significance</td><td>Dependence</td><td>Chainage</td></tr>
<tr><td rowspan="3">This frontage is anchored by the hard Weybourne cliffs to the east (SMP 6). The frontage is very sensitive to the dominant wave climate and to storm conditions, as well as the presence of a gap between the Blakeney Overfalls and Sheringham Shoal. Behaviour of this frontage is sensitive to the movement of frontage H. The extent of natural rollback of the shingle ridge is limited by the higher ground to the south (located roughly at the A149 coast road).</td><td>Shingle ridge</td><td>Primary</td><td>Transient</td><td>49.5 to 58.4</td></tr>
<tr><td>Course of tidal River Glaven</td><td>Secondary</td><td>Transient</td><td>49.5 to 53.5</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Internal interaction</td><td colspan="4">External interaction</td></tr>
<tr><td>The nature of the Salthouse-Cley and Blakeney Freshes marshes is controlled by the ability of the tidal River Glaven to drain saline flood waters from the marshes. If the channel becomes blocked as a result of rollback of the shingle ridge, this will compromise the ability of the river to drain saline flood water.</td><td colspan="4">The sediment transport pathways along this frontage do not influence the growth of Blakeney Spit as it is fed by eastward pulsing sediment to the west of its distal end.</td></tr>
</table>

| | | |
|---|---|---|
| | **Sea level / climate change** | |
| | For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report. | |
| Influence: Factors that may influence evolution of other areas | If the tidal River Glaven becomes blocked by rollback of the shingle ridge, the fresh water outfalling through the tidal sluice at Cley will attempt to find an alternative, natural route to the North Sea. The surrounding area (including frontage G) would become brackish, with saline water inundation only occurring on a breach of the ridge/spit. | |

## Section 4 – Baseline management scenarios[20,21]

| | |
|---|---|
| No active intervention (NAI) | **Scenario description**<br>This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.<br>**Shoreline response**<br>There are unlikely to be significant changes in the shape of the shoreline due to drift effects in frontage G under the NAI scenario. Initially, continued rollback of the distal end of the spit (at a rate of about one metre a year) and westward growth (at a rate of about 3.5 metres a year) may cause a further reduction in the tidal prism as the whole system continues to roll back. This rollback would cause a narrowing of the mouth of the River Glaven and Blakeney channel and would promote sedimentation behind the spit. This could cause a change in sediment transport patterns in the area, causing a decrease in the pulse feed.<br><br>Following failure of the defences by the end of epoch 1 (and towards the beginning of epoch 2 for a couple of defences), there would be flooding of a significant area of reclaimed freshwater marsh (Blakeney Fresh marshes). These previously freshwater marshes would gradually transgress to brackish areas and then to saltmarshes. Defence failure would cause a significant change in the geomorphology and ecological characteristics of this frontage. It is likely that the course of the tidal River Glaven, particularly near Blakeney chapel at the northern edge of Blakeney Eye (towards the east of this frontage), would alter dramatically to a more natural position. There would also be continued rollback of the spit towards land during this epoch, but a reduction in its westward movement due to a reduced pulse feed mechanism. |

[20] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, within this assessment of baseline scenarios, it was not considered relevant to quantify these effects due to the uncertainty surrounding this issue.
[21] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

| Frontage G – Blakeney Spit | Chainage: 42.3km 49.5km |
|---|---|

Into epoch 3, sea level rise could overtake sedimentation behind the spit and this would increase the volume of tidal exchange behind the spit itself. As a result, the distal end of the spit could be left as a barrier island that could become misaligned with the shingle ridge. This would then form a similar geomorphological feature to that seen at Scolt Head Island. The sandy barrier island would begin to encroach on the existing marsh, further narrowing the Blakeney channel and reducing the tidal prism. The back-barrier marshes (Morston saltmarshes and the newly-formed saltmarsh at Blakeney Freshes) would continue to accrete vertically in line with sea level rise due to a good supply of fine-grained sediment.

| Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Most of the defences would have failed by the end of epoch 1. | Continued rollback of the distal end of the spit (one metre a year) and westward growth (3.5 metres a year), narrowing the mouth of the River Glaven and Blakeney channel. Possible decrease in pulse feed to the distal end of the spit. | No defences would remain. | Flooding of previously freshwater marshes after defence failure would increase the tidal exchange behind the spit. Marshes would gradually become saltmarshes. Accretion along marshes could still occur in line with sea level rise. | No defences would remain. | Sea level rise is likely to outpace sedimentation further increasing tidal exchange behind the spit. The distal end is likely to become a detached barrier island. This new barrier island would move back gradually, encroaching on the existing saltmarsh, leading to coastal squeeze. |

With present management (WPM)

**Scenario description**

This scenario assumes that the current policy for the frontage continues. This will usually involve maintaining defences to give a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

## Frontage G – Blakeney Spit    Chainage: 42.3km    49.5km

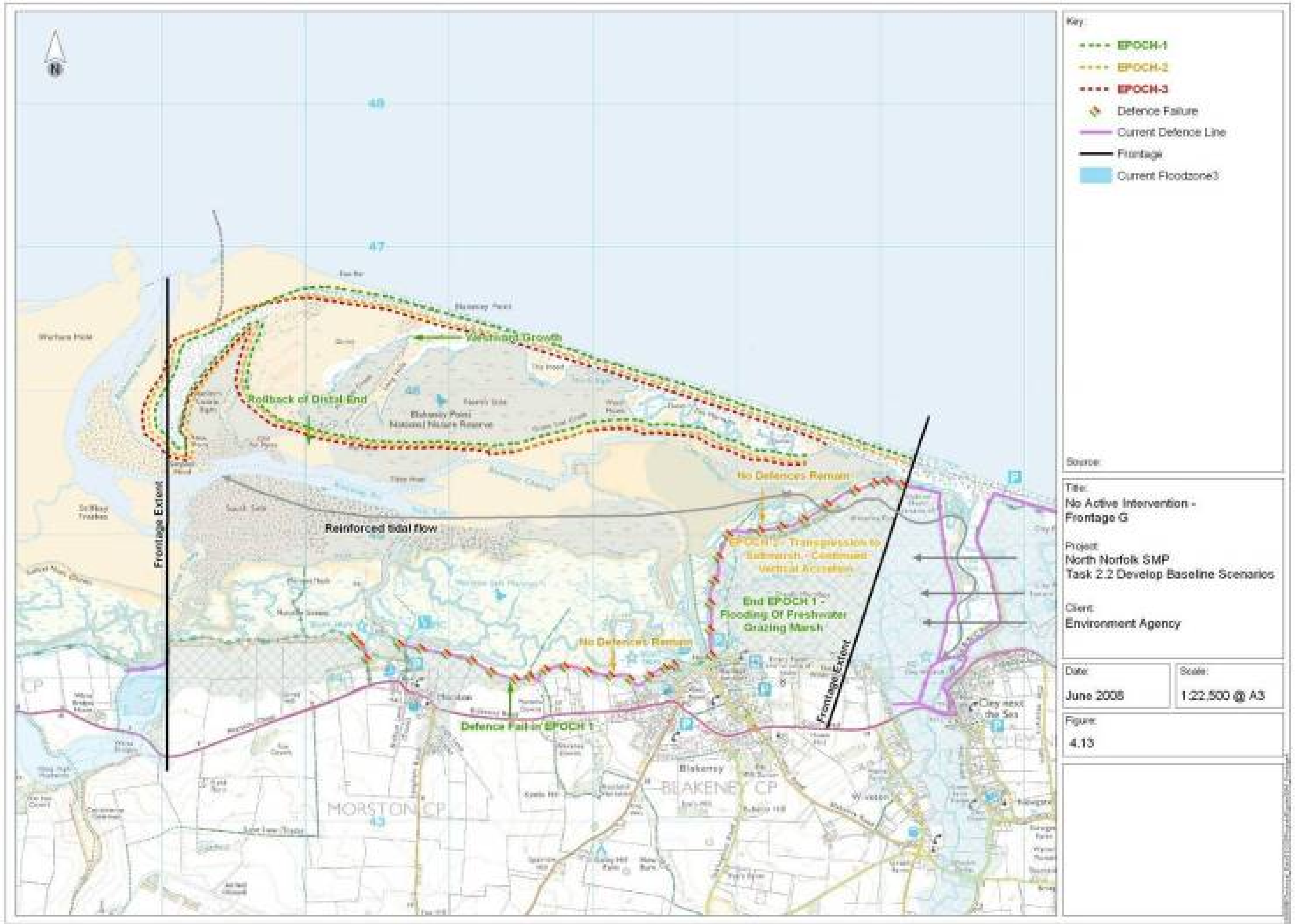
**Shoreline response**

Initially, the development of the frontage under this scenario would copy that of the NAI scenario. As a result, there would be westward growth of the spit (at around 3.5 metres a year) and continued rollback of the distal end of the spit (at a rate of about one metre a year). This would cause a further reduction in the tidal prism, leading to a narrowing of the mouth of the River Glaven and Blakeney channel and promoting increased sedimentation behind the spit. This could cause a change in sediment transport patterns in the area, causing a decrease in the pulse feed.

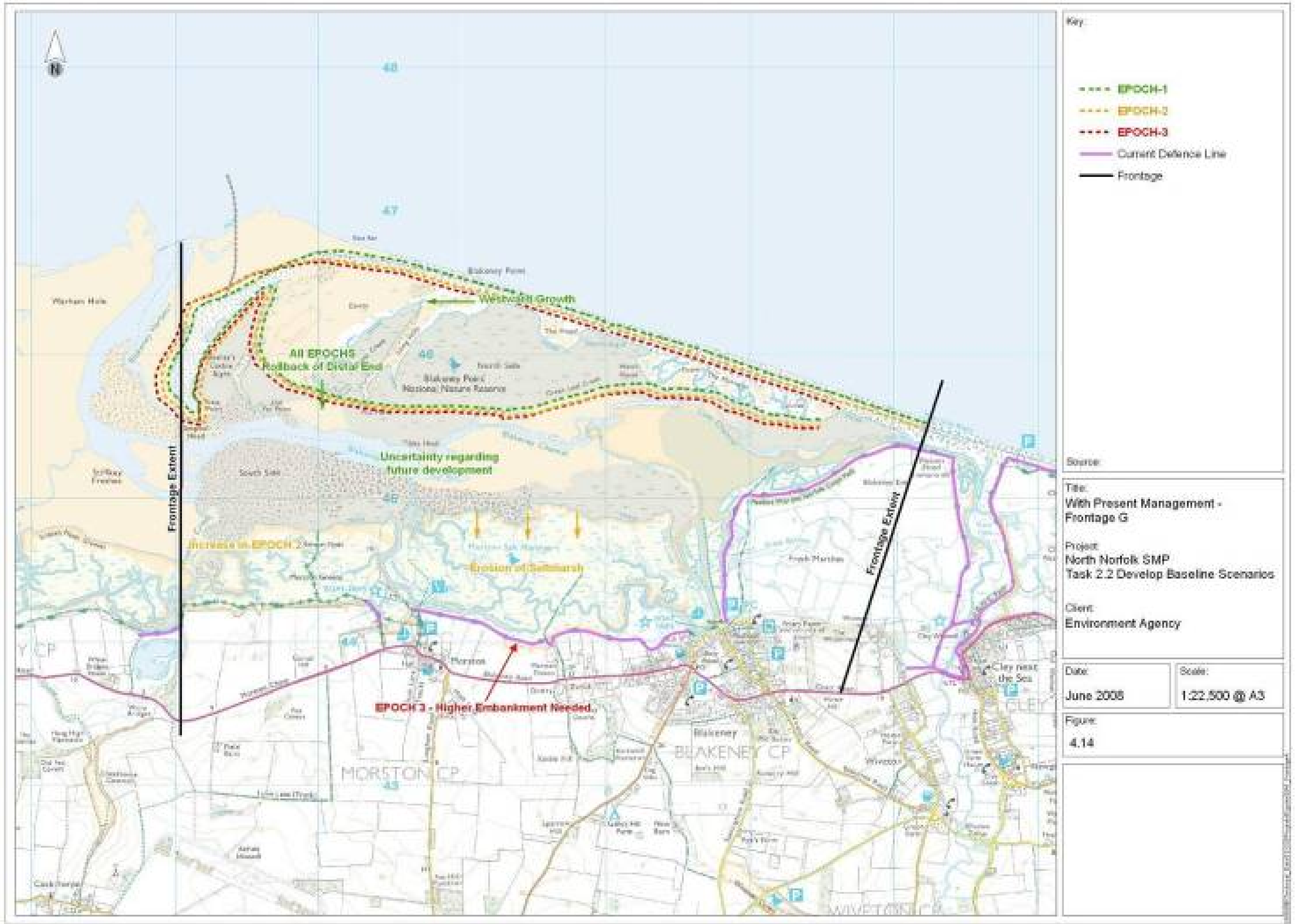
However, into epoch 2 with defences still present, there would be continued growth of the spit towards the west and rollback of the distal end, with an associated reduction in tidal prism and sedimentation behind the spit. Increases in sea level rise would allow more water to enter the area behind the spit, but accretion is likely to continue in line with this increase. There is likely to be erosion of the saltmarsh edge and a gradual reduction in the total area of saltmarsh. As the whole system continues to roll back, constrained by the hard defences the Glaven/Blakeney channel is also likely to become squeezed, reducing its capacity and possibly causing a reduction in the size of boat that can access Blakeney through the channel.

By epoch 3, the effects of the coastal squeeze occurring between the rolling back spit and the hard defences would have closed the Glaven/Blakeney channel and caused a considerable amount of saltmarsh loss. There will need to be a higher standard of protection to the earth embankments as the former shingle ridge that marked the edge of the spit begins to move closer to the embankments.

| Frontage G – Blakeney Spit | | | | | | Chainage: 42.3km 49.5km |
|---|---|---|---|---|---|---|
| | Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
| | **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| | Defences would remain. | Continued rollback of the distal end of the spit (one metre a year) and westward growth (3.5 metres a year), narrowing the mouth of the River Glaven and Blakeney channel. Possible decrease in pulse feed to the distal end of the spit. | Defences would remain. | Continued rollback of the distal end of the spit leading to further narrowing of the River Glaven and Blakeney channel. Coastal squeeze would occur between the spit and the fixed embankments, causing erosion of the saltmarsh edge (overall loss of saltmarsh). | Defences would remain. | Coastal squeeze would have closed the River Glaven/ Blakeney channel (threatening existence of Blakeney as a coastal town) and caused a considerable amount of saltmarsh loss. Need for higher embankments that protect the freshwater marshes and Blakeney itself. |



Windward Growth
Rollback of Distal End
Blakeney Point National Nature Reserve
Reinforced tidal flow
Frontage Extent
No Defences Remain
EPOCH 2 - Transgression to Saltmarsh - Continued Vertical Accretion
End EPOCH 1 - Flooding Of Freshwater Grazing Marsh
No Defences Remain
Defence Fail in EPOCH 1
Frontage Extent
MORSTON CP
BLAKENEY CP
Key:
EPOCH-1
EPOCH-2
EPOCH-3
Defence Failure
Current Defence Line
Frontage
Current Floodzone3
Source:
Title:
No Active Intervention - Frontage G
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:22,500 @ A3
Figure:
4.13


Westward Growth
All EPOCHS
Rollback of Distal End
Uncertainty regarding
future development
Increase in EPOCH 2
Erosion of Saltmarsh
EPOCH 3 - Higher Embankment Needed
Frontage Extent
Frontage Extent
Blakeney Point
Warham Hole
Morston
Blakeney
BLAKENEY CP
MORSTON CP
Cley next the Sea
Key:
EPOCH-1
EPOCH-2
EPOCH-3
Current Defence Line
Frontage
Source:
Title:
With Present Management - Frontage G
Project:
North Norfolk SMP
Task 2.2 Develop Baseline Scenarios
Client:
Environment Agency
Date:
June 2008
Scale:
1:22,500 @ A3
Figure:
4.14

## F3.6.8 Frontage H – Cley and Salthouse

**Frontage H – Cley and Salthouse** **Chainage 49.5km 58.4km**

Blakeney Eye to Kelling Hard (eastern boundary of SMP study area).

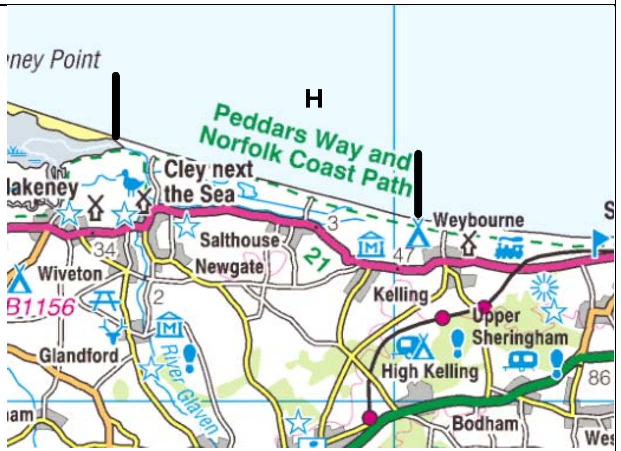
### Section 1 – Description

**General**

This frontage covers the villages of Cley-next-the-Sea and Salthouse. The Cley Marshes Nature Reserve is also located between the shingle ridge and A149 coast road. This frontage is inherently linked to the neighbouring frontage (frontage G) due to the similar nature of the area behind the shingle ridge and the reliance on continued drainage of the tidal River Glaven to preserve the natural environment at these locations.

**Physical**

This section of Blakeney between Kelling Hard and Blakeney Eye is a post-glacial feature. In front of the ridge there is a shingle beach with a steep profile and few bar features. These beaches generally reflect the waves back offshore due to their steep berm face.




There are two internationally recognised freshwater marshes along this frontage. Towards the western edge is Blakeney Freshes, formed in the 17th century by enclosing the natural coastal saltmarsh with earth embankments. This area now provides 168 hectares of freshwater grazing marsh, small areas of reedbed and numerous drainage ditches. Raised earth embankments provide tidal protection to the west, north and east, with higher ground providing protection to the south. Also, the Cley-Salthouse marshes stretch along most of this frontage. They consist of 310 hectares of freshwater grazing marshes, with reedbeds and saline lagoons towards the rear of the ridge. These marshes are bound to the west by an earth embankment (Cley west bank) and the River Glaven estuary, to the north by the shingle ridge and to the east and south by higher ground. There is a small fluvial flow through the marshes that is fed by springs to the east.

| Frontage H – Cley and Salthouse | Chainage 49.5km 58.4km |
|---|---|
| | The River Glaven outfalls to the west of this frontage through a tidal outfall sluice located at the main coast road (A149). As the spit has continued to roll back, the course of the River Glaven has been moved further inland to provide continued drainage of the freshwater marshes and the fluvial reaches of the river. |
| Defences and man-made features | A vegetated earth flood bank runs roughly northwards from Cley to the east of the River Glaven (Cley west bank). Cley east bank, running north to south from the car park at Walsey Hills to the shingle ridge, divides the Cley-Salthouse marshes into two separate flood compartments. Apart from this, there are no other man-made defence lines, although the shingle ridge running north west to south east between Blakeney Eye and Kelling Hard acts as a natural defence and was re-profiled by bulldozers up to 2005. This has now been left to reform back to its natural profile. Realignment of the tidal River Glaven was also carried out in 2005 as a result of repeated blockages occurring at the downstream end of the channel due to the rollback of the spit. This was causing damage to the fresh marshes as saline flood water could not be quickly evacuated. There was also river flooding upstream of the tidal sluice in Cley and Wiveton. The previous management, which involved regular dredging of the channel, was also deemed unsustainable. The recent realignment will provide continued drainage for around 200 years, at which time rollback of the spit is likely to infill the channel again. |

| **Frontage H – Cley and Salthouse** | **Chainage** | **49.5km** | **58.4km** |
|---|---|---|---|

**Section 2 – Baseline information (current data relevant to the frontage)**

Tide and water levels (mODN)

| | LAT | MLWS | MLWN | MSL | MHWN | MHWS | HAT | Spring range | Neap range | Correction CD/ODN |
|---|---|---|---|---|---|---|---|---|---|---|
| **Blakeney** | N/A | N/A | N/A | N/A | 1.20 | 2.60 | N/A | | | |

Extremes (mODN)

| | Source/method | 1:1 | 1:10 | 1:25 | 1:50 | 1:100 | 1:200 | 1:500 | 1:1000 |
|---|---|---|---|---|---|---|---|---|---|
| **Weybourne** | Royal Haskoning (2007) | 3.32 | 3.86 | 4.07 | 4.23 | 4.39 | 4.56 | 4.77 | 4.93 |

Notes:

Currents

| | | **Notes** |
|---|---|---|
| Av. flood | | Current data deduced from tidal diamond N on Admiralty chart no. 108. The flow pattern over much of the rising tide is relatively strong over mid-tide and towards the west, changing to a weak flow towards the east over high water. On the ebb, the flow is strong and towards the east, reversing to a weaker flow towards the west at low water, flowing into the ebb tide from the Wash. |
| Av. ebb | | |
| Net residual | | |

Wave climate

The dominant incident wave direction is from the north east. The dominant waves arrive from the north east and north north east, but refraction causes the waves to approach the coast from different directions (north to north west). Along this frontage waves typically originate from 30°N. The annual 10 per cent exceedance significant wave height is between one and 1.5 metres (Futurecoast 2002). The 1:100 year wave height is between six and eight metres (Anglian Water 1988).

Notes: Up to 2006 there was a programme of re-profiling operating along Blakeney ridge between EA profile numbers N2C7 and N2B3. This re-profiling was stopped in 2006 and the ridge has now been left to regain its natural profile. There has been a progamme of drainage improvements and channel realignment undertaken at Cley marshes to ensure that, if overtopping occurs, saline flood water drains quickly and effectively off the freshwater marshes.

| Frontage H – Cley and Salthouse | | | | | | | | Chainage | 49.5km | 58.4km | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Section 2 – Baseline information (current data relevant to the frontage)** | | | | | | | | | | | |
| | **Average rates (myr$^{-1}$) unless stated)**[22] | Cliff/backshore feature | | | | Intertidal | | | | Nearshore | Source |
| | Location | general | crest | face | toe | backshore | general | MHWS | MLWS | Trend | |
| | Shingle ridge | | | | | | **-1.00** | | | Erosion | Hardy (1964) |
| | Average of EA profiles N2C7 to N2B3 | | | | | | -0.58 | | | Erosion | EA Coastal Trends Analysis (2007) |

| | | | | | |
|---|---|---|---|---|---|
| Accretion/ erosion | **Material** | The ridge is comprised of shingle which is largely fossil material. | | | |
| | **Sources** | External | Erosion of Holderness cliffs (fine).<br>Erosion of cliffs along north Norfolk coast (fine). | Internal | Nearshore seabed, cliff erosion and recycling of intertidal sediments (coarse).<br>Offshore banks (during high magnitude, low frequency events). |

| | | | | |
|---|---|---|---|---|
| Sediment | **Movement:** There is a westward sediment transport pathway along the north Norfolk coast during low magnitude, high frequency events involving relatively small volumes of sediment. There are seasonal reversals in this direction (Evans et al 1998). During high energy surge conditions there may be a sudden increase in patterns of sediment movement, with material from the Burnham Flats being transported. This leads to | **Location** | **Net drift ($m^3$/yr x 1000)** | **Source** |
| | | Weybourne to base Blakeney Point | 10 to 15 (westward) | Vincent (1979). Refers to sand. Same volume for gravel. |

[22] The rate highlighted in bold is the one used when determining NAI and WPM baseline scenarios (section 4). In this case, despite the rate of -1.00myr$^{-1}$ being stated in 1964, it is the generally accepted rate of shingle ridge rollback along this frontage. The more recent EA monitoring data are also likely to be skewed by the re-profiling activities that occurred up to 2006.

**Section 2 – Baseline information (current data relevant to the frontage)**

| | | | | | |
|---|---|---|---|---|---|
| | changes in normal sediment pathways and delivery and moves signficant amounts of sediment during single events (HR Wallingford 2002). There is a strong onshore-offshore sediment transport mechanism from the gravel ridge under the action of storm waves from the north east, with the potential for sand to be carried offshore more than one kilometre to the east-west orientated sand belts covered by sand waves known as Blakeney Overfalls and the Pollard. | | | | |

| Frontage H – Cley and Salthouse | Chainage 49.5km 58.4km |
|---|---|
| **Section 3 - Geomorphology** | |
| Process description: Overall description of current processes: sources, transport and sinks | The shingle ridge that stretches along the whole of this frontage is a post-glacial feature consisting of glacial till, separated from the rising ground of the Salthouse-Weybourne scarp by a valley filled with Holocene alluvium. Shingle deposited during the last glaciation would have been washed out from the sea bed and accreted on the beach. It has been suggested that the position of accretion was selective due to the wave refraction pattern. The combination of sea level, offshore bathymetry and wave climate caused preferential accretion in the Weybourne area (to the east of this frontage). As a result of this model, there is thought to be no significant source of shingle active today. The shingle along this frontage has formed into a beach that reflects wave energy back offshore by the steep face of the berm.<br><br>There is a significant offshore feature along this frontage, Sheringham Shoals, which consists of gravelly sand.<br><br>The tidal River Glaven outfalls to the west of this frontage through a tidal sluice located at the main coast road (A149). As a result of shingle ridge rollback, the course of the river has been gradually forced inland. |
| Patterns of change | **Past development:**<br>In the past, the eastern end of the spit (that is, the western edge of this frontage) has been maintained by bulldozing. This acted to halt the natural rollback of the shingle ridge and caused the active part of Blakeney Spit to become misaligned with the ridge.<br>**Recent trends:**<br>Bulldozing activity has now stopped and, as a result, the western edge of this frontage has restarted a trend of rollback inland over the saltmarsh. The shingle ridge is now becoming realigned to Blakeney Spit again.<br><br>**Future evolution (unconstrained):**<br>There are likely to be no changes in the drift effects along this frontage. The most important profile changes will be due to extreme events, as shingle ridges usually react to high-magnitude low-frequency events by rolling back. As the ridge continues to move inland, the rate of movement may increase significantly. The rollback towards land would continue until it is in balance with the natural energy environment. The shingle ridge would gradually re- |

<table>
<tr><th colspan="6">Frontage H – Cley and Salthouse    Chainage 49.5km 58.4km</th></tr>
<tr><td></td><td colspan="5">profile to a low barrier that would be prone to occasional breaching and flooding of the low-lying hinterland. As it is already seaward of its natural position, initial rollback of the shingle ridge is likely to cause some breakdown of the barrier. The marshes of Cley and Salthouse would change to natural saltmarsh habitats.</td></tr>
<tr><td rowspan="9">Dependency: Factors affecting the evolution of the frontage both internally and externally</td><td>Control and sensitivities</td><td>Control features</td><td>Significance</td><td>Dependence</td><td>Chainage</td></tr>
<tr><td rowspan="4">This frontage is anchored by the hard Weybourne cliffs to the east (SMP 6). The frontage is extremely sensitive to the dominant wave climate and to storm conditions. Behaviour of this frontage is sensitive to the movement of frontage G. The extent of natural rollback of the shingle ridge is limited by the higher ground to the south (located roughly at the A149 coast road).</td><td>Shingle ridge</td><td>Primary</td><td>Transient</td><td>49.5 to 58.4</td></tr>
<tr><td>Course of tidal River Glaven</td><td>Secondary</td><td>Transient</td><td>49.5 to 53.5</td></tr>
<tr><td>Weybourne cliffs</td><td>Primary</td><td>Fixed</td><td>Outside study area</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Internal interaction</td><td colspan="4">External interaction</td></tr>
<tr><td>The nature of the Salthouse-Cley and Blakeney Fresh marshes is controlled by the ability of the tidal River Glaven to drain saline flood waters from the marshes. If the channel becomes blocked as a result of rollback of the shingle ridge, this will compromise the ability of the river to drain saline flood water.</td><td colspan="4">The sediment transport pathways along this frontage do not influence the growth of Blakeney Spit as it is fed by eastward pulsing sediment to the west of its distal end.</td></tr>
<tr><td colspan="5">Sea level / climate change<br>For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report .</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Influence: Factors that may influence evolution of</td><td colspan="5">If the tidal River Glaven becomes blocked by rollback of the shingle ridge, the fresh water outfalling through the tidal sluice at Cley will try to find an alternative, natural route to the North Sea. The surrounding area (including frontage G) would become brackish, with saline water inundation only occurring on a breach of the ridge/spit.</td></tr>
</table>

| Frontage H – Cley and Salthouse | Chainage 49.5km 58.4km |
|---|---|
| other areas | |

## Section 4 – Baseline management scenarios[23,24]

| | |
|---|---|
| No active intervention (NAI) | **Scenario description**<br>This scenario assumes that defences are no longer maintained and will therefore fail over time. Exact timing of defence failure cannot be deduced. However, an epoch of failure can be determined, as described in the 'Assessment of coastal defences' report.<br>**Shoreline response**<br>The development of this frontage under a scenario of NAI is likely to be similar to the unconstrained scenario discussed above in section 3. There are a number of earth embankments in the western section of this frontage (Cley west bank and Cley east bank) that act to maintain the Cley-Salthouse marshes as freshwater grazing marshes with reedbed and saline lagoons. Also, another embankment runs along the west side of the tidal River Glaven and encloses the freshwater grazing marsh known as Blakeney Freshes. There is also a tidal outfall sluice on the River Glaven (located at the A149) that protects Cley-next-the-Sea and Wiveton from tidal flooding. The shingle ridge itself is not protected from the natural rollback process.<br><br>The earth embankments are predicted to fail towards the end of epoch 1 under this scenario. During epoch 1, there would be continued rollback of the shingle ridge during high-magnitude low-frequency extreme events. However, due to the lack of shingle available to feed a rebuild of the ridge at a more inland location, it is likely to form a lower barrier with significantly lower sections where overwash has been focused. However, the management of the freshwater marshes (Cley-Salthouse flood management scheme) would continue to discharge saline flood water effectively back into the upper Glaven estuary (the tidal River Glaven) following a breach. This type of process is already taking place. For example, during the surge event of 9 November 2007, there was |

[23] All management scenarios assume that the current management practices undertaken in neighbouring SMP areas will continue. The potential effect of wind farms offshore of this study frontage has been noted. However, in this assessment of baseline scenarios it has not been considered relevant to quantify these effects due to the uncertainty surrounding this issue.
[24] All assessments of shoreline response have a band of uncertainty that increases for later epochs.

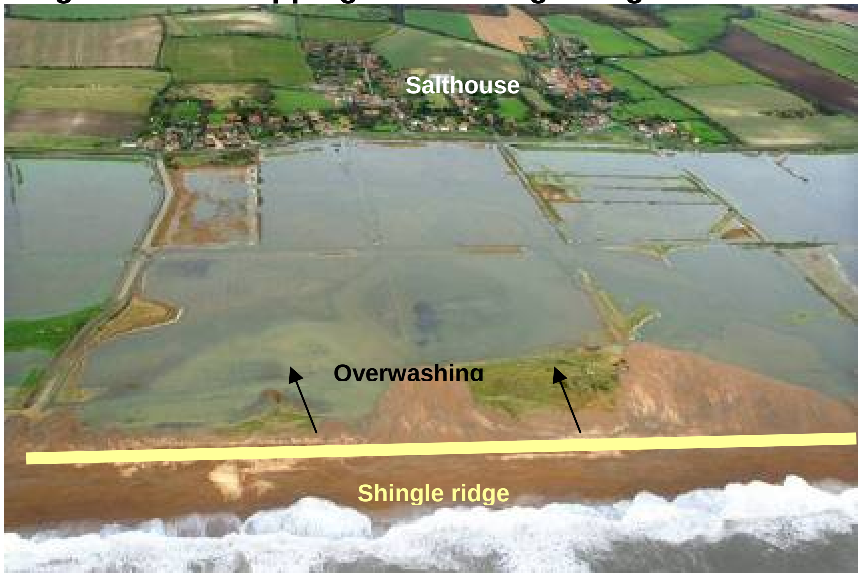
significant overwashing
of the shingle ridge and flooding of the low-lying hinterland behind (diagram 1). Following this event, both North Norfolk District Council and Natural England noted that the drainage system worked effectively to drain the saline flood water within the specified five to seven days (after which saline inundation of freshwater marshes is environmentally unacceptable due to the damage caused by the saline water to freshwater habitats and saline lagoon features).

Following failure of the earth embankments towards the end of epoch 1, there is likely to be a significant change in the geomorphology and ecological characteristics of the frontage. Failure of the earth embankments would result in more tidal water behind the shingle ridge and increased tidal exchange over Blakeney Freshes and Cley-Salthouse freshwater grazing marshes. It is likely that the course of the tidal River Glaven, particularly near Blakeney chapel at the northern end of Blakeney Eye, would change dramatically to a more natural position. The shingle ridge would continue to move inland and the rate of movement could increase significantly until it is in balance with the natural energy environment. The barrier would also become increasingly susceptible to more frequent breaching and flooding of freshwater grazing marshes. Combined with the increased tidal exchange mentioned previously, it is likely that the once freshwater grazing marshes would see a transgression to increasingly saline lagoon and natural saltmarsh habitats.

Following failure of the tidal sluice (predicted during epoch 2), there is likely to be tidal flooding upstream at Cley-next-the-Sea and Wiveton. The extent of this tidal flooding is shown on figure 4.15.

Although outside the scope of this task in terms of epochs, it is useful to mention that the recent (2005) realignment of the tidal River Glaven channel to mitigate blockages caused by shingle ridge rollback has a predicted a life expectancy of 200 years. As blockages of shingle become more frequent around this time, there will be another significant change in course of the river as fluvial flow combined with tidal exchange attempts to redirect the channel around the blockage.

**Diagram 1 Overtopping of the shingle ridge in front of Salthouse on 9 November 2007**



**Frontage H – Cley and Salthouse** **Chainage: 49.5km 58.4km**

| Epoch 1: Years 0 to 20 (2025) | | Epoch 2: Years 20 to 50 (2055) | | Epoch 3: Years 50 to 100 (2105) | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Most of earth embankments would remain. Cley-Salthouse flood management scheme effectively evacuates saline flood water from freshwater grazing marshes. | Continued rollback of shingle ridge (one metre a year), with associated overwashing and flooding of freshwater grazing marshes. Cley-Salthouse marshes and Blakeney Freshes remain freshwater dominated. | Complete failure of all defences. | Rate of movement of ridge would increase and it would re-profile. The ridge would be more susceptible to breaching and flooding. More tidal water over the freshwater marshes. Downstream extent of tidal River Glaven would take a natural meandering alignment. Previously freshwater marshes would see a transgression to natural saltmarsh habitats. | No defences remain. | Rate of movement of ridge likely to be similar to epoch 2. Sedimentation would occur over the Blakeney and Salthouse-Cley marshes. Saltmarsh development would continue. |

With present management (WPM)

**Scenario description**

This scenario assumes that the current policy for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided now and regularly inspecting and maintaining the defences.

**Shoreline response**

With present management, the rollback of the shingle ridge is likely to be the same as for the NAI scenario as it is not currently managed. This rollback, at a rate of around one metre a year for all epochs, would cause a gradual squeeze of the freshwater marshes between the new dune line and the higher ground, marked by the main coast road (A149).

Although rollback and gradual re-profiling of the shingle ridge is likely to cause a generally lowered ridge crest height, causing increased inundation of the backshore areas, the drainage system would continue to evacuate saline flood water into the tidal River Glaven and subsequently out into the sea. As a result, the nature of the Blakeney Freshes and Salthouse-Cley marshes would be the same. There would need to be a higher standard of protection for the earth embankments and drainage system throughout epoch 2 and particularly in epoch 3.

| **Epoch 1: Years 0 to 20 (2025)** | | **Epoch 2: Years 20 to 50 (2055)** | | **Epoch 3: Years 50 to 100 (2105)** | |
|---|---|---|---|---|---|
| **Defences** | **Natural coast** | **Defences** | **Natural coast** | **Defences** | **Natural coast** |
| Defences would remain. | Continued rollback of shingle ridge (one metre a year). More frequent inundation of backshore areas, but drainage system will effectively evacuate saline flood water. | Defences would remain. | Continued rollback of shingle ridge. Need for increased protection along existing embankments and continual improvements to drainage system. | Defences would remain. | Continued rollback of shingle ridge with increased need for a better standard of protection along embankments and urgent need for improvements to drainage system. Previously freshwater marshes are likely to turn increasingly saline. |

# F4 Flood risk

## F4.1 Introduction

This task describes the likelihood of flooding along the north Norfolk coast under the no active intervention (NAI) scenario for the three following epochs:

- present day to 2025 (short term)
- 2025 to 2055 (medium term)
- 2055 to 2105 (long term).

Annex G1 of the SMP guidance on procedures (volume 2, March 2006) provides support on classifying the risks according to the **likelihood** of the feature being lost or damaged and the scale of the **impact**. It presents the following risk matrix for each feature under each of the three epochs, see table F4.1.

**Table F4.1: Risk matrix**

| | | | | |
|---|---|---|---|---|
| **Impact** | High | Medium high risk | High risk | Very high risk |
| | Medium | Low risk | Medium risk | High risk |
| | Low | Negligible risk | Low risk | Medium risk |
| | | Low | Medium | High |
| | | **Likelihood** | | |

The **likelihood** of the feature being damaged or lost depends on flood risk and/or coastal erosion. SMP guidance on procedures (volume 2, March 2006) states that,

> 'For the purpose of the SMP it can be assumed that, should flood defences be breached, the whole flood plain can be defined to be "at risk". The flood risk areas should be based on the information produced by the Environment Agency e.g. the Flood Map'
>
> (p.43, section 2.5, paragraph 4)

For the North Norfolk SMP, a different approach has been developed and applied that fits the policy level of detail and available data. The outcome consists of maps that show how the likelihood of flooding and erosion varies in space and time.

Section F4.2 describes the method for flooding. Section F4.3 presents the results of flooding for the different epochs. Conclusions are presented in section F4.4.

## F4.2 Approach

### F4.2.1 Overview

The approach assesses the likelihood of flooding within compartments taking into consideration the following:

- the maximum tidal flood extent
- the design standard
- the condition of the defences for each epoch

As the condition of the defence and flood extent changes during epochs, it has been necessary to choose particular years within the epochs to assess the likelihood of flooding. Present day was chosen as the baseline and then the end of each epoch, that is 2024, 2054 and 2105.

### F4.2.2 Defining the maximum tidal flood extent

The first step to determining the likelihood of flooding is defining the maximum flood extent that could occur for each point in time.

For the present day, the tidal flood zone (supplied by the Environment Agency) has been used as this is the best available information that is widely accepted. However, the flood zones were adjusted to reflect only the tidal flood extent. Flood zones resulting from the influence of tides on river flooding were not considered. Effectively, they are outside the scope of the SMP.

For the future points in time, there is much more uncertainty involved and dependence on external factors. So, the maximum extent at the end of each epoch would be the 1:1000 year water levels (flood zone 2) plus the sea level rise (based on Defra FCDPAG3, 2006), as shown in table F4.2.

**Table F4.2: 1:1000 year water levels plus sea level rise**

| Location/coastline | 2024<br>EWL (mODN) | 2054<br>EWL (mODN) | 2105<br>EWL (mODN) |
|---|---|---|---|
| Hunstanton to Brancaster Staithe | 6.33 | 6.58 | 7.25 |
| Burnham Overy Staithe to Wells | 5.71 | 5.96 | 6.63 |
| Stiffkey to Kelling | 5.45 | 5.70 | 6.37 |

Extreme water levels change significantly over the frontage, so it is not possible to apply a single level for the entire coastal frontage. It is also not practical to apply a different water level for every kilometre. Coastal sections were chosen to allow a moderately staggered change in water levels.

### F4.2.3 Defining the compartments

In the event of defences being overtopped or breached, it is highly unlikely that the entire flood zone would experience tidal flooding. So the flood plain has been divided into compartments using the tidal flood defences and higher ground.

### F4.2.4 Defining failure of defences

Once the compartments were defined, the probability of defences failing was addressed. The chance of a breach depends on many factors such as the flood defence characteristics that determine performance (both in terms of geometry, fill material and subsoil), wave action, freeboard and uncertainty in tidal extreme water levels and bank survey. However, for this level of study, it was decided that the condition grade and standard of the defence would be used as the indication.

Originally, the defence standard was going to be used with the condition of the defence to determine the likelihood of flooding. However, it was discovered that all defences (except one) have a design standard of 1:10 years. So, the deciding factor on the likelihood of the flood zones flooding through the different epochs is their condition grade.

The Environment Agency supplied the present day condition of the defences (graded 1 to 5, with 5 being the worst and 1 being the best). Based on no active intervention and the “defence assessment” task, the condition of each defence section was determined in 2024, 2054 and 2105. The condition was then translated into likelihood of flooding:

- Condition 1 = very low likelihood of flooding
- Condition 2 = low likelihood of flooding
- Condition 3 = medium likelihood of flooding
- Condition 4 = high likelihood of flooding
- Condition 5 = very high likelihood of flooding.

The likelihood of flooding for each compartment is based on the worst condition of the whole group of defences protecting the compartment.

This was carried out using the present day situation and at the end of each epoch, that is 2024, 2054 and 2105. A “common sense” check was also carried out and any deviation from the approach has been recorded in the summary tables in section F4.5.

## F4.3 Results

Figure F4.1 illustrates the properties at risk in the urban areas and how the flood extent increases throughout the epochs. The performance of defences is particularly critical for the properties in Brancaster, Brancaster Staithe, Burnham Overy Staithe and Wells-next-the-Sea.

### F4.3.1 Present day

The condition of the present day defences varies between grade 4 (including Brancaster and Titchwell sea banks) and grade 1 (including sand dunes of Holme Nature Reserve and Wells sea banks) (figure 2). Around 50 per cent of the critical defences are grade 3 condition. However, there is a continuous line of grade 2 defences at Burnham Norton (Norton marsh) and Holkham (west of Wells-next-the-Sea). Table F4.4 summarises the reasoning behind the illustration of the likelihood of flooding (shown in figure F4.1) and includes the critical defences.

Most of the areas likely to flood are marshes and farmland. However, certain established settlements and key features also fall within flood compartments. Sections of the A149 are liable to flooding within compartments NN21, NN20, NN18, NN19, NN13, N11 NN8 and NN07. Also, certain urban areas are within flood zones:

- Holme-next-the-Sea (NN02)
- Brancaster Staithe (NN04 - NN06)
- Wells-next-the-Sea (NN13)
- Stiffkey (NN14)
- Morston (NN15)
- Blakeney (NN17 and NN18)
- Cley-next-the-Sea (NN18 and NN20).

### F4.3.2 Likelihood of flooding in 2024 under NAI

Generally, the condition of the front-line defences varies between grade 5 (including Hunstanton to Brancaster, Burnham Overy Staithe and Cley-next-the-Sea) and grade 4 (including Deepdale marsh and Norton marsh), with the exception of a grade 2 defence at Wells harbour channel (see figure F4.1).

Figure F4.1 also illustrates that the maximum potential tidal flood extent is slightly larger than the present day tidal flood zone. The increase in the tidal flood zone is relatively small due to the rapid increase in land level. The likelihood of flooding in compartment NN012 might be affected by nearby compartments NN10 and NN11.

The calculation of the likelihood of flooding of compartments is recorded in table F4.5.

### F4.3.3 Likelihood of flooding in 2054 under NAI

By 2054, nearly all the flood defences are in grade 5 condition under NAI, as illustrated in figure F4.1. Table F4.6 shows the reasoning for the likelihood of flooding.

The increase in the tidal flood zone is still relatively small. However, this small increase is likely to affect the populated areas of Holme-next-the-Sea, Thornham, Brancaster, Brancaster Staithe, Burnham Market, west Wells-next-the-Sea, Stiffkey and Blakeney.

### F4.3.4 Likelihood of flooding in 2105 under NAI

The likelihood of flooding is the same as in 2054 (see figure F4.1) as the defences were already in condition 5. Table F4.7 summarises the calculation and defences considered.

The increase in the tidal flood zone is relatively larger in comparison to previous epochs. This increase will extend flood risk in the particularly vulnerable urban areas previously mentioned.

### F4.3.5 Properties at flood risk

Table F4.3 indicates the predicted number of residential and commercial properties in the tidal flood zone likely to be affected, without taking into account the likelihood of flooding. As the tidal flood zone increases from present day to epoch 3, so does the number of properties at risk.

**Table F4.3: Predicted number of residential and commercial properties in the tidal flood zone**

| Flood cell | All properties | | | | Residential properties | | | | Commercial and other properties | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Present day | 2025 | 2055 | 2105 | Present day | 2025 | 2055 | 2105 | Present day | 2025 | 2055 | 2105 |
| Hunstanton to Holme | 77 | 120 | 154 | 229 | 38 | 75 | 108 | 175 | 39 | 45 | 46 | 54 |
| Thornham | 2 | 3 | 5 | 8 | 2 | 3 | 5 | 8 | 0 | 0 | 0 | 0 |
| Titchwell to Brancaster | 20 | 29 | 34 | 43 | 3 | 6 | 8 | 24 | 17 | 23 | 26 | 19 |
| Brancaster golf club | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| Brancaster and Brancaster Staithe | 63 | 89 | 99 | 140 | 39 | 63 | 72 | 107 | 24 | 26 | 27 | 33 |
| Burnham Deepdale and Burnham Norton | 26 | 27 | 29 | 38 | 26 | 27 | 28 | 35 | 0 | 0 | 1 | 3 |
| River Burn valley | 38 | 40 | 44 | 83 | 35 | 37 | 41 | 73 | 3 | 3 | 3 | 10 |
| Burnham Overy Staithe | 22 | 22 | 22 | 36 | 22 | 22 | 22 | 33 | 0 | 0 | 0 | 3 |
| Overy marshes | 86 | 97 | 106 | 114 | 61 | 67 | 74 | 79 | 25 | 30 | 32 | 35 |
| Wells quay | 62 | 98 | 116 | 130 | 34 | 61 | 68 | 77 | 28 | 37 | 48 | 53 |
| Wells east | 151 | 192 | 209 | 235 | 123 | 161 | 174 | 199 | 28 | 31 | 35 | 36 |
| Stiffkey to Morston | 59 | 61 | 65 | 90 | 52 | 54 | 57 | 78 | 7 | 7 | 8 | 12 |
| Blakeney quay | 27 | 46 | 65 | 79 | 15 | 27 | 37 | 45 | 12 | 19 | 28 | 34 |
| Blakeney Freshes | 0 | 3 | 3 | 6 | 0 | 1 | 1 | 4 | 0 | 2 | 2 | 2 |
| River Glaven valley | 164 | 180 | 189 | 221 | 137 | 147 | 156 | 177 | 27 | 33 | 33 | 44 |
| Cley and Salthouse marshes | 20 | 35 | 35 | 55 | 16 | 31 | 31 | 48 | 4 | 4 | 4 | 7 |
| **Totals** | **818** | **1,043** | **1,176** | **1,508** | **603** | **782** | **882** | **1,162** | **215** | **261** | **294** | **346** |

## F4.4 Conclusions

The approach taken in this task maintains the practical and transparent values promoted by the SMP guidance. In epoch 1 (present day to 2025), there is a dramatic change in the likelihood of flooding with many of the defences deteriorating to grades 4 and 5. In epoch 2 (2026 to 2055) there are subtle changes in the likelihood of flooding with the risk within compartments varying from high to very high. In epoch 3 (2056 to 2105) the likelihood of flooding does not change and remains very high.

Despite the dramatic change in likelihood of flooding, the tidal flood zones have a relatively small increase from present day to 2105 due to the rapid increase in land level. Compartments NN01 and NN02 (Old Hunstanton to Thornham) show the largest increase in the tidal flood zone area.

These results show that the defences along the north Norfolk coast protect large areas of marshland and small areas with people, properties, infrastructure and cultural heritage along the edge of marshes, coastline and rivers. These findings will be taken into account in the policy appraisal.

## F4.5 Detailed results

**Table F4.4: Present day likelihood of flooding**

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN01 | 4 | DEF_1_002, DEF_1_003 | High | |
| NN02 | 4 | DEF_1_045, DEF_1_047 | High | |
| NN02a | 4 | DEF_1_059c | High | |
| NN03 | 3 | DEF_1_065 | Medium | |
| NN03a | 3 | DEF_1_062, DEF_1_063, DEF_1_064b, DEF_1_065 | Medium | |
| NN04 | 4 | DEF_1_067 | High | There is a gap at the seaward defence line. However Lidar indicates raised ground at the gap |
| NN05 | 3 | DEF_1_069 | Medium | The critical defence limits a small area of the east corner of the compartment |
| NN06 | 4 | DEF_1_071 | High | |
| NN07 | 2 | DEF_1_073, DEF_1_074, DEF_1_076 | Low | |
| NN08 | 3 | DEF_1_077 | Medium | Decision on flooding likelihood depends on a small section of the compartment limited by DEF_1_077 |
| NN09 | 3 | DEF_1_077, DEF_1_078, DEF_1_079, DEF_1_081 | Medium | |
| NN10 | 3 | DEF_1_081, DEF_1_082, DEF_1_083 | Medium | |
| NN11 | 3 | DEF_1_083, DEF_1_091 | Medium | DEF_1_091 protects the eastern corner of the compartment from the harbour |
| NN12 | 2 | DEF_1_086, DEF_1_087, DEF_1_088, | Low | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| | | DEF_1_090 | | |
| NN13 | 2 | DEF_1_092, DEF_1_093 | Low | |
| NN14 | 2 | DEF_1_094 | Low | |
| NN15 | 3 | DEF_1_096, DEF_1_097, DEF_1_098 | Medium | |
| NN16 | 3 | DEF_1_098 | Medium | The eastern seaward corner is not limited by defences |
| NN17 | 3 | DEF_1_099, DEF_1_100, DEF_1_101, DEF_1_102, DEF_1_105, DEF_1_113 | Medium | |
| NN18 | 4 | DEF_1_109 | Medium | The defence limiting the compartment is a secondary defence. Likelihood of flooding can only be lower than the front-line compartments NN17, NN19 and NN20 |
| NN19 | 4 | DEF_1_109 | Medium | Critical defence is a secondary defence so flooding likelihood does not depend on it |
| NN20 | 4 | DEF_1_109 | Medium | Critical defence is a secondary defence so flooding likelihood does not depend on it |
| NN21 | 3 | DEF_1_116 | Medium | |

**Table F4.5: 2024 likelihood of flooding**

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN01 | 5 | DEF_1_002, DEF_1_003, DEF_1_004, DEF_1_042 | Very high | |
| NN02 | 5 | DEF_1_044, DEF_1_045, DEF_1_047, DEF_1_048, DEF_1_049, DEF_1_053, DEF_1_055, DEF_1_056, DEF_1_057, DEF_1_058, DEF_1_059 | Very high | |
| NN02a | 5 | DEF_1_059a, DEF_1_059b, DEF_1_059c, DEF_1_059d, DEF_1_059e, DEF_1_059f | Very high | |
| NN03 | 5 | DEF_1_065 | Very high | |
| NN03a | 5 | DEF_1_062, DEF_1_063, DEF_1_064b, DEF_1_065 | Very high | |
| NN04 | 5 | DEF_1_066, DEF_1_067, DEF_1_068, DEF_1_069 | Very high | There is a gap at the defence frontages. However, Lidar indicates that the gap is raised ground |
| NN05 | 4 | DEF_1_069, DEF_1_070 | Very high | The critical defence limits a small area of the east corner of the compartment |
| NN06 | 5 | DEF_1_070, DEF_1_071 | Very high | |
| NN07 | 4 | DEF_1_073, DEF_1_074, DEF_1_076 | High | |
| NN08 | 5 | DEF_1_077 | Very high | Decision on flooding likelihood depends on a small section of the compartment limited by a grade 4 defence |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN09 | 5 | DEF_1_077, DEF_1_078, DEF_1_079, DEF_1_081 | Very high | |
| NN10 | 5 | DEF_1_081, DEF_1_081a, DEF_1_082, DEF_1_07183 | Very high | |
| NN11 | 5 | DEF_1_083, DEF_1_091 | Very high | DEF_1_091 protects the eastern corner of the compartment from the harbour |
| NN12 | 4 | DEF_1_086, DEF_1_087, DEF_1_088, DEF_1_090 | High | |
| NN13 | 4 | DEF_1_092, DEF_1_094 | High | |
| NN14 | 4 | DEF_1_094 | High | |
| NN15 | 5 | DEF_1_096, DEF_1_007, DEF_1_098 | Very high | |
| NN16 | 5 | DEF_1_098 | Very high | The eastern seaward corner is not limited by defences |
| NN17 | 5 | DEF_1_099, DEF_1_100, DEF_1_101, DEF_1_102, DEF_1_105, DEF_1_113 | Very high | |
| NN18 | 5 | DEF_1_109 | Very high | The defence limiting the compartment is a secondary defence. Likelihood of flooding can only be lower than the front-line compartments NN17, NN19 and NN20 |
| NN19 | 5 | DEF_1_105, DEF_1_109, DEF_1_113, DEF_1_114, DEF_1_115, DEF_1_116 | Very high | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN20 | 5 | DEF_1_108, DEF_1_109, DEF_1_113, DEF_1_114, DEF_1_115, DEF_1_116 | Very high | |
| NN21 | 5 | DEF_1_116 | Very high | |

**Table F4.6: 2054 likelihood of flooding**

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN01 | 5 | DEF_1_002, DEF_1_003, DEF_1_004, DEF_1_042, DEF_1_043 | Very high | |
| NN02 | 5 | DEF_1_044, DEF_1_045, DEF_1_046, DEF_1_047, DEF_1_048, DEF_1_049, DEF_1_050, DEF_1_051, DEF_1_052, DEF_1_053, DEF_1_054, DEF_1_055, DEF_1_056, DEF_1_057, DEF_1_058, DEF_1_059 | Very high | |
| NN02a | 5 | DEF_1_059a, DEF_1_059b, DEF_1_059c, DEF_1_059d, DEF_1_059e, DEF_1_059f | Very high | |
| NN03 | 5 | DEF_1_060, DEF_1_061, DEF_1_065 | Very high | |
| NN03a | 5 | DEF_1_062, DEF_1_063, DEF_1_064, DEF_1_064a, DEF_1_064b, DEF_1_065 | Very high | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN04 | 5 | DEF_1_066, DEF_1_067, DEF_1_068, DEF_1_069 | Very high | There is a gap at the defence frontages. However, lidar indicates that the gap is raised ground |
| NN05 | 5 | DEF_1_069, DEF_1_070 | Very high | |
| NN06 | 5 | DEF_1_070, DEF_1_071 | Very high | |
| NN07 | 5 | DEF_1_073, DEF_1_074, DEF_1_076 | Very high | |
| NN08 | 5 | DEF_1_074, DEF_1_075, DEF_1_076, DEF_1_077 | Very high | |
| NN09 | 5 | DEF_1_077, DEF_1_078, DEF_1_079, DEF_1_080, DEF_1_081 | Very high | |
| NN10 | 5 | DEF_1_080, DEF_1_081, DEF_1_081a, DEF_1_082, DEF_1_083 | Very high | |
| NN11 | 5 | DEF_1_083, DEF_1_086, DEF_1_089, DEF_1_090, DEF_1_091 | Very high | |
| NN12 | 5 | DEF_1_086, DEF_1_087, DEF_1_088, DEF_1_089, DEF_1_090 | Very high | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN13 | 5 | DEF_1_092, DEF_1_093 | Very high | |
| NN14 | 5 | DEF_1_094 | Very high | |
| NN15 | 5 | DEF_1_096, DEF_1_097, DEF_1_098 | Very high | |
| NN16 | 5 | DEF_1_098 | Very high | The eastern seaward corner is not limited by defences |
| NN17 | 5 | DEF_1_099, DEF_1_100, DEF_1_101, DEF_1_102, DEF_1_103, DEF_1_104, DEF_1_105, DEF_1_106, DEF_1_107, DEF_1_108, DEF_1_113 | Very high | |
| NN18 | 5 | DEF_1_107, DEF_1_108, DEF_1_109 | Very high | |
| NN19 | 5 | DEF_1_105, DEF_1_106, DEF_1_107, DEF_1_108, DEF_1_109, DEF_1_110, DEF_1_111, DEF_1_112, DEF_1_113, DEF_1_114 | Very high | |
| NN20 | 5 | DEF_1_108, DEF_1_109, DEF_1_110, DEF_1_111, DEF_1_112, DEF_1_113, DEF_1_114, DEF_1_115, DEF_1_116 | Very high | |
| NN21 | 5 | DEF_1_116 | Very high | |

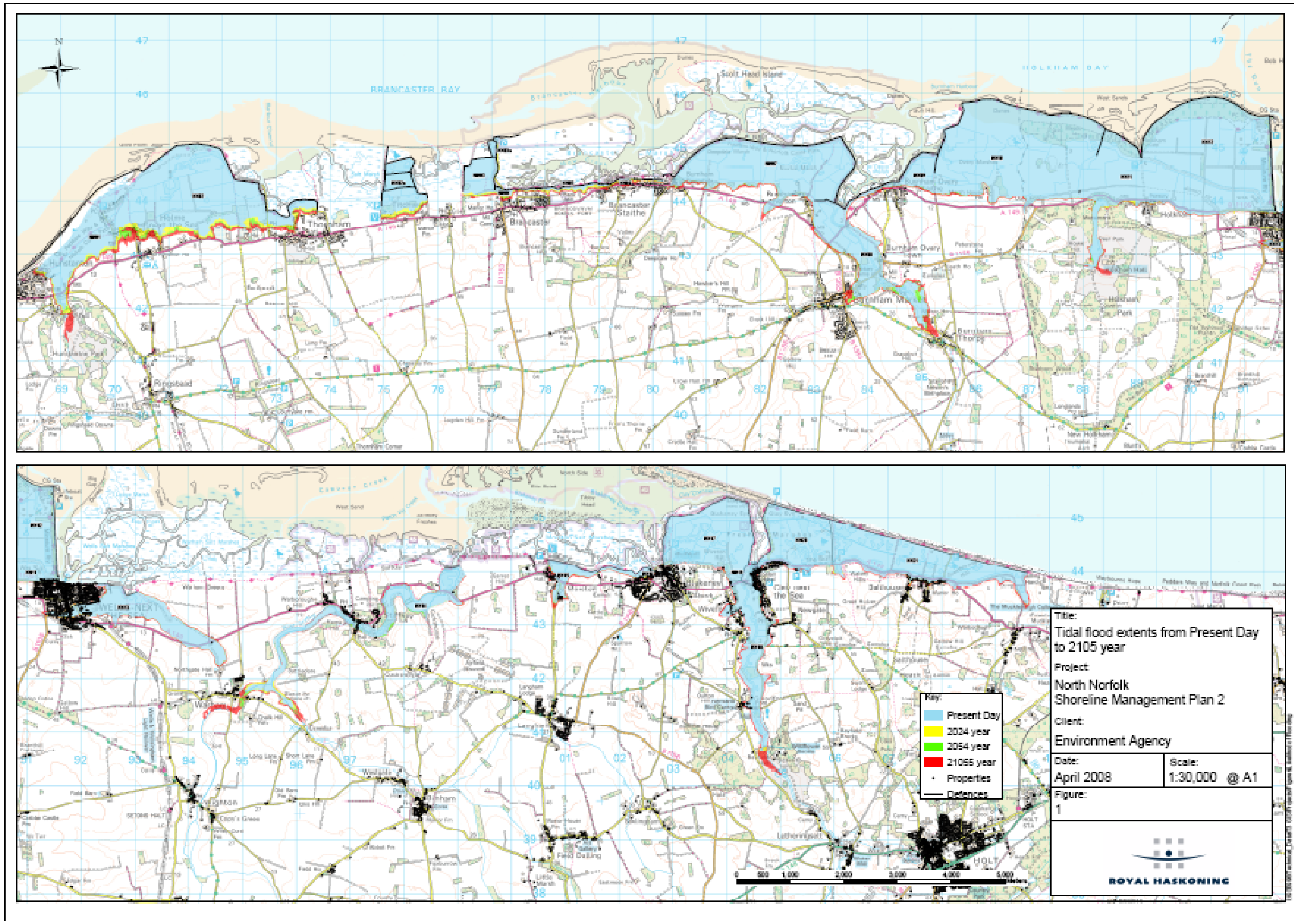
**Table F4.7: 2105 likelihood of flooding**

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN01 | 5 | DEF_1_002, DEF_1_003, DEF_1_004, DEF_1_042, DEF_1_043 | Very high | |
| NN02 | 5 | DEF_1_044, DEF_1_045, DEF_1_046, DEF_1_047, DEF_1_048, DEF_1_049, DEF_1_050, DEF_1_051, DEF_1_052, DEF_1_053, DEF_1_054, DEF_1_055, DEF_1_056, DEF_1_057, DEF_1_058, DEF_1_059 | Very high | |
| NN02a | 5 | DEF_1_059a, DEF_1_059b, DEF_1_059c, DEF_1_059d, DEF_1_059e, DEF_1_059f | Very high | |
| NN03 | 5 | DEF_1_060, DEF_1_061, DEF_1_065 | Very high | |
| NN03a | 5 | DEF_1_062, DEF_1_063, DEF_1_064, DEF_1_064a, DEF_1_064b, DEF_1_065 | Very high | |
| NN04 | 5 | DEF_1_066, DEF_1_067, DEF_1_068, DEF_1_069 | Very high | There is a gap at the defence frontages. However, lidar indicates that the gap is raised ground |
| NN05 | 5 | DEF_1_069, DEF_1_070 | Very high | |
| NN06 | 5 | DEF_1_070, DEF_1_071 | Very high | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| NN07 | 5 | DEF_1_073, DEF_1_074, DEF_1_076 | Very high | |
| NN08 | 5 | DEF_1_074, DEF_1_075, DEF_1_076, DEF_1_077 | Very high | |
| NN09 | 5 | DEF_1_077, DEF_1_078, DEF_1_079, DEF_1_080, DEF_1_081 | Very high | |
| NN10 | 5 | DEF_1_080, DEF_1_081, DEF_1_081a, DEF_1_082, DEF_1_083 | Very high | |
| NN11 | 5 | DEF_1_083, DEF_1_086, DEF_1_089, DEF_1_090, DEF_1_091 | Very high | |
| NN12 | 5 | DEF_1_086, DEF_1_087, DEF_1_088, DEF_1_089, DEF_1_090 | Very high | |
| NN13 | 5 | DEF_1_092, DEF_1_093 | Very high | |
| NN14 | 5 | DEF_1_094 | Very high | |
| NN15 | 5 | DEF_1_096, DEF_1_097, DEF_1_098 | Very high | |
| NN16 | 5 | DEF_1_098 | Very high | The eastern seaward corner is not limited by defences |
| NN17 | 5 | DEF_1_099, DEF_1_100, DEF_1_101, DEF_1_102, DEF_1_103, DEF_1_104, DEF_1_105, DEF_1_106, DEF_1_107, DEF_1_108, | Very high | |

| Compartment name | Worst condition of defences | Critical defence IDs | Likelihood of flooding | Comments |
|---|---|---|---|---|
| | | DEF_1_113 | | |
| NN18 | 5 | DEF_1_107, DEF_1_108, DEF_1_109 | Very high | |
| NN19 | 5 | DEF_1_105, DEF_1_106, DEF_1_107, DEF_1_108, DEF_1_109, DEF_1_110, DEF_1_111, DEF_1_112, DEF_1_113, DEF_1_114 | Very high | |
| NN20 | 5 | DEF_1_108, DEF_1_109, DEF_1_110, DEF_1_111, DEF_1_112, DEF_1_113, DEF_1_114, DEF_1_115, DEF_1_116 | Very high | |
| NN21 | 5 | DEF_1_116 | Very high | |

## Figure F4.1: Predicted change of flood extent in epochs 1, 2 and 3



# F5 Erosion risk

## F5.1 Introduction

The aim of this task is to identify the erosion risk along the north Norfolk coastline. This section will summarise each frontage in terms of the assets at risk at the end of each epoch.

Within this task there will be two activities. These are mainly based on the outcomes of the assessment of baseline scenarios previously formulated for the SMP (see section F3 of this appendix):

- Derivation of assets at risk for the ‘no active intervention’ (NAI) scenario.
- Demonstration of the above through mapping the assets at risk.

The NAI scenario will discuss the assets at risk from erosion during the three epochs:  epoch 1 (present day to 2025), epoch 2 (2026 to 2055) and epoch 3 (2056 to 2105).

The ‘with present management’ scenario is not included in the analysis of assets at risk from erosion as it is assumed that present management will ensure that the assets are suitably protected from erosion risk up to the end of epoch 3 (that is, 2105).

As with the derivation of areas and assets at flood risk (section F4 of this appendix), the North Norfolk SMP has developed an alternative approach from the SMP guidance to ascertain the assets at risk from both flooding and erosion. The outcome consists of maps showing how the likelihood of flooding and erosion varies in space and in time.

## F5.2 Approach

### F5.2.1 Overview

Using the outcomes of the baseline scenarios report (section F3 of this appendix), which provided the predicted future shoreline position at the end of the three epochs, the assets at risk from erosion at the end of each epoch could be identified.

This section will illustrate this by mapping the assets at risk and in which epoch they are vulnerable. Results are presented in a series of maps for each frontage.

For those frontages where there seem to be no assets at risk from erosion, the predicted shoreline evolution can be seen in the baseline scenarios analysis, see section F3 of this appendix.

It is important to stress here that the predicted future shoreline evolution put forward in the baseline scenarios assessment includes a degree of uncertainty that increases into the later epochs. As this assessment of erosion risk is based on these best estimates, it will also carry a degree of uncertainty, which will also increase into the later epochs.

## F5.3 Super-frontage 1 (frontages A and B)

### F5.3.1 Frontage A

This frontage comprises mainly of the Old Hunstanton dunes frontage. Erosion risk along this frontage comes from rollback of the natural dune system. The assets at risk from erosion are illustrated in figure F5.1.

Epoch 1
The assumed erosion rates indicate that, during epoch 1 (present day to 2025), the beach huts behind the dunes at Old Hunstanton are at risk from coastal erosion under no active intervention.

Epoch 2
No additional assets at risk from erosion.

Epoch 3
Under no active intervention, the houses in front of the Golf Course Road would be at risk from erosion between 2055 and 2105. Also, the golf links clubhouse would be at risk from erosion during this epoch with subsequent effects on the use of the golf course itself.

### F5.3.2 Frontage B

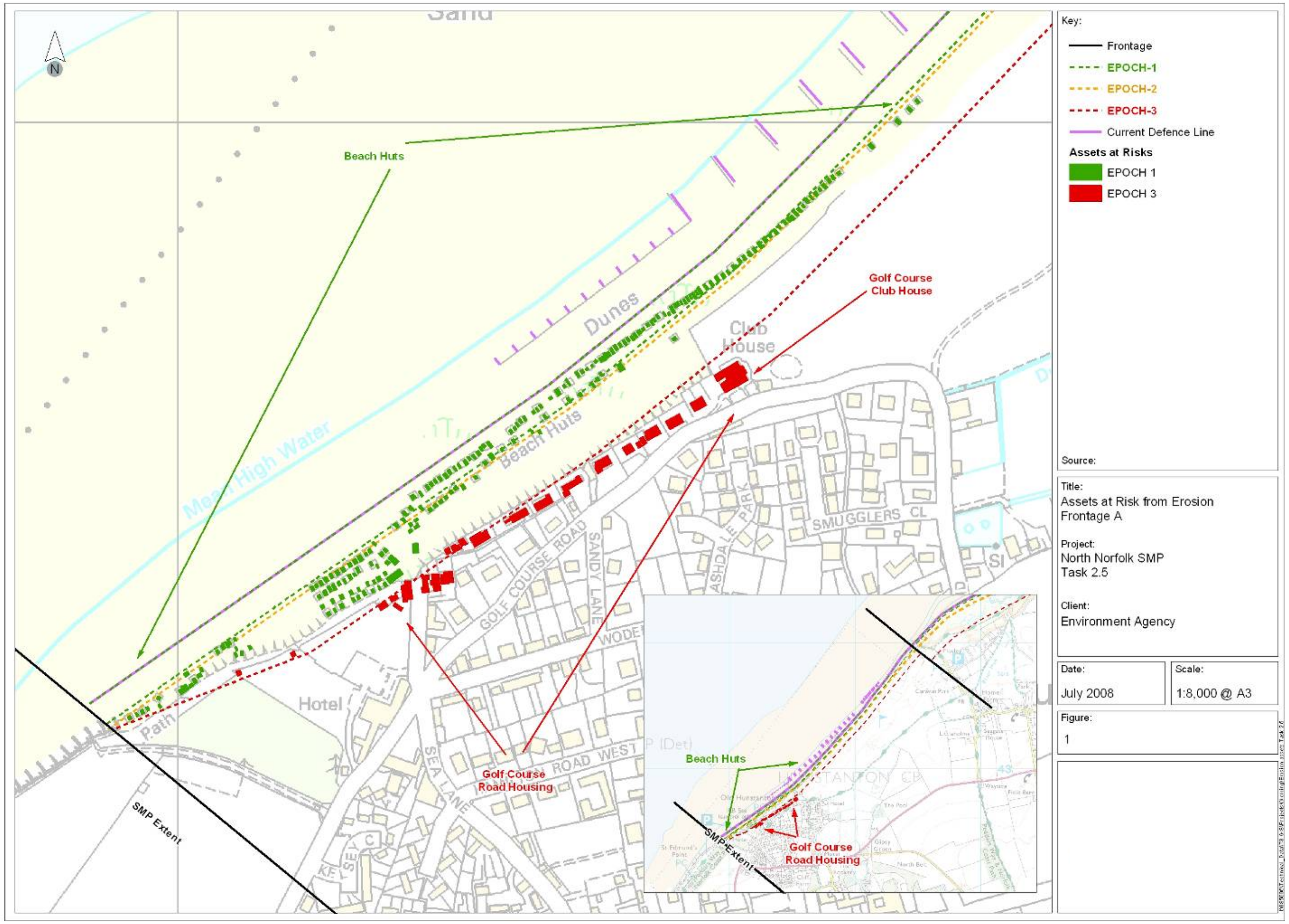
This frontage runs from Holme-next-the-Sea to Thornham. As with frontage A, erosion risk along this frontage comes from rollback of the natural dune line. Highlighted assets at risk are shown in figure F5.2.

Epoch 1
No assets at risk from erosion.

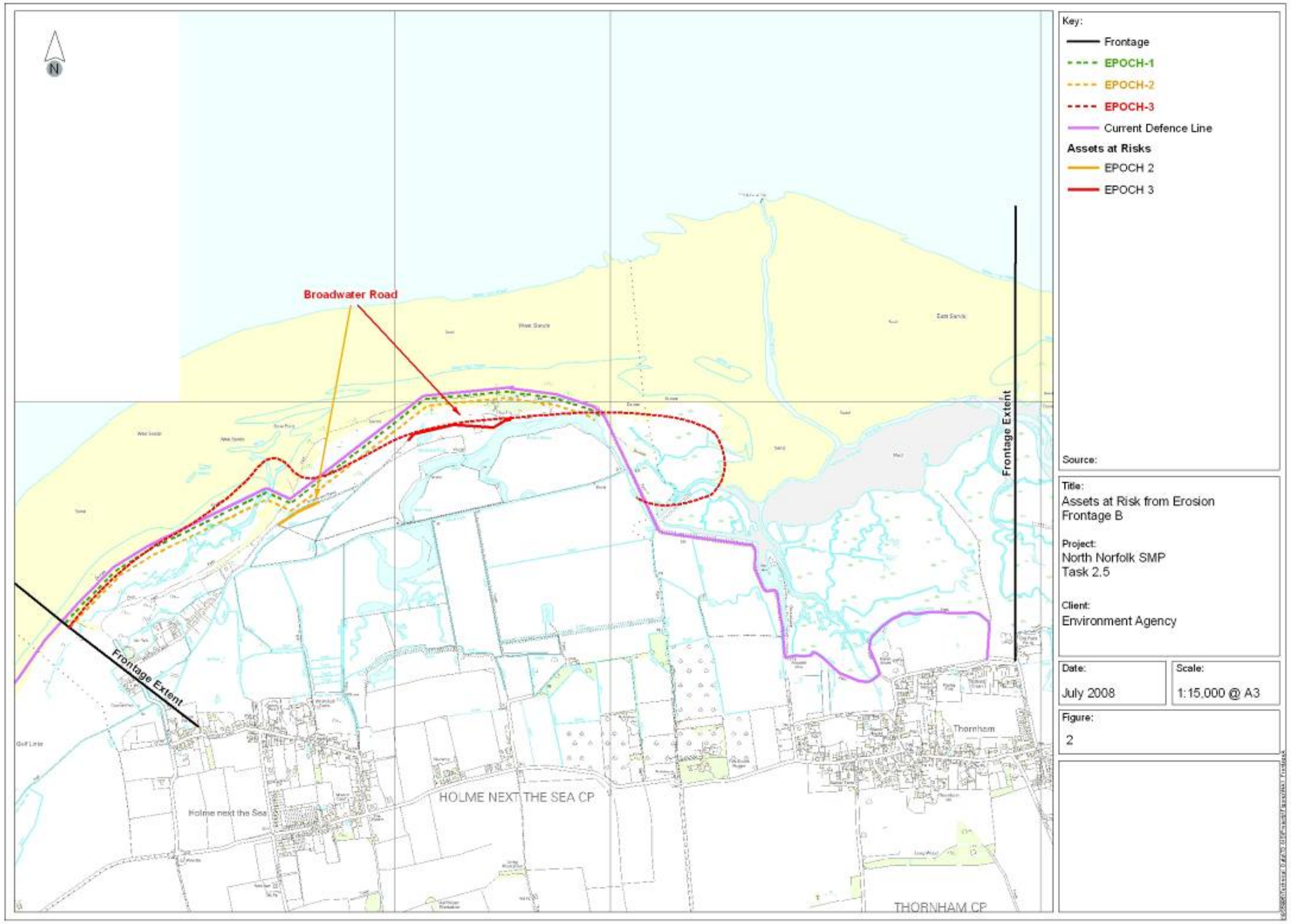
Epoch 2
There is a section of Broadwater Road that would be at risk from erosion during epoch 2. This could inhibit access to the Holme Nature Reserve and the beach.

Epoch 3
Erosion risk during the final epoch could cut off a section of Broadwater Road and stretches of the coastal footpath. This could restrict access to The Firs, part of the Holme Nature Reserve, where there is a popular visitor centre and car park managed by the Norfolk Wildlife Trust. This is not at risk from erosion.

## Figure F5.1 Frontage A assets at risk from erosion



## Figure F5.2 Frontage B assets at risk from erosion



# F5.4 Super-frontage 2 (frontages C to F)

## F5.4.1 Frontage C

Frontage C covers the length of Brancaster bay. As with frontages A and B, erosion risk along this frontage comes from rollback of the natural dune line. The location of the frontage and the assets at risk from erosion are shown in figure F5.3.

<u>Epoch 1</u>
No assets at risk from erosion.

<u>Epoch 2</u>
Under no active intervention, the Royal West Norfolk golf club is at risk from erosion within the next 50 years. This is based on present erosion rates and residual life of the defences currently estimated between 20 and 35 years.

<u>Epoch 3</u>
Epoch 3 could threaten the Titchwell RSPB reserve area of fresh water. This could reduce the tourist value of the area as some visitors travel a long way to visit this reserve.

## F5.4.2 Frontage D

This frontage covers the area known as Scolt Head Island. The baseline scenarios assessment has detailed maps of the frontage boundaries. This frontage has a high level of flood risk following failure of the existing sea banks and inundation of the former reclaimed areas. However, there are no erosion-specific processes occurring along this frontage so there are no assets at risk from erosion.

## F5.4.3 Frontage E

This frontage covers Holkham bay. As with frontages A to C, the risk from erosion is brought about by rollback of the natural dune line.

<u>Epoch 1</u>
Under no active intervention, Wells-next-the-Sea could lose its coastguard look-out, lifeboat house and beach huts from coastal erosion during this epoch. These assets are shown in figure F5.4 with a focus on the area where the assets are located.

<u>Epoch 2</u>
No additional assets at risk from erosion.

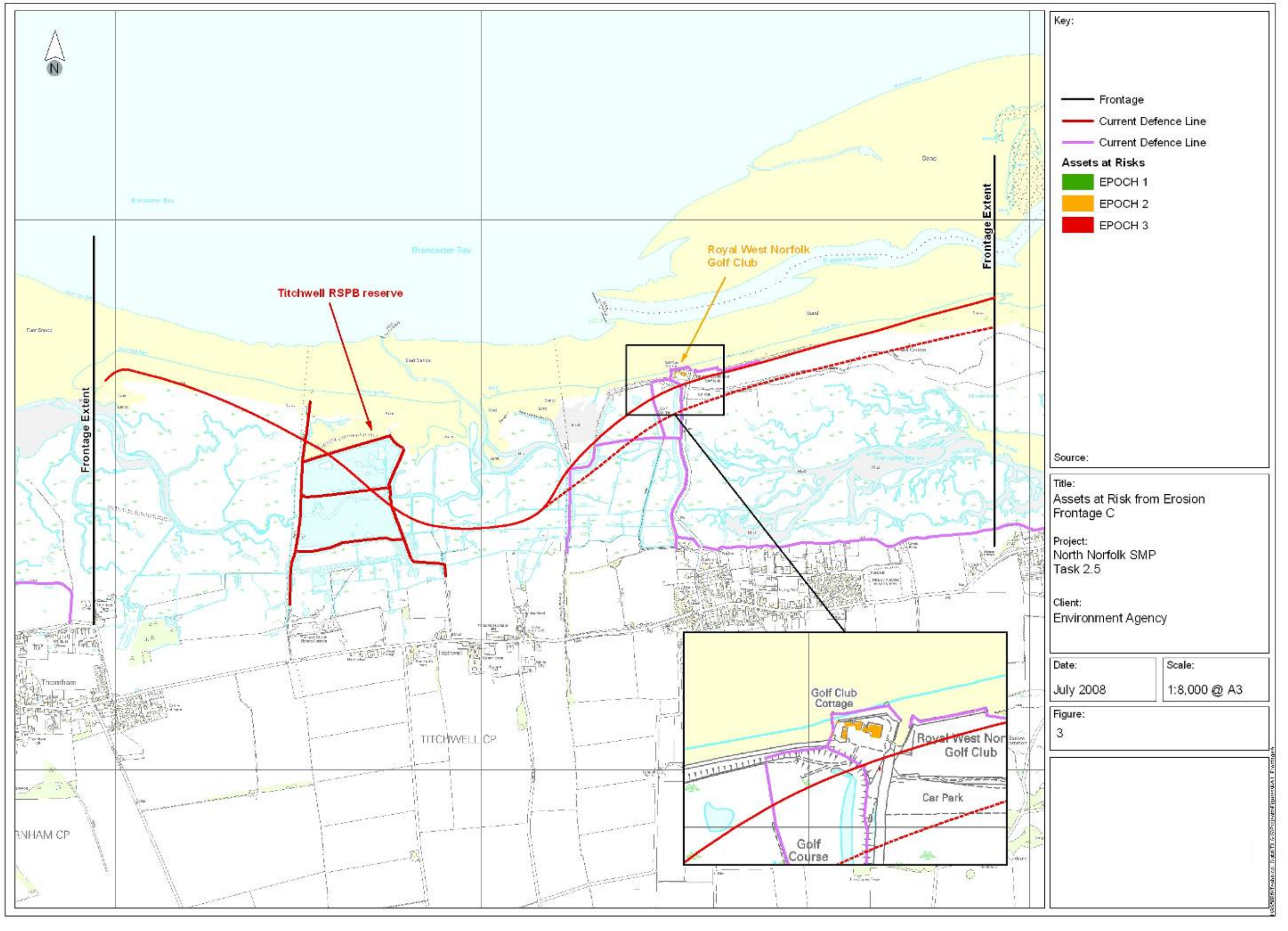
Epoch 3

This epoch holds the additional risk of losing Holkham Gap car park as well as the boating lake and Wells Beach Road car park. This would consequently affect the amenities associated with the car park area, such as the café and toilets.

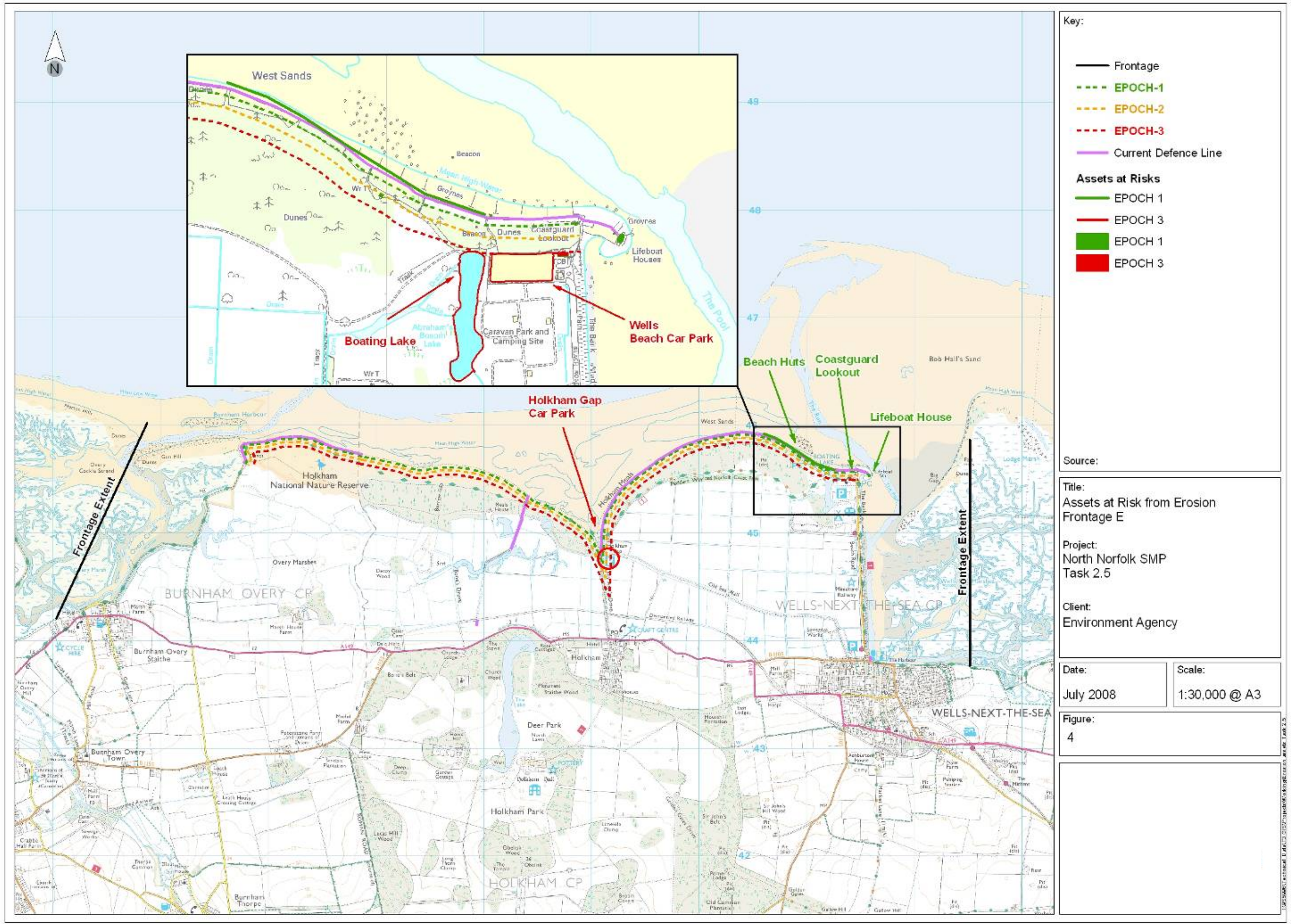
### F5.4.4 Frontage F

This frontage comprises the Warham and Stiffkey marshes coastline. Although this frontage will be characterised by loss of saltmarsh due to erosion at the seaward edge of the saltmarsh, there are no assets at risk from this erosion in any epochs. The baseline scenarios assessment provides detailed maps of the predicted shoreline evolution over the three epochs.

## Figure F5.3 Frontage C assets at risk from erosion



## Figure F5.4 Frontage E assets at risk from erosion



## F5.5 Super-frontage 3 (frontages G and H*)*

### F5.5.1 Frontage G

Frontage G mainly comprises Blakeney Point spit and the area behind it. This frontage is at risk from flooding following defence failure and inundation of the former reclaimed areas. However, there are no assets at risk from coastal erosion.

### F5.5.2 Frontage H

The final frontage begins at Cley-next-the-Sea and completes the North Norfolk SMP frontage at Kelling Hard, including the village of Salthouse. Erosion risk along this frontage will be brought about by rollback and collapse of the shingle ridge as detailed in the baseline scenarios assessment. Figure F5.5 below shows the locations of the assets and the epoch that they are likely to fail.

<u>Epoch 1</u>
Under no active intervention, Beach Road car park at Salthouse is at risk from loss due to coastal erosion within the next 20 years at present rates of erosion.

<u>Epoch 2</u>
The Cley-next-the-Sea coastguard look-out and the nature reserve hides at Cley Eye would be lost from coastal erosion under no active intervention.

<u>Epoch 3</u>
No additional assets at risk from erosion.

## F5.6 Conclusion

As indicated above, it is clear that there are a number of assets at risk from coastal erosion along the north Norfolk coastline from Old Hunstanton to Kelling Hard. Figures F5.1 to F5.5 highlight those assets believed to be at risk due to coastal erosion and the epoch that this is likely to occur. These findings will be taken into account in policy appraisal in stage 3 of the SMP.

## Figure F5.5 Frontage H assets at risk from erosion