Kelling to Lowestoft Ness Shoreline Management Plan

Appendix C: Baseline Process Understanding

Contents

C1 Assessment of Shoreline Dynamics

C1.1 INTRODUCTION

This report should be viewed as supplementary to information held within Futurecoast[1] and more specifically the Shoreline Behaviour Statements for the following areas:

- Weybourne to Happisburgh
- Happisburgh to Winterton
- Winterton to Benacre Ness

It contains relevant information produced post Futurecoast or at a level of detail not included within Futurecoast e.g. alongshore variations in sediment transport rates. The two must be read in conjunction with one another to provide a full understanding of dynamics and behaviour across different spatial and temporal scales.

---

[1] Futurecoast was a Defra-commissioned project to look at future coastal evolution around the coast of England and Wales. Further details are available on the Defra website.

C1.2 OVERVIEW

The coastline between Weybourne and Lowestoft has been retreating and changing in orientation over the last millennia in response to sea level rise and the large-scale drowning of the North Sea basin since the last glaciation. The rate of recession has been slowed by the construction and maintenance of coastal defences, which means that much of the coast is not commensurate with the shoreline energy conditions, which has implications for future shoreline management. Foreshore steepening is a prevalent feature of beaches throughout the frontage and this characteristic has been exacerbated by the coastal defences. Along much of the coast, the beach is a veneer on top of a clay platform, which can be easily eroded when the beach is stripped during storms.

The coastline is characterised by cliffs of varying composition and height between Weybourne and Happisburgh, a narrow dune field between Happisburgh and Winterton, which fronts an extensive flood risk area, and a second section of cliffs between Winterton and Lowestoft. As a result of a range of cliff failure processes (the type of failure being dependent upon the local geology), the cliffline has been shaped into a series of steep to near-vertical cliffs and undercliffs, but in places the cliffs have been regraded, e.g. infront of the main conurbations. Nesses and spits are also a characteristic feature of the shoreline, which suggests that this is a drift-dominated system.

The nearshore and offshore zones are characterised by shoals and sand banks, which also have an influence on coastal exposure and wave patterns. This results in complex sediment transport patterns in the nearshore zone and also has an impact on alongshore transport. This is particularly important between Great Yarmouth and Lowestoft, where the system of nearshore banks are present. The future changes in bank position are very uncertain and therefore for the SMP analysis it has been assumed that the banks remain in their current configuration.

Key sources of sediment are from cliff erosion and beach erosion, which are believed to contribute up to 0.8 M tonnes per year and to 0.665 M tonnes per year respectively (Balson, 1999; McCave, 1978). There are also interactions between the offshore, nearshore and beach zones, which still remain poorly understood or quantified, despite the recent work as part of the Southern North Sea Sediment Transport Study (2002). It has been speculated that the offshore bank system is a long-term sink of sediment (ABP, 1996), which will be mostly sand-sized. Tidal currents tend to sweep the bed clean of fines and there is a large, eastwards plume carrying suspended sediment offshore in this area (ABP, 1996, Dyer and Moffatt, 1998). A large proportion of the sediment supplied by the North Norfolk cliffs is fined-grained which tends to be immediately washed offshore (McCave, 1978). It is estimated that 45% of material is lost in this way (UEA, 1971).

The coast is extremely exposed and therefore very dynamic, with large storm events dramatically changing the beach level and resulting in changes in exposure to backshore elements, either natural, such as dunes, or artificial, such as seawalls. The alongshore drift rates are also dependent upon the varying degrees of exposure along the shoreline – these variations are due to both changes in coastal orientation and the presence of offshore sand banks (which are discussed in more detail below). In broad terms, the drift rates increase from Kelling to Happisburgh, where rates are greatest, then decrease again down to Lowestoft (SNSSTS, 2001). Strong tidal currents also play an important role along this coastline; these are mainly shore-parallel but are affected by the offshore banks. Analysis by HR Wallingford along the Cromer to Overstrand frontage determined that these currents alone are strong enough to transport large volumes of sediment, up to the size of small gravel and therefore under the combined effect of wave agitation play an important role in sediment transport. HR Wallingford (Strategy Studies, 2001 – 2003) identified that a particular feature of this shoreline is that the strongest tidal currents occur about high water during an exceptionally high tide, which will also occur during storm surges. During storm surges the predominant wave direction is from the north or north-west, which creates large waves along this frontage. This combination of events occurs a number of times during a winter and is responsible for the winter flattening of the beach profile and beach stripping.

C1.3 KELLING HARD TO CROMER

LARGE SCALE

Interactions:

A key control on evolution of this stretch of coast is the cliffed nature of the shoreline (Futurecoast, 2002). Although unconsolidated, the cliffs provide some resistance to erosion, particularly in the vicinity of Cromer, where chalk outcrops.

The change in coastal orientation at Cromer means that the degree of exposure differs from the shoreline to the south of Cromer. Here waves are predominately from the north-east, whereas on the east-facing coast, waves shift to a more easterly direction. This directly affects the alongshore transport rates and also the exposure to certain storm conditions.

An important characteristic of this shoreline is the alongshore drift divide (termed statistical null point; SNSSTS, 2002). This means that sediment is moved both westwards and eastwards; eastward drift is low, but increases towards the west (SNSSTS, 2002). Studies have shown an increasingly statistical preference for material to drift west from the west of Cromer and a corresponding but more dominant tendency for eastward drift from the east of Sheringham. The position of the null point is not static as it depends upon the wave conditions, which vary in time, but is believed to be located between Weybourne and Sheringham (SNSSTS, 2002).

It has been estimated that approximately 10,000 to 15,000 m^3/year of sand and the same volume of shingle are transported westwards from Weybourne (SNSSTS, 2002), with the erosion of the beach and cliffs at Weybourne thought (by some) to be an important source of sediment, particularly shingle, for Blakeney Point to the east (not in this SMP area) (Andrews et al., 2000).

Nearshore sediment movement is predominately tidally-driven, and there is a weak eastwards movement in a nearshore stream from the Wash area towards Cromer. Wave stirring tends to enhance this pattern and during storms, waves play a more important role, with surge plots showing a strong west to east sediment flow across the Burnham Flats (to the east of the SMP area) close along the shore towards and past Cromer. This means that during surges, there is a greater supply of sand working along the nearshore stream, with a possibility that this material may supply finer material to the Cromer frontage.

SNSSTS (2002) found there to be little link between the inshore system and the sediment stream further offshore, which suggests that although sediment may be lost from the beaches it is not transported any further offshore.

Key sediment sources are cliff erosion and alongshore drift, with potential of finer material via the nearshore stream, particularly during storm conditions.

Movement:

There has been large-scale erosion of this coastline because the cliffs offer little resistance to erosion and the coast at a very large scale is still responding to the drowning of the North Sea and continued sea level rise since the last glaciation. Further details on evolution of the North Sea are provided in Futurecoast offshore reports.

This long-term retreat has been slowed through the construction of defences, but prior to these the cliffs were retreating at an average rate of 1m/year (Cromer Coastal Strategy Study, 2001). Recession rates can be highly variable over the short-term; Cambers (1976) demonstrated how recession rates between West Runton and East Runton varied from 0 to over 3m in any single year (reported in SNSSTS, 2002).

Foreshore steepening is a prevalent feature of beaches throughout this region (Futurecoast, 2002). It has been postulated that lowering of the foreshore (a sand/shingle beach overlying a chalk bedrock platform) exerts a significant control on the rate of cliff recession and that this process has been increased due to defences restricting the recession (Cromer Coastal Strategy Study, 2001). This limits the extent to which beaches are able to retain additional sediment and prograde (Futurecoast, 2002).

LOCAL SCALE: KELLING HARD TO SHERINGHAM

Interactions:

This section is north facing unlike the remainder of the frontage between Weybourne and Winterton, which means its exposure to waves and storms is slightly different from areas to the east. A review of sediment transport studies (SNSSTS, 2002) found that rates of 160,000 m^3/year (Vincent, 1979) and 200,000 m^3/year (Onyett & Simmonds, 1983; cited in SNSSTS, 2002) westwards have been quoted; these are rates for sand rather than shingle transport and are also potential rather than actual transport. These are much larger rates than quoted for areas to the east. This area does, however, fall within the zone identified for the transport null point (as identified in SNSSTS, 2002), so drift rates vary both in magnitude and direction. It has been suggested (Vincent, 1979) that the increase in drift rates from Weybourne towards Blakeney is due to the decreasing fetches for westerly winds.

This section of cliffs has the highest proportion of shingle for the North Norfolk cliffs, which ranges from 7 to 17%, with sand representing 40 to 50% (BGS, 1996). This stretch therefore represents an important source of shingle, although drift shows that this is distributed both to the east and west, with some of it likely to remain locally.

The beach along this section is largely comprised of shingle, but this does not appear to have affected the trend of steepening, which is apparent along much of this SMP frontage. Despite the feed of sediment from the cliffs, the beaches are not building in this area and Leggett et al. (1998) actually noted an average reduction in beach volumes of 7% in 5 years between Heacham and Cromer, with the erosion increasing from Heacham to Cromer (SNSSTS, 2002).

Movement:

The cliffs are eroding at a gradual rate (North Norfolk SMP, 1996) and in a fairly linear fashion, however this is sometimes exacerbated with occasional slumping events (Futurecoast, 2002).

Net narrowing and steepening of the foreshore has also been taking place, although Ordnance Survey maps show the width of the backshore and foreshore to have fluctuated over the past 100 years (Futurecoast, 2002).

Predictions of shoreline evolution:

These cliffs are highly susceptible to erosion and under continued sea level rise there will be a trend for retreat. Futurecoast (2002) predicted that this would be fairly gradual, with mainly avalanche-type failures occurring, and a net retreat of between 10 and 50m over the next 100 years (assuming an unconstrained coast). The shingle ridge at Weybourne is likely to roll back as the adjoining cliffed frontage erode (North Norfolk SMP, 1996).

LOCAL SCALE: SHERINGHAM

Interactions:

Alongshore transport has been modified through the construction of groynes along this frontage and it has been suggested that an unnatural amount of shingle at Sheringham has been retained (Futurecoast, 2002).

There have been various predictions of sediment transport rates and these are reported in more detail in the SNSSTS (2002). Although some predictions suggest an east to west sediment transport, there is a general consensus that the drift is actually from west to east, although this area still lies within the zone of the statistical null point of sediment transport. A slightly higher rate of potential sediment transport exists to the east of the frontage, as compared to the west, but the actual rate is sediment-limited (SNSSTS, 2002).

Shingle is believed to be predominately sourced from the west, both from cliff erosion and reworking of the beach sediments. The cliffs along this section are sandier, with sand representing over 60% (BGS, 1996). The chalk exposures may also contribute some shingle-sized sediment.

Towards Sheringham the shingle appears to gradually become more of a veneer, suggesting that a limited amount of shingle is being moved into this region. There has recently been a small build up of sand at the toe of the seawall.

There is a high onshore-offshore component of sediment transport and it is likely that sand and finer sediment can be easily mobilised and moved offshore, particularly during storm conditions.

Movement:

The cliffline position has been halted by defences over the last century and the centre of the town now protrudes well seaward of adjacent areas. There has however been retreat of the mean low water line, meaning that there has been net narrowing and steepening of the intertidal zone (SMP3b, 1995; Futurecoast, 2002). The earliest maps show that further outcrops of chalk were previously exposed along the Sheringham frontage; retreat of mean low water since this time means that these are now covered by water at all tidal states (Futurecoast, 2002). An average rate of retreat of between 0.2 and 0.3m/year was determined from analysis of Ordnance Survey maps dating back to 1889 (Futurecoast, 2002).

The likely mechanism for failure is through simple landsliding, but a single event could result in 10 to 50m retreat (Futurecoast, 2002).

Predictions of shoreline evolution:

Defences have been holding the cliffline in a seaward position; therefore further evolution will depend upon the future management of these defences. If defences were removed it is likely that an initial rapid rate of cliff erosion would follow as they become more exposed to wave attack. This rate would then slow and a net change of 50 - 100m over the next 100 years has been predicted by Futurecoast (2002). This compares with predictions made in the SMP3b (1995) of 80 - 105m over 75 years.

LOCAL SCALE: SHERINGHAM TO CROMER

Interactions:

There is a slight change in orientation at Sheringham, meaning that this section of coast is subject to slight differences in the degree of exposure. As a result of this change there is an increase in potential drift rates moving east from Sheringham, which has sediment starvation implications (SNSSTS, 2002b).

There is considerably less shingle present on the beaches to the east of Sheringham, suggesting a lack of both local input and alongshore drift. The cliffs along this section tend to comprise of lower shingle content than those to the west and are sandier in composition. The cliffs also contain chalk erratics, but erosion of these produces chalk rubble on the beach, which is quickly broken down and removed by waves.

Between Sheringham and Cromer the chalk forms a wide wave cut platform as the less resistant glacial deposits have been differentially eroded away. This should form a slightly protective influence on the shoreline as the nearshore zone is resultantly shallower, therefore waves break earlier. It has been postulated that the lowering of the chalk bedrock platform exerts a significant control on the rate of cliff recession at Cromer (Cromer Coastal Strategy Study, 2001).

Movement:

Failure of the cliffs is more complex and less uniform than observed between Kelling and Sheringham, probably due to both differences in exposure and cliff composition. The main mechanism of cliff is by landslide (SMP3b, 1995; Futurecoast, 2002), with events being episodic and unpredictable, although higher rates of erosion will tend to coincide with storms and surges. During the 1953 surge, some unprotected stretches of the cliffline cut back by 30m (SNSSTS, 2002). Rotational failures may also occur (SMP3b, 1995).

Despite the short-term irregularity of the cliff recession, longer-term rates appear to be more uniform and Camber (1976) determined average annual rates of between 0.65 and 0.75m/year based on comparison of cliff positions on Ordnance Survey maps of 1880 and 1967 (reported in Cromer Coastal Strategy Study, 2001). The SMP3b (1995) also reported long-term retreat rates of 0.5 to 1.0m/year, based upon historical mapping.

SNSSTS (2002) reported that analysis of shoreline change showed that cliff and beach recession was four times higher on the eastern side of Sheringham compared to the west, however it is uncertain which time period this conclusion was based upon.

Predictions of shoreline evolution:

A net retreat of 50 to 100m over the next 100 years has been predicted by Futurecoast (2002), assuming an unconstrained coastline, which is similar to that predicted by SMP3b (1995) of 80 - 105m over 75 years.

LOCAL SCALE: CROMER

Interactions:

Cromer marks another location where the orientation of the coastline changes. As noted for Sheringham to Cromer, there is an increase in potential drift rates moving eastwards, implying that the drift rate out of the eastern end of the frontage (towards Overstrand) is likely to be higher than the rate of sediment arriving at the western end (i.e. from Runton) (SNSSTS, 2002). This difference in volume leads to beach erosion, and then cliff recession. The sharp change in beach orientation in the vicinity of Cromer Pier is also thought to locally emphasise the increase in drift rates from west to east along this part of the coast.

Modelling of sediment transport concluded that the open-beach drift rate to the east of the pier is considerably larger than to the west, thus implying the likelihood of beach erosion along the Cromer frontage (Cromer Coastal Strategy Study, 2001)

There are inputs of both sand and shingle from both cliff erosion and reworking of beach material, but sand appears to be the main component. The seawalls along the seafront at Cromer now effectively prevent any additional locally derived sediment being added to the beaches to compensate for losses.

It is also postulated that there is a potential sand transport pathway onshore at Cromer; surge conditions brings the nearshore tidal stream closer inshore, and sometimes even becomes attached to the coast, causing a greater amount of material to be transported in the nearshore zone (SNSSTS, 2002).

Cromer is an important divide point on the coast and it is thought that any material that passes to the east of Cromer is exclusively transported southeast towards Happisburgh and Winterton without being returned to the north. This is likely to be mostly sand but may include some shingle.

Movement:

The cliffline position at Cromer has been held over the last century due to defences being built to protect the town. This has resulting in the town extending further seaward than adjacent stretches. There has, however, been retreat of mean low water, resulting in narrowing beaches (Futurecoast, 2002) and SMP3b (1995) reported a long-term retreat rate of 1 to 2m/year.

However, beach accretion has been taking place updrift of the pier at west of Cromer, which may be accentuated by a change in coastline orientation at this point (Futurecoast, 2002).

Predictions of shoreline evolution:

Defences have been holding the cliffline in a seaward position; therefore further evolution will depend upon the future management of these defences. If defences were removed there would be initially rapid rates of erosion as the cliffs would be more exposed to wave attack, this rate would then slow and a net change of 50 - 100m over the next 100 years has been predicted by Futurecoast (2002). This compares with predictions made in the SMP3b (1995) of 70 - 90m over 75 years.

Cromer Coastal Strategy Study (2001) made predictions of shoreline change under a ‘Do Nothing’ scenario (but only assuming that scenario at the strategy scale, i.e. not taking into account potential change in sediment feed from updrift). This study concluded that the timing of failure was very difficult to predict, but there would be an initial surge (up to 10m/year), before a more gradual rate of erosion (1.875m/year) was reached in years 6 to 50. Due to the possibility of single large-impact events, the study added that there was a possibility that there could be 30m+ of erosion in any one year.

C1.4 CROMER TO HAPPISBURGH

LARGE SCALE

Interactions:

Numerous analyses of sediment transport rates have been undertaken and these are reported in more detail in SNSSTS (2002). These present a confusing pattern of transport, so in response HR Wallingford produced a conceptual sediment budget which indicates a smoothly increasing alongshore drift rate from Cromer to Happisburgh, with rates of 73,000m^3/year at Overstrand, 188,000m^3/year at Trimingham, 341,000m^3/year at Mundesley and 356,000m^3/year at Paston (Cromer Coastal Strategy Study, 2001). The alongshore sediment transport pathway continues south towards Lowestoft, therefore this is a sediment source area for beaches along the rest of the SMP area. It has been hypothesized that there is a 40 to 50 year lag time from when material is released from the North Norfolk cliffs (Clayton, 1989).

Peak alongshore sediment transport tends to take place at a distance 150m offshore, with a secondary peak located approximately 300 to 400m offshore (Overstrand to Walcott Coastal Strategy Study, draft). From COSMOS results undertaken as part of this strategy study, it was found that between Overstrand and Mundesley, 30 to 50% of alongshore transport takes place at depths greater than –4mOD.

The Overstrand to Walcott Strategy Study identified a general pattern of beach volume losses between Cromer and Walcott and calculated an average annual loss in the region of 48,000m^3/year. This conclusion was supported by earlier studies (reported in the strategy). The strategy goes on to report that erosion of the glacial till sediments beneath the beach was found to result in erosion of the base of the beach.

Various studies have concluded that an offshore sediment transport pathway from the beaches to the nearshore and then to the offshore banks exists (further details of the research are included in SNSSTS, 2002). This may be responsible for the temporary loss of fine and sand-sized material as it becomes drawn into the sediment circulation cells, within the nearshore zone, before once again being returned onshore. Once material is moved further offshore it is unlikely to be returned to the shore and the North Norfolk Offshore Banks (NNOBs) are thought to be a permanent sink for material. This offshore transport tends to occur during storms when material on the nearshore banks is reworked and transported northwards in pulses to the NNOBs.

In addition to acting as a sink for sands and fine sediments, the North Norfolk Offshore Banks, including Haisborough Sand, also shelter this coastline from severe storm events and thus limit the magnitude of alongshore drift along this coastline. This results in the increase in potential drift rates, noted above, not being a monotonic one (SNSSTS, 2002).

Movement:

The shoreline is characterised by high cliffs that have been subject to a large degree of sub-aerial exposure and recession, such that they are now characterised by significant failures, such as rotational slides and slump scars. An average rate of retreat (for the undefended cliffs) of 1m/year has been determined for between 1880 and 1985 (Ostend to Cart Gap Strategy Study, 2001).

Foreshore steepening is a prevalent feature of beaches throughout this region (Futurecoast, 2002). Cross-shore transport affects beach volumes, especially where they front cliffs. During storms, beach draw-down occurs, so that there is a greater water depth and hence greater wave heights at the top of the beach (or at the toe of a defence structure). This leads to a greater amount of erosion at the toe cliff, overtopping and/or undermining of a seawall (Overstrand to Walcott Coastal Strategy Study, draft) and in extreme cases the removal of the backshore. The absence of a backshore in this region indicates that there is no net gain of sediment (Futurecoast, 2002). There are, however, seasonal changes.

Predictions of shoreline evolution:

Long-term future evolution has been predicted in Futurecoast (2002) and this is supplemented by strategy studies (HR Wallingford, 2001, 2002, 2003). These indicate the importance of episodic cliff top failure events rather than continuous year-by-year loss in causing cliff retreat. Where the coast is defended, removal of defences would result in a dramatic initial surge of cliff top retreat before the establishment of a relatively uniform long-term average annual recession rate with episodic events separated by periods of very slow or no retreat. This response was also demonstrated through CLIFFSCAPE modeling, carried as part of the Strategy Studies (HR Wallingford, 2001- 2003), which indicated that the greatest rates of retreat were in the first 10 years of failure. This modeling also demonstrated that there was a feed back mechanism through cliff inputs to the beaches, which resulted in a reduction of cliff erosion rates over a 50 year period. Conversely if defences remained in place, areas of undefended coast showed greater rates of retreat, than under a 'Do Nothing' scenario, due to the reduction in sediment input from the cliffs.

LOCAL SCALE: CROMER TO OVERSTRAND

Interactions:

The net drift direction along this stretch is southwards, with key inputs from cliff and beach erosion in the north-east. It is thought that once material is moved south of Cromer, it is not transported back north-westwards.

The cliffs have a very low shingle content and are comprised of between 40 and 70% mud (BGS, 1996), making them prone to landsliding. Sand released will feed beaches both locally and areas to the south, but fines will be moved offshore under the high tidal action.

Movement:

The cliffs are characterised by major rotational failures caused by groundwater processes; mudflows and debris falls also occur (SMP3b, 1995; Futurecoast, 2002). The Cromer Coastal Strategy Study identified these cliffs as being prone to regular, small-scale recession events with debris falls and mudslides. These failures can cause sudden and dramatic (up to 30m in one event) recession of the cliff top edge. A catalogue of landslide events for the Cromer to Overstrand cliffs is presented in

Cromer Coastal Strategy Study (2001). Cambers (1976) reported a long-term recession rate of 0.65-0.75m/year, based on a comparison of cliff positions on Ordnance Survey maps of 1880 and 1967 (reported in Cromer Coastal Strategy Study, 2001).

Predictions of shoreline evolution:

In SMP3b (1995) two predictions were made (for 1994 – 2068); one for Cromer of 70 to 90m and one for Overstrand of 130 to 150m: these were based on extrapolation of historical rates. A prediction of 18.75m every 10 years was reported in the Cromer Coastal Strategy Study (2001), assuming a 'Do Nothing' scenario (but only assuming this scenario along the Cromer frontage). For an 'unconstrained' coast the prediction in Futurecoast (2002) was for 50 to 100m over the next 100 years.

LOCAL SCALE: OVERSTRAND

Interactions:

The net drift direction along this stretch is southwards, with key inputs from cliff and beach erosion in the north-east. Alongshore drift rates of between 42,000 and 73,000m^3/year southwards have been reported (see SNSSTS, 2002) and Haisborough Sand is thought have an important influence on reducing wave energy and therefore transport rates along this section.

The presence of low intertidal and subtidal ridges and runnels that run diagonally across the beach may be a mechanism by which alongshore drift is diverted offshore (SNSSTS, 2002). Also during storms, sand is moved to below the low tide level; it is possible that this material is thus placed in the zone of alongshore transport, from where it is transported south and permanently moved from the beach.

Movement:

Defences have halted cliff erosion and retreat along the Overstrand frontage over the last few decades and work by Cambers (1976; reported in the Overstrand to Walcott Strategy Study, draft) showed that between 1885 and 1985 there was less than 20m erosion. If undefended, the cliffs would be subject to major rotational failures caused by groundwater processes; mudflows and debris falls (SMP3b, 1995; Futurecoast, 2002; Overstrand to Walcott Strategy Study, draft).

Predictions of shoreline evolution:

The Overstrand to Walcott Strategy Study predicted that with the failure of defences there would be a dramatic initial surge of cliff top retreat, possibly involving the loss of up to 50m within the first 5 years, before the establishment of a relatively uniform long-term average annual recession rate with episodic events separated by periods of very slow or no retreat. A long-term retreat rate (including for sea level rise) of between 0.75 and 2.6m/year was proposed.

SMP3b (1995) predicted a retreat of between 130 and 150m between 1994 and 2068, whereas for an unconstrained coast, Futurecoast predicted a retreat of between 50 and 100m over the next 100 years.

LOCAL SCALE: OVERSTRAND TO MUNDESLEY

Interactions:

The cliffs between Overstrand and Trimingham tend to be dominated by clay, resulting in them being prone to large landsliding and complex failures (Futurecoast, 2002). South of Trimingham there is a greater proportion of sand, but along both stretches the shingle content is very low (BGS, 1996). The cliffs therefore provide some sediment to the beach both locally and downdrift to the south. However, the absence of a backshore along much of this shoreline indicates that there is no net gain of sediment. Sediment is transported along the entire East Anglian coastline, although there is a lag time between cliff erosion and the sediment reaching the beaches to the south.

There is potential for mud and fine sand to be lost offshore. McCave (1978) suggested that there is a gradual winnowing of the sand as it moves along its alongshore pathway, with an offshore movement of fines due to tidal action. Alternatively the presence of low intertidal and subtidal ridges and runnels that run diagonally across the beach may be a mechanism by which alongshore drift is diverted offshore (SNSSTS, 2002). Also during storms, sand is moved to below the low tide level (Overstrand to Walcott Coastal Strategy Study, draft). It is possible that this material is thus placed in the zone of alongshore transport, from where it is transported south and permanently moved from the beach. An estimate of the average volume transported offshore between Overstrand and Mundesley, during a storm, is approximately 370,000m^3/year (Overstrand to Walcott Coastal Strategy Study, draft).

Movement:

The cliff type means that massive rotational failures are common, with mudflows and debris falls also occurring (SMP3b, 1995; Futurecoast, 2002). The average rate of retreat for the cliffs at Trimingham was in the region of 1.4-1.7m/year prior to the construction of defences, but the cliffs have been subject to occasional slumps, such as those experienced at Overstrand in the 1990s. In the SMP 3b (1995) a long-term historical rate of 1 to 2m/year was reported. Cambers (1976) reports a single event where 13m of cliff erosion took place, but more recently there have been reports of 40m in a single event. Work by Clayton and Coventry (1986; reported in the Overstrand to Walcott Coastal Strategy Study, draft) suggested a maximum recession of 175m between Overstrand and Trimingham for the period 1885 to1985.

Predictions of shoreline evolution:

The cliffs at Mundesley are characterised by large, deep-seated failures, with up to 40m lost every 40 years through occasional events (Futurecoast, 2002).

Futurecoast predicted a retreat of between 50 and 100m over the next 100 years for an unconstrained coast. This is more conservative than the estimate reported in SMP3b (1995) of 100 to 110m of erosion at Trimingham between 1994 and 2068. Overstrand to Walcott Strategy Study (draft) predicted long-term (up to 50 years) recession rates of between 0.75m/year and 2.6m/year; the study recommends that this rate be expressed as 26m every 10 years, to be representative of the large-scale failures that are common along this frontage.

LOCAL SCALE: MUNDESLEY

Interactions:

Alongshore drift is predominately southwards, although groynes erected along this frontage do reduce the natural rate of drift.

At Mundesley, the highest alongshore transport rate is approximately 150m offshore, but there is significant transport up to 400m offshore, and it has been predicted that between 30% and 50% of the alongshore drift occurs at depths greater than -4m OD (Overstrand to Walcott Coastal Strategy Study, draft).

Defences have been erected to slow the erosion of the cliffs along this section. The cliffs along the town frontage have also been regraded and effectively removed from the sediment system. This reduces the amount of sediment derived locally; therefore this area is currently dependent upon sediment fed from the north, both from cliff erosion and beach reworking. The cliffs are predominately sandy (between 60 and 70%) along the frontage (BGS, 1996) and therefore could provide beach-building material, however as they tend to contain fine sand rather than coarse sand, there is potential for some of the sediment to be moved offshore.

Movement:

Along the town frontage, there has been no change in shoreline position due to the defences; however, the beach has generally been becoming steeper in a west to east direction over the period 1885 to 1969 (Overstrand to Walcott Coastal Strategy Study, draft).

Predictions of shoreline evolution:

The SMP3b (1995) predicted a potential shoreline retreat at Mundesley of between 60 and 70m between 1994 and 2068. Futurecoast predicted that over the next 100 years the coast could retreat between 50 and 100m, assuming an unconstrained coast. Under a ‘Do Nothing’ scenario, the Overstrand to Walcott Coastal Strategy Study predicted that within the first 5 years of defence failure, there would be a dramatic initial surge of cliff top retreat, possibly involving the loss of up to 50m. This would be followed by the establishment of a relatively uniform long-term average annual recession rate with episodic events separated by periods of very slow or no retreat. The study estimated a long-term average recession rate of 2.6m/year or 26m every 10 years.

LOCAL SCALE: MUNDESLEY TO BACTON

Interactions:

There is a net southwards movement of material between Mundesley and Bacton, although rates vary in magnitude and direction (Futurecoast, 2002). The Overstrand to Walcott Coastal Strategy Study (draft) determined rates of between 240,000 and 350,000m^3/year in a southwards direction. The majority of this material is sand-sized. The rate of sediment transport is understood to increase in a southwards direction meaning that more sediment is leaving the area in an alongshore direction than is entering it from the north-west.

Movement:

The nature of the cliffs changes slightly at Mundesley and the cliffs become sandier and better drained. The large deep-seated failures, as evident to the north, are not present and erosion is a more gradual process (Futurecoast, 2002). Some landsliding occurs, but this is believed to predominately shallow (SMP3b, 1995). These cliffs are affected by regular, small-scale recession events, with cliff top losses of probably in the order 1 to 5m per failure event (Overstrand to Walcott Coastal Strategy Study, draft). The SMP3b (1995) reported long-term erosion rates for mean low water of 1 to 2m/year.

Predictions of shoreline evolution:

Futurecoast predicted a net retreat of between 50 and 100m over the next 100 years, based on an unconstrained coastline. The SMP 3b (1995) estimated rates for Mundesley and Bacton of 60m to 70m and 100 to 110m respectively, for the period 1994-2068. Rates were not available from the strategy study at the time of this review.

LOCAL SCALE: BACTON AND WALCOTT

Interactions:

Along this section the topography changes, with the cliffs dropping down to almost beach-level. Concrete seawalls have been built in front of what was probably a low cliff (<5m high) between Bacton Green and Walcott. However, despite the cliffs having a high proportion of sand (approximately 60%; BGS, 1996) they do not represent a significant source of sediment for this frontage because they are very low in height (up to 5m). This area would therefore naturally rely on input from further updrift, from both cliff and beach erosion.

During storm conditions the lower lying land is vulnerable to localised flooding and sand displacement onto the road (SMP3b, 1995).

Movement:

Defences and management, e.g. the landslide remedial measures at Bacton Gas Terminal, have held the shoreline position, although mean low water has retreated at an approximate rate of 1 to 2m/year, resulting in narrowing beaches (SMP3b, 1995; Futurecoast, 2002).

Predictions of shoreline evolution:

Defences are currently holding the position of the cliffline; therefore future change depends upon the management of these defences. Futurecoast (2002) predicted a net retreat of between 50 and 100m over the next 100 years, based on an unconstrained coastline; the study also noted that there could be inundation of the low-lying land at Walcott during extreme events, but that the extent would be restricted by the hinterland topography. The SMP 3b (1995) estimated rates for Bacton and Walcott of 100 to 110m for the period 1994-2068. The Overstrand to Walcott Strategy Study (draft) reported that should the defence fail the cliffs would be prone to regular, small-scale recession events, with cliff top losses of probably in the order 1-5m per failure event.

LOCAL SCALE: OSTEND TO HAPPISBURGH (CART GAP)

Interactions:

Numerous attempts have been made to model rates of sediment transport between Mundesley and Happisburgh, however the simple methods used have led to inaccuracies. In their recent Ostend to Cart Gap Strategy Study (2001), HR Wallingford estimated the average drift rate for the period 1979 to 1994 to be just over 500,000m^3/ year. The rate of transport at Happisburgh it thought to be the highest along this SMP area, therefore more sediment is leaving than is entering from the north-west. Analysis of beach profile and alongshore transport interaction between Ostend and Cart Gap (Ostend to Cart Gap Coastal Strategy Study, 2001) showed that the highest rate of drift occurs just below the mean tidal level, where the beach is approximately 0.5m below Ordnance Datum, around 50 to 60m offshore.

Flood and ebb tidal streams have a significant impact on the coastline between Ostend and Cart Gap under the modelled wave condition (Ostend to Cart Gap Coastal Strategy Study, 2001). At the time of high water on flood tide, the peak east/southward drift on the upper beach increased; and at low water, ebb tides act to reduce or reverse the local drift from dominantly southward to northward.

The cliffs between Ostend and Happisburgh have a very high content of mud (between 60 and 75%; BGS, 1996) and therefore do not contribute greatly to the beach budget. Although at Happisburgh the cliffs are sandier, this stretch of coast is dependent upon a supply of sediment from alongshore.

Movement:

The cliffs between Walcott and Happisburgh have a very high fine content and contain a mixture of clayey and sandy deposits (BGS, 1996). The clay deposits are generally more resistant to erosion by the sea, and often remain as an outcrop, jutting seaward from the cliffs while sandy deposits on either side retreat more rapidly (Ostend to Cart Gap Coastal Strategy Study, 2001). The cliffs near Happisburgh village are of a different character and are retreating mainly in response to marine undercutting rather than through groundwater processes.

This shoreline has shown a history of net retreat and pre-defence (1886 to 1938 maps) the averaged erosion rate varied between 0.4 and 0.8 m/year according to location (reported in Ostend to Cart Gap Coastal Strategy Study, 2001). An analysis of post defence erosion rates undertaken in 1995 using the 1970 OS plan and the NNDC 1994 survey data concluded that erosion rates ranged between 0.4 and 1.2m/yr, i.e. that on average, erosion rates were higher than the pre-defence rates (Ostend to Cart Gap Coastal Strategy Study, 2001). However, the study does note that the analysis used data collected after the failure of some of the defences in 1991, which may partially explain this apparent inconsistency.

Between Ostend and Cart Gap, the shoreline has shown an increasing rate of erosion in response to the failure of existing defences, which have come to the end of their lives; in 1991 a breach of this frontage occurred (further details are provide in the Ostend to Cart Gap Coastal Strategy Study (2001)). In this study, HR Wallingford analysed sets of survey data for the frontage to the south of Happisburgh village and found that cliffline has receded at varying rates, but particularly rapidly following the loss of a hard point, mid-way along the eroding face in 1998. Following loss of this point (which may be attributed to a hard point in cliff material) erosion proceeded to cut back rapidly.

Predictions of shoreline evolution:

It has been predicted that within the next 5 years, the cliffline along the Beach Road area in Happisburgh village frontage will recede some 30 to 75m from its current position and that, erosion will be focussed in the area of Happisburgh Caravan Park with a rapid cutback of the cliffline by 110m between years 5 and 10 (Ostend to Cart Gap Coastal Strategy Study, 2001). This prediction assumes that defences remain intact along the Happisburgh to Ostend frontage and did highlight the fact that there is considerable uncertainty surrounding the prediction of erosion along this frontage.

The SMP3b had predicted net movement of between 115 and 130m at Happisburgh (between 1994 and 2068) and a more conservative estimate was made by Futurecoast of 50 to 100m in 100 years, but this assumes an unconstrained coast, therefore taking into account increased sediment input from cliff erosion to the north of this frontage.

C1.5 HAPPISBURGH TO WINTERTON

LARGE SCALE

Interactions:

The key difference in terms of coastal behaviour along this stretch of coast is that it is low-lying and therefore there is no geological control on the rate of the erosion (Futurecoast, 2002). There is also no local source of sediment for the region, which relies on inputs from updrift areas. It has been hypothesised that there is a 10-20 year lag time for the material to be transported along this length (Clayton, 1989).

Waves and surge tides tend to dominate the processes taking place at the shoreline, whilst tidal currents are dominant offshore. Alongshore transport is southwards and takes place both on the beach and along the nearshore bar, which is located approximately 200-300m offshore of mean low water and runs roughly parallel to the coastline (Happisburgh to Winterton Strategy Review, 2002). The nearshore bar is seen to be quasi-permanent and can vary in magnitude and over seasonal or longer timescales. Cross-shore transport takes place between the nearshore bar and beach (Happisburgh to Winterton Strategy Review, 2002). It has been estimated that up to 60% of alongshore transport could take place along the nearshore bar during storm conditions (Happisburgh to Winterton Strategy Review, 2002).

There is a strong tidal influence in this region, which is evident by the formation of a series of ebb and flood channels, which run close to the shore (Futurecoast, 2002). The channels are aligned north-west/south-east and cut into the nearshore sediments. Their proximity to the coastline effects the configuration of tidal currents and wave transformation inshore. This has been related to the variation in beach profile between Happisburgh and Winterton, which changes from steepening to flattening.

Similar to other area there has been a net lowering of the underlying shore platform, which along this stretch is composed of clays. During storms the beaches are stripped of material exposing the clay platform beneath to wave attack. Any sediment eroded from the platform is rapidly moved offshore resulting in a net lowering of the platform, despite the return of beach material following the storm (Happisburgh to Winterton Strategy Review, 2002).

Winterton Ness is believed to be a key location for offshore sediment transport, which feeds into the nearshore bank system to the south, but volumes of exchange are unknown.

Movement:

The key cause of change is from flooding and this coastline is highly susceptible. The long history of breaches suggests that at least since historical times there has not been a substantial dune system along this region, nor significant dune progradation, despite input of sediment from cliff erosion (Futurecoast, 2002).

Since the 1950s, retreat of the coast has been halted through the construction of seawalls and their subsequent maintenance. There has, however, been a continued retreat of mean low water resulting in steepening beaches (SMP3b, 1995; Futurecoast, 2002). At Sea Palling this has been countered through construction of offshore reefs and beach recharge.

LOCAL SCALE: HAPPISBURGH TO WINTERTON (NESS)

Interactions:

Estimates of average annual potential alongshore drift at Happisburgh range from 400,000m^3/year between 1979 and 1986 (SMP3b, 1995) and 429,000 m^3/year between 1975 and 1994 (Ostend to Cart Gap Strategy Study, 2001), which take account of the local wave climate and coastal defences, such as groynes. A figure of 505,000m^3/year between 1975 and 1994 (reported in Ostend to Cart Gap Strategy Study, 2001) was suggested for the natural coastline. These very high transport rates have consequences on beach management in that the installation of drift-interrupting structures, such as groynes, result in rapid changes in beach plan shape (SNSSTS, 2002).

The construction of shore-parallel detached breakwaters at Sea Palling reduce the rate of alongshore drift in their immediate vicinity; results of modelling illustrate that to the north of the reefs the average annual rate of sand transport was 55,000 m^3/year (range: 15,000 – 150,000 m^3/year southwards), within the reef area the average rate was 15,000m3/year (range: 1,000 to 40,000 m^3/year southwards) and a few kilometres south of the reefs the drift rate was 150,000 m^3/year (range: 50,000 to 250,000m^3/year southwards) (Happisburgh to Winterton Strategy Review, 2002). This represents a recovery in drift rates to the south of the reefs.

However, from analysis of sediment transport pathways using COSMOS, HR Wallingford (1999) determined that alongshore sediment transport is predominantly within the intertidal zone and along the nearshore bar. Studies have shown that up to 60% of transport could take place along the nearshore bar under storm conditions; analysis by HR Wallingford (1999) did illustrate that the reefs do cause some disruption to this transport pathways as the reefs have been constructed on the bar itself; but that this still represents on important sediment pathway.

Beach recharge has been implemented locally, representing an artificial input to the sediment system. In places, some of this material has been temporally stored in the form of embryo dunes, which have developed in front of the walls (Happisburgh to Winterton Strategy Review, 2002).

Movement:

The coastline between Happisburgh and Winterton shows a long history of beach volatility and flooding of the low-lying areas, and rollback of the dune ridge (Futurecoast, 2002). The Happisburgh to Winterton Strategy Study reports that between 1886 and 1905 much of the coast was in a state of relative stability, but during 1905 to 1946 the whole coast eroded by approximately 0.7m/year.

Most of this shoreline is now artificially held and defended by seawalls, which front the sand dunes. The wall was constructed in response to the last major breach of the sand dune defences along the Happisburgh to Winterton frontage, which occurred in 1953. It was constructed along the shoreline in stages and was only completed in 1989. Therefore since the 1950s there has been little net change in the shoreline position, although there has been retreat of mean low water, resulting in narrowing beaches. Long-term changes for the coastline north of Winterton to Happisburgh show that between 1883 and 1906, the shoreline retreated at a rate of approximately 2.3m/year, with a volume loss of 13,800m^3/year; and from 1906-1952 retreated at a rate of 0.3m/year, with a loss of 450m^3/year (UEA, 1971).

Between Cart Gap and Sea Palling, approximately 8,000m^3/year of erosion took place between January 1992 and January 2000. Immediately around the reefs, 330,000m^3 of material has built up as salients around the breakwaters at Sea Palling, although there is net erosion of the beach opposite the gaps between the reefs. Accretion behind the reefs reduced from 25,000m^3 to 4,000m^3 at the most southerly reef from 1992-2000 (Happisburgh to Winterton Strategy Review, 2002). The total net change across the Happisburgh frontage was accretion in the region of 343,000 m$^{3.}$ During this 8-year period, 1,550,000 m^3 of material was added to the beach as recharge material, hence there has been a net loss of 1,207,000 m^3 or an average annual loss of 151,000 m^3/year between 1992 and 2000 (Happisburgh to Winterton Strategy Review, 2002). Over the short term (1997-1999), these losses were predicted to be in the region of 50,000 m^3/year, but are held accountable by relatively calm winters in 1997 and 1998-2000 (Happisburgh to Winterton Strategy Review, 2002). These figures highlight the significance of winter storms and storm surges in controlling the short-term behaviour of the coast in this region.

Predictions of shoreline evolution:

This region will be affected by increased erosion along Happisburgh cliffs and it has been suggested (Futurecoast, 2002) that because of this increased erosion, there is potential for the beaches between Happisburgh and Winterton to receive an increased supply of material following a greater rate of updrift erosion. Despite this, a net retreat of between 50 and 100m over the next 100 years has been predicted by Futurecoast for an unconstrained coast, but it has also been recognised that it is unlikely that the dune ridge along this frontage would be sufficient to prevent large-scale inundation of the low-lying hinterland.

For this area, the SMP 3b (1995) predicted various rates ranging from 35 to 85m over the period 1994 to 2068, which was based upon extrapolation of historical rates. The CHaMP (2003) predicted a shoreline change of 70m over the next hundred years, through applying a simple extrapolation of an average historical rate and assuming no defences along the Happisburgh to Winterton frontage.

The probability of breach was investigated by the Happisburgh to Winterton Strategy Review (2002). This study identified that the most likely place for failure, under a Do Nothing scenario was at Bramble Hill, where the dunes are narrow. At Horsey, there is a more significant dune width, which should be sufficient to prevent an immediate breach following seawall failure. The study also concluded that even a breach 340m wide would result in the flooding of several tens of kilometres.

LOCAL SCALE: WINTERTON NESS

Interactions:

At the nose of the ness there is a localised northward component of drift, however along most of this shoreline there is a net southward alongshore drift of sediment, although drift rates and direction can vary considerably. Alongshore drift has been estimated at approximately 290,000 m^3/year (Onyett and Simmonds, 1983; reported in SNSSTS, 2002). There are local inputs of sand from erosion of the dunes themselves, but this area is also fed from areas to the north.

Winterton Ness represents the approximate northern limit of the complex nearshore banks and channel system, which extends down the coast to Lowestoft. Within this banks system there is a complex circulation and re-circulation of sediment between the shore, the inner banks and the outer banks (SNSSTS, 2002). Winterton Ness appears to be linked to this bank system and it is thought that a proportion of the sand-sized material moving south along the shore from the north, leaves the shore at Winterton Ness to feed into the Caister and Scroby banks via subtidal spurs. The volume of sediment leaving the shore is unknown.

There is also believed to be a feed of sand to Winterton Ness; sediment flux residuals show a strong nearshore flow of material curving southeast from Cromer, setting slightly against the coast north of Winterton Ness before leaving the coast to the south and increasing again.

Winterton Ness forms a key coastal location as it is a remnant headland of the Northern Upland and therefore is a key control on evolution of the coast both to the north and south.

Movement:

Comparison with a very early map, dating from the 1600s, suggests that there has been significant erosion of this ness over the last 400 years, as the ness is shown as a large promontory in the 1600s (Futurecoast, 2002). It is uncertain when this erosion occurred, because over the last century the trend has been one of sediment redistribution, with accretion at the nose of the ness (Futurecoast, 2002). Accretion took place opposite Winterton Village at a rate of approximately 1.1 to 1.4m/year between 1883 and 1952; during this time, the ness gained material in the region of 1.7 million m^3 (24,600m^3 /year) (UEA, 1971).

In recent years the nose of the ness has remained quite stable in position, although there has been a net retreat of mean low water over the last 40 years to the north of the ness and accretion to the south (SMP3b, 1995; Futurecoast, 2002).

Broad analysis of very recent beach profile data (1992-2002), undertaken as part of the CHaMP (2003), indicated average retreat rates of 2.1m/ year in the vicinity of Winterton Coastguard Station. This analysis also indicated that to the south of the Coastguard Station, the beach face has accreted at an average rate of 2m/year over the same period.

Predictions of shoreline evolution:

The ness is expected to continue to fluctuate in position, which will result in trends of both erosion and accretion along this frontage (Futurecoast, 2002). The SMP 3b (1995) predicted accretion of between 65 and 80m at Happisburgh. From simple extrapolation of short-term erosion rates, the CHaMP predicted that, if the observed short-term retreat south of Winterton continued, then the entire dune field would be eroded, and the former Winterton cliff would become re-exposed to wave action.

The future of this site is, however, dependent upon the future management of the coastline between Happisburgh and Winterton.

C1.6 WINTERTON TO LOWESTOFT

LARGE SCALE

Interactions:

It has been suggested that a key control on the evolution of this coastline are the remnant headlands of the Northern Upland (Winterton Ness) and the Southern Upland (Lowestoft and Kessingland) and between them the geomorphological influence of the former Yare Valley (Futurecoast, 2002; SNSSTS, 2002).

A key characteristic of this stretch of coast is the nearshore banks, which have a significant influence on shoreline evolution through affecting wave exposure along the coastline and also acting as a sediment pathway. The banks are also thought to be an integral part of the wider coastal system and possible act as a significant control contributing to holding the coastal position along this stretch of coast (and also possibly areas both to the north and south). These banks lie close inshore between Winterton and Lowestoft, approximately 1 to 10 km from the coast. The banks do not have a solid foundation and are therefore highly mobile; therefore their influence on wave conditions (and thus sediment transport at the shore) varies over time (Futurecoast, 2002). The banks provide protection to the adjacent sections of shoreline during storms, but can also cause wave focussing between them.

The North Norfolk Offshore Banks (NNOBs), which lie further offshore to the north-east of this area, are unlikely to have any impact on the local wave climate because of their distance from the shore.

Alongshore drift along this frontage is predominately southwards and there are significant links with the coastline to the north, which is a key source of sediment, both from cliff and beach erosion. There are localised variations in direction, in part dependent upon the nearshore banks. There does not appear to be a sediment pathway north along the shore from south of Lowestoft Ness, therefore the area is dependent upon alongshore input from the north. There is thought to be an approximately 40 to 50 year lag time between when material is released from cliffs to the north and when it reaches Lowestoft beaches (Clayton, 1989).

Beaches all along this frontage are very volatile and cross-shore transport during storm is an important issue as beach draw-down occurs, so there is a greater water depth and hence greater wave heights at the top of the beach (or at the toe of a defence structure). This leads to a greater amount of erosion at the toe cliff, overtopping and/or undermining of a seawall and in extreme cases the removal of the backshore. This drawn-down sediment forms a nearshore bar (sometimes referred to as a sub-tidal or sub-littoral bar); some of this material is released to the nearshore banks during the storm where some material is returned onshore to re-build the beach and some material is transported further offshore.

A complex circulation of sediment between the shore and nearshore bars/banks and offshore banks, where a series of sediment circulation cells are thought to exist along the length of the coastline. There are understood to be a number of pathways by which sediment can leave the shore, via subtidal spurs. Material is first transported offshore from the nearshore bars, before being transported around the nearshore banks in an anti-clockwise direction (Halcrow, 1998, Townend & McLaren, 1990;

SNSSTS, 2002). Whether material then rejoins the shore can depend on the relative position of channels and banks to the south. The nearshore banks can in effect leapfrog material along the coast resulting in a variation in sediment supply to the shoreline (SNSSTS, 2002).

The majority of the nearshore banks are comprised of fine grade material. The amount of material lost from the nearshore banks is replaced by a supply from the shoreline, so that the volume of the banks remains relatively stable. A broad relationship is hypothesised to exist between the nearshore and offshore sand banks, such that when the banks are in deficit of material, the beaches are observed to be full, but this has not been proven (Gorleston to Lowestoft Coastal Strategy Study, 1999).

Movement:

The majority of the coast has been retreating with Great Yarmouth Denes being the main exception. It would be expected that with an increasing rate of transport from Cromer to Happisburgh, fuelled by recession of the cliffs between, the coastline between Happisburgh and Great Yarmouth would be gaining sand, yet North Denes, a stretch of coastline to the north of Great Yarmouth, is the only area along this section of coastline where a greater amount of material arrives at the shoreline than leaves (Ostend to Cart Gap Coastal Strategy Study, 2001).

Leggett et al. (1998) calculated an average reduction in beach volumes of 10% in 5 years between Great Yarmouth and Southwold (to the south of the SMP area), with the rate of beach loss reducing to the south (reported in SNSSTS, 2002).

The ness features, which characterise this coast, exhibit variation in both volume and position over time. Lowestoft Ness in particular has changed considerably over the last century, with much of its original volume now diminished.

The nearshore banks are quasi-permanent features, which wax and wane both in position and in height, and a 100 to 150 cycle in their behaviour has been postulated. The bank system as a whole is believed to be moving northwards (Gorleston to Lowestoft Coastal Strategy Study, 1999).

LOCAL SCALE: NEWPORT AND CALIFORNIA

Interactions:

A small net southward transport of sediment takes place around Caister-on-Sea, but this is subject to variability and there is potential for sediment transfer to the north as well as south (Futurecoast, 2002).

At Newport, dunes back the shoreline and erosion of these provides sand sized sediment to downdrift areas. To the south, at Scratby, the dunes are replaced by sand cliffs, which fail predominately through slab failures and debris falls (SMP3b, 1995). Cliff erosion around Scratby and California supplies sand and mud to the local sediment budget; approximately 70% of this is fine and muds (BGS, 1996), which tend to be washed offshore, while the other 30% of sand could stay on the beach, but is more likely to become incorporated into the drift stream, both along the beach and subtidal bar. Material is then either transported downdrift towards Caister, temporarily lost to a nearshore bank/subtidal bar before being returned to the beach, or lost to the offshore bank system (Futurecoast, 2002).

Onshore-offshore transport is more significant than net alongshore transport, as infrequent storm processes tend to drive beach behaviour in place of steady alongshore processes (Futurecoast, 2002). Under storm conditions material is drawn down from the beach to form a nearshore bar; sometimes referred to as a sub-tidal or sub-littoral bar. Some of this material is released to the nearshore and offshore banks during the storm and some material is returned onshore to re-build the beach.

Movement:

Accretion in the region of 0.4m/year took place at Scratby and East End between 1883 and 1906. This trend later switched to erosion, resulting in a net loss of 441,600m^3 between 1883-1952 (UEA, 1971); this is possibly associated with movement of Winterton Ness and the redistribution of sediment. The SMP (1995) reported retreat rates of 0 to 0.5m/year in the north of this area, and 0.5 to 1.0m/year to the south.

There has been a net foreshore steepening between Newport and California since the 1890s. To the south, a slight embayment has formed between California and Caister-on-Sea, with a general translation in the beach position rather than foreshore steepening (Futurecoast, 2002).

Predictions of shoreline evolution:

Futurecoast (2002) predicted that over the next century there would be a trend of net shoreline retreat of 50 to 100m (assuming an unconstrained coast), with some realignment of the coast south of California where the slight promontory would be exposed to wave action. This corresponds with estimates reported in the SMP (1995) of 30 to 45m of erosion at Scratby and 25 to 40m of erosion at California for the period 1994 to 2068.

Happisburgh to Winterton Strategy Review identified the potential for breach at the southern end of Newport and therefore risk of inland flooding, but the study concluded that this should be limited to ‘The Valley’ area.

LOCAL SCALE: CAISTER-ON-SEA

Interactions:

Sediment transport is predominately southwards, but drift rates are dependent upon the configuration of the nearshore banks (reported in SNSSTS, 2002). HR Wallingford (1998; reported in SNSSTS, 2002) found that in general, drift rates into the area were greater than rates out of the area. Various studies have been undertaken to assess sediment transport rates, which are discussed in SNSSTS (2002), but the rate of sand transport is believed to be about 100,000 to 200,00 m^3/year southwards.

The beach levels at Caister-on-Sea are strongly linked to the level of material in the nearshore bar, which fluctuates on a seasonal timescale and in response to storms.

Movement:

Over the past century, there have been significant changes in the coastal alignment; with erosion since at least the 1890s. Between 1910 and 1920s, there was a period of particularly rapid dune erosion along Caister frontage and the area to the north (Futurecoast, 2002). This erosion of the dune line has been accompanied by a general translation in the beach position rather than a net steepening trend.

At the southern end of the Caister frontage sand has accumulated, forming a small ness feature known as Caister Point. Caister Point appears to be a quasi-permanent feature along this shoreline (Futurecoast, 2002), which has moved northwards since the 1880s. SNSSTS (2002) reported that since the 1930s the Ness has been prograded over 300m. The SMP 3b (1995) reported an average long-term rate for mean low water of greater than 2m/year accretion for this region.

Predictions of shoreline evolution:

The evolution of this shoreline is dependant upon the configuration of the nearshore banks, as these affect both inshore wave climates and alongshore drift rates. The SMP3b (1995) predicted that the future shoreline position could either accrete up to 60m or erode up to 40m for the period 1994 to 2068. Futurecoast (2002) also stated that the future evolution of Caister Point is uncertain, but predicted that the Caister frontage would erode between 50 and 100m over the next 100 years (assuming an unconstrained coast).

Studies undertaken prior to the construction of the breakwaters (Halcrow, 1998), predicted that for a ‘no active intervention’ scenario, the coast could retreat in excess of 40m at the worst point. It was further identified that any breach in the defences would result in dune erosion and possible breach of the dunes, resulting in inundation of the low-lying hinterland.

LOCAL SCALE: NORTH DENES

Interactions:

Net sediment transport between Caister Point and Gorleston is generally to the south, but a localised northerly sediment drift occurs around South Denes due to the complex wave transformation that result from the offshore banks (SNSSTS, 2002). Drift rates along this frontage are, however, lower than those experienced to the north. There have been various estimates of sediment transport along this coast (discussed in SNSSTS, 2002), but there is an average rate of 1,000 to 10,000m^3/year southwards.

Cross-shore transport becomes more significant than alongshore transport processes south of Caister Point towards Corton and changes during storms are a key aspect in shoreline evolution in this area (Futurecoast, 2002). Under storm conditions material is drawn down from the beach to form a nearshore bar, sometimes referred to as a sub-tidal or sub-littoral bar. Some of this material is released to the nearshore banks during the storm, while some material is returned onshore to re-build the beach and some material is transported further offshore.

The beach levels along this stretch are strongly linked to the level of material in the nearshore bar, which fluctuates on a seasonal timescale and in response to storms (Futurecoast, 2002). Futurecoast (2002) argues that there is no knowledge to support the exchange of sediment between the shoreline and the nearshore and offshore banks, hence once material is lost to the offshore zone, it is unlikely to be returned onshore to this location. It is not known whether there is a link between the smaller feature at Caister Point and the much larger feature of Caister Ness.

Movement:

North Denes is a large sand and shingle spit that is backed by a dune complex, which extends south from Caister Ness to the River Yare at Great Yarmouth, and which has been fixed in position by urbanisation. This is one of the few locations along the SMP coastline that is accreting. The SMP 3b (1995) determined a long-term average advance of mean low water of between 0.5 and 1.0m/year. Caister Ness is a relatively modern feature, which is not shown on the earliest Ordnance Survey maps; since 1906, accretion has been a gradual process that has continued, particularly on the north side of the ness, up to the present day. (Futurecoast, 2002). There has also been progradation along Great Yarmouth North Denes. The CHaMP (2003) reported that there has been an advance of High Water at a rate of 1m/year over the past decade.

Predictions of shoreline evolution:

Evolution of this area is dependent in part on the configuration of nearshore banks. Futurecoast (2002) predicted that there would be continued accretion of the foreshore and dunes in this area of 0 to 50m over the next 100 years, but this was assuming that bank configuration remained the same. Futurecoast did, however, state that there is great uncertainty over the potential future evolution of Caister Ness. The CHaMP (2003) concluded that North Denes should continue to be relatively stable over the next 30-50 years. The SMP3b (1995) also identified the potential for both accretion and erosion to occur along this frontage and suggested a range of up to 150m accretion to 20m retreat for the period 1994 to 2068.

LOCAL SCALE: GREAT YARMOUTH

Interactions:

Based on the average wave climate and a number of bank conditions at Great Yarmouth North Denes, littoral drift would be expected to be northward, however, HR Wallingford (1998) found that the gross northward and southward components of drift are almost equal, and that net drift was only 5% of the gross drift. From various studies of alongshore transport, SNSSTS (2002) suggest an average annual rate of between 1,000 and 10,000 m^3/year.

Extension of the piers at Gorleston Harbour means that alongshore drift takes place offshore of the mouth of the River Yare. It is thought that once material has by-passed the mouth of the River Yare it is unable to return to the north (Futurecoast, 2002) and therefore there is a potential net loss from this section of coast.

The construction of the Outer Harbour has been completed since the previous version of the SMP was issued. The effect of the Outer Harbour on sediment movements is not clear, and monitoring is a requirements of the consent. The results of this monitoring, when available, will be used to update the understanding of sediment interactions in this area.

Movement:

From 1883 until 1952, 25,000m^3/year of material accreted along South Denes. The beaches at South Denes are now eroding, which is thought to be largely a result of wave reflection off the Great Yarmouth Harbour Arm.

Accretion has been gradual over the frontage, but more notable on the north side of the ness and where there the progradation of the Great Yarmouth North Denes is taking place (see section above). The beach profile has remained relatively stable, with slight fluctuations in the position of mean high and mean low water.

Predictions of shoreline evolution:

Futurecoast (2002) predicted future fluctuations in shoreline position along this frontage of between 0 and 50 m over the next 100 years. The range of predicted movement presented in the SMP 3b (1995) was 20m erosion to 60m accretion.

LOCAL SCALE: GORLESTON

Interactions:

Alongshore transport is predominately southwards at Gorleston but moderate with rates of between 1,000 and 10,000m^3/year (SNSSTS, 2002; Gorleston to Lowestoft Coastal Strategy Study, 1999). Rates are affected by the configuration of the nearshore banks, with reversals in net direction occurring in some years. Within the nearshore zone, sediments can bypass the River Yare, but are likely to be the finer sediment grades, i.e. sands or silts (Futurecoast, 2002). It is thought that extension of piers to the north and construction of defences has caused the zone of southerly drift that once bypassed the River Yare, to be moved offshore and between 1927 and 1952, erosion of the beach took place, the material of which was lost to the nearshore and seaward. Sediment transport modelling by HR Wallingford (1998) has shown the potential for movement of 14,000 to 24,000 m3/year sand to the north and south within a 300m wide zone off the mouth of the River Yare, but it has been conclude that it is unlikely that beach material can bypass Great Yarmouth Harbour Entrance in the surf zone to the north or south (Gorleston to Lowestoft Coastal Strategy Study, 1999). It has also been recognised that should the sand enter the deep waters of Yarmouth Roads, it is not likely to be returned directly to the Gorleston frontage (HR Wallingford, 1998).

There is a possible sediment transport pathway further offshore, however it has been suggested that there is the potential for an onshore component of transport, with material returning to the shoreline at Hopton.

Futurecoast (2002) argues that there is no knowledge to support the exchange of sediment between the shoreline and the nearshore and offshore banks, hence once material is lost to the offshore zone it is unlikely to be returned onshore to this location. This is also supported by the fact that the seabed offshore of Gorleston is muddy, which indicates that it is not a source of material to the beaches which are predominantly sand, but a sink for fine material drawdown from the beaches (Gorleston to Lowestoft Coastal Strategy Study, 1999).

The River Yare is thought only to have an influence on the immediate vicinity (500-1000m) due to the reflection of waves from the South Pier at Great Yarmouth, with little influence on the beach at Gorleston (Delft, 1986).

A generally wide transport stream runs along this section of coast as seen around the River Yare, where alongshore movements can take place in both directions within a 300m zone from the shore (HR Wallingford, 1998). COSMOS modelling carried out as part of the Gorleston Coastal Protection Scheme (Halcrow, 2003) supports these findings whereby there are generally two distances offshore where peak drift occurs; approximately 150m and 300 to 400m. It is inferred that the most inshore peak relates to the incident wave climate while the more offshore peak relates to the tidal stream. A nearshore bar sits within this, at around 200m chainage, which represents cross-shore transport, as described below.

Although the cliffs along this frontage have been regraded and are protected by a seawall, the potential input of sediment would be almost entirely sand-sized (BGS, 1996).

Movement:

The condition of Gorleston Beach has changed over time. The beach was in a poor condition in the 1880s, but there was then accretion during the early 1900s, at a rate of 2.9m/year up until 1927, resulting in a fairly wide and extensive beach (Gorleston to Lowestoft Coastal Strategy Study, 1999). After this date, beach levels started to drop again: this period of deterioration corresponds with the completion of extended impermeable pier structures at the harbour entrance, but it is argued in SNSSTS (2002) that this deterioration may also be attributed to the configuration of the offshore banks. Subsequent periods of accretion and erosion lead to the supposition that beach levels in this area undergo a 100 to 150 year cyclic development (see Gorleston to Lowestoft Coastal Strategy Study, 1999).

Due to defences, there has been no change in shoreline position over the last century. Over the long-term (1883-1998), mean low water advanced in the northern half and retreated along the southern half of the beach. However, over the short-term, between 1993 and 1998, the beach at Gorleston advanced along its entire length (Gorleston to Lowestoft Coastal Strategy Study, 1999).

Predictions of shoreline evolution:

Using simple extrapolation of long-term rates, the Gorleston to Lowestoft Coastal Strategy Study (1999) concluded that the likely recession of mean low water over the next 50 years to be approximately 110m, assuming a ‘Do Nothing’ scenario. Futurecoast predicted retreat rates to be 50 to 100m over the next 100 years, but this was an unconstrained scenario for the whole coast. The SMP 3b (1995) predicted 30 to 50m of erosion for the period 1994 to 2068.

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: GORLESTON TO HOPTON

Interactions:

Alongshore transport is predominately southwards, although at lower rates than those experienced to the north, but there is large natural variability in the average annual drift; from published rates SNSSTS (2002) suggested an average rate of 10,000 to 40,000m^3/year southwards. The nearshore banks are also thought to affect the alongshore transport of material on a longer timescale (Futurecoast, 2002).

It has been suggested that the behaviour of this coastline is primarily attributed to the topography of the nearshore banks (Delft, 1986). When the banks are in deficit of material the beaches are observed to be full; conversely, when the banks are in surplus of material, the beaches are low in volume (Gorleston to Lowestoft Coastal Strategy Study, 1999).

The cliffs, although protected, do provide a sediment input of predominately sand (over 80%; BGS, 1996).

Movement:

Despite coastal defences, the cliffs between Gorleston and Hopton receded at a rate of 0.55m/year between 1889 and 1998 (Gorleston to Lowestoft Coastal Strategy Study, 1999). This is slightly lower than the rate recorded between Hopton and Corton of 0.78m/year (Gorleston to Lowestoft Coastal Strategy Study, 1999). This highlights the fact that timber revetment only slows rather than halts erosion and also the importance for groundwater erosion as well as marine erosion.

The shoreline between Gorleston and Hopton has been subject to steady retreat and beach steepening over both the short and long term (Gorleston to Lowestoft Coastal Strategy Study, 1999; Futurecoast, 2002). Beach losses were in the region of 2,008,600m^3 (29,110m^3/year) (UEA, 1971), however in some places there has been recent beach advance.

Predictions of shoreline evolution:

Using simple extrapolation of long-term rates, the Gorleston to Lowestoft Coastal Strategy Study (1999) concluded that the likely recession of mean low water over the next 50 years will be approximately 80m, assuming a ‘Do Nothing’ scenario. Futurecoast predicted retreat rates of the cliffline to be 50 to 100m over the next 100 years, but this was an unconstrained coast. SMP 3b (1995) did not make a specific prediction at this location, but erosion of 30 to 50m was predicted for Gorleston and 60 to 80m for Hopton (for the period 1994 to 2068).

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: HOPTON

Interactions:

Alongshore drift is southwards at a rate of between 10,000 and 40,000 m^3/year (SNSSTS, 2002). The rate is affected by configuration of the nearshore banks and therefore there is large variability in annual drift rates (Gorleston to Lowestoft Coastal Strategy Study, 1999). Onshore-offshore movement of sediment is a key process, since alongshore energy is only 10% of the onshore-offshore component of sediment transport.

It has been postulated that there is an onshore component of sediment transport, with material moved offshore at Great Yarmouth returning to the shore around Hopton. Volumes of sediment associated with this transport mechanism are unknown.

Movement:

The long-term cliff erosion rate along this frontage is 0.71m/ year (Gorleston to Lowestoft Coastal Strategy Study, 1999). There has also been a long-term trend of retreat of mean low water at a rate of between 0.5 and 1.0m/year (SMP 3b, 1995). However, recent surveys have indicated beach advance along this section (Gorleston to Lowestoft Coastal Strategy Study, 1999).

Predictions of shoreline evolution:

Using simple extrapolation of long-term rates and taking into account defence residual life, the Gorleston to Lowestoft Coastal Strategy Study (1999) concluded that the likely recession of mean low water over the next 50 years to be approximately 100 to 110m, assuming a ‘Do Nothing’ scenario. Futurecoast predicted retreat rates to be 50 to 100m over the next 100 years, but this was an unconstrained scenario for the whole coast and for the cliffline. The SMP 3b (1995) predicted 60 to 80m of erosion (for the period 1994 to 2068).

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: HOPTON TO CORTON

Interactions:

Alongshore drift is southwards at a rate of between 10,000 and 40,000 m^3/year (SNSSTS, 2002). The rate is affected by configuration of the nearshore banks and therefore there is large variability in annual drift rates (Gorleston to Lowestoft Coastal Strategy Study, 1999). Onshore-offshore movement of sediment is a key process, since alongshore energy is only 10% of the onshore-offshore component of sediment transport.

Movement:

Between Hopton and Corton, cliff erosion has been taking place at approximately 0.78m/year (Gorleston to Lowestoft Coastal Strategy Study, 1999) despite the presence of defences. This highlights the importance of groundwater processes in cliff failure.

The long-term trend for the mean low water between Hopton and Corton indicated beach retreat, with losses in the region of 2,900,000m^3 between 1883 and 1952 (approximately 43,000m^3/year; UEA, 1971). There has been a recent advance of mean high water between 1993 and 1998 (Gorleston to Lowestoft Coastal Strategy Study, 1999).

Onshore-offshore movement of sediment is a key process along this shoreline, with material being moved offshore during storms.

Predictions of shoreline evolution:

The Gorleston to Lowestoft Coastal Strategy Study (1999) estimated recession of mean low water over the next 50 years to be between 70 and 90m, assuming a ‘Do Nothing’ scenario and taking account of residual defence life. A more conservative prediction was made by Futurecoast (2002), but for an unconstrained coastline, of 50 to 100m over the next century.

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: CORTON

Interactions:

Alongshore transport is predominately southwards and approximately 100,000m^3/year around Corton, which is higher than along the Great Yarmouth frontage.

Cliffs along this section are defended and have been regraded, but contain a high proportion of sand (over 80%) and therefore would contribute potential beach-building sediment to the system.

Onshore-offshore movement of sediment is a key process along this shoreline, with material being moved offshore during storms.

Movement:

Both the long-term (1883-1998) and short-term (1993-1998) trends at Corton have indicated beach retreat, which has been amplified by significant erosion events at Corton and Gunton in the past (Futurecoast, 2002). Between 1889 and 1998, the cliffs around Corton Woods were recorded to have receded by 0.18m/year (Gorleston to Lowestoft Coastal Strategy Study, 1999).

A promontory is forming as a result of defences at Corton and this is likely to act as a control on evolution, helping to stabilise the coastline immediately to the north, but accentuating downdrift erosion through reduced sediment supply (Futurecoast, 2002).

Predictions of shoreline evolution:

The Gorleston to Lowestoft Coastal Strategy Study (1999) estimated recession of mean low water over the next 50 years to be approximately 100m, assuming a ‘Do Nothing’ scenario and taking account of residual defence life. A more conservative prediction was made by Futurecoast (2002), but for an unconstrained coastline, of 50 to 100m over the next century. The SMP predicted erosion of between 45 and 65m for the period 1994 to 2068.

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: LOWESTOFT DENES

Interactions:

There is a net southward drift, but rates and direction vary; from the various studies, SNSSTS (2002) have proposed a drift rate of between 10,000 and 40,000 m^3/year; but the configuration of the nearshore banks has a significant effect on the net drift.

There is a feed of material from the north, but as the cliffs along the Gorleston to Lowestoft coast are mainly contributing sand, the shingle is probably mainly relict. Sand will also be sourced from dune erosion.

As for the rest of this shoreline, there is a high onshore-offshore energy and during storms much of the beach material can be scoured leaving the backshore vulnerable to wave attack (Futurecoast, 2002). Some of this material is then returned to the beaches, but a proportion is also lost offshore. Under storm conditions the potential sediment transport near the shore is rapid, although it is predominantly the sand-sized sediments that are mobilised away from the beaches (Futurecoast, 2002).

Movement:

There has been a long-term net retreat of mean low water at a rate greater than 2m/year (SMP3b, 1995; Gorleston to Lowestoft Coastal Strategy Study, 1999), although position has fluctuated slightly over time. Historical Ordnance Survey maps also indicate that there has also been erosion of dunes along this frontage of approximately 150m since 1887 (Futurecoast, 2002). Despite the net retreat over the long-term, there has been a slight flattening of the beaches along this stretch (Futurecoast, 2002).

Predictions of shoreline evolution:

The Gorleston to Lowestoft Coastal Strategy Study (1999) estimated retreat of mean low water over the next 50 years to be approximately 130m, assuming a ‘Do Nothing’ scenario and taking account of residual defence life. This is consistent with the estimate made by Futurecoast (2002) of 100 to 200m over the next 100 years. The risk of inundation of the low-lying hinterland was also identified. A very conservative estimate of erosion for Gunton was predicted by the SMP 3b (1995) of 0 to 15m.

It has been identified that this frontage is susceptible to changes in the nearshore banks system, but these are difficult to predict due to the complexity of the system (Futurecoast, 2002).

LOCAL SCALE: LOWESTOFT

Interactions:

Sediment transport is predominantly to the south with average rates of 40,000m^3/year at Lowestoft. There is no local input of sediment; therefore this frontage relies on inputs from the north.

Lowestoft Ness is believed to be a site of offshore movement, due to both the swift tidal currents around the ness at Lowestoft and the sand bank orientation (McCave, 1978; reported in SNSSTS, 2002). This may explain the higher proportion of shingle on the Lowestoft beaches than observed to the north (Gorleston to Lowestoft Coastal Strategy Study, 1999).

Some of this material may be returned to the beaches, but a proportion is also permanently lost offshore. Futurecoast (2002) argues that there is no knowledge to support the exchange of sediment between the shoreline and the nearshore and offshore banks, hence once material is lost to the offshore zone, it is unlikely to be returned onshore to this location.

The nearshore transport system is around Lowestoft complex, as the area immediately offshore is subject to a highly complex current regime.

Movement:

The shoreline position has not changed due to the presence of defences along this frontage. However, long-term trends (1983-1998) indicate that the beach has been retreating despite some beach advance in the short-term, between 1993 and 1998 (Gorleston to Lowestoft Coastal Strategy Study, 1999). There has been a net steepening of beaches along this stretch (Futurecoast, 2002).

Lowestoft Ness has been largely built upon, fixed by coastal defences and maintained since at least the 1900s, such that it is now no longer recognisable as a ness feature. In the 1880s, the shoreline at Lowestoft Ness stood several hundred meters seaward of its present position (Futurecoast, 2002), but was eroding at 3.6m/year (UEA 1971). By the early 1900s, a large proportion of the ness volume had been lost (approximately 1,838,500m^3 between 1883 and 1952), but the shoreline still stood seaward of its present position. This volume loss may be related to either (i) the dispersal and migration northward of a bank that was once located offshore of Lowestoft Ness in 1846 and protected the ness from wave attack; or (ii) the changing pattern of ebb and flood flows, generated by the banks and channels (Futurecoast, 2002).

By the 1920s most of the ness had been lost, with the retreat of the shoreline back to the seawall position both north and south of Ness Point.

Futurecoast (2002) links erosion of the shoreline at Lowestoft Ness to the nearshore and offshore bank systems, such as those at Holm Sand and Lowestoft Bank, where eroded sediment either accumulates or is transported elsewhere.

Predictions of shoreline evolution:

The Gorleston to Lowestoft Coastal Strategy Study (1999) estimated recession of mean low water over the next 50 years to be between 80 and 100m, assuming a ‘Do Nothing’ scenario and taking account of residual defence life. This is consistent with the estimate made by Futurecoast (2002) of 100 to 200m over the next 100 years. Futurecoast also identified the risk of significant inundation of the low-lying land (denes) behind, although this would be limited by the relict cliffline, which lies at the back of the denes. A very conservative estimate was made by the SMP 3b (1995) of 30 to 35m erosion.

C1.7 REFERENCES

(a) Key References

Futurecoast (2002). Halcrow.

Winterton Dunes Coastal Habitat Management Plan (2003). Final Report. Posford Haskoning.

Southern North Sea Sediment Transport Study (SNSSTS) (2002). Phase 2, Sediment Transport Report. Report EX4526. http://www.sns2.org HR Wallingford.

Sheringham to Lowestoft Shoreline Management Plan (1995). Sediment Sub-cell 3B. Phase 1. Volume 2: Studies and Reports. Halcrow.

North Norfolk Shoreline Management Plan (1996) Sheringham to Snettisham Scalp. Volumes 1 and 2. L.G. Mouchel & Partners Ltd

Cromer Coastal Strategy Study (2001). HR Wallingford Report EX4363. HR Wallingford.

Overstrand to Walcott Coastal Strategy Study (draft). HR Wallingford.

Ostend to Cart Gap Coastal Strategy Study (2001) HR Wallingford Report EX4342. HR Wallingford.

Happisburgh to Winterton Sea Defences: Stage Three Strategy Review (2002). Halcrow.

Gorleston to Lowestoft Coastal Strategy Study (1999). Part One Appendices A - C. Consultation Draft. Halcrow.

(b) Other References

ABP (1996). Southern North Sea Sediment Transport Study. Literature Review and Conceptual Sediment Transport Model. Report No. R.546, May 1996.

Andrews, J. E. et al. (2000). Sedimentary evolution of the north Norfolk barrier coastline in the context of Holocene sea level change. In: Holocene Land-Ocean interaction and environmental change around the North Sea. Geological Society Special Publication 166, 219-251.

Balson, P.S. (1999). The Holocene Evolution of Eastern England. Evidence from the Offshore Southern North Sea. Proceedings of the 4th International Symposium of Coastal Engineering. Sci. of Coastal Sedim. Proc.

British Geological Survey (BGS) (1996). Sediment Input from Coastal Cliff Erosion. Operational Investigation 577. Technical Report 577/4/A.

Cambers, G. (1976). Temporal Scales in Coastal Erosion Systems. Transactions of the Institute of British Geographers 1, 246-256.

Clayton, KM (1989). Sediment Input from the Norfolk Cliffs, Eastern England – A Century of Coast protection and its Effect. Journal for Coastal Research, 5(3) 433-442.

Delft (1986) Great Yarmouth Outer Harbour: Littoral drift study. Delft Hydraulics Laboratory.

Halcrow (1998). Caister Beach Coast Protection: Engineer's Report. March 1998.

Halcrow (2003) Gorleston Coast Protection Scheme: Sediment Budget. Great Yarmouth Borough Council.

HR Wallingford (1998). Research on the Behaviour and Engineering Significance of Coastal and Offshore Banks. Report SR512.

HR Wallingford (1999). Simulation of the sediment budget for the Happisburgh to Winterton Reefs. PICES application study.

Leggett, D.J., Lowe, J.P. & Cooper, N.J. (1998). Beach evolution on the Southern North Sea coast. In: Edge, B.L. Proceedings of the International Conference on Coastal Engineering, Copenhagen, 2759 – 2772. ASCE.

McCave, I.N. (1978). Grain size trends and transport along beaches: example from Eastern England. Marine Geology 28, 43-51.

Townend, I.H.T. & McLaren, P. (1990). The relationship between bank development and coastal response, East Anglia UK. Unpublished manuscript.

University of East Anglia (UEA) (1971). East Anglian Coastal Study Reports 2 and 3.

Vincent, C.E. (1979). Alongshore sand transport rates – a simple model for the East Anglian coastline. Coastal Engineering 3: 113-136.

C2 Defence Assessment

The Table below provides a summary of the existing defences along the SMP frontage together with an assessment of residual life. An assessment of residual life under a ‘no active intervention’ policy was undertaken using the condition data together with NADNAC *condition deterioration curves* (CDC), using the Table below as a guide.

Defence Description	**Estimate of residual life (years) under NAI policy**				
	Existing Defence Condition Grade:				
	Grade 1	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**
Seawall (concrete/ masonry)	25 to 35	15 to 25	10 to 15	5 to 7	0
Revetment (concrete/ rock)	25 to 35	15 to 25	10 to 15	5 to 7	0
Timber groynes and other timber structures (e.g. breastwork/ revetments)	15 to 25	10 to 20	8 to 12	2 to 7	0
Gabion	10 to 25	6 to 10	4 to 7	1 to 3	0
Note: Grade 5 is not used in the CPSE, but is included here as a measure of failure.					

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
6.01 Kelling to Sheringham		Between Weybourne West and Kelling Hard there are no built defences. At Weybourne the shingle bank (approx. 300m long) provides local flood protection. This is supported at the rear by a low timber palisade. Residual Life: Palisade: <5-10 yrs	Low, unconsolidated cliffs along much of this frontage. These cliffs disappear at Weybourne and a shingle bank protects low-lying land behind. The cliffs are present again to the east of Weybourne and increase in height towards Sheringham.
6.02 Sheringham	*1900*: West concrete wall constructed. *1920-1930*: Central and east concrete walls constructed. *1950-1974*: Timber groynes added to defences along area *1960*: Upgrade to west wall. *1993-1994*: Upgrade to central concrete walls including placement of rock armour revetment at toe. *1997*: Some timber groynes replaced with rock; remainder refurbished.	A vertically faced concrete seawall and promenade run along this section. The central seawall and promenade have a rock armour revetment placed along the toe. The seawall along the eastern section is a low concrete structure, which serves to reduce the rate of erosion rather than provide full protection. Groynes exist along this frontage: timber to the west and east with rock along the central section. Residual Life: Seawall (west): <15 yrs Timber Groynes: c20 yrs Seawall (central): c50 yrs Rock Groynes: c50 yrs Seawall (east): <15 yrs	Unconsolidated cliffs, between 20 and 25m in height, and in places include large chalk boulders (erratics). Cliffs have been re-graded and form a grassed slope along the town frontage. The beaches are composed of shingle and there is an upper pebble-sized beach. This is underlain by a chalk platform. The beach in front of the town is relatively narrow.
6.03 Sheringham to Cromer	*1976*: Groynes and revetments built and small masonry wall along the central section.	Timber revetment between Sheringham and West Runton has largely failed and is considered redundant (i.e. maintenance of this no longer part of present management practice). Timber groynes are present between these points. Two short stretches of masonry wall are present at the beach access points at West Runton and East Runton. Residual Life: Timber Groynes: <15 yrs	Unconsolidated cliffs, 20 to 40m high, which in places include large chalk boulders (erratics). These cliffs lie on a chalk platform, which dips eastwards. The beach composition changes slightly from that to the east and is predominately sandy with a thin veneer of shingle.

---

[2] Residual life based upon condition grade, assuming a 'do nothing' scenario. Classed as: <(5-10) yrs; <15yrs; c20yrs, <(35-40)yrs; c50yrs; >50yrs (rare).

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
6.04 Cromer	*1900 - 1910*: Concrete wall built along most of frontage. *1930*: Small east extension to concrete wall. *1968 - 1976*: Timber Groynes introduced.	Victorian concrete seawall and promenade back a timber groyned beach. The sections of seawall protecting the core of the town are generally poor. These walls currently rely on a high beach in front of them, but existing beach levels are becoming too low to maintain structural stability. Residual Life: Seawalls: c20 yrs (although some sections are less than this) Groynes: <15 yrs	Unconsolidated cliffs, which have been regraded and grassed along the town frontage. The cliffs vary in height between 20 and 50m and in places include large chalk boulders (erratics). These cliffs lie on a chalk platform, which dips eastwards. The chalk outcrops at the base of the cliffs. The beach is predominately sandy with a thin veneer of shingle at the base of the cliffs.
6.05 Cromer to Overstrand	*1960*: Timber Groynes. *1976*: Further Timber Groynes constructed, along with timber revetment at western extremity.	The timber revetment has already largely failed over this stretch and is considered redundant (i.e. maintenance of this no longer part of present management practice). Timber groynes remain along this frontage. Residual Life: Groynes: <5-10 yrs	Unconsolidated cliffs that reach heights of up to 60m. The cliffs are characterised by significant failures, such as rotational slides and slump scars and vary in composition along the shoreline. There is very little permanent backshore along this shoreline, and in places no backshore is present.
3b06 Overstrand	*1908*: Small stretch of concrete wall built. *1949*: Small section of steel breastwork built west of concrete wall. *1950s/1960s*: Rock gabions placed on cliff face near main access. *1955*: Concrete wall continued eastwards (small section). *1960*: Timber revetment and groynes constructed east side of concrete wall. *1967*: Timber revetment and groynes constructed west of concrete wall.	Concrete seawall over northern section, with timber revetment over southern section, the latter serving to mainly reduce rather than halt erosion. Steel groynes along the whole frontage. Residual Life: Seawall: <(5-10) yrs Timber Revetment: <(5-10) yrs Groynes: <15 yrs	Unconsolidated cliffs that reach heights of up to 30m. The cliffs are characterised by significant failures, such as rotational slides and slump scars and vary in composition along the shoreline. There is very little permanent backshore along this shoreline, and in places no backshore is present.

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
	1970: Timber revetment and groynes extended eastwards.		
6.07 Overstrand to Mundesley	*1930*: West concrete apron constructed at Trimingham. *1967*: South end construction of timber revetment and groynes. *1972 - 1974*: Extension of the concrete apron at Trimingham eastwards and timber revetment and groynes constructed along much of remainder the frontage. *1987*: Timber revetment and groynes built at western end of this frontage onto older 1970 revetment (See Section above).	Between Overstrand and Trimingham there are no built defences remaining along this section of shoreline. At Trimingham, the timber revetment has mostly failed (only the concrete apron remains). The groynes along this section are also generally in poor condition. <u>Residual Life:</u> Concrete Apron: <15 yrs Groynes: <5 yrs South of Trimingham, defences consist of the timber revetment, which serves to reduce rather than halt erosion, coupled with a timber groyne field. <u>Residual Life:</u> Timber Revetment: <15 yrs Groynes: <15 yrs	Unconsolidated till cliffs that can reach heights of up to 75m. The cliffs are characterised by significant failures, such as rotational slides and slump scars and vary in composition along the shoreline. The cliffs gradually reduce in height towards Mundesley. There is very little permanent backshore along this shoreline, and in places no backshore is present. Occasionally chalk is exposed on the foreshore. Towards the south the chalk layer disappears and is replaced by a clay platform. Occasionally this is exposed and subject to marine erosion.
6.08 Mundesley	*1910*: Concrete promenade constructed - south end of section. *1947*: Recurved concrete wall extension northwards of existing promenade. *1950*: Groynes constructed along frontage and steel breastwork erected north of wall (short distance). *1970*: Southern extension of concrete wall and apron south.	A timber revetment, then a row of steel piles retaining concrete cubes protects the northern half of this frontage. These all serve to slow rather than halt erosion. Hard defences are in place at the base of the southern section of cliffs in the form of a concrete wall and a small promenade. The entire length is timber groyned. <u>Residual Life:</u> Seawall: <c20 yrs Timber Revetment: <15 yrs Block Revetment: <15 yrs Groynes: <15 yrs	Unconsolidated cliffs approximately 25-35m in height. The cliffs are slightly sandier than those to the north and the failures are typically due to shallow landslides. There is very little permanent backshore along this shoreline, and in places no backshore is present. The beach rests on a clay platform and occasionally this is exposed and subject to marine erosion.
6.09 Mundesley to Bacton Gas Terminal	*1964*: Timber breastwork constructed. *1966*: Groyne field constructed along section.	The entire length is fronted by a timber revetment, which is semi-buried, which serves to reduce rather than halt erosion. There are also timber groynes throughout this length.	Low, unconsolidated cliffs, between 5 and 10m high, which generally fail through landsliding but which are presently stable.

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
		Residual Life: Timber Revetment: <15yrs Groynes: <5-10 yrs	There is very little permanent backshore along this shoreline, and in places no backshore is present.
6.10 Bacton Gas Terminal	*1960s*: Timber breastwork and groynes constructed at northern end (consistent with works to the north – see section above).	The length north of Tulsa Way is fronted by a timber revetment, which is semi-buried, which serves to reduce rather than halt erosion. Timber groynes are present throughout this length. Residual Life: Timber Revetment: <15yrs Groynes: <5-10 yrs	Low, unconsolidated cliffs, between 5 and 10m high.
6.11 Bacton, Walcott and Ostend	*1954*: Concrete wall and apron with steel piled toe constructed along much of section. Timber groynes also constructed along section. *1991*: Timber revetment at southern end of Ostend wall.	Protection against erosion and localised flooding is provided by a sloping concrete seawall and wave wall. Timber groynes are present throughout this length. Residual Life: Timber Revetment: <15yrs Groynes: <5-10 yrs Seawall: <15 yrs	Unconsolidated till cliffs which drop down to beach level at Walcott, creating a short gap in the line of cliffs that run from Cromer to Happisburgh. There is very little permanent backshore along this shoreline, and in places no backshore is present. The beach rests on a clay platform and occasionally this is exposed and subject to marine erosion
6.12 Ostend to Eccles	*1958 - 1959*: Small section of timber and steel revetment built in front of Happisburgh. *1961*: Timber revetment and groynes constructed along frontage. *1970*: Small section of concrete wall north of this. *2003*: Line of rocks placed at cliff toe along Happisburgh village frontage.	The whole length of shoreline here is protected by a timber revetment, which serves to reduce rather than halt erosion, and timber groynes. Some sections of the timber revetment are in the process of failing. The timber revetment and groynes fronting Happisburgh have now largely failed and is redundant. A line of rock armour presently provides protection, although this serves only to reduce rather than halt erosion. There are no defences to the cliffs south of the village. Residual Life: Timber Revetment: <5-10 yrs Groynes: <5-10 yrs	Unconsolidated cliffs, which increase in height towards Happisburgh. The beaches are predominately sandy, but there is occasionally shingle exposed in low runnel features. The sand forms a relatively thin layer on top of a clay platform. This is occasionally exposed, particularly during storm events.

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
		Rock Barrier at Happisburgh: <5-10 yrs	
6.13 Eccles to Winterton Beach Road	*1930-1970s*: Timber and steel groynes built in stages along this section. *1950s*: Sections of concrete wall constructed. *1958*: Concrete wall extended southwards. *1968*: Further southern extension of concrete wall. *1981 - 1983*: Extension of northern concrete wall. *1986*: Concrete sea wall is built at Cart Gap. *1987*: Upgrade of section of southern wall. *1993 - 1994*: Rock revetments and breakwaters constructed along northern end of section. *1995*: Four reefs (Reefs 5 to 8) were completed. *1997*: Five reefs (Reefs 9 to 13) were constructed. *Ongoing*: replacement of steel and timber groynes and sand renourishment at regular intervals *2000*: Beach recharge between March and May for a section of the coastline.	North of Sea Palling a concrete seawall, fronted by steel groynes, provides defence: this prevents erosion of the thin strip of land fronting the expansive flood plain to the south. Timber groynes front this wall. This beach receives occasional sand renourishment. Residual Life: Seawall: c20 yrs Groynes: c20 yrs From Sea Palling to Waxham the nine offshore rock reefs retain a high beach level in front of the concrete seawall. There is some re-establishment of dune over and in front of the wall. Residual Life: Rock reefs: c50yrs Seawall: <35-40 yrs Between Waxham to Bramble Hill a concrete seawall, fronted by a mixture of old and new groynes, provides defence. This beach receives occasional sand renourishment. The stability of the wall is entirely dependent upon the condition of the beach. Residual Life: Seawall: <5-10 yrs (due to beach loss) Old Groynes: <5-10 yrs New Groynes: c20 yrs The concrete seawall continues between Bramble Hill and Winterton Ness. There are no new groynes here at present, therefore seawall stability is threatened by failure of the existing groynes. Residual Life:	A narrow strip of foredunes back a mainly sandy beach. The backshore is very narrow and in places is absent but between Eccles and Waxham there is a wider backshore and foreshore due to beach management works. There is a vast low-lying hinterland, which is potentially at risk from flooding. The beach cover is thin and occasionally erosion has resulted in exposure of the underlying clays and subsequent down cutting. At Winterton Ness there is an extensive sand dune complex, which backs a sandy beach. The ness is known to fluctuate in position. The beach is wide and sandy, but the foreshore is steeply dipping.

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
		Seawall: <5-10 yrs (due to beach loss) Groynes: <5-10 yrs South to Winterton Beach Road the seawall becomes covered by encroaching dunes. These are naturally formed and, although established and relatively stable as a body, are still mobile. Residual Life: Seawall: <15 yrs (due to beach loss) Groynes: <5-10 yrs	
6.14 Winterton to Scratby	No manmade defences present.	There are no built defences. The sand dunes provide a natural defence. But these narrow towards the south and the present erosion on their seaward face is of concern.	Between Winterton and Hemsby, there is a wide dune system, which is backed by low relict cliffs. A low area known as The Valley separates these two morphological elements. This low area becomes reduced in width to the south. Towards the south the dunes narrow and become replaced by unconsolidated cliffs up to 15m high; which are mud-dominated. The backshore beach is wide and sandy, but the foreshore is steeply dipping.
6.15 California to Caister-on-Sea	*1995-1996:* Backshore rock berm constructed	A rock berm, set approximately 10m from the cliff toe, limits cliff erosion at California. At the southern end of the berm the cliff/dune face is covered by a concrete and asphalt seawall, which is acting as a “strong point” on this stretch of coast. Residual Life: Rock Berm: <35-40yrs Seawall: <35-40 yrs	The sandy beach is backed by unconsolidated cliffs up to 15m high; at California there is a higher proportion of sands than to the north. The cliffs rapidly reduce in height to the south of California.
6.16 Caister-on-Sea	*1954*: First works, construction of small section of concrete wall at southern end. *1970*: Concrete wall and apron	The concrete and asphalt seawall continues along this stretch. To protect this wall, two “Y”-shaped rock groynes retain beach sand. South of this the concrete wall is protected by the sand beach retained by 4 rock reefs in	The cliffs are replaced by a low dune ridge, which fronts a gently rising hinterland. The beaches are narrow along this section,

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
	built and steel groynes placed in front of wall. *1975*: Southward extension of this wall with mastic (splashwall, pitching and apron) and concrete sections. *1981 & 1985*: Rock armour placed along sections of concrete wall *1995*: Rock groynes constructed towards southern end.	front of the holiday village. <u>Residual Life:</u> Rock groynes and reefs: c50 yrs Seawall: <35-40 yrs The concrete wall continues south of the reefs, although the beach is narrower and wall stability will be entirely dependent upon the health of this beach. Existing steel groynes are buried but were already dilapidated and redundant. <u>Residual Life:</u> Seawall: c20 yrs	but the construction of groynes and reefs at Caister have resulted in wide beaches at this point, but the beach cuts back immediately south of the reefs. The beach widens again towards the Lifeboat Station, where there is an accumulation of material at Caister Point, forming a small ness feature. The beaches are predominately sandy, but there is a veneer of shingle around mean high water.
6.17 Great Yarmouth	*1930*: Concrete wall constructed along frontage. *1954*: Concrete wall constructed along frontage. *1960*: Steel breakwater concrete breakwater, steel wall forming North Pier. *1973*: Timber groynes.	The larger seawall running from Caister reduces to a small cut-off-wall behind the dunes dividing the natural shore from the area of development. The sand dunes provide a natural defence, which although established and relatively stable, still form a mobile system. <u>Residual Life:</u> Seawall c. 50 years (dependent upon dune health/ width) Towards the south the seawall becomes re-exposed and Great Yarmouth seafront is protected by a low concrete seawall and promenade, however, the wide beach forms the primary defence. <u>Residual Life:</u> Seawall: >50 yrs South of Great Yarmouth, Pleasure Beach, the beach narrows and the main defence is the concrete wall and promenade. At the southern end is the North Pier, a groyne of steel, timber and concrete forming part of the entrance to Gt. Yarmouth Port. The southern section of this frontage has timber groynes.	Dunes front a low-lying hinterland, these are currently accreting, but are relatively low in form. This system reduces in size to the south, and at the Pleasure Beach there is very little dune development, probably due to human pressure, but the dunes become more substantial again towards the south, where access to the beach is more restricted. The sandy beach is wide and flat, but the backshore narrows towards the south.

Policy Unit	Defence History	Summary of present defences and Residual Life^2	Natural Features
		<u>Residual Life:</u> Seawall: c20 yrs Groynes: <15 yrs Harbour Arm: c20 yrs	
6.18 Gorleston	*1930*: Concrete wall. *1950*: Extension southwards of concrete wall. *1970*: Stone armour placed. *1973*: Timber Groynes constructed. *1980s* Further extension of wall south.	The whole of this section is fronted by a sloping concrete seawall. The South Pier (forming part of the entrance to Gt. Yarmouth Port) at the northern end has a spur breakwater to help retain the beach. This section of coastline is timber groyned. <u>Residual Life:</u> Seawall: c20 yrs Groynes: <5-10 yrs Harbour Arm: c20 yrs	Unconsolidated cliffs reach heights of between 10 and 15m, but these have been regraded and grassed behind the sea wall. There is a narrow predominately sandy foreshore, but a wide, flat backshore at the northern end, which narrows considerably towards the south.
6.19 Gorleston to Hopton	*1975*: Timber revetment and groynes constructed along section.	The entire length is fronted by a timber revetment, which is semi-buried, which serves to reduce rather than halt erosion. There are also timber groynes throughout this length. <u>Residual Life:</u> Timber Revetment: <15yrs Groynes: <5-10 yrs	Unconsolidated cliffs reach heights of between 10 and 15m; the cliffs have been regraded and grassed behind the defences. There is a narrow predominately sandy foreshore. Where a backshore is present there is commonly shingle present. The beach height varies along the frontage and is greater along the southern end.
6.20 Hopton	*1965*: Concrete wall constructed. *1975*: Northern Timber revetment consistent with the area to the north (see Section above). Timber groynes also constructed along frontage.	The northern section is fronted by a timber revetment, which is semi-buried, which serves to reduce rather than halt erosion. The southern section of frontage is fronted by a sloping concrete seawall. The whole of this section is timber groyned. <u>Residual Life:</u> Seawall: c20 yrs Timber Revetment: <15yrs Groynes: <5-10 yrs	Unconsolidated cliffs reach heights of between 10 and 15m. There is a narrow predominately sandy foreshore. Where a backshore is present there is commonly shingle present.
6.21 Hopton to Corton	*1970 to 1973*: Concrete wall and Timber revetment (north-Hopton	The northern section of this area is fronted by the Hopton concrete seawall, which extends to protect the ex MoD site.	Unconsolidated cliffs reach heights of between 10 and 15m.

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
	seawall) and timber groynes.	South of the wall the cliffs are fronted by timber revetment, although this serves to reduce rather than halt erosion. There are timber groynes throughout this length. <u>Residual Life:</u> Seawall: <15 yrs Timber Revetment: <5-10 yrs Groynes: <5-10 yrs	There is a narrow predominately sandy foreshore; where a backshore is present there is commonly shingle present. Along the majority of this frontage, low dunes have developed in front of the cliff toe.
6.22 Corton	*1967*: Corton concrete seawall. *1975*: Timber groynes. *1986*: Extension south of concrete seawall and apron. *1988*: Concrete armour (tripods) placed along 1986 wall. *2001*: Failure of piles and base of seawall. *2003*: New rock armour protection to seawall.	Rock revetment fronting concrete seawall. <u>Residual Life:</u> Seawall: c20 yrs	The cliffs reach heights of over 20m. There is a predominately sandy foreshore and the beach is extremely narrow and low.
6.23 Corton to Lowestoft	*1967*: Concrete wall at northern end. *1970*: Timber groynes.	The cliffs at the northern end are protected by a concrete seawall, set back behind the beach. There are no seawalls in front of other sections of Gunton Warren. There are timber groynes throughout. <u>Residual Life:</u> Seawall: c20 yrs Groynes: <5-10 yrs	The cliffs become set inland by several metres and are fronted by a beach and dune system. The beach material becomes slightly coarser towards Lowestoft and the beach is higher than at Corton.
6.24 Lowestoft North	*1940*: Concrete apron constructed. *1953*: Concrete wall and splash wall constructed. *1970*: Timber groynes constructed. *Late 1980s*: some concrete armour and piling constructed. *Early 1990s*: Rock breakwaters and armour placed.	There is a concrete wall, promenade and second splash wall. An old concrete wall remains at low water, possibly assisting in retaining the beach. At Lowestoft Ness the defences have been further protected with the addition of rock armouring. The remnants of groynes front the whole shoreline, although these are now considered redundant (i.e. maintenance of this no longer part of present management practice).	There is a cliff line set some distance inland, but the hinterland backing the shoreline is low-lying. The beaches comprise a higher proportion of shingle than those to the north. At Lowestoft this hinterland has been significantly modified and little of the original morphology remains. To the north the beach levels are quite healthy, but the beach narrows rapidly to the south and at

Policy Unit	Defence History	Summary of present defences and Residual Life[2]	Natural Features
		Residual Life: Seawall (North Denes): c20 yrs Seawall (Lowestoft Ness): c50 yrs	Lowestoft Ness itself there is no beach present. Lowestoft Ness is no longer recognisable as a ‘ness’ feature and the entire area has been built upon and artificially maintained since at least the early 1900s.

C3 Other Considerations

C3.1 CLIMATE CHANGE AND SEA LEVEL RISE

(a) Introduction

The global climate is constantly changing, but it is generally recognised that we are entering a period of change, particularly with respect to rising sea levels and the anticipated implications of climate change and sea level rise present a significant challenge to future coastal management. Over the last few decades, there have been numerous studies into the impact of potential changes in the future, however, there remains considerable uncertainty both within the science of future climate modelling and associated with future global development patterns.

(b) Sea level rise

The East Anglia coast is believed to be still responding to changes during the last 10,000 years when sea levels rose rapidly, flooding the North Sea Basin, but there is now concern over human-induced acceleration in sea level rise due to climate change. Relative sea level change depends upon changes in global sea level (eustatic change) and in land-level (isostatic change).

Isostatic change is the change in land level as the crust slowly readjusts to unloading of the weight of the ice since the last Ice Age. Therefore, areas which were covered by ice, i.e. northern England and Scotland, have been experiencing a rise in land levels over the last few thousand years, whereas along the East Anglian coast the land has been subsiding at a rate of between 0.7 and 2mm/year (see Figure below).

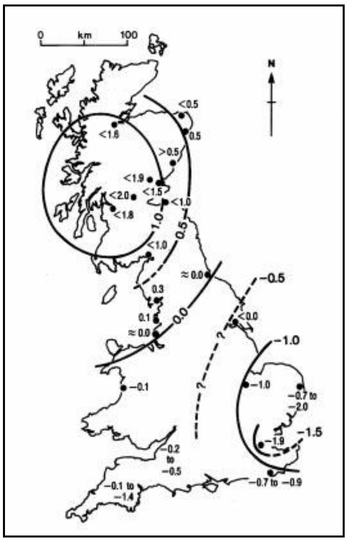

Figure C3.1 Estimates of relative land changes (mm/yr): positive values indicate relative land uplift; negative values are relative land subsidence. Effects of sediment consolidation are not included [Source: Ian Shennan, 1989].

Eustatic change can be influenced by climatic changes (e.g. increased temperature causes an increased volume of water through thermal expansion and melting ice). Evidence suggests that global-average sea level rose by about 1.5mm/year during the twentieth century; this is believed to be due to a number of factors including thermal expansion of warming ocean waters and the melting of land (alpine) glaciers[3], but after adjustment for natural land movements, it has been calculated that the average rate of sea-level rise during the last century around the UK coastline was approximately 1 mm/year[3].

Predictions of sea level change have been developed by the UK Climate Impacts Programme (UKCIP) for four possible future climate scenarios: Low, Medium-Low, Medium-High and High; these span a range of emissions scenarios and different climate sensitivities. The Table below presents the current UKCIP (2002) estimates of future sea level change for Eastern England for the two extreme scenarios, low emissions scenario and high emissions scenario. The Table also includes the Defra 2003 recommendation for consideration of sea level rise, which has been used in the SMP assessments.

Regional Isostatic Subsidence	UKCIP Net Sea-level Change 2080s (relative to 1961-90)		Defra recommendation for Anglian Region (2003)
	Low Emissions scenario	High Emissions scenario	
1.2 mm/yr	220 mm	820 mm	6mm/year
(Data from Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report) (data available from website: *www.ukcip.org.uk*). UKCIP do advise, however, that these could vary by ± 50% because regional variations in global sea level rise.			

(c) Storminess

It has been postulated that climate change may increase storminess around the UK, but although the UKCIP02 studies indicate some increase in storminess, there is a high degree of uncertainty and little agreement between models, regarding changes in mid-latitude storm intensity, frequency and variability. Therefore although this is recognised as an uncertainty within the predictions, no detailed analysis of potential impacts has been undertaken.

(d) Precipitation

In addition to sea level rise and storminess, the other climate change factor that is important to coastal evolution is precipitation. UKCIP02 predictions suggest that winters will become wetter but summers may become drier throughout the UK. However, there is potential for heavy winter precipitation to become more frequent. This may have an impact on the soft cliffs along this coastline could increase the likelihood of large-scale slope failures, but although this is recognised as an uncertainty this has not been directly taken into account in the shoreline evolution predictions, as effects are likely to be localised, but where large-scale failure are a potential hazard this has been recognised in the scenario assessments.

C3.2 OFFSHORE BANKS

Between Winterton Ness and Lowestoft, there is a shore-parallel bank system is composed of numerous shallow sand banks separated by ebb and flood-dominated channels. The banks have no geological foundation and are thus the result of a unique combination of high sediment availability within a zone of strong tidal convergence. This produces a local system that is highly mobile, thus influencing and altering wave and current interactions, which in turn restructure the bank formations.

---

[3] Hulme,M., Jenkins,G.J., Lu, X., Turnpenny,J.R.,Mitchell,T.D., Jones,R.G., Lowe,J., Murphy,J.M., Hassell,D., Boorman,P., McDonald,R. and Hill,S. (2002) Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp

Sandbanks can interact with the coast in a variety of ways (Halcrow, 2002):

- They can provide a physical barrier to incoming wave energy, which directly reduces the energy of waves reaching the coast, and therefore reduces the degree of beach or cliff erosion within the shelter of the bank. Recent studies on Scroby Sand have shown that the presence of this bank may reduce the wave height of waves with a 50-year return period by over 75%. This effect is greatest at low tide when water depths over the crest of the bank are reduced (Posford Duvivier, 1997).
- They may refract incoming waves to focus wave energy onto the shore enhancing beach or cliff erosion on short coastal sections. Subsequent changes in sandbank configuration may change the focus of wave attack and historically there have been variations in the amount of protection the banks have provided due to their changing configuration
- They may provide an offshore sink of sand, which may be exchanged with the coast. Sandbanks on the north east Norfolk and Suffolk coasts are connected to the shore by small headlands or ‘nesses’ which occur on sections of coast where alongshore sediment transport paths converge. These points may represent ‘corridors’ for sediment exchanges between the littoral system and the offshore bank system. Scroby Sand, which is connected to the coast near Great Yarmouth, is thought to have increased steadily in volume since 1865, which has enhanced its protective value to the coast (Posford Duvivier, 1997).

The bank system therefore exerts an important control on the behaviour of this coastline. However, they are not static in their position and changes in their configuration affect their influence on the coast. Some research has suggested that the tidal channels, which separate the banks, show cyclic decay and growth behaviour over a 100 to 150 year period: but this is, however, based upon data only covering the last 170 years, so cannot be considered conclusive. It is not, therefore, possible to predict the future development of the banks due to the inherent complexity of the system. Although the broad area over which the banks operate is not expected to change over the next century, local areas are likely to be affected by changes in bank height and position; which may potential result in increased erosion in some areas or, conversely, accretion. Due to the difficulty in predicting future positions of the banks, it has been assumed for the SMP that the bank configuration remains the same as present.

C3.3 OFFSHORE DREDGING ACTIVITIES

A review of aggregate dredging and disposal activities in the study area was undertaken as part of the SNSSTS (HR Wallingford, 2002). No further investigations have been undertaken by this SMP, this section therefore summarises the key conclusions from the SNSSTS report, which reviewed details of work carried out for the Crown Estate by the (then) Hydraulics Research Station from as early as 1965.

Dredging of sand and shingle from the seabed has been undertaken since at least the 16th century. More recently there have been concerns that such removal of sediment has had an impact on coasts and in particular on the observed rates of erosion. The key dredging area that could have an impact on the SMP coast is the ‘East Coast Region’, which lies seawards of the coastline between Caister Ness and Lowestoft. Dredging in this area resulted in the extraction of over 9.6 million tonnes of sand and gravel.

Potential impacts of dredging on the coast have been identified as:

- Beach drawdown: this may result if extraction takes place so close to a beach that, during storms, the beach sediments are combed down into the dredged depression.
- Changes in wave refraction: this may result where depressions left by dredging altering the bathymetry sufficient to change the way in which waves refract as they approach a shoreline.
- Alteration of tidal currents: this could be caused by the dredged depression, at least locally, with the possibility of altering natural sediment transport processes on the seabed or even along a nearby coast.
- Reduction in onshore transport of sediment: this might arise if the material extracted would otherwise have travelled to a coast, or if the depression in the seabed caused by dredging intercepted and trapped other sediments travelling through the area on route to the coast.
- Reduction in shelter provided by a sandbank or similar seabed feature due to lower crest levels: this could conceivably occur either directly, i.e. by dredging on the bank itself, or indirectly by dredging too close to a bank provoking an equivalent of beach drawdown.
- Impact on natural sediment transport processes in and around the extraction area due to the actual process of dredging affecting the sediment content of the seawater.

Extensive research has been carried out to investigate these possible effects. Research by HR Wallingford in the late 1960s concluded that, in general, the lowest limit of beaches is about –7m to –8m below lowest tidal level along the East Coast whilst dredging tends to take place in depths greater than about 18m below lowest tidal level; meaning that drawdown is not an issue. Research at Wallingford in the early 1970s, using early computer models of wave transformation, concluded that in south-east England, it was unlikely that dredging would have significant effects on wave refraction, provided extraction was in water depths greater than 14m below lowest tidal level (Motyka & Willis, 1974).

These various possibilities are all fully considered in a modern-day environmental assessment of any proposed marine aggregate dredging, and there is a set of UK Government procedures that must be followed before dredging is allowed (SNSSTS includes further details on these). Under the latest arrangements for the Government View, a dredging licence application has to be accompanied by both an Environmental Statement/ Assessment and a “Coastal Impact Study” and both documents are widely distributed. Therefore the physical effects of virtually all of the existing offshore dredging areas in the study area have been investigated in the last 10 years, together with a number of proposed new extraction areas.

The SNSSTS states that recent studies carried out off Great Yarmouth have concluded that changes in bed levels in and around the dredging areas were not distinguishable from natural variations and that there has been no infilling of the dredged depression, for example by sand, and that the changes to waves and tidal currents have not affected even the seabed immediately adjacent to the licensed area.

For further information on dredging, refer to the SNSSTS, Appendix 1 (HR Wallingford, 2002; report available from website http://www.sns2.org).

C3.4 GREAT YARMOUTH OUTER HARBOUR DEVELOPMENT PROPOSALS

In 1986, the Great Yarmouth Outer Harbour Act 1986 granted powers to construct, maintain and operate an Outer Harbour. Since this time various studies have been undertaken to assess the potential impacts of such a development. In February 2000, Posford Duvivier produced a design report offering two alternative layouts. In each scheme, the harbour is formed by two breakwaters with the main breakwater springing from the north side of the entrance of the River Yare then curving round parallel with the coast line in a northerly direction 600m offshore. Protection from the north is provided by the lee breakwater located 835m to the north which thrusts out in a south-easterly direction from the beach (www.eastport-gy.co.uk). An entrance 190m wide is provided in the east face of the Harbour. As part of the proposed schemes, part of the harbour basin would be dredged down to minus 9.5 CD to provide a balance of material and the remainder of the harbour would be dredged to minus 8.5 CD.

The Gorleston to Lowestoft Coastal Strategy Study (Halcrow, 1999), made an assessment of the potential impacts of the Outer Harbour development, which involved a review of studies by HR Wallingford (1998). It was concluded that:

- At the northern end of the Outer Harbour, the development of a localised area of northward littoral drift, of approximately 20,000m^3/year, could result in losses to the beaches to the north as sand is transported towards Caister Ness.
- At Gorleston beach, without intervention, there could be a loss of up to 24,000m^3/yr of beach material supplied from South Denes, under average annual wave conditions.
- The impact on the offshore sand banks is likely to be minor since sediment transport over the bank is not significantly modified (HR Wallingford, 1998).
- Impacts along Waveney District Council’s frontage and at Lowestoft Harbour will be insignificant provided that the losses from the beaches up-drift are managed.

In addition, the HR Wallingford study (1998) concluded that:

- The short-term impact on alongshore drift within 300 metres of the coast is restricted to approximately 1.5 km to the north and 2 km to the south.
- The magnitude of impact is comparable with predicted natural variability, albeit it represents a permanent effect.
- If future conditions gave rise to net northerly drift of sediment (rather than the current southerly drift), the existence of the Outer Harbour will have no direct impact (this is owing to the effect of the existing South Pier).

The 1998 study also recommended the following:

- To instigate a monitoring programme, concentrated at intervals up to 2 km south of the Harbour development, extending to LAT (Lowest Astronomical Tide).
- Arrangements for liaison with the affected authorities to evaluate the effect of monitoring.
- Regular removal of built up sand to the north of the lee breakwater, and its use to replenish Gorleston Beach. This is expected to be a relatively modest commitment; current estimates predict gross southerly movement of around 40,000 cubic metres a year.

- Further modelling and detailed consideration at the next stage of Harbour design to ensure that the northerly (lee) breakwater effectively traps sediment from southerly littoral drift, rather than diverting it offshore, where it would be unavailable for beach replenishment.

Since these studies, the design of the Outer Harbour has been revised and construction completed. Construction of the traditional river port's new outer harbour began in June of 2007, with a joint venture between Van Oord UK Ltd and BAM Nuttall Ltd undertaking to build two breakwaters with a total length of 1,400m as well as the dredging and re-use of some 1.6m cu/m of sand to provide 17.6 hectares of land and the construction of 450m of quay. The new facility features two ro-ro berths which will accommodate vessels of up to 200m length.

An uncertainty identified by a subsequent broad-scale study (SNSSTS, HR Wallingford, 2002) relates to the feed of sediment between the Great Yarmouth Banks and the Lowestoft banks, which depends on the position of the Holm Channel. The study was unable to comment further but stated that this may be significant in the development of Great Yarmouth Outer Harbour extension and therefore required more detailed study.

Further information on the Outer Harbour is available from the East Port website (http://www.eastportuk.co.uk/deep-water-outer-harbour).

C3.5 GORLESTON REEFS

The 50-year strategy for the Gorleston Coast Protection Scheme proposed the construction of 8 shore-parallel reefs positioned approximately 175m offshore from the seawall in the north and the most southerly reef approximately 90m offshore from the seawall, so that they taper in against the shoreline. The scheme would also comprise refurbishment of the existing seawall and an initial beach recharge behind the reefs of approximately 100,000m^3 of sand, sourced from the beach between the two piers on the accreting town beach.

The reefs are expected to reduce alongshore transport by an average of 5,000m^3 per year, therefore the scheme also proposes an ongoing recharge in the order of 25,000m^3 sand will be deposited 500m south of the proposed reefs once every five years as a mitigation measure against any consequent loss of material from the immediate frontage and downdrift.

The aim of the scheme would be to utilise the cross-shore transport of sediment, by initiating wave breaking and the subsequent deposition of material landwards of the reefs, similar to the scheme in place at Sea Palling.

Modelling has been undertaken by Halcrow (2004) to investigate the impacts of the scheme. From this the study concluded that because the reefs are positioned just inshore of the zone of peak alongshore transport, the majority of alongshore sediment transport would still able to take place. Halcrow estimated that the rock reefs could reduce alongshore drift by 5,000m^3/year (Halcrow, 2002a), but this would be mitigated through the recharge. The reefs would be expected to stabilise the beach through reducing cross-shore losses, although some sediment was expected to be supplied to the nearshore bank system during storms.

The study by Halcrow did not model impacts over the wider frontage, i.e. between Great Yarmouth and Ness Point, Lowestoft, but an assessment of impacts was based on an understanding of coastal processes and the modelling undertaken in the local area. Based upon the reported drift divide at Corton (to the south), it was concluded that the construction of the reef scheme at Gorleston would be unlikely to have any significant impacts on the coastline to the south.

At the time of this review, the reef scheme is currently under consideration, with monitoring in place. There is also a proposal in place for seawall refurbishment, which will be subject to availability of funds from Defra.

C4 Baseline Case 1 – No Active Intervention (NAI)

C4.1 INTRODUCTION

This report provides analysis of shoreline response conducted for the scenario of “No Active Intervention”. This has considered that there is no expenditure on maintaining/ improving defences and that therefore defences will fail at a time dependent upon their residual life (see Defence Assessment, Section C2) and the condition of the beaches.

The analysis has been developed using the understanding of coastal behaviour from both Futurecoast and the baseline understanding report produced (see Section C1), existing coastal change data (see Section C4.4) and information on the nature and condition of existing coastal defences.

Maps illustrating potential flood and erosion risk are included at the end of the appendix.

C4.2 SUMMARY

The following text provides a summary of the analysis of shoreline response with details specific to each location and epoch contained within the Scenario Assessment Table.

(a) Epoch 0-20 years (to 2025)

During this period there will be increased pressure on the coastline, with continued diminishing beaches along much of the shoreline.

The more substantial defences, such as seawalls and reefs will remain along the majority of frontages, but there will be failure of timber revetments and groynes during this period. Therefore at locations where defences have tended to slow erosion, there will be an initial acceleration in retreat rates. This will put increased stress on the remaining defences.

Where defences remain, beaches will narrow as exposure increases due to continued transgression of the coastal system and deeper nearshore areas. These areas will increasingly become promontories as adjacent areas retreat.

Along the undefended coast, it is expected that cliff erosion will continue at rates experienced over the past 20 years, although there are exceptions to this such as Happisburgh, where defences have recently failed. There will be increased input of sediment into the system, but it is expected that this will mainly result in maintaining rather than building beaches.

Along most sections breaches and tidal inundation will be averted due to defences remaining, but the probability of natural defences, such as at Newport and Winterton, being breached will increase. At Winterton and Great Yarmouth the beach and dunes are expected to continue their role as a natural defence.

(b) Epoch 20-50 years (to 2055)

There will be increased pressure on the coastal system due to accelerating sea level rise. During this period many of the remaining seawalls will fail, accelerated by narrow beaches and increased exposure where these have previously been held in advanced positions. This will result in very rapid erosion at these locations, where shoreline position has been unnaturally held for over 120 years in some cases. The erosion is likely to remain rapid for 5 to 10 years before a position more commensurate with shoreline energy is reached, when rates more similar to those pre-defences, should continue. At a limited number of locations the seawall may remain. Here beaches are likely to disappear, as there will be deeper water and greater wave exposure at the seawalls. These conditions will not be conducive to beach retention and any sediment arriving on these frontages is likely to be rapidly transported offshore again.

Rock reefs and berms will continue to reduce wave energy at the shore and therefore slow erosion but these are likely to diminish in effectiveness during this period as sea levels rise, resulting in increased sediment transport behind reefs and increased energy at the backshore.

Along undefended sections, cliff and dune erosion will continue at rates slightly higher than those currently, due to sea level rise. This will release more material into the system, which will help maintain beaches.

A key change to the shoreline will occur along the Happisburgh to Winterton stretch, where failure of short stretches of defence will result in large-scale inundation of the Broadland area. This will also threaten the integrity of the remaining defences. Elsewhere, such as at Newport and Great Yarmouth there will also be increased risk of breach and inundation of low-lying areas.

(c) Epoch 50-100 years (to 2105)

All defences will have failed or deteriorated by the end of this period. The rock reefs may still have an impact on wave energy, but this will be much diminished from the current situation.

The long-term picture is one of a more connected coastline, in a position more commensurate with shoreline energy. Along most of the shoreline there will be a more naturally functioning sediment transport system. There will, however, still be continued shoreline retreat, in response to rising sea levels, despite input of sediment into the system from cliff retreat. At some locations, beaches may continue to narrow where cliff retreat is slower than the advancing sea level.

Where defences have remained up to the start of this period, the shoreline will extend several tens of metres seaward of the adjacent shoreline, therefore as defences fail there will be a very rapid recession as the shoreline attains a position more commensurate with shoreline energy. Along undefended stretches the cliff erosion will continue at accelerated rates due to sea level rise. The input of sediment should allow beaches to be maintained at the foot of the cliffs and to develop at retreated positions.

There is uncertainty over the final morphology of the Happisburgh to Winterton shoreline along the now frequently inundated Broadland area under this scenario, but it is possible that a beach ridge system will develop in a retreated position, allowing continued sediment transport to Winterton Ness.

Along other areas which front low-lying land there will be an increased risk of inundation with rising sea levels.

C4.3 NAI SCENARIO ASSESSMENT TABLE

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Kelling Hard to Sheringham	The short length of palisade along the shingle ridge fails in the first half of this period.	No defences.	No defences.
	Cliff erosion will continue at similar rates to those experienced historically, with a net retreat of the cliff line of between 5 and 15m by year 2025. Erosion will be greater at the western end of this frontage due to the slight build up of beach at Sheringham (to the east) providing greater protection to the cliffs. With failure of the palisade, the shingle ridge at Weybourne will retreat in line with the cliffs, but this is likely to occasionally breach, resulting in local-scale inundation of the low-lying land behind. There will be very little input from alongshore to this system due to the low sediment transport rates along this stretch of coast. The cliffs themselves contribute some beach building material (mainly sand), which may build or at least maintain the beaches as the shoreline retreats. There will be no changes in sediment transport to areas both west and east.	Cliff erosion will continue at an increased rate, due to sea level rise, with a net change in cliff line position of between 20 and 30m by 2055. Cliff erosion will release sand and some shingle to the beach. Under continued sea level rise this may not be sufficient to maintain beaches under the increased energy. Therefore beaches are expected to start to narrow. Some of the shingle from the system will be moved both to the east and west, but the finer sediments are likely to be lost offshore. There will be increased risk of breach of the shingle ridge at Weybourne, although a low ridge is likely to remain, retreating in line with the adjacent cliffs.	Cliff erosion will continue at an increased rate, with a net change in cliff line position of 40 to 60m by 2105. Cliff erosion will release some sand and shingle, but under sea level rise this may not be sufficient and therefore a narrowing beach and loss of beach volume is expected. This may increase the rate of cliff retreat, meaning that during this period there will still be a beach present at the foot of the cliffs. There will inundation of the low-lying area at Weybourne as the shingle ridge diminishes in size and is more frequently over washed. There will be continued shingle supply to the west and this may even increase due to increased wave energy at the shoreline.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Sheringham frontage	The timber groynes will fail during this period as will the seawall to the west. In front of the town the seawall and rock groynes will remain in place.	The central seawall and rock groynes will remain for most of this period.	The central seawall and rock groynes will fail at the start of this period.
	There will be no change in cliff line position due to the defences. The cliffs will also remain stable. There is little beach currently present and this would not build due to (1) no local input due to protection of the cliffs; (2) little input to the area due to low drift rates; and (3) increased exposure of the beach as the promontory becomes more pronounced. As the natural response of the shoreline is restricted, the beaches will steepen and narrow. The rock groynes will increasingly reduce the longshore transport, which will impact on areas to the east, but there may still be transport to the west.	The natural response of the coast to retreat would be restricted due to the seawall, with the shoreline position held, but beach width significantly reduced, due to coastal squeeze under sea level rise and the lack of local sediment input from the protected cliffs. The defended section would become a more pronounced promontory, with beach loss to the west and east. This will be exacerbated by sea level rise, which will result in increased exposure of the beaches. Some material will be held by the rock groynes along the town frontage, therefore a narrow beach may remain through this period, but this will be close to disappearing by 2055.	Loss of the defence will lead to very rapid erosion of cliffs with retreat of the shoreline to a position aligned with adjacent shorelines to west and east. The actual rate will depend on the cliff composition and also on the break down of the defence and infrastructure of Sheringham. It is likely that there would a rapid initial recession of the cliffs in the first 5 to 10 years, with up to 75m of erosion possible, followed by a lower long-term recessions rate, with relatively frequent landslides and cliff failure. Therefore an average net retreat of 80 to 140m is expected by 2105, however over 30m of erosion could occur during a single storm surge event. A natural beach would be present in front of the new shoreline position due to the feed of sediment from the cliff erosion and possible increased input of shingle from the west.
Sheringham (East)	The low wall along this section will fail during this period, as will the timber groynes.	No defences.	No defences.
	Initially the cliff line position will be held, but as the wall fails there will be rapid retreat of the cliff line, as it has previously been held as	Erosion of the cliffs will continue, particularly immediately downdrift of the defences at Sheringham, with a retreat of 20 to 60m by	Erosion of the cliffs will continue, with a net cliff line retreat of 45 to 110m by 2105. There will be increased feed from the west, which may

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	a promontory. This retreat will also be slightly exacerbated by the reduced feed of sediment from the east due to the defences along the Sheringham frontage. A net retreat of 15 to 30m is expected. The cliff erosion will feed beaches locally allowing a beach to be retained in front of the retreated cliff line.	2055. There will be very little feed of sediment from the west, meaning that despite local feed from cliff erosion, the beaches may narrow and reduce in volume, particularly as there will be some longshore sediment drift to the east.	help to maintain beaches, even under rising sea levels.
Sheringham to West Runton	Timber revetment will fail early during this period, with failure of timber groynes towards the end of the period.	No defences.	No defences.
	As the timber revetments fail there will be a period of rapid cliff line retreat, probably during the first five years following defence failure, followed by linear retreat of the cliffs and establishment of a fairly regular average annual recession rate, with episodic events separated by periods of low retreat. By 2025 the net amount of cliff line recession is likely to be between 15 and 25m, although rapid erosion may occur as the result of a single event, i.e. storm surge, when over 30m of erosion could occur. Erosion is likely to be greatest at the southern end as the coast becomes realigned. Beaches will probably be maintained through this local feed. There would be little supply to areas to the east due to low drift rates.	There would be continued linear retreat of the cliffs, with approximately 20 to 60m erosion by 2055 but with the possibility of a large recessional event in response to an extreme storm. There could be slightly increased erosion at the boundaries of defences as Sheringham becomes more of a promontory and interrupts even the low supply of sediment to this frontage. Material supplied by this erosion would be sufficient to maintain beaches locally, but of little significance to feeding beaches elsewhere.	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 60 to 140m by 2105.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
West Runton to Cromer	Along majority of frontage there are no defences, but the short stretches of masonry wall will start to fail during this period.	No defences.	No defences.
	There will be continued erosion of the cliffs, apart from along the short stretches of wall at West Runton and East Runton. Net cliff line retreat will be between 5 and 20m by 2025. Small embayments will form on either side of the walls and by the end of the period it is likely that these walls will start to be outflanked. Cliff erosion will feed beaches locally and downdrift. There will also be some increased feed (although drift rates low) from the west therefore a similar beach to today should be maintained.	As short stretches of walls are outflanked there will be rapid erosion of the cliff line behind and the small promontories will become eroded with the development of a more linear cliff line in plan. For a short time the structures may interrupt longshore drift along the frontage, but this will reduce as the cliffs behind erode, leaving them as isolated structures. A cliff line retreat of 15 to 40m is expected by 2055. The beaches are likely to remain in a similar form to present as they will receive some sediment from cliff erosion and from updrift, but as the defences fail at Cromer there will be greater longshore transport to downdrift areas.	There would be increased cliff erosion, due to rising sea levels, with linear retreat of the shoreline, resulting in 30 to 60m of retreat by 2105. Minimum change in beach width/ volume would occur due to the supply of sediment from cliff erosion both locally and along updrift areas.
Cromer	Along most of the frontage the seawall will remain in place for this period. The groynes will fail towards the end of the period.	Complete failure of the seawall at the start of this period.	No defences.
	The seawall will continue to hold the cliff line position along most of the frontage. Narrower, steeper beaches will develop due to the lack of local input and the low drift rates. Failure of the groynes toward the end of the period will also result in more	There will be continued failure of the seawall, which will result in very rapid erosion of the cliffs behind. There could be a loss of up to 50m in places, within the first five years of the defences failing.	There would be continued cliff recession at a relatively uniform rate characterised by periodic landslides, with lower periods of erosion in between. A net retreat of between 100 and 160 m is expected by 2105. There could also be occasionally large-scale failures

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	throughput of sediment. There will also be loss of some beach material to the south, particularly once the groynes deteriorate by a sufficient amount. The increased exposure of the shoreline will mean that less of a beach can be maintained particularly without the presence of groynes. As the beaches become less effective, some sections of the wall may start to fail with breaches developing along short sections. At these locations there will be reactivation of the regraded cliffs and rapid retreat because this area has developed as a promontory and is therefore very exposed. This will start to accelerate failure of adjacent sections of seawall.	Cliff retreat will be greatest along the central section of the frontage, where the shoreline protrudes most seaward. Erosion in the first five years following defence failure would be rapid. This would be followed by a more uniform rate of erosion, dependent upon surge frequency and occasional landslide events. There could be dramatic, sudden erosion events associated with severe storm surge events. By 2055, erosion of 70 to 120m would be expected although the actual rate will depend on the cliff composition and also on the breakdown of the defence and infrastructure of Cromer. A natural beach would form in front of the new shoreline position due to the feed of sediment from the cliff erosion. There would be increased feed to beaches to the south.	associated with storm surges. Cliff erosion would feed beaches locally and downdrift, although beaches would be more likely to be maintained rather than significantly build.
Cromer to Overstrand	Timber revetments continue to fail over period, with failure of timber groynes in the first half of the period.	No defences.	No defences.
	There will be continued cliff erosion but this will initially accelerate as the timber revetments fail. There will be a net retreat of between 5 and 40m by 2025. At the start of this period erosion is likely to	There will be continued erosion of the cliffs, accelerated by sea level rise, with a net retreat of between 40 and 80m by 2055. This will provide local sediment and there will also be input of sediment from the cliff	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 95 – 140m by

Location	**Predicted Change for 'No Active Intervention':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	be greatest in the north and central sections of this stretch, with the development of a shallow embayment between the held points of Cromer and Overstrand. Once defences fail at Overstrand erosion will increase along the eastern section of coast. Despite the local sediment feed, there would be little net change in beach volume as excess sediment is moved southwards, particularly as the groynes fail, and the cliffs contain a high proportion of mud, which will be lost offshore.	erosion at Cromer. Under rising sea levels this is unlikely to build the beaches, but the beaches should remain in their present form. There will be continued feed of the sediment to the south.	2105.
Overstrand	The seawall will fail during this period, together with the timber revetment and groynes.	No defences.	No defences.
	Defences will start to fail, with breaches occurring along sections. Here there will be reactivation of the regraded cliff and cliff retreat will be rapid, as the development of a promontory over the last 100 years has resulted in the shoreline becoming very exposed. Cliff failure will accelerate failure of adjacent section of the seawall and by the end of the period all of the seawall will be lost. A net retreat of 75 to 110m is expected by 2025. The beach will be maintained through the local supply of sediment and there will be	There will be continued cliff erosion, increasing as a result of sea level rise. This will provide sediment to beaches locally and to downdrift areas. This stretch will also receive sediment from the north. The finer sediments will be lost offshore with sand and shingle maintaining beaches to their present form. Net change in cliff line position will be 100 to 140m by 2055.	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 140 to 185m by 2105.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	continued sediment feed to downdrift beaches.		
Overstrand to Vale Road Beach Access	Much of frontage is undefended and where timber revetment and groynes exist these are mainly redundant.	No defences.	No defences.
	Cliff erosion will continue along this section. Net change in cliff line position by the end of this period will be between 5 and 30m. Rates along this section are not likely to be significantly altered by changes at Overstrand, although there will be more feed into this area by the end of the period. The beach will be maintained by local cliff erosion.	There will be continued cliff erosion, increasing as a result of sea level rise. This will provide sediment to beaches locally and to downdrift areas. This stretch will also receive sediment from the north. The finer sediments will be lost offshore with sand and shingle maintaining beaches to their present form. Net change in cliff line position will be 35 to 75m by 2055.	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 85 to 150m by 2105.
Vale Road Beach Access to Mundesley	Existing timber revetment and groynes will fail at least by the end of the period.	No defences.	No defences.
	As defences along this section fail there will be recommencement of cliff erosion along this section. It is likely that initially cliff erosion would be greater than historic rates, but would decrease towards the end of the period, once a more natural shoreline position were reached. Erosion would be particularly rapid around Marl Point, where a slight promontory has formed due to the presence of defences over the last 35 to 70 years. There would be a net retreat in the	Retreat of the shoreline would continue but at a rate more similar to that historically (pre-defence), with a net cliff line retreat of 35 to 75m by 2055. This would result in a supply of sediment both to local beaches and beaches downdrift. However, it is unlikely that beach volume would increase significantly, due to the high rate of potential transport along this frontage. It is also likely that there would be increased	Cliff retreat would continue, although rates of sediment transport may reduce as the shoreline reaches a more natural position to the south at Mundesley. A net retreat of 75 to 160m is expected by 2105. Beaches will be maintained by cliff erosion both locally and to the north.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	order of 20 to 40m by 2025. Associated with this cliff erosion there would be significant input both to the local beach and to downdrift areas. It is unlikely that the beach volume would increase significantly due to the continuous transport of sand and shingle southwards and movement of fines offshore.	throughflow of sediment, due to the failure of defences, and subsequent shoreline erosion, to the south at Mundesley.	
Mundesley	Defences will mostly remain effective until the end of the period.	The seawall will fail at the start of this period.	No defences.
	There will be no change in cliff line position, due to the defences. Increased sediment input from the north will help to maintain a beach in front of the seawalls over this period, as material passes through this section to beaches further south. The groynes will also continue to help trap sediment. However, as this area increasingly becomes a promontory over the next 20 years, increased exposure will mean that material will not remain on the beaches and a net narrowing trend will occur. With erosion of the cliffs either side of this section there will be an increased risk of outflanking.	As this area becomes increasingly exposed there will be greater pressure on the defences. The seawall will fail at the start of the period, with breaches forming along earlier sections resulting in rapid cliff erosion behind and acceleration of the failure of the rest of the seawall. Cliff retreat would initially be rapid as large coastal realignment occurs, before a rate of erosion more akin to those experienced pre-defences is reached. A net retreat of between 75 and 100m by 2055 would be likely. This would result in an increased sediment feed both locally and to areas to the south. A beach would therefore be present in front of the cliffs.	There would be continued cliff erosion, but this is likely to slow as the coast reaches a more natural position. With this local supply of sediment the beach would be maintained, with a translation of the profile likely to place rather than steepening. A net retreat of 100 to 150m would be expected to take place by 2105. There would also be a feed of sediment to the south.
Mundesley to	Both the groynes and timber revetment will	No defences.	No defences.

<table>
<tr><th rowspan="2">Location</th><th colspan="3">Predicted Change for ‘No Active Intervention’:</th></tr>
<tr><th>Years 0 – 20 (2025)</th><th>Years 20 – 50 (2055)</th><th>Years 50 – 100 (2105)</th></tr>
<tr><td>Bacton</td><td>fail during this period.</td><td></td><td></td></tr>
<tr><td></td><td>There will be continued cliff erosion, but at increased rates as the defences fail. This will partly be countered by the increased feed of sand, transported from north of Mundesley, which might maintain present beach volumes, and the defences to the south slowing transport. The expected retreat of the cliffs over this period is 10 to 30m by 2025.
There would be a throughput of sand to the south.</td><td>There would be continued cliff erosion at rates more similar to those experienced pre-defences, but with some increase due to rising sea levels. A net cliff line retreat of 40 to 70m by 2055.
There will be increased sediment input to this area due to failure of defences to the north, which, together with the local sediment input, will help maintain beaches despite rising sea levels.</td><td>There will be input to this area from cliff erosion to the north; however there would be continued cliff retreat with 90 to 125m by 2105. This would supply sediment both locally and downdrift.</td></tr>
<tr><td>Bacton and Walcott</td><td>The timber groynes will fail at the start of this period. The seawall along southern section will fail towards the end of the period.</td><td>No defences.</td><td>No defences.</td></tr>
<tr><td></td><td>Initially the cliff erosion to the north of Tulsa Way will continue to be slowed by the revetment, but as this fails there will be an initial surge in erosion as the coast tends towards a more natural shoreline position, with 10 to 30m retreat by 2025.
Along the southern section the coastline will be held by the seawall, but as this fails cliff erosion will be initiated and again this rate will initially be rapid. The rate of cliff retreat along this section will gradually slow aided by the maintenance of a beach in front due to feed from the north and from the cliff erosion. The net retreat by 2025 will be between 5</td><td>Erosion of the low cliffs along this section will continue, accelerated by sea level rise. The net retreat by 2055 will be between 35 and 70m.
With cliff erosion there would be a supply of sediment to the beach, resulting in some improvement in the beaches locally. Under alongshore drift this would be moved southwards to supply downdrift areas.
There would be risk of inundation of low-lying land at Walcott, but this should not be permanent.</td><td>There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 85 to 120m by 2105.
There would be inundation of the low-lying land at Walcott during extreme events. The extent of inundation would, however, be restricted by the hinterland topography. Under normal conditions the beach should be sufficient to protect this area. As the cliffs on either side erode, the beach would roll back</td></tr>
</table>

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	and 10m. Where the cliff line drops down to beach level, there is a high potential for inundation of the lower-lying hinterland at Walcott.		over the low-lying hinterland.
Ostend to Happisburgh	Along the northern half of the frontage, timber revetment and groynes will fail. Along the Happisburgh frontage defences will fail within next 5-10 years. To the south defences have already failed.	No defences.	No defences.
	Along the northern half of the frontage the cliff line will initially be held, but as defences fail there will be an initial surge of cliff retreat, with the possibility of 80 to 100m retreat of cliff line by the end of the period as the shoreline tends towards a position commensurate with shoreline energy. At Happisburgh rapid erosion will continue, but should start to slow by the end of this period, as a more sustainable shoreline position is reached. A beach should be maintained in a retreated position, particularly due to the increased feed of sediment from the north. To the south of the village erosion is likely to continue, but at slower rates than those experienced over last few years.	During this period rates of cliff retreat should start to slow from the rapid rates experienced following defence failure, with a net retreat of 130 to 150m by year 2055. Rapid erosion will continue for a longer period along the northern section, but should then slow as the coastal plan shape becomes smoother. There will be input both locally and from erosion to the north, which should help maintain a beach at the toe of the cliffs. There will also be continued southward transport of sand.	There will be input to this area from cliff erosion to the north; however there would be continued cliff retreat with 170 to 200m by 2105. This would supply sediment both locally and downdrift.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Eccles on Sea	The seawall and groynes will remain effective along most the frontage.	Seawall and groynes will fail at the start of this period.	No defences.
	The defences along this section are likely to remain during this period; therefore the coastline (foredune) position will not alter. The beach in front of the seawall along this section would be maintained due to feed from cliff erosion directly to the north, which should improve the life of defences. The greatest risk of failure will be at the northern end of the seawall, due to retreat of the cliff line to the north. Due to the time lag of sediment supply there is unlikely to be an input from erosion of the cliffs to the north of Bacton.	Despite sediment feed the beach would be too far seaward, which would result in increased exposure and therefore transport, rather than retention, through this area. This will result in lower beach levels and increase exposure of the wall. This will result in the seawall becoming breached. As there is no substantial dune ridge behind the seawall, it is probable that this area would be subject to breach and subsequent inland flooding. It is possible that a beach may build up again - possibly in the form of a beach barrier susceptible to frequent breaches, the position of this would be several tens of metres landward; this would enable a continued throughput of sediment.	There would be a continued net retreat of this shoreline and the area would be vulnerable to frequent breach and flooding. There is potential for low dunes to reform along this frontage, but under a prevailing offshore wind regime the dunes would be unlikely to reach any great height, and would still be susceptible to breaches during storms.
Sea Palling to Waxham	Reefs and seawall will remain.	Reefs and seawall will remain.	Reefs remain.
	The shoreline position will continue to be held by the seawall. The offshore breakwaters will maintain a beach along this section over the 20-year period and as the beaches build up sufficiently, there will be some throughflow of sediment. Due to the time lag of sediment supply there is unlikely to be an input from erosion of the	The reefs will continue to maintain a beach during this period, although over time, with rising sea levels, they will become less effective. This will help sustain the life of the seawall, although it is likely that this will start to deteriorate. The reefs will also help to reduce the volatility of the beach. This means that the shoreline position will be held during	The reefs would probably remain, but with some deterioration, but their effectiveness would be reduced because of coastal system retreat. There would therefore be increased throughput of material to the south. There would be outflanking on either side and therefore the area behind would become inundated through breaches both to the north

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	cliffs to the north of Bacton.	this period. However there will be outflanking to both north and south, resulting in backdoor flooding of the area behind this wall. There would still be sediment movement across the area but less retention due to higher alongshore drift rates and movement of sand both north and south.	and south.
Waxham to Winterton dunes	Seawall may fail, together with the old groynes. The new groynes should remain.	New groynes will fail early on during this period.	No defences.
	The coastline (foredunes) will be held for the first half of the period. As the reef fields to the north fill with sediment there should be an increased throughput of sediment. However, despite this feed of sediment, the seawall is likely to fail in stages, as much of the sediment will be moved southwards rather than remaining on the beach. Therefore the beaches in front of the seawall will narrow as a result of the natural retreat of the coastal system. There is a high risk of seawall breach at Bramble Hill and should this occur, it would be unlikely for the dunes to sustain a barrier and there would be large-scale inundation of the low-lying hinterland. It is possible that a beach may build up again - possibly in the form of a beach barrier susceptible to frequent breaches, the position	The groynes will fail during this period, and the beach along this section will disappear both due to the groynes failing and increased sea levels. This will increase pressure on any remaining sections of seawall. There would be extension of the existing breach and development of others, resulting in large-scale inundation of the low-lying broadlands behind. There should still be a sediment pathway across the frontage, particularly within the nearshore zone, but as the breach locations enlarge this area could start to act as a sediment sink, reducing the throughput of sediment to Winterton Ness. There may then be development of a beach ridge in front of the low-lying area at a retreat position.	There would be a continued net retreat of this shoreline and the area would be vulnerable to frequent breach and flooding. There is potential for low dunes to reform along this frontage, but under a prevailing offshore wind regime the dunes would be unlikely to reach any great height, and would still be susceptible to frequent breaches during storms. Sediment links to the south should be maintained via the nearshore bar.

Location	**Predicted Change for 'No Active Intervention':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	of this would be several tens of metres landward. Therefore sediment transport to the ness should continue during this period.		
Winterton-on-Sea	No defences	No defences.	No defences.
	There will be redistribution of beach material as the ness continues to fluctuate in position and there is some feed to the south. This will result in both dune erosion and accretion through development of embryo dunes. However the net change to this whole section is likely to be small over the 20-year period, although erosion of up to 40m may occur in places. The width of the dunes here means that breach of the dunes is unlikely during this period. The foreshore width will also change as the ness migrates.	Due to the natural variability in the position of the ness and interactions with the offshore, there is a great deal of uncertainty regarding its future evolution. However, this area will be affected by the frequency of breaching to the north. This will have an impact on the sediment transport to the area and therefore it is expected that there will be erosion of the dunes. Sediment within the ness is likely to be redistributed resulting in accretion elsewhere along this stretch. It is however possible that some material will also be lost offshore. The large dune belt at this location should prevent breaching. The net change by 2055 could be accretion of 30m and erosion of 40m, with the greatest erosion expected at the northern end of the ness.	Due to the natural variability in the position of the ness and interactions with the offshore, there is a great deal of uncertainty regarding its future evolution. There is likely to be retreat of the dune system particularly along the northern boundary, in response to the reduced sediment feed to the area, with a possible retreat of up to 50 to 100m. Some of this material may be redistributed to areas to the south, but some is also likely to be lost offshore, therefore the volume of Winterton Ness is expected to decrease.
Newport and Scratby	No defences.	No defences.	No defences.
	There will be continued deterioration of the dunes, with 10 to 30m of retreat possible by	Continued deterioration of the dunes will occur, resulting in an increasingly narrow belt	There will probably be total loss of the dunes along this section by the end of this period,

Location	**Predicted Change for 'No Active Intervention':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	year 2025. Along the Scratby frontage, this may result in reactivation of the sand cliffs during this period. There is a possible risk of breach at the southern end of Newport, where the dunes are lower and narrower, but flooding would be restricted to the 'valley' and is unlikely to impact on the sediment transport regime alongshore. No change in sediment feed to this area is expected therefore the beach is likely to remain in its current form.	of dunes and likely loss of the dunes by the end of this period. This will result in inundation into the 'valley'. Flooding will be constrained by the natural topography. There is still likely to be continued sediment transport to areas to the south. Along the Scratby frontage, there will be erosion of the sand cliffs during this period, but at a slower rate than the dunes, which may help to provide some stability to this frontage. The backshore position is expected to retreat by 35 to 60m by 2055.	depending upon the redistribution of sediment eroded by Winterton Ness. This will result in reactivation of the relict low sand cliff line behind, which will release some sediment into the system, but beaches are likely to narrow. Net retreat is likely to be between 45 and 100m by 2105. There will be localised flooding of low-lying areas.
California	Rock berm will remain in place.	The rock berm will remain for much of this period.	No defences.
	The rock berm will continue to reduce erosion during this period. There will therefore be continued cliff retreat, with a net change of up to 5m by 2025. As the cliff retreats the berm will become less effective, but will continue to slow erosion and help maintain a beach in front of the cliff toe. The beach in front of the berm will narrow.	Erosion of the cliffs will continue, but will increase slightly, as the effectiveness of the rock berm in controlling erosion reduces as it becomes more detached from the cliffs. As the berm breaks down the erosion rate will increase. A net retreat of 30 to 50m by 2055. Initially, the berm may restrict sediment transport of the eroded material (although some will still take place along the nearshore bar), but this effect will reduce as the berm fails. The beach seaward of the berm will become narrower as sea level rises.	Erosion of the cliffs will continue at a faster rate both due to failure of the berm and increasing sea levels. There will be a net retreat of 80 to 100m by 2105, with the area becoming less of a promontory. A healthier beach is likely to develop in a retreated position.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
California to Caister (reefs)	Seawall, rock reefs and groynes will remain.	Seawall will fail by the end of this period, but rock groynes and reefs will remain.	Rock reefs and groynes deteriorate.
	The coastline position (cliffs/ dunes) will be held by the seawall. Behind the reefs the beach should remain healthy, with continued feed from the north. To the south, the beach narrows and this situation is not likely to change. There will continued feed of sediment to the south.	For much of the period the backshore will remain in its present position. The reefs and groynes will continue to maintain a beach, through reducing alongshore drift and beach volatility, which will help sustain the life of the seawall. The area will continue to receive sand from the north. The structures will reduce longshore transport of sand to the south but some sediment transport will still take place to the south, along the nearshore bar.	This area will increasingly become a promontory as the backshore position is held. This will put increased pressure on the reefs and groynes. These will probably remain, but with some deterioration, but their effectiveness would be reduced because of coastal system retreat. There would therefore be increased throughput of material to the south. There would also be outflanking on either side. Here there will be retreat of the coast, with potentially 50 to 100m by 2105.
Caister (reefs to Lifeboat Station)	The seawall will remain.	Seawall will fail during period.	No defences.
	The seawall will maintain a coastline position, but there may be both accretion and erosion of the dunes and beach which front it, associated with the natural movement of Caister Point ness; the evolution of which is very uncertain. The dunes along the northern section are wide enough to prevent a breach. Some stability will be provided by the influence of the reefs to the north and Caister Ness to the south.	The amount of sediment reaching this frontage will be reduced by the rock groynes and reefs. This will result in beach narrowing and steepening, which will be exacerbated by sea level rise. This and the subsequent erosion of the dunes will threaten the integrity of the seawall and this is likely to fail during this period, resulting in retreat of the backshore position of between 30 and 60m by 2055.	There may be slightly increased feed to this area as the effectiveness of the groynes and reefs to the north decreases. There will be continued backshore retreat along this stretch of between 80 and 110m by 2105 due to increased exposure resulting from sea level rise. Sediment transport will continue to areas to the south.

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Caister to Great Yarmouth (Pleasure Beach)	The seawall will remain.	The seawall will remain.	Seawall reaches end of residual life.
	The coastline position will be held by the seawall, but the width of the dune belt in front of the wall is likely to fluctuate during the natural movement of Caister Ness. The net change in the dune position is likely to be ± 20 to 30m by 2025. The coast is dependent upon feed from the north, which is unlikely to change over this period. There will be continued southwards transport.	The seawall will remain and prevent backshore retreat and inundation of the hinterland, although the width of the dune belt may change, through the natural movement of the ness. There is uncertainty over the future evolution of Caister Ness. There will be some foreshore narrowing as sea level rise, but a healthy beach will remain. The coast is dependent upon feed from the north, which is unlikely to change over this period. There will be continued southwards transport.	There is uncertainty over the future evolution of Caister Ness. There will be sediment supplied from the north, which will help to sustain the beach system. The most vulnerable area will be to the north, where the dunes are narrowest and there could be breach of the seawall here, resulting in inundation of the area behind. Along the central section the dunes are of a sufficient width to prevent inundation and protect the seawall. Although there will be further foreshore narrowing as sea level rise, the beach is expected to remain wide enough to provide a 'natural' defence.
Great Yarmouth South Beach	Seawall and groynes will remain. Harbour Arm will remain as a port structure.	Seawall and groynes fail towards the start of this period. Harbour Arm will remain as a port structure.	Harbour Arm will remain as a port structure.
	The seawall will hold the position of the coastline and as this restricts the natural coastal response there will be some beach narrowing likely along this stretch and therefore deterioration in the condition of the	There will be continued beach narrowing and erosion of any remaining dunes. Loss of the groynes will mean than less material is retained here. This, together with increased exposure due to sea level rise, will put	The seawall will totally fail towards the start of this period due to the lack of a beach. This will result in large-scale inundation of the low-lying land behind. There should be continued transport

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	remaining dunes. The North Pier will continue to trap some sediment. However, the increasing exposure of this southern section means that less of a beach will be retained here.	increased pressure on the seawall, which will start to fail through breaches along the poorest sections. This will result in inundation of the low-lying area behind.	southwards via the offshore bar.
Gorleston-on-Sea	Seawall will remain, but groynes fail during this period. Harbour Arm will remain as a port structure.	Seawall will fail towards the start of the period. Harbour Arm will remain as a port structure.	Harbour Arm will remain as a port structure.
	Cliff line retreat will be prevented by the seawall; therefore there will be no change in cliff line position. There will be beach narrowing, particularly along the southern section, which is not protected by the breakwater, particularly as the groyne fields will no longer hold beach material.	Continued beach narrowing, despite feed from the south and north (due to local drift reversals), which will threaten the integrity of the seawall. This will result in rapid cliff erosion, as this area has been held as a promontory and is therefore in an exposed position. Some protection will still be afforded by the spur; therefore beaches are likely to remain wider at the northern end of this section. Net change by 2055 is predicted to be 45 to 80m retreat. There will be increased throughput of sediment to the south, due to the lack of groynes.	There would be continued cliff erosion, accelerated by sea level rise, with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 70 to 130m by 2105.
Gorleston-on-Sea to Hopton-on-Sea	Timber revetment and groynes will fail by the end of the period.	No defences.	No defences.
	Initially there will be continued slow erosion of the cliffs, as the revetment will reduce	There will be continued cliff erosion, which will increase due to sea level rise. By 2055	There would be continued cliff erosion with linear retreat of the shoreline. Minimum

Location	**Predicted Change for 'No Active Intervention':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	wave attack. This will be accompanied by beach narrowing and the removal of the low dunes at the toe of the cliffs, particularly as the groynes fail. As the revetment starts to fail there will be an initial surge in cliff erosion, before a more linear retreat rate is established. A net retreat of 15 to 30m is predicted by 2025. Cliff erosion will feed beaches both locally and downdrift.	there will be a net retreat of 40 to 65m. A beach will be maintained at the toe of the cliffs, due to feed from the north and local cliff input.	change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 80 to 130m by 2105.
Hopton-on-Sea	Seawall will start to fail by the end of the period.	No defences.	No defences.
	For most of this period, the cliff line will be held by the seawall. As retreat of the coast is restricted there will be beach narrowing, with the section developing as a promontory. As beach levels deteriorate the seawall will start to fail in sections, resulting in rapid cliff erosion behind, with 15 to 30m erosion occurring by 2025.	There will be continued cliff erosion, but rates will slow slightly from those initially following defence failure. A net retreat of 45 to 70m is likely by 2055. A beach will be maintained through both alongshore transport and local input of sand from the cliffs.	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 90 to 130m by 2105.
Hopton-on-Sea to Corton	Timber revetment will fail during this period	No defences.	No defences.
	As the revetment fails there will be retreat of the cliffs. This will initially be quite rapid for the first 5 years following failure, but should slow slightly towards the end of the period. A net retreat of 10 to 25m would be expected.	There will be continued cliff erosion, which may increase due to sea level rise. A net retreat of the cliff line of 45 to 65m is expected by 2055. A beach will be maintained at the toe of the cliffs, due to feed	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 105 to 130m by

Location	Predicted Change for 'No Active Intervention':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	Material released from the cliffs will feed local beaches and also beach downdrift, resulting in a possibly beach build-up to the north of Corton.	from the north and local cliff input.	2105.
Corton	Seawall and rock revetment will remain	Seawall will fail at the start of this period.	No defences.
	The cliff line position will be held. There are currently no beaches and this situation will not change because Corton is too exposed, making it impossible for a beach to be retained. There will be continued transport south although this may be reduced as material becomes trapped updrift of Corton.	As Corton increasingly becomes a promontory there will be increased exposure of the seawall and this will be increased by sea level rise. The seawall will gradually start to fail in sections, resulting in rapid erosion of the cliffs behind and accelerating failure of adjacent seawall sections. The rock revetment may initially slow the retreat. Cliff erosion will feed beaches both locally and downdrift, and as the cliffs retreat an improved beach will form. Net retreat of the cliffs of 50 to 100m by 2055 is expected.	There would be continued cliff erosion with linear retreat of the shoreline. Minimum change in beach width/ volume would occur due to the local supply of sediment from cliff erosion. Erosion may be up to 85 to 170m by 2105.
Gunton Warren	Timber groynes will fail.	No defences.	No defences.
	Due to the reduced input of sediment from the north, due to the defences at Corton, there will be beach narrowing and continued deterioration of the dunes, but the cliffs are set back therefore there will not be reactivation of these. There will be a net retreat of the dunes of 10 to 30m. Sediment transport to the south will continue	There will be continued erosion of the dunes and beach narrowing, due to sea level rise, with retreat of the backshore position by 40 to 90m by 2055, with loss of the dunes and erosion of the sand cliffs. The input from Corton and beyond will maintain beaches along this stretch.	There would be continued cliff erosion with linear retreat of the shoreline. A net beach narrowing is expected particularly along the southern section, where the coast will be affected by the large-scale inundation of the land behind. Erosion may be up to 90 to 180m by 2105.

Location	**Predicted Change for 'No Active Intervention':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	at a similar rate, for despite the loss of groynes, there will be reduced alongshore drift from the north.		
Lowestoft North Beach	Seawall will remain.	Seawall will remain.	Failure of seawall.
	The shoreline position (as defined by the seawall) will be held, but the beaches along the northern section will continue to narrow as this stretch becomes more exposed. The area is dependent on a feed of sediment from the north and although this will increase slightly the beach is too exposed at the southern end for a beach to be retained.	The seawall will continue to prevent flooding and will hold the backshore position. However there will be no beach present, particularly at the southern end of the frontage. Any beach sediment will be lost offshore into deeper water.	There will be failure of the seawall and large-scale inundation of the low-lying area behind will occur.

C4.4 NAI DATA INTERPRETATION

(a) Introduction

A number of data sets were used in the predictions of future shoreline response and evolution under the scenario of no active intervention, these included:

- Futurecoast historical shoreline change data (reported in the assessment of shoreline dynamics report (Section C1)).
- Other historical change data sets: e.g. at some locations cliff position data sets are available (reported in the assessment of shoreline dynamics report (Section C1)).
- Futurecoast predictions of future shoreline change under an ‘unconstrained’ scenario: this assumed that all defence structures were removed and other coastal defence management interventions ceased therefore is not directly comparable to a ‘no active intervention’ scenario.
- Environment Agency beach profile data: this data is only relevant to the first 20 years as it only covers period 1991 to present.
- Prediction of future shoreline response under ‘do nothing’ scenario from first SMP.
- Other predictions of future shoreline response under no active intervention (or ‘do nothing’) scenario, e.g. from strategy studies completed since the first SMP.

The affect of accelerating sea level rise was also taken into account; as a *guide*, data was used from the first SMP, which calculated the increase in erosion resulting from sea level rise by application of the Bruun Rule (1988). The percentage adjustment calculated was as follows:

Location	**Approximate % adjustment for sea level rise (SLR)**
Sheringham	31% increase in erosion
Cromer	29% increase in erosion
Overstrand	15% increase in erosion
Trimingham	10% increase in erosion
Mundesley	17% increase in erosion
Bacton	10% increase in erosion
Walcott	10% increase in erosion
Happisburgh	13% increase in erosion
Eccles	21% increase in erosion
Sea Palling	86% increase in erosion
Horsey	67% increase in erosion
Winterton	81% decrease in accretion
Hemsby	72% decrease in accretion
Scratby	50% increase in erosion
California	60% increase in erosion
Caister	66% decrease in accretion
Great Yarmouth North Denes	87% decrease in accretion
Great Yarmouth North Beach	79 - 90% decrease in accretion
Great Yarmouth South	83% decrease in accretion
Gorleston	67% increase in erosion
Hopton	33% increase in erosion
Corton	44% increase in erosion
Gunton	-
Lowestoft	17% increase in erosion

(b) Data assessments (NAI)

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
Kelling Hard to Sheringham	Historical data suggests a fluctuation in both backshore and low water positions. Net change of MLW and MHW ranges between 0.2 and 0.4m/yr erosion. (No cliff data). Data suggests a net steepening of foreshore, with retreat of profile.	Moderate (10-50m)	▪ EA profile data: cliff retreat rates of between 0.1 and 0.7m/yr and retreat of MSL of between 0.1 and 0.8m/yr.	Assumed similar rates to those experienced over last 20 years will continue, therefore used average of EA data.	Assumed similar rates to those experienced historically plus SLR component - used Futurecoast MLW data plus the SLR multiplier for Sheringham.	Assumed similar rates to those experienced historically plus SLR component - used Futurecoast MLW data plus the SLR multiplier for Sheringham.	Futurecoast score: very low
Sheringham frontage	Historical data suggests a fluctuation in both backshore and low water positions. Coastal position defended for much of record. Average rate of change of MLW ranges between 0.1 and 0.3m/yr erosion. Data suggests a net steepening of foreshore, but backshore position fixed.	High (50-100m)	▪ EA profile data: Retreat of MSL of between 0 and 0.3m/yr. Retreat of Backshore between 0.1 and 0.4m/yr. ▪ SMP1 prediction of 80 - 105m over 75 years.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear, based on historical trends.	Rapid initial rate of erosion expected to far exceed historical rates, so for first 5 years estimated how much coast had been held up by (taking Futurecoast MLW rates for last c.150 years plus SLR multiplier) then used Futurecoast MLW rate plus SLR multiplier. Also considered a large single failure event occurring in period. Also assumed that net affect would be straightening of coast – i.e. increased erosion along central promontory.	Futurecoast score: very low Although tendency for simple failure, a single event could result in 10 to 50m erosion. Little data available on pre-defence erosion rates.
Sheringham (East)	(see above)	(see above)	▪ (see above)	Defences expected to hold cliff line position for first part of period, followed by rapid	Assumed cliff erosion will occur at pre-defence rates – used Futurecoast MLW rates	Assumed cliff erosion will occur at pre-defence rates – used Futurecoast MLW rates plus SLR multiplier, but	(see above)

---

[1] Futurecoast predictions did not consider an acceleration of sea level rise.

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
				erosion as it fails – used Futurecoast MLW rates for last c.80 years of the coast being held.	plus SLR multiplier. Also assumed that erosion immediately downdrift of Sheringham would be greater.	assumed some reduction due to cliff feed both locally and from updrift once Sheringham defences fail.	
Sheringham to West Runton	Net retreat of cliffs: range of 0.2 to 0.6m/yr. Fluctuation in MLW: +0.3 to -0.1m/yr. Data suggests a slight flattening of the foreshore.	High (50-100m)	▪ EA profile data: Retreat of cliff between 0.1 and 0.8m/yr. Retreat of Backshore between 0.1 and 1.4m/yr. Retreat of MSL between 0 and -1m/yr/ ▪ SMP1 prediction of 80 - 105m over 75 years.	Revetment expected to fail at some time. Assumed revetment reduced erosion by c. a third for last c.25 years. Used Futurecoast cliff data, with consideration of effect of reduced feed from the north.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component. Also assumed increased erosion at boundaries of defences.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component. Also assumed increased erosion at boundaries of defences.	Futurecoast score: very low Complex failure mechanism therefore variable along coast and during a single event could have over 30m retreat.
West Runton to Cromer	(see above)	(see above)	▪ (see above)	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component.	(see above)
Cromer	Coastal position defended for much of record – no cliff data available. Average retreat of MLW: 0.3 to 0.4m/yr. Data suggests a net steepening of foreshore.	High (50-100m)	▪ EA profile data: Both profiles at location suggests an advance of back of beach position at a rate of 0.3m/yr, with one profile suggesting an average advance of MSL at 0.3m/yr and the other suggesting retreat at 0.3m/yr. ▪ SMP1 reported a long-term retreat rate of 1 to 2m/year. ▪ Cambers (1976) reported a long-term recession rate of 0.65-0.75m/yr.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	Rapid initial rate of erosion expected to far exceed historical rates, so for first 5 years estimated how much coast had been held up by (taking Futurecoast MLW/ Camber's rates for last c.120 years plus SLR multiplier) then used Futurecoast MLW rate plus SLR multiplier. Also considered a large	Continued erosion of cliffs assumed at historical MLW rate – used Futurecoast MLW/ Camber's rates plus SLR multiplier.	Futurecoast score: very low Little data available pre-defences. During a single event could have over 30m retreat.

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	**Prediction[1]**		**0-20**	**20-50**	**50-100**	
			▪ SMP1 prediction of 70 - 90m over 75 years. ▪ Cromer SS predicted initial surge (up to 10m/year), before a more gradual rate of erosion (1.875m/year) in years 6 to 50.		single failure event occurring in period. Also assumed that net affect would be straightening of coast – i.e. increased erosion along central promontory.		
Cromer to Overstrand	Net retreat of both cliff and MLW at a rate between 0.8 and 0.9m/yr. Data suggests a net steepening of foreshore, with a translation of profile.	High (50-100m)	▪ EA profile data: net retreat of MSL at one profile -0.6m/yr, but a cyclical fluctuation in MSL position noted at the other profile available. ▪ Cambers (1976) reported a long-term recession rate of 0.65-0.75m/yr. ▪ No direct prediction in SMP1 but: 70 to 90m for Cromer and 130 to 150m for Overstrand over 75 years. ▪ A prediction of 18.75m every 10 years was reported in the Cromer SS.	Timber revetments expected to continue to fail, therefore initial surge as coast held for last 25 years. Therefore assumed Futurecoast MLW/ Camber's rate to calculate 'catch-up', assuming revetments have reduced 'natural erosion' by a third. Futurecoast MLW/ Camber's rate used to predict erosion after initial surge. Compared to Cromer SS prediction.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered some reduction due to feed from Cromer cliff erosion. Compared to Cromer SS prediction.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered some reduction due to feed from Cromer cliff erosion. Compared to Cromer SS prediction.	Futurecoast score: very low Cliffs subject to major rotational failures and a single event could result in over 30m erosion.
Overstrand	Average cliff retreat of -0.1m/yr and average MLW retreat of -0.7m/yr, but coast defended for some of period.	High (50-100m)	▪ No reliable EA data available. ▪ Cambers (1976) reported that between 1885 and 1985 there was less than 20m erosion. ▪ SMP1 predicted 130 to 150m over 75 years. ▪ Overstrand to Walcott SS predicted that with the failure of defences there would be a dramatic initial surge of cliff top retreat, possibly involving the loss of up to 50m within the first 5 years long-term retreat rate (including for sea level rise) of	Timber revetments expected to continue to fail, therefore initial surge as coast held for last 95 years. Therefore assumed Futurecoast MLW/ Camber's rate to calculate 'catch-up' and then Futurecoast MLW/ Camber's rate used to predict erosion after initial surge. Compared to Cromer SS prediction.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered some reduction due to feed from Cromer cliff erosion. Compared to Overstrand – Mundesley SS prediction.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered some reduction due to feed from Cromer cliff erosion. Compared to Overstrand – Mundesley SS prediction.	Futurecoast score: very low Little data relating to undefended coast. Cliff subject to major rotational fails – a single event could cause more than 30m

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
			between 0.75 and 2.6m/yr.				erosion.
Overstrand to Vale Road Beach Access	Average cliff retreat rates of between 0.6 and 1.9m/yr. Average MLW retreat rates of between 0.9 and 1.3m/yr. Data suggests foreshore steepening at one location but flattening at another location.	High (50-100m)	▪ EA data: variable data quality but MSL rates from +0.3 to -1.6m/yr. Back of beach position shows net retreat at average rates of 0.1 to 2m/yr. ▪ SMP1 reported long-term retreat rate of 1-2m/yr. ▪ Clayton and Coventry (1986) suggested a maximum recession of 175m between Overstrand and Trimingham for the period 1885 to1985. ▪ SMP1 predicted 100 to 110m over 75 years. ▪ Overstrand to Walcott SS predicted long-term (up to 50 years) recession rates of between 0.75m/year and 2.6m/year	Assumed cliff erosion will continue at recent rates – but with consideration of slightly increased feed as defences fail to north. Used combination of Futurecoast and EA data.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	Futurecoast score: very low Massive rotational failures are common and unpredictable. Historical over 13m erosion has occurred during one event.
Vale Road Beach Access to Mundesley	(see above)	(see above)	▪ (see above)	Used combination of Futurecoast and EA data.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	(see above)
Mundesley	Coast defended for much of period. Net retreat of MLW: 0.7m/yr. Foreshore steepening identified.	High (50-100m)	▪ EA data: Shows fluctuation in position. MSL rates of retreat: -0.9 to -3.2m/yr. ▪ Overstrand to Walcott SS identified steepening of beach in west to east direction between 1885 and 1969. ▪ SMP1 predicted 60 to 70m erosion up to 2068.	No change in cliff position as defences expected to remain.	Initial surge expected as defences fail due to coast being held for last c.115 years. Used Futurecoast MLW rate to estimate surge assuming these rates for 115 years plus SLR component. Used Futurecoast MLW rate	Assumed cliff erosion will continue – used Futurecoast MLW rate plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	Futurecoast score: very low Little data relating to pre-defence erosion rates,

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	**Prediction[1]**		**0-20**	**20-50**	**50-100**	
			▪ Overstrand to Walcott SS predicted that with the failure of defences there would be a dramatic initial surge of cliff top retreat, possibly involving the loss of up to 50m within the first 5 years long-term retreat rate (including for sea level rise) of between 0.75 and 2.6m/yr.		plus SLR component for erosion post-surge. Comparison with Overstrand – Mundesley SS prediction and assumed that coast will straighten, so adjustments made using the OS maps.		
Mundesley to Bacton	Net retreat of MLW: 1.0m/yr. Net retreat of cliff line: 0.9m/yr. No change in profile identified.	High (50-100m)	▪ EA data: One profile shows accretion of both back of beach position and MSL, the other profile shows erosion. ▪ SMP1 reported long-term erosion rates for MLW of 1 to 2m/yr. ▪ No direct prediction in SMP1, but estimated rates for Mundesley and Bacton of 60m to 70m and 100 to 110m respectively, for the period 1994-2068. ▪ No rates available from Overstrand to Walcott SS.	Assumed cliff erosion will continue and increase as defences fail, but affected by increased feed from north - used Futurecoast MLW rate.	Assumed continued cliff erosion at rates more similar to those experienced pre-defences. Used combination of Futurecoast rates and predictions made by SMP1.	Assumed continued cliff erosion at rates more similar to those experienced pre-defences. Used combination of Futurecoast rates and predictions made by SMP1.	Futurecoast score: very low Simpler cliff failures than to north, with 1-5m erosion due to a single event.

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	**Prediction[1]**		**0-20**	**20-50**	**50-100**	
Bacton and Walcott	Net retreat of MLW: 1.2m/yr. Net retreat of beach of beach: 0.9m/yr. Coastal position held for much of period.	High (50-100m) and inundation of low-lying land.	▪ EA data: very variable data: some profiles suggest net accretion, others suggest net erosion. ▪ SMP1 reported long-term erosion rates for MLW of 1 to 2m/yr. ▪ SMP1 predicted 100 to 110m erosion by 2068.	At northern end of frontage, combination of EA and Futurecoast data used, but assumed that revetment will reduce this by c. a third at one end and that erosion will be initially halted then initiated. At southern end, assumed that cliff erosion will commence, once seawall fails, initially at an accelerated rate calculated by assuming coastal erosion held for 60 years and using EA and Futurecoast data.	Assumed cliff erosion will continue in uniform manner – used Futurecoast MLW and Back of Beach data plus SLR component. Also identified breach potential.	Assumed cliff erosion will continue in uniform manner – used Futurecoast MLW and Back of Beach data plus SLR component.	Futurecoast score: very low Little data pre-defences. Uncertainty over amount of feed from cliff erosion to north.
Ostend to Happisburgh	Net retreat of MLW: average trend = 0.8-0.9m/yr. Net retreat of cliff line: average trend= 0.9m/yr. Both flattening and steepening trends identified from data.	High (50-100m)	▪ EA data: unreliable data, therefore not used. ▪ Pre-defence rates (1886 to 1938 maps) of 0.4 and 0.8 m/year erosion reported in Ostend to Cart Gap SS. ▪ Post-defence erosion rates of 0.4 and 1.2m/yr reported in Ostend to Cart Gap SS. ▪ SMP1 predicted 115 to 130m erosion by 2068. ▪ Ostend to Cart Gap SS predicted 30 to 75m cliff erosion within next 5 years, with rapid cutback of the cliffline by 110m between years 5 and 10.	Used Futurecoast rates combined with recent observations of change at Happisburgh once defences fail.	Assumed continued cliff erosion, but increased feed from north and cliff should reach a more equilibrium position. Used Futurecoast MLW rates and pre-defence rates to estimate change, plus SLR component.	Assumed continued cliff erosion, but increased feed from north and cliff should reach a more equilibrium position. Used Futurecoast MLW rates and pre-defence rates to estimate change, plus SLR component.	Futurecoast score: very low Uncertainty over continuation of spring-back effect. Uncertainty over amount of feed from cliff erosion to north.
Eccles on Sea	Data variable, but average retreat trend - = 0.5m/yr for MLW and -0.1m/yr for the	High (50-100m)	▪ EA data: unreliable data, therefore not used. ▪ Happisburgh to Winterton SS	Sea wall assumed to remain therefore no change in backshore position, but foreshore	Sea wall expected to breach, with erosion of low-lying land behind (for SMP purposes	Continual breaches expected (for SMP purposes assumed to be to extent of EA IFM).	Futurecoast score: low High

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
	beach of beach position. Coastline held for much of period.		reports that between 1886 and 1905 much of the coast was in a state of relative stability, but during 1905 to 1946 the whole coast eroded by approximately 0.7m/yr. ▪ UEA report 2.3m/yr retreat 1883-1906 and 0.3m/yr for 1906-1952. ▪ SMP1 predicted variable rates ranging 35 – 85m by 2068. ▪ CHaMP (2003) predicted a shoreline change of 70m over the next 100 years	expected to narrow, as experienced historically.	assumed to be to extent of EA IFM).		uncertainty of coastal response post defence failure and amount of feed from cliff erosion to north.
Sea Palling to Waxham	Fluctuating MLW position – no clear trend.	(see above)	▪ EA data: no clear trend due to recharge. ▪ Beach recharge since 1992. ▪ (also see above)	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow, as experienced historically.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow, as experienced historically.	Sea wall expected to breach, with erosion of low-lying land behind (for SMP purposes assumed to be to extent of EA IFM).	Futurecoast score: low High uncertainty of coastal response post defence failure and amount of feed from cliff erosion to north.
Waxham to Winterton dunes	Long term retreat trend of between 0.7 and 0.8m/yr for MLW and 0.2m/yr for back of beach position.	(see above)	▪ EA data: Variable rates for various profiles which show both accretion and erosion trends. ▪ High chance of breach identified for Horsey from Happisburgh – Winterton Strategy Review. ▪ (also see above)	Initially shoreline position will be held, but failure expected during period – breach potential identified from Happisburgh – Winterton Strategy Review. Dune response assessed through geomorphological knowledge and input from CHaMP.	Large scale inundation identified from Happisburgh – Winterton Strategy Review.	Large scale inundation identified from Happisburgh – Winterton Strategy Review.	Futurecoast score: low High uncertainty of coastal response post defence failure and amount of feed from cliff erosion to north.

Location	**Futurecoast data**		**Other**	**Prediction of shoreline change for NAI**			**Uncertainty**
	Historical	**Prediction[1]**		**0-20**	**20-50**	**50-100**	
Winterton-on-Sea	No data for ness point, but to north: retreat trend of 1.6m/yr for MLW and 1.1m/yr for back of beach position. To south: no clear trend for MLW, but accretion of back of beach of 0.2m/yr.	High (50-100m)	▪ EA data: poor data for one profile, other suggests retreat of MSL of -7.4m/yr and retreat of back of beach position of -7.8m/yr. ▪ UEA, 1971 report accretion opposite Winterton Village at 1.1 to 1.4m/year between 1883 and 1952. ▪ CHaMP (2003), indicated average retreat rates of 2.1m/yr at Winterton Coastguard Station and accretion to the south of the Coastguard Station at an average rate of 2m/year between 1992 and 2002. ▪ SMP1 predicted accretion of between 65 and 80m by 2068.	Ness position expected to fluctuate – between 1880s and last OS survey area in front of Lifeboat Station was accreting. There has since been period of rapid erosion, but area still significantly seaward of 1880s position. Combination of EA data and Futurecoast data used to estimate range.	Ness position expected to fluctuate – between 1880s and last OS survey area in front of Lifeboat Station was accreting. There has since been period of rapid erosion, but area still significantly seaward of 1880s position. Combination of EA data and Futurecoast data plus SLR component used to estimate range, but consideration of impact of changes to the north.	Ness position expected to fluctuate – but net erosion expected due to changes to the north. Estimate based on natural fluctuation rates from Futurecoast plus SLR component and understanding of how coast has changed historically.	Futurecoast score: low Large uncertainty over ness evolution and evolution of coast to the north.
Newport and Scratby	Poor data for foreshore, but cliff retreat average rate of -0.2m/yr.	High (50-100m)	▪ EA data suggests a range of cliff retreat rates for 1992-2002 of 1.3 - 1.9m/yr and change in back of beach position of 1.5 to 1.7m/yr. MSL data shows no clear trend apart from at one site: erosion at 1.3m/yr. ▪ UEA (1971) reported accretion at 0.4m/year between 1883 and 1906, but the trend later switched to erosion. ▪ SMP1 reported retreat rates of 0 to 0.5m/year in the north of this area, and 0.5 to 1.0m/year to the south. ▪ SMP1 predicted 30-45m erosion at Scratby up to 2068. ▪ Happisburgh to Winterton Strategy Review identified the potential for breach at the	Erosion of dunes expected to continue – EA data used together with Futurecoast data. Area also expected to be affected by movement of Winterton Ness	Erosion of dunes expected to continue – EA data used together with Futurecoast data plus SLR component – but slower rates expected at Scratby where sand cliffs are present. Breach potential based upon Happisburgh to Winterton Strategy Review.	Total loss of dune expected, but erosion of sand cliff expected – combination of EA and Futurecoast rates used, plus SLR component. Breach potential based upon Happisburgh to Winterton Strategy Review.	Futurecoast score: low Uncertainty regarding dune survival.

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
			southern end of Newport				
California	(see above)	High (50-100m)	▪ EA data pre-berm is poor, but post-berm there was no change in cliff position and an advance of MSL. ▪ SMP1 predicted 30-45m erosion at California up to 2068. ▪ (also see above)	Berm expected to continue to slow erosion – EA data used.	Assumed berm will break down therefore erosion will increase – Futurecoast and SMP1 data used plus SLR component, assuming initial surge based on coast being held for c. 40 years followed by steady rate. Some straightening of coast expected.	Cliff erosion expected to continue – rates based on Futurecoast data plus SLR component, but assuming slight reduction due to increased feed from north.	Futurecoast score: low
California to Caister (reefs)	(see above)	High (50-100m)	▪ EA data shows no clear trend for the upper beach, but a pre-reef data suggest erosion at 6.9m/yr (but limited data) and post-reef shows accretion at rate of between 0.4 and 0.9m/yr. ▪ Caister Point appears to have moved northwards since the 1880s. ▪ SNSSTS (2002) reported that since the 1930s the Ness has been prograded over 300m. ▪ SMP1 reported an average long-term rate for MLW >2m/yr accretion. ▪ SMP1 predicted that the future shoreline position could either accrete up to 60m or erode up to 40m up to 2068. ▪ prior to the construction of the breakwaters (Halcrow, 1998), predicted that under do nothing there could be greater than 40m erosion at the worst point.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed coastline position (cliffs/ dunes) will be held by reefs and groynes.	Assumed reefs will remain, but outflanking on either side. Rates based on Futurecoast and Halcrow (1998) plus SLR component. Also consideration of reefs still reducing sediment feed to south.	Futurecoast score: medium

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
Caister (reefs to Lifeboat Station)	Net retreat of mean low and an average rate of 1.0m/yr. Also net retreat of back of beach position at an average rate of -1.2m/yr. The foreshore shows a general steepening trend.	High (50-100m)	▪ EA data shows at northern end erosion of beach between 4.6 and 5.6m/yr, but accretion at southern end of frontage of dunes at average rate of 2.3m/yr. ▪ SMP1 reported an average long-term rate for MLW >2m/yr accretion. ▪ SMP1 predicted that the future shoreline position could either accrete up to 60m or erode up to 40m up to 2068. ▪ prior to the construction of the breakwaters (Halcrow, 1998), predicted that under do nothing there could be greater than 40m erosion at the worst point.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed seawall will fail towards end of period. Erosion based upon assumption that coastline has been held for c. 80 years, but would have eroded at Futurecoast rates, but also taking into account impact of Caister Point.	Assumed reefs will remain, but outflanking on either side. Rates based on Futurecoast and Halcrow (1998) information plus SLR component. Also consideration of reefs still reducing sediment feed to south.	Futurecoast score: medium Evolution of Caister Point ness uncertain.
Caister to Great Yarmouth (Pleasure Beach)	Frontage defended for most of period. Net accretion trend illustrated – with apparent step change between 1960 and 1980. Average rate of MLW = 3.4m/yr, average rate of back of beach position change = 3.5m/yr.	Accretion of 0 to 50m	▪ EA data shows accretion ranging from 2.4 to 5.9m/yr across beach profile. ▪ CHaMP (2003) reported that there has been an advance of High Water at a rate of 1m/year over the past decade. ▪ SMP1 reported a long-term average advance of MLW between 0.5 and 1.0m/yr. ▪ SMP1 suggested a range of up to 150m accretion to 20m retreat up to 2068. ▪ CHaMP (2003) concluded that North Denes should continue to be relatively stable over the next 30-50 years.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Width of dunes assumed to be sufficient to maintain line of dunes as natural defence, apart from along northern section, where potential for breach identified using EA IFM.	Futurecoast score: low Uncertainty over ness evolution. Uncertainty over impact of changing configuration of nearshore banks.
Great Yarmouth South Beach	Frontage defended for most of period. Net accretion trend for	Fluctuations in shoreline position	▪ EA data shows accretion of between 0.5 and 2.2m/yr across beach profile, but data at southern	Assumed coastline position (cliffs/ dunes) will be held by the	Due to SLR assumed that net foreshore retreat will occur, with erosion	Assumed total failure of wall and inundation as identified on EA IFM.	Futurecoast score: low Uncertainty

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	**Prediction**[1]		**0-20**	**20-50**	**50-100**	
	northern end of frontage: average rate of MLW = 0.3m/yr and for back of beach = 0.1m/yr. Despite this net steepening trend illustrating by foreshore. At southern end profile indicates net retreat (although fluctuating): average rate of MLW = 0.6m/yr erosion, Back of beach position = 0.5m/yr erosion.	between 0 and 50 m	end was poor. ▪ SMP1 predicted 20m erosion to 60m accretion by 2068.	seawall.	of remaining dunes. Risk of inundation identified from EA IFM.		over impact of changing configuration of nearshore banks.
Gorleston-on-Sea	Frontage defended for most of period, therefore little change in cliff position. Foreshore data illustrates a fluctuating trend, with both erosion and accretion since 1880s. Net change over the period is small.	High (50-100m)	▪ EA data shows erosion of beach and retreat of MSL at rate between 2.8 and 3.5m/yr. ▪ Gorleston to Lowestoft SS reported that the beach was in a poor condition in the 1880s, but there was then accretion during the early 1900s, at 2.9m/yr up until 1927. Then beach levels dropped again – possible cyclic behaviour proposed. ▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 110m. ▪ SMP1 predicted 30 to 50m of erosion up to 2068.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed seawall will fail towards start of period and there will be catch up due to coast being held for c.95 years. Used Futurecoast cliff retreat rates for Gorleston to Hopton section, plus SLR component to calculate initial surge and then assumed rates to be uniform for rest of period.	Assumed continued cliff erosion at uniform rate, using Futurecoast cliff retreat rates for Gorleston to Hopton section, plus SLR component,	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Gorleston-on-Sea to Hopton-on-Sea	Net retreat of MLW at an average rate of 0.5m/yr and cliff retreat at 0.4m/yr. Foreshore shows a steepening trend.	High (50-100m)	▪ EA data suggest generally stable beach with little change. ▪ Gorleston to Lowestoft SS reported cliff erosion at 0.55m/yr between 1889 and 1998, with timber revetment in place for	Assumed that timber revetment will fail and that there will be some catch up effect as the revetment has slowed erosion. Therefore assumed that revetment	Assumed uniform rate of cliff retreat using Futurecoast cliff retreat and Gorleston to Lowestoft SS data and SLR component. Unlikely to be significant	Assumed uniform rate of cliff retreat using Futurecoast cliff retreat and Gorleston to Lowestoft SS data and SLR component.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore

<table>
<tr><th rowspan="2">Location</th><th colspan="2">Futurecoast data</th><th rowspan="2">Other</th><th colspan="3">Prediction of shoreline change for NAI</th><th rowspan="2">Uncertainty</th></tr>
<tr><th>Historical</th><th>Prediction[1]</th><th>0-20</th><th>20-50</th><th>50-100</th></tr>
<tr><td></td><td></td><td></td><td>some of period.
▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 80m.
▪ No specific prediction in SMP1: but predictions 30 to 50m erosion for Gorleston and 60 to 80m erosion for Hopton up to 2068.</td><td>had reduced erosion by a third for 30 years then a more uniform rate of retreat is reached: used combination of Futurecoast cliff retreat and Gorleston to Lowestoft SS data.</td><td>increase in feed from north.</td><td></td><td>banks.</td></tr>
<tr><td>Hopton-on-Sea</td><td>Both MLW and cliff show a net retreat at an average rate of 0.9m/yr.
Foreshore shows a steepening trend.</td><td>High (50-100m)</td><td>▪ EA data poor.
▪ Gorleston to Lowestoft SS reported long-term cliff erosion at 0.71m/yr between 1889 and 1998 but that recent surveys have indicated beach advance.
▪ SMP1 reported long-term trend of retreat MLW at a rate of between 0.5 and 1.0m/yr.
▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 100-110m.
▪ SMP1 predicted 60 to 80m erosion up to 2068.</td><td>Assumed that for first part of period shoreline will be held then cliff erosion as seawall fails in sections. Initial surge determined from assuming coast held for c.40 years and using combination of Futurecoast MLW/cliff data and Gorleston to Lowestoft SS data. Then more uniform rate of retreat calculated using same data.</td><td>Assumed uniform rate of retreat will continue – used Futurecoast MLW/cliff data and Gorleston to Lowestoft SS data plus SLR component. Consideration of increased input of sediment from erosion to the north.</td><td>Assumed uniform rate of retreat will continue – used Futurecoast MLW/cliff data and Gorleston to Lowestoft SS data plus SLR component.</td><td>Futurecoast score: low
Uncertainty over impact of changing configuration of nearshore banks.</td></tr>
<tr><td>Hopton-on-Sea to Corton</td><td>(as above)</td><td>High (50-100m)</td><td>▪ EA data shows generally stable, but net retreat of cliff at average rate of -0.3m/yr.
▪ Gorleston to Lowestoft SS reported cliff erosion at 0.78m/yr between 1889 and 1998 but recent advance of MHW (1993-1998).
▪ UEA reported long-term retreat of MLW.
▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 70-</td><td>Assumed that timber revetment will fail and that there will be some catch up effect as the revetment has slowed erosion. Therefore assumed that revetment had reduced erosion by a third for 30 years then a more uniform rate of retreat is reached: used combination of Futurecoast cliff retreat and Gorleston to</td><td>Assumed uniform rate of cliff retreat using Futurecoast cliff retreat and Gorleston to Lowestoft SS data and SLR component. Unlikely to be significant increase in feed from north.</td><td>Assumed uniform rate of cliff retreat using Futurecoast cliff retreat and Gorleston to Lowestoft SS data and SLR component.</td><td>Futurecoast score: low
Uncertainty over impact of changing configuration of nearshore banks.</td></tr>
</table>

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
			90m.	Lowestoft SS data.			
Corton	Low rate of cliff retreat even before defences. Net MLW retreat at an average rate of 0.6m/yr.	High (50-100m)	▪ EA data shows net retreat of both upper beach and MSL of between 1.1 and 1.7m/yr. ▪ Gorleston to Lowestoft SS reported cliff erosion at 0.18m/yr between 1889 and 1998. ▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 100m. ▪ SMP1 predicted 45- 65m erosion up to 2068. ▪	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed seawall failure at start of period and initial period of 'catch-up'. Initial surge determined from assuming coast held for c.40 years and using combination of Futurecoast MLW data and Gorleston to Lowestoft SS data. Then more uniform rate of retreat calculated using same data.	Assumed uniform rate of cliff retreat using Futurecoast MLW and Gorleston to Lowestoft SS data and SLR component.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Gunton Warren	Net retreat of MLW and cliffs: 1.7m/yr and 1.6m/yr respectively.	(see above)	▪ EA data shows that along northern section it has been generally stable but erosion increases towards south. Rates ranged from 0.1 to 1.2m/yr. ▪ SMP1 predicted erosion of 0-15m up to 2068. ▪ Both SMP1 and Gorleston to Lowestoft SS reported long-term net retreat of MLW >2m/yr for Lowestoft Denes.	Assumed that beach and dune erosion will continue - used EA data rates.	Assumed beach and dune erosion will continue – used combination of EA and Futurecoast data plus SLR rise component. Also considered feed of sediment from north.	Assumed beach and dune erosion will continue – used combination of EA and Futurecoast data plus SLR rise component. Also considered feed of sediment from north.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Lowestoft North Beach	Coastline defended for much of period. Net retreat of MLW at an average rate 1.1m/yr. Foreshore shows a steepening trend.	Very High (100-200m) and risk of flooding	▪ EA data showed that at northern end there has been some accretion, although levels fluctuate – average rate = 0.6m/yr. Data for southern section was poor. ▪ Lowestoft Ness has eroded considerably – UEA reports 3.6m/yr in 1880s. ▪ SMP1 predicted erosion of 30-35m up to 2068.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed cliff failure, with shoreline retreat calculated assuming coast has been held for over 100 years using Futurecoast MLW rate as an average.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.

Location	Futurecoast data		Other	Prediction of shoreline change for NAI			Uncertainty
	Historical	Prediction[1]		0-20	20-50	50-100	
			▪ For do nothing Gorleston to Lowestoft SS predicted retreat of MLW over next 50 years of 130m along Lowestoft Denes and 80-100m at Lowestoft Ness.				

C5 Baseline Case 2 – With Present Management (WPM)

C5.1 INTRODUCTION

This report provides analysis of shoreline response conducted for the scenario of “With Present Management”. This has considered that all existing defence practices are continued, accepting that in some cases this will require considerable improvement to present defences to maintain their integrity and effectiveness and has taken account of the fact that some presently redundant structures do not form part of this existing defence management (see Defence Assessment, Section C2).

The analysis has been developed using the understanding of coastal behaviour from both Futurecoast and the baseline understanding report produced (see Section C1), existing coastal change data (see Section C5.4) and information on the nature and condition of existing coastal defences.

C5.2 SUMMARY

The following text provides a summary of the analysis of shoreline response with details specific to each location and epoch contained within the Scenario Assessment Table.

(a) Epoch 0-20 years (to 2025)

Overall the picture is one of increased stress on the shoreline, with diminishing beaches and higher exposure to wave activity.

There will be a continuation of present day trends throughout the SMP area. As the coastal system continues to transgress, this will squeeze the intertidal zone as nearshore areas deepen and defences prevent natural landward movement of the shoreline. This problem will be exacerbated by the defence of much of the cliff line continuing to reduce the natural input of sediment to the beaches.

Stress on the coast will be greatest where there are seawalls, although under this scenario, there will be no loss of cliff to erosion in these areas and defended areas will remain protected. Elsewhere, other structures such as timber revetments only limit the rate of cliff retreat. Historically it has been estimated that these reduce erosion rates by approximately one-third, and over this period it is expected that they will perform to a similar effectiveness. However, these structures have short remaining life spans and most will require replacement within this time period.

Along the undefended coast, it is expected that cliff erosion will continue at rates experienced over the past 20 years, although there are exceptions to this such as at Happisburgh, where defences have recently failed. Breaches and tidal inundation would be averted under this scenario, but the probability of natural defences being occasionally breached, e.g. at Weybourne and Newport, is likely to increase. In other areas, such as Winterton and Great Yarmouth, where dunes provide a natural defence, little change to the present situation is expected.

(b) Epoch 20-50 years (to 2055)

During the period 20 to 50 years, the stress on the coast will have reached levels where a naturally functioning system will have begun to break down.

Along this coastline, a number of promontories will be forming, where defended stretches are adjacent to non-defending stretches, which are continuing to retreat. These promontories will begin to inhibit sediment transfer between areas.

Due to defences, along much of the shoreline, the natural retreat of the shoreline will be inhibited, therefore beaches will have narrowed and lowered considerably; in some areas they will have disappeared altogether. This will be exacerbated by accelerated sea level rise; without the ability of the shoreline to respond by moving landward, there will be deeper water and greater wave exposure at the seawalls. These conditions will not be conducive to beach retention and any sediment arriving on these frontages is likely to be rapidly transported offshore again. This will also increase the vulnerability of these defence structures and more frequent work to maintain their integrity will be required, to prevent erosion and maintain the shoreline in its present position.

The constraints imposed by the timber revetments and other erosion-reducing structures are also likely to result in some beach narrowing. The rate of retreat in these areas is likely to increase as a result of sea level rise and limited sediment supply. Timber revetments and groynes will need to be reconstructed in retreated positions when they fail, to reflect this shoreline movement, so they do not become isolated and ineffective.

Along undefended sections of coastline, erosion of the cliffs will accelerate, in response to sea level rise. Breaches and tidal inundation of defended flood risk areas would be averted, under this scenario, although natural defences, e.g. at Weybourne and Newport, are likely to be frequently breached. In other naturally defended areas such as Winterton and Great Yarmouth, there is some uncertainty over the mobility of the beach and dune systems, but it is not expected that there will be any risks imposed by such movement as these systems will remain wide and healthy.

(c) Epoch 50-100 years (to 2105)

The long-term picture is one of a very fragmented shoreline, characterised by a series of concreted headlands and embayments. The natural movement of sand and shingle sediment will have been seriously interrupted and there is potential for more of this beach-building material to be washed offshore.

Seawalls will have created a series of large promontories, in many cases extending 100-200m out from the adjacent eroded shoreline. These promontories will be highly exposed to waves in deeper water, requiring much more substantial defences to be constructed. These defences would also need to be extended landward to prevent outflanking of the present seawalls. There will be no beaches present along these frontages and the groynes will have become redundant.

These prominent areas will also act as a series of terminal groynes upon beach sediment transport, effectively eliminating the exchange of sand or shingle alongshore throughout much of the SMP area. As such, these may help to stabilise beaches on their up-drift side, but will also probably exacerbate erosion down-drift. The deeper water at these headlands is expected to result in any sediment reaching these points being deflected offshore rather than moving down the coast.

The rate of cliff retreat in the areas between these promontories is expected to increase as sea level continues to rise. This applies both to areas that are undefended, and to those that have erosion-reducing structures in place. Frequent rebuilding of the timber revetment and groynes is to be expected to accommodate greater exposure and failure, and necessary relocation as the shoreline retreats. This increased sediment supply locally, together with the trapping effect of the promontories, will help to retain the beaches in these areas, although these are not expected to be substantial bodies of sand.

Breaches and tidal inundation of defended flood risk areas would continue to be averted under this scenario, although much more substantial seawalls would be required, as beaches will not be retained in front of these structures. The effectiveness of the natural defences at Weybourne and Newport will progressively reduce. In other naturally defended areas such as Winterton and Great Yarmouth, there may be some deterioration of the beach and dune systems, but the size of these systems suggest that this is unlikely to produce any significant flood or erosion risks.

C5.3 WPM SCENARIO ASSESSMENT TABLE

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Kelling Hard to Sheringham	A low timber and steel palisade prevents landward movement of the shingle bank at Weybourne (prevents breaching and flooding).		The timber and steel palisade may become technically impossible as shingle rollback outpaces maintenance of the defences.
	Cliff erosion would continue at similar rates to those experienced historically. This would vary according to cliff composition. The shingle bank at Weybourne would be held in its position by the backing defences, preventing a breach in this barrier, although the narrowing beach in front is likely to be overtopped with increasing frequency. There would be no input of shingle to this frontage from alongshore due to the low sediment transport rates along this stretch of coast. The cliffs themselves would contribute some beach building material, which will help to maintain the beaches as the shoreline retreats. There would be continued, low sediment transport from this area to both the west and the east: with predominately sand to the east and shingle, from reworking of beach deposits, to the west.	There would be continued cliff erosion and shoreline retreat by 2055. Whilst the cliffs will supply some shingle to the beaches along this frontage, this may be insufficient to maintain present beach volumes. Sea level rise may increase energy at the shoreline and remove more material from the shingle beach, as the cliffs inhibit landward movement. This might increase shingle supply to the west, but see beaches here narrow and steepen. It is likely that retreat of the beach position would render the palisade at Weybourne obsolete and this would need to be reconstructed landward of its present position.	There would be continued cliff erosion and shoreline retreat by 2105. Whilst the cliffs will supply some shingle to the beaches along this frontage, this is likely to be insufficient to maintain present beach volumes. Sea level rise may increase energy at the shoreline and remove more material from the shingle beach, as the cliffs inhibit landward movement. The translation of beach position would render the palisade at Weybourne obsolete and this would need to be reconstructed landward of its present position at regular intervals.
Sheringham frontage	A vertically faced concrete seawall and promenade, the central seawall and promenade have a rock armour revetment placed along the toe. Groynes exist along this frontage: timber to the west with rock along the central section.		
	The seawall and rock revetment would hold	The seawalls will continue to hold the cliffs in	The cliffs will continue to be held in their

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	the cliffs in their present position. The beach would not change from its present form, but it would begin to experience some reduction in volume as retreat is prevented. There would be continued, low sediment transport into this area from the east, but is not thought to be of sufficient volume to sustain the current beach level. The volume of sand and shingle material being transported from Sheringham to the west will not be significantly different from present values.	a fixed position. These would prevent transgression of the beach inland as sea levels rise and, coupled with the absence of direct feed from cliff erosion, beaches will steepen and narrow. The groynes will, however, capture some littoral drift and maintain a narrow beach in front of the cliff but this will be close to disappearing by 2055.	present position, by the seawall and rock revetment. There is unlikely to be any beach present. Cutback of the shoreline to the east and west of the seawall would continue, so that Sheringham increasingly forms a promontory.
Sheringham (East)	The seawall along the eastern section is a low concrete structure, which serves to reduce the rate of erosion rather than provide full protection. Timber groynes exist along this frontage.		
	The rate at which erosion of the cliffs takes place would be limited by the presence of defences, but erosion would continue at a rate similar to that currently taking place. The beach would not be dissimilar from that at present.	Erosion of the cliffs below the low wall would continue. Rates would increase with sea level rise. This would provide a small amount of sand and shingle to the beach here and to the east. The beach would continually narrow in front of the concrete wall.	Erosion of the cliffs below the low wall would continue. Rates would increase with sea level rise. This would provide a small amount of sand and shingle to the beach here and to the east. The beach would continually narrow in front of the concrete wall.
Sheringham to Cromer	Two short stretches of masonry wall in close proximity to the beach access points at West and East Runton. Timber groynes between Sheringham and West Runton.	Two short stretches of masonry wall in close proximity to the beach access points at West and East Runton – outflanked during this epoch. Timber groynes between Sheringham and West Runton (relocated landward to accommodate erosion).	Timber groynes between Sheringham and West Runton (relocated landward to accommodate erosion).

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	Where masonry walls protect the beach access points, there will be no change in cliff position. Elsewhere the cliffs will erode at the current rate. There will be very little shingle or sand supply to and from adjacent beaches (some limited supply to Cromer frontage), but continued cliff erosion will maintain the beaches in a similar state to present.	Erosion of the cliffs will continue. Cutback will take place alongside the beach access points, to the extent that they eventually become outflanked either side and behind to become isolated structures and redundant as defences. The protruding promontories will temporarily inhibit sediment bypass along the frontage until these structures are completely outflanked by the cliff erosion. It will be technically inappropriate to maintain the present masonry walls as defences in the current location. The cliffs will release some sand and shingle. There will be little if any sediment input from the updrift frontages or to adjacent areas, with the beach remaining similar to that seen at present.	Cliff erosion will continue, with rates increased as sea levels rise. Sediment feed from local cliff erosion will maintain beaches similar to those seen at present. There will be no shingle or sand supply to and from adjacent frontages due to the increased prominence of those areas.
Cromer	Seawall and Groynes.		Seawall (groynes redundant).
	The seawall would hold the cliffs in their present position. The beach will experience some narrowing, as there is only minor supply of sand and shingle from the west.	The cliffs would not experience any change and continue to be held in their present position by the seawall. The cliffs either side of the seawall would cutback, so this will become a more prominent frontage. As this promontory becomes more pronounced, restricting sediment supply, and sea level rise increases exposure to greater wave activity, beaches here will narrow and steepen significantly. Only minor beach	The cliffs at Cromer would form a well-defined promontory with no beach. The groynes would become redundant and substantial works are likely to be required to retain the seawalls. This would also require extending the walls to prevent outflanking, with cut back to both east and west. The seawall promontory would probably eliminate any sediment from bypassing and supplying areas to the south.

Location	**Predicted Change for ‘With Present Management’:**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		retention is likely due to the groynes.	
Cromer to Overstrand	Timber groynes.		
	Erosion of the cliffs would continue at a rate similar to present. The groynes would retain some of this material to hold beaches similar to those today, whilst the remainder would be transported to the adjacent coastline downdrift or moved offshore (mainly fines).	Erosion of the cliffs would continue, increasing as a consequence of sea level rise. Groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. A large proportion of the material released from cliff erosion along this section will be lost offshore (mainly fines), while any sand not lost offshore will be retained by the groynes, to retain a beach similar to that seen today.	The cliffs will continue to erode. Groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. A large proportion of the material released from cliff erosion along this section will be lost offshore (mainly fines), while any sand not lost offshore will be retained by the groynes. Sediment transport into and from this section of coastline will be prevented by the development of promontories either side. This may result in greater material retention within this bay, which could see an increase in the size of beach, or at least maintain beaches similar to those today.
Overstrand (North)	Seawall fronted by groynes.	Seawall (groynes redundant).	
	The cliffs will be held in their present position. Groynes will only hold the beach to a limited extent, less than that at present, as this area is already forming a promontory and is relatively exposed. There will be some sediment supply across	The seawall will continue to hold the cliffs in their present position, although as this area becoming increasingly prominent, it is probable that much more substantial structures would be required to sustain the integrity of these defences. Cutback will take place at the north and south ends of the seawall.	The seawall will hold the cliffs in their present position, although extensive increase in the wall structure and its maintenance will be necessary to maintain its integrity. This will include extending the seawall landwards to prevent outflanking due to erosion either side. The prominence of this frontage will mean that there will be no beach present, and sediment

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	this frontage, from north to south.	It is highly probable that the beach will no longer exist. Increased water depths and foreshore exposure due to sea level rise will prevent the groynes from retaining sand material (these becoming redundant). Sand-sized sediment will continue bypass the seawall, but supply to the south may start to be restricted by this promontory.	supply from the cliffs to the north, to beaches to the south, will have been cut off.
Overstrand (South)	Timber revetment (with some rock in places), fronted by groynes.		
	Cliff erosion will continue, at rates similar to present. This erosion, and supply from the north, will provide a beach but this is likely to be reduced from that present today due to defences to the north.	Erosion of the cliffs would continue, increasing as a consequence of sea level rise. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. It is probable that beach width will narrow as sediment supply from the north becomes depleted as a result of the promontory forming at Overstrand, and material locally is transported to the south.	Erosion of the cliffs would continue, increasing as a consequence of sea level rise, and exacerbated by the blocking effect of the defences at Overstrand preventing sand bypassing. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. It is probable that there would be little beach material present as a result of lack of feed from the north and material locally is transported rapidly to the south.
Overstrand to Vale Road Beach Access	No defences.		
	There will be significant unabated cliff erosion through both marine and groundwater processes.	Unabated cliff erosion would continue at an accelerated rate due to rising sea levels. A large proportion of the material released	Continued cliff erosion will take place. Some of the sand material released from the cliffs will supply the fronting beach and maintain a narrow beach similar to that present today,

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	The sand beach will be similar in form and size to that at present.	from cliff erosion along this section will be lost offshore (mainly fines). Sand not lost offshore will be retained on the beach, which will be similar to that seen today, whilst the remainder will be transported southward to feed beaches along other frontages.	whilst the remainder will be rapidly transported southward. The influence of defences at Mundesley could result in a slightly slower rate of erosion along the southern part of this frontage, but could also result in more of the material eroded from this frontage being lost offshore rather than transported to beaches further south.
Vale Road Beach Access to Mundesley	Timber Revetment and Groynes.		
	Defences here will restrict cliff erosion to a rate similar to that presently taking place. A beach, albeit narrowing in width, will be maintained with sand and shingle supplied primarily via erosion of the cliffs along the frontage directly to the north, with a constant transport of sand through this frontage to feed beaches further south.	There will be limited erosion of the cliffs, although this erosion may accelerate substantially at the northern end as cliff erosion occurs on the adjacent frontage. Despite the feed of sand from the north, the beach will narrow and steepen in front of the timber revetment as sea levels rise and sediment transport rates potentially increase here due to greater exposure. The timber revetment and groynes will need to be reconstructed further back from their present position.	Erosion rates will remain restricted by the timber structures. However, this erosion may accelerate substantially at the northern end as cliff erosion occurs on the adjacent frontage, whilst being reduced towards the southern end as the promontory created by defences at Mundesley traps more beach material. A bay formation is likely to be well defined between Overstrand and Mundesley by this time. The nature of the bay, and extension of the shoreline to meet with the promontory formed by the seawall at Mundesley, means that there will still be transport of sand through this frontage, although exposure at the southern end means that this could become a point for offshore losses. It is likely that frequent reconstruction of the

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
			timber revetment and groynes would be required (in set back positions) due to exposure levels increasing.
Mundesley	Concrete seawall at the base of the cliffs fronted by groynes.		Concrete seawall (groynes redundant).
	The cliffs will be held in their present position by the seawall. Only a narrow beach will be maintained by the groynes, trapping sediment supplied from the north, as exposure of the frontage increases.	The cliffs will be retained in their present position, increasingly forming a promontory as the shoreline to the north and south cuts back. This will inhibit natural shoreline transgression and increase exposure to waves. As a result of this and rising sea levels, it is likely that there will be no beach retained, despite the groynes and sediment supply from the north (the groynes would become redundant). Sediment arriving from the north will be rapidly transported southward to the adjacent shores, but less sediment will actually bypass Mundesley.	The seawall will continue to hold the cliffs in their present position, although extensive increase in the wall structure and its maintenance will be necessary to maintain its integrity. Continued cutback of the cliffs to north and south will require extension of the defences to prevent outflanking. There would be no beach present as a result of the exposure of this promontory. The influence of defences at Mundesley could help to reduce erosion directly to the north, through trapping sediment, but exacerbate erosion directly to the south through starving it of sediment supply. It is possible that material supplied from the cliffs to the north is unable to bypass this promontory and could be transported offshore and lost from the shoreline sediment system.

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Mundesley to Bacton	Timber revetment and groynes.		
	There will be erosion of the cliffs at a rate similar to that taking place at present. The groynes will trap some of the material supplied from the north, maintaining the beach in a form similar to that at present, although in a retreated position. Sediment feed into and from this frontage will continue.	The timber revetment will provide some protection to the cliffs, but erosion will continue. The rate of retreat is likely to increase as a result of sea level rise. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. Beach material will continue to be supplied from the north and be transported along this frontage and to the south. The beaches are expected to be similar in character to those at present, albeit in a retreated position. Some narrowing may have occurred as a result of reducing sediment transport from the north (caused by defence at Mundesley) although this may be countered by increased erosion of the cliffs along this frontage.	Cliff erosion will have increased over historic rates as a result of sea level rise and the cessation of sediment supply from the north, caused by the protrusion of Mundesley. Sediment feed into this frontage from the north will be minimal, if any at all. Despite erosion and sediment feed from the cliffs here, beaches are likely to drop in volume and narrow. Frequent rebuilding of the timber revetment and groynes is to be expected to accommodate greater exposure and relocation as the shoreline retreats.
Bacton and Walcott	Concrete seawall and timber groynes.		Seawall (groynes redundant).
	The seawall will hold the low cliff line in its present position. Sand will continue to be supplied to this area from cliff erosion on frontages to the north, and will be transported to beaches further	The low cliff line will continue to be held in its present position by the seawall. Despite the groynes, beaches are likely to become only ephemeral features maintained by interactions between the beach and	The low cliff backshore will continue to be held in its present position by the seawall. The position of the wall will have become increasingly exposed as sea level rises and sediment feed will have been greatly reduced

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	south. The groynes will retain some beach material, although these beaches are likely to be lower and narrower than the present day due to the reduced feed into this area.	nearshore bar, as a consequence of sea level rise, defence position preventing shoreline transgression, and increasing interruptions to sediment feed from the north.	by defence measures to the north. As a consequence, there will be no beaches present and the groynes will have become redundant. Substantial works will be required to maintain the seawalls. Any material reaching this area is likely to be transported sub-tidally and transported directly to the south.
Ostend to Happisburgh Village	Timber revetment and groynes.		
	There would be erosion of the cliffs at a rate similar to that taking place presently. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. The groynes would help to trap some of the material supplied from the north, maintaining the beach in a form similar to that present today. Sediment feed into and from this frontage will continue.	The timber revetment will provide some protection to the cliffs, but erosion will continue. The rate of retreat is likely to increase as a result of sea level rise. Retreat would be greater at the southern end as erosion of the cliffs to the south continue to potentially outflank the shoreline position here. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. Some beach material will continue to be supplied from the north and be transported along this frontage and to the south. The beaches are expected to be similar in character to those at present, albeit in a retreated position. Some narrowing may have occurred as a result of reducing sediment	Cliff erosion is likely to increase due to sea level rise, and the reduced amount of sediment arriving from the north as a result of defence measures there. This area will be part of a larger embayment between Walcott and the end of the Eccles Seawall. Frequent rebuilding of the revetment and the groynes would be needed in retreated positions as this shoreline movement takes place. Beach levels along this frontage may become reduced as a result of less sediment supply from adjacent frontages and increased exposure conditions restricting beach retention until the shoreline has retreated to a position commensurate with shoreline energy.

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	Years 20 – 50 (2055)	Years 50 – 100 (2105)
		transport from the north (caused by defences at Mundesley).	
Happisburgh Village	Rocks against cliff toe.		
	The defences are expected to have very limited impact and the cliffs are likely to experience significant erosion in excess of historic rates (as the shoreline tends towards a position commensurate with shoreline energy). The extent to which a beach is retained in front of the cliffs depends upon the extent of erosion but at best is likely to be very narrow. Frequent replacement of the rocks to a newly retreated position is expected to be necessary. There will be continued southwards transport of sand.	The defences are expected to have very limited impact and the cliffs are likely to continue to retreat at a rate in excess of that experienced historically until the shoreline reaches a position commensurate with shoreline energy. It is likely that the beach will improve along this frontage as the shoreline position retreats. This will be supplied by the cliff erosion and some sediment supply from the cliffs directly to the north. Frequent replacement of the rocks to a newly retreated position is expected to be necessary. There will be continued southwards transport of sand.	The defences are expected to still have very limited impact although cliff erosion is expected to return to its historic rate. As such there may be no requirement to replace the rocks with the same frequency as previously. A sand beach similar to that present today to the south of this frontage is expected to front the beach. This will be supplied by the natural erosion and some sediment supply from the cliffs directly to the north. Sediment arriving from the north will be transported through this frontage onto that to the south.
Happisburgh Village South	No defences.		
	The cliffs will continue to erode at their pre-defence historic rate, as the cliffs have probably reached a position commensurate with current energy.	The cliffs will continue to erode, but at a faster rate due to sea level rise, forming an embayment between the northern end of the Eccles seawall and Walcott.	The cliffs will continue to erode, forming an embayment between the northern end of the Eccles seawall and Walcott. A sand beach similar to that present today,

<table>
<tr><th rowspan="2">Location</th><th colspan="3">Predicted Change for ‘With Present Management’:</th></tr>
<tr><th>Years 0 – 20 (2025)</th><th>Years 20 – 50 (2055)</th><th>Years 50 – 100 (2105)</th></tr>
<tr><td></td><td>A sand beach similar to that present today, largely maintained by this cliff erosion, is expected to front the beach.
There will be continued southwards transport of sand.</td><td>A sand beach similar to that present today, largely maintained by this cliff erosion, is expected to front the beach.
The seawall to the south will help to maintain a wider beach at the southern end of the embayment, possibly enabling some small dune development.
There will be continued southwards transport of sand.</td><td>largely maintained by this cliff erosion, is expected to front the beach.
The seawall to the south will help to maintain a wider beach at the southern end of the embayment, possibly enabling some small dune development. This prominent position of the seawall to the south could, however, significantly restrict the supply of sediment to that frontage via the beach, although some transport could still take place via the nearshore bar.</td></tr>
<tr><td>Eccles on Sea</td><td colspan="2">A seawall with rock toe, which protects against flooding, and groynes.</td><td>Seawall only (groynes redundant).</td></tr>
<tr><td></td><td>The backshore dunes would be held in their present position by the seawall.
The groynes would trap sand transported from cliff erosion to the north to maintain a beach similar to that at present.
Sediment would continue to be transported southward onto adjacent frontages.</td><td>The seawall would continue to hold the shoreline in its present position, increasingly forming a discontinuity between this frontage and the eroding cliff to the north. There will be outflanking problems at the northern end of the wall, which will require extension.
This discontinuity will also create more difficulties in retaining a beach along this frontage and these would disappear at the northern end as a result of increased exposure and reduced sediment supply.
The beaches at the southern end of the frontage would not be affected so drastically, and would not be so dissimilar from now. Although these would have narrowed as a result of sea level rise, sediment re-</td><td>The holding of the shoreline by the seawall next to the area of unabated erosion will further exacerbate the discontinuity in sediment supply and problems with outflanking. Significant work is likely to be required to ensure the integrity of the seawall as a defence.
It is probable that by 2105 there will be no beach along this frontage, other than ephemeral sand depositions, as sea level rise will produce higher water levels and higher waves, and conditions that are more volatile and less conducive to beach stability. It is likely that the re-nourishment operations to the south will no longer be of sufficient magnitude to match beach supply requirements.</td></tr>
</table>

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		nourishment to the south will help maintain these.	
Sea Palling to Waxham	Offshore breakwaters (reefs) and beach recharge (200,000-300,000m^3 every 3 years).		
	There would be little change to the position of the backshore dunes, beach or sediment transport from the present position/regime.	The seawall will hold the backshore dunes in their present position. The beach is likely to reduce in volume as a result of increasing sea levels and decreasing sediment supply, but should remain in a reasonable condition due to re-nourishment and trapping efficiency of the reefs. Some sediment will take place onto adjacent frontages to the north and south.	The backshore dunes will be held in their present position by the seawall. The beach is likely to diminish considerably in size as, coupled with the reduction in natural supply, existing re-nourishment quantities may become insufficient to accommodate the increased volatility and removal of material resulting from sea level rise and greater exposure conditions. This may require strengthening of the seawall in between the reefs to maintain their integrity. Sediment removed from this frontage is likely to be dispersed to north and south, although the retention potential on these frontages will have also reduced significantly.
Waxham to Winterton Ness	Seawall, with rock toes immediately to the south of reefs between Waxham and Horsey. Fronted by groynes.		
	There would be little change to the position of the backshore dunes, beach or sediment transport from the present position/regime.	The seawall will hold the backshore dunes in their present position. The groynes will retain some sand material, but the beach will become narrower due to sea level rise and prevention of the landward	The backshore will be held in its present position by the seawall. The entire length of shoreline between Happisburgh and Winterton would form a controlling promontory on the shoreline to the north and south. It is uncertain as to how

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		transgression of the beach landwards. There is likely to be some cutback at the southern end of the seawall, as this shoreline increasingly becomes a promontory, and the wall may require extension to maintain protection against flooding. (However, the evolution of Winterton Ness remains uncertain). Sand transported off this frontage will move southwards onto Winterton Ness.	Winterton Ness to the south may behave over this timescale, but if it does erode, defences will need extending to prevent outflanking. Assuming that it accretes there would not be cutback or outflanking at the downdrift section of the seawall. Despite the input of sediment from re-nourishment to the north, the beach is likely to disappear over this frontage, as defences would prevent its landward translation due to sea level rise. Groynes might offer some limited trapping and narrow low beaches could be an ephemeral feature. However, most sand arriving on this frontage is likely to be rapidly transported to the south, or possibly lost offshore. Significant work is likely to be required to ensure the integrity of the seawall as a defence.
Winterton-on-Sea	No defences.		
	There is a great deal of uncertainty attached to the evolution and processes at Winterton Ness. It is assumed for the purposes of this scenario that its alongshore position will not alter considerably over the next 100 years, i.e. the only positional change will be cross-shore movement in response to sea level	There is a great deal of uncertainty attached to the evolution and processes at Winterton Ness. It is assumed for the purposes of this scenario that its alongshore position will not alter considerably over the next 100 years, i.e. the only positional change will be cross-shore movement in response to sea level	There is a great deal of uncertainty attached to the evolution and processes at Winterton Ness. It is assumed for the purposes of this scenario that its alongshore position will not alter considerably over the next 100 years, i.e. the only positional change will be cross-shore movement in response to sea level rise. It is

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	rise. It is also assumed that the dune complex acts as a sediment store and will release sand at a rate similar to that at present, regardless of supply to the ness. By 2025 the beach and dunes will be of similar character to that at present, with little net change in overall position.	rise. It is also assumed that the dune complex acts as a sediment store and will release sand at a rate similar to that at present, regardless of supply to the ness. The reduction of natural sediment feed to this area will begin to erode the dune field to compensate and supply sand to beaches further south. The dune and beach system may translate landward due to rising sea levels.	also assumed that the dune complex acts as a sediment store and will release sand at a rate similar to that at present, regardless of supply to the ness. The coastline to the north will have developed into a well-defined promontory and sediment supply to Winterton will be significantly reduced if not diminished completely, the only source being re-nourishment at Sea Palling. This would be likely to result in further erosion of the dunes, without which there would not be sediment supplied to beaches further south. The foredune position will be retreated from present day.
Newport and Scratby	No defences.		
	Despite continued sediment supply, transgression of the coast will result in deterioration of the dune ridge, with occasional breaching by the sea. The beach would remain similar in character to that at present. Sand would be transported through this frontage to beaches further south.	Transgression as a result of sea level rise, coupled with inadequate sediment availability, will result in the further deterioration and probable loss of the dunes as a natural defence by the end of the period. This backshore position is likely to retreat, with erosion of the low sand cliffs (and flooding of low spots). The beach will start to narrow, as the sand cliffs behind prevent its translation landward. There would be some sediment feed into the	In the absence of the dunes the backshore would comprise a beach ridge only, fronting gently rising ground (sand cliffs). This would be expected to suffer erosion and flooding where lower lying. The beach would be narrower. Sand eroded from this frontage would supply beaches to the south. Eventually (probably >100 years) this shoreline will begin to stabilise (erosion will be slowed) in response to the promontory forming between

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		adjacent frontage to the south.	California and Caister.
California	Rock bund offset from the cliff toe.		
	The backshore cliffs will continue to erode slowly, at a rate similar to that at present. The beach in front of the rock bund will be narrow but maintained by sediment supplied from Winterton Ness. Sediment will continue to be transported through this frontage onto beaches further to the south.	Erosion of the cliffs will increase in frequency as sea levels rise and the defences are more regularly overtopped. As a result of sea level rise and the presence of the bund, the beach seaward of the bund is likely to become narrowed to a point of virtual non-existence, although sand eroded from the cliffs will be retained behind the structure. Sediment transport from the north will continue to beaches further south, primarily along the nearshore bar.	Cliff erosion will remain restricted by the defence but would continue to occur with greater frequency as exposure levels increase. There will be no beach in front of the structure but sand eroded from the cliffs will be retained behind the structure. Sediment supplied from the north may no longer be transported onto the beaches further south as the bund and the promontory to the south pushes this further offshore.
California to Caister (reefs)	Seawall fronted by rock groynes (to north) and intertidal rock reefs (to south).		
	The groynes and reefs will continue to trap material supplied from the north and the beach will maintain in its present position. There may be some foreshore erosion around the low water mark, which will be at a rate similar to present. Sand sized sediment will be supplied to the adjacent downdrift frontage. There will be no change to the backshore position during this period.	The backshore will remain in its present position. There will be some beach narrowing due to sea level rise, but the beaches will remain wide and sufficiently healthy to provide protection to the seawall. Sediment arriving from the north will be held at this location, with surplus sand being transported further to the south. Sediment transport along the beach will	The backshore will be held in the same position as at present, forming a more defined promontory with the shoreline to the north. This is likely to result in increased exposure of the rock groynes and seawall as a beach becomes more difficult to maintain under pressure of rising sea levels and transgression of the coast. Sediment from the north may no longer be deposited in this area, as the groyne/reef-held

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		cease, as the reef-held shoreline becomes a more defined promontory. Any material supplied to downdrift frontages will be transported via the nearshore bar and not via the beach.	shoreline becomes a more defined promontory. This could be detrimental to continuity of the nearshore bar and sediment bypass would be minimal, if it takes place at all.
Caister (reefs to Lifeboat Station)	Seawall.		
	The seawall will prevent retreat of the backshore. Sand will be supplied from beaches to the north, although the beach to the south is likely to remain narrow. Some stability will be provided to this beach by the controlling influence of the reefs to the north and Caister Ness to the south.	The seawall will prevent retreat of the backshore. To the south of the reefs, beach narrowing and steepening will occur, as a result of sea level rise and diminished alongshore sediment supply.	The seawall will prevent retreat of the backshore. Increased exposure due to rising sea levels will diminish beach retention capability and potential reduction in sediment supply means that there will no longer be a beach in front of the wall. Substantial works may be required to maintain the integrity of this defence. Sediment transport, if any at all, is likely to take place via the nearshore bar, and bypass this area to supply Caister Ness and Great Yarmouth with sand material.
Caister to Great Yarmouth (Pleasure Beach)	Set-back concrete wall (behind wide low dune field).		
	The seawall will prevent any erosion or inundation of the hinterland.	The seawall will prevent any erosion or inundation of the hinterland.	The seawall will prevent any erosion or inundation of the hinterland.

<table>
<tr><th rowspan="2">Location</th><th colspan="3">Predicted Change for ‘With Present Management’:</th></tr>
<tr><th>Years 0 – 20 (2025)</th><th>Years 20 – 50 (2055)</th><th>Years 50 – 100 (2105)</th></tr>
<tr><td></td><td>The dunes and beach may be mobile but will exhibit little net change in character.</td><td>There is some uncertainty over the future evolution of Caister Ness, this being a relatively recently formed feature, and there may be some oscillation of the backshore dunes, as changes to the beach take place. There will be some foreshore narrowing as sea levels rise and the sediment supply regime alters, but the beach is expected to remain wide and healthy.
There will be a feed of sand-sized material to the south, transported by alongshore processes, although rates of transport are likely to be low.</td><td>There is some uncertainty over the future evolution of Caister Ness, this being a recently formed feature, and there may be some oscillation of the backshore dunes, as changes to the beach take place. There will be further foreshore narrowing as sea levels rise and the sediment supply from the north becomes reduced, but the beach is expected to remain wide enough to provide adequate “natural” defence.
There will be a feed of sand-sized material to the south, transported by alongshore processes. Rates of transport are likely to remain low, although these might increase over time with increased sea levels and wave exposure.</td></tr>
<tr><td>Great Yarmouth South Beach</td><td colspan="3">Seawall, fronted by groynes. Harbour arm at southern end.</td></tr>
<tr><td></td><td>The seawall will prevent landward movement of the shoreline.
Despite feed of sand from the north, the beach is not expected to improve compared to its present condition, remaining low and narrow in places.
Sand material will be transported beyond the harbour arm via the nearshore bar.</td><td>The seawall will prevent landward movement of the shoreline.
The beach will narrow and steepen due to sea level rise, and the seawall restricting its landward transgression. In places the seawall will need to be improved to maintain its integrity as a defence.
Sediment supply to and beyond this frontage will continue, fed by the wide beach and</td><td>The seawall will prevent landward movement of the shoreline.
The beach will disappear along its southern reaches due to sea level rise and increased exposure, and the seawall restricting its landward transgression. Substantial works may be required to the seawall in places to maintain its integrity as a defence.
Sediment supply to beyond this frontage will</td></tr>
</table>

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
		dunes between Caister and Great Yarmouth.	probably continue via the offshore bar, fed by the wide beach and dunes between Caister and Great Yarmouth.
Gorleston-on-Sea	Concrete seawall fronted by timber groynes. Harbour breakwater with a spur to retain the beach at the northern end.		
	The mouth of the River Yare, and the cliffs will be held in their present position by the seawall. The groyned beach will be retained by sand supplied from the north and south, due to local net drift reversals and from offshore, via linkages with the nearshore bar.	The mouth of the River Yare, and the cliffs will be held in their present position by the seawall. Whilst sediment supply from the north and south will continue, there will be narrowing of the beach due to sea level rise and landward movement restricted by the seawall.	The mouth of the River Yare, and the cliffs will be held in their present position by the seawall. A small beach is likely to remain in the shelter of the harbour arm, but this would be much narrower and steeper than that present today due to the greater exposure resulting from sea level rise. A more substantial seawall may be required to provide integrity of defence. Cutback arising from erosion of the cliffs to the south would require extension of the defences to prevent outflanking. This location will form a "hard-point" acting as a headland control upon shoreline evolution to the south.

Location	**Predicted Change for 'With Present Management':**		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
Gorleston-on-Sea to Hopton-on-Sea	Timber revetment and groynes.		
	The timber revetment will provide some protection the cliffs, but they will continue to erode at their current rate. The groynes would trap some of the material supplied from the north and from erosion of these cliffs. This would maintain a beach but this is expected to gradually narrow due to insufficiency of sediment. Sediment feed to north and south will continue from this frontage.	The timber revetment will provide some protection to the cliffs, but erosion will continue. The rate of retreat is likely to increase as a result of sea level rise. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. Beach material will continue to be supplied from the cliffs and from the north, and be transported along this frontage and to the south. The beaches are expected to be similar in character to those at present, albeit in a retreated position and narrowing will have occurred as a result of limited sediment input.	The cliffs will recede landwards at an increasing rate as sea levels continue to rise and accelerate erosion. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. Retention of the shoreline position at Gorleston and Hopton, to the north and south, would result in this section becoming an embayment, which would eventually stabilise (>100 years). However, this could help to retain beach material and prevent further narrowing of the beach, although alongshore sediment supply would be reduced.
Hopton-on-Sea	Seawall and groynes.		
	The cliffs would be held in their present position by the seawall. The groynes, trapping sediment supplied from the north, would maintain a narrow beach. Sediment bypass would take place, with feed onto the frontage to the south.	The cliffs will be held in their present position by the seawall. The beach will become very narrow due to sea level rise and inability to move landwards. Sediment transport would be accelerated across this frontage.	The seawall will continue to hold the cliffs in their present position, although extensive increase in the wall structure and its maintenance will be necessary to maintain its integrity. Continued cutback of the cliffs to north and south will require extension of the defences to prevent outflanking. There would be no beach present as a result

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
			of the exposure of this promontory. The influence of defences at Hopton could help to reduce erosion directly to the north, through trapping sediment, but exacerbate erosion directly to the south through reducing sediment supply.
Hopton-on-Sea to Corton	Timber revetment and groynes		
	The cliffs will erode and the beach will narrow at their present rate. The groynes will trap some beach material. There will be some sediment supply from the beaches to the north, and feed to the south.	The cliffs will continue to erode back. The revetment and the groynes would be rebuilt in retreated positions as this shoreline movement takes place. Beach material will continue to be supplied from the cliffs and from the north, and be transported along this frontage and to the south. The beaches are expected to be similar in character to those at present, albeit in a retreated position and narrowing will have occurred as a result of limited sediment input.	Cliff erosion will take place at an increasing rate by the year 2105, as sea levels continue to rise and accelerate erosion. The revetment and the groynes would need to be rebuilt in retreated positions as this shoreline movement takes place. Retention of the shoreline position at Hopton and Corton, to the north and south, would result in this section becoming an embayment, which would eventually stabilise (>100 years). However, this could help to retain beach material and prevent further narrowing of the beach, although alongshore sediment supply would be reduced.
Corton	Rock revetment fronting concrete seawall. Concrete wall only in front of Corton Woods.		
	The cliffs will be held in the present position by the seawall. Deeper waters at the seawall will mean that the beach will no longer exist, except along	The cliffs will be held in the present position by the seawall. Work would be required to stabilise the defences as a result of increased exposure to waves and prevent cliff face erosion. Erosion either side will	The cliffs will be held in the present position by the seawall. The structures would require significant work to ensure their defence integrity. Erosion either side will require the defences to be extended to prevent

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	the southern section. Sediment transport from north to south will diminish as a result of the prominence of this section of shoreline. This will accentuate erosion further south and increase exposure of the wall in front of Corton Woods.	require the defences to be extended to prevent outflanking. There would be no beach present. This promontory would continue to prevent sediment transport from the north, accentuating erosion to the south.	outflanking. There would be no beach present. This pronounced promontory would act a broader shoreline control, helping to stabilise the shoreline immediately to the north, and acting as a hard point to stabilise shoreline position to the south, albeit not before further erosion takes place.
Gunton Warren	Timber groynes.		
	The sand cliffs/dune line is not expected to retreat but will become increasingly exposed. This will occur as the beach narrows in response to diminished sediment supply from the north. The existing groynes would need to be reconstructed in a retreated position.	Lack of sediment feed, inhibited by the promontory formation at Corton, and sea level rise, will produce narrowing and transgression of the beach. This will result in loss of the vegetated dune and erosion of the sand cliffs. Groynes would need to be reconstructed in a retreated position.	The cliffs will erode, fronted by a narrow beach, supplied by this erosion and trapped by the groynes, which would need to be reconstructed in a retreated position. An embayment will form between Corton to the north and Lowestoft Denes to the south, which will act to stabilise this area in the longer term, and assist in retention of beach material during this epoch. Sediment feed to and from this shoreline will be virtually zero.
Lowestoft North Beach	Concrete seawall (with rock armour at Lowestoft Ness).		
	The seawall will prevent any erosion or inundation of the hinterland. The present shingle beach is expected to have disappeared by 2025, due to	The seawall will prevent any erosion or inundation of the hinterland. Significant work may be required to maintain the integrity of the built defences.	The seawall will prevent any erosion or inundation of the hinterland. Significant work may be required to maintain the integrity of the built defences.

Location	Predicted Change for 'With Present Management':		
	Years 0 – 20 (2025)	**Years 20 – 50 (2055)**	**Years 50 – 100 (2105)**
	insufficient sediment supply and high levels of exposure to waves.	There will be no beach present. Any beach material reaching this point will be lost offshore.	There will be no beach present. Any beach material reaching this point will be lost offshore.

C5.4 WPM DATA INTERPRETATION

(a) Introduction

A number of data sets were used in the predictions of future shoreline response and evolution under the scenario of ‘with present management’, these included:

- Futurecoast historical shoreline change data (reported in the assessment of shoreline dynamics report (Section C1)): primarily focussed on changes post-defences.
- Other historical change data sets: e.g. at some locations cliff position data sets are available (reported in the assessment of shoreline dynamics report (Section C1)).
- Futurecoast predictions of future shoreline change under a ‘with present management practices’ scenario: this assumed that all present management practices were to continue.
- Environment Agency beach profile data: this data is only relevant to the first 20 years.

The affect of accelerating sea level rise was also taken into account (see Section C3.1).

Location	**Futurecoast data**		**Other**	**Prediction of shoreline change for WPM**			**Uncertainty**
	Historical	**Prediction**[5]		**0-20**	**20-50**	**50-100**	
Kelling Hard to Sheringham	Historical data suggests a fluctuation in both backshore and low water positions. Net change of MLW and MHW ranges between 0.2 and 0.4m/yr erosion. (No cliff data). Data suggests a net steepening of foreshore, with retreat of profile.	Retreat same as past trends.	▪ EA profile data: cliff retreat rates of between 0.1 and 0.7m/yr and retreat of MSL of between 0.1 and 0.8m/yr.	Assumed similar rates to those experienced over last 20 years will continue, therefore used average of EA data.	Assumed similar rates to those experienced historically plus SLR component. Therefore used Futurecoast MLW data plus the SLR multiplier for Sheringham.	Assumed similar rates to those experienced historically plus SLR component. Therefore used Futurecoast MLW data plus the SLR multiplier for Sheringham.	Futurecoast score: very low
Sheringham frontage	Historical data suggests a fluctuation in both backshore and low water positions. Coastal position defended for much of record. Average rate of change of MLW ranges between 0.1 and 0.3m/yr erosion. Data suggests a net steepening of foreshore, but backshore position fixed.	No change in shoreline position.	▪ EA profile data: Retreat of MSL of between 0 and 0.3m/yr. Retreat of Backshore between 0.1 and 0.4m/yr.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	Futurecoast score: very low.
Sheringham (East)	(see above)	(see above)	▪ (see above)	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	(see above)
Sheringham to West Runton	Net retreat of cliffs: range of 0.2 to 0.6m/yr.	Retreat same as past trends.	▪ EA profile data: Retreat of cliff between 0.1 and 0.8m/yr. Retreat of Backshore between 0.1 and	Revetment expected to fail at some time. Assumed revetment	Linear retreat of cliff assumed – used Futurecoast cliff data	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine	Futurecoast score: very low

---

[5] Magnitude of change related to historic change.

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
	Fluctuation in MLW: +0.3 to -0.1m/yr. Data suggests a slight flattening of the foreshore.		1.4m/yr. Retreat of MSL between 0 and -1m/yr/	reduced erosion by c. a third for last c.25 years. Used Futurecoast cliff data, with consideration of effect of reduced feed from the north.	and EA data to determine likely rate, plus SLR component. Consideration of effect of reduced feed from the north. Also assumed increased erosion at boundaries of defences.	likely rate, plus SLR component. Consideration of effect of reduced feed from the north. Also assumed increased erosion at boundaries of defences.	Complex cliff failure mechanism therefore variable along coast and during a single event could have over 30m retreat.
West Runton to Cromer	(see above)	Retreat same as past trends.	- (see above)	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component. Consideration of effect of reduced feed from the north.	Linear retreat of cliff assumed – used Futurecoast cliff data and EA data to determine likely rate, plus SLR component. Consideration of effect of reduced feed from the north.	(see above)
Cromer	Coastal position defended for much of record - average retreat of MLW: 0.3 to 0.4m/yr. Data suggests a net steepening of foreshore.	No change in shoreline position.	- EA profile data: Both profiles at location suggests an advance of back of beach position at a rate of 0.3m/yr, with one profile suggesting an average advance of MSL at 0.3m/yr and the other suggesting retreat at 0.3m/yr.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	Futurecoast score: very low
Cromer to Overstrand	Net retreat of both cliff and MLW at a rate between 0.8 and 0.9m/yr. Data suggests a net steepening of foreshore, with a translation of profile. .	Retreat same as past trends.	- EA profile data: net retreat of MSL at one profile -0.6m/yr, but a cyclical fluctuation in MSL position noted at the other profile available. - Cambers (1976) reported a long-term recession rate of 0.65-0.75m/yr. - No direct prediction in SMP1 but: 70 to 90m for Cromer and 130 to	Timber revetments expected to continue to fail, therefore initial surge as coast held for last 25 years. Therefore assumed Futurecoast MLW/ Camber's rate to calculate 'catch-up', assuming revetments have reduced 'natural erosion' by a third.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered reduction of feed due to Cromer defences.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Also considered reduction of feed due to Cromer defences.	Futurecoast score: very low Cliffs subject to major rotational failures and a single event could result in over 30m

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
			150m for Overstrand over 75 years. ▪ A prediction of 18.75m every 10 years was reported in the Cromer SS.	Futurecoast MLW/ Camber's rate used to predict erosion after initial surge. Compared to Cromer SS prediction.			erosion.
Overstrand (North)	Average MLW retreat of -0.7m/yr, but coast defended for some of period.	Retreat same as past trends.	▪ No reliable EA data available. ▪ Cambers (1976) reported that between 1885 and 1985 there was less than 20m erosion. ▪ SMP1 predicted 130 to 150m over 75 years.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	Futurecoast score: very low Little data relating to undefended coast.
Overstrand (South)	Average MLW retreat of -0.7m/yr, but coast defended for some of period.	Retreat same as past trends.	▪ No reliable EA data available. ▪ Cambers (1976) reported that between 1885 and 1985 there was less than 20m erosion. ▪ SMP1 predicted 130 to 150m over 75 years.	Assumed erosion continues at rate similar to present – used Futurecoast MLW/ Camber's rate.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Consideration of reduced feed due to defences to north.	Cliff erosion assumed to continue in linear fashion, therefore Futurecoast/ Camber's rates used plus SLR component. Consideration of reduced feed due to defences to north.	Futurecoast score: very low Cliff subject to major rotational fails – a single event could cause more than 30m erosion.
Overstrand to Vale Road Beach Access	Average cliff retreat rates of between 0.6 and 1.9m/yr. Average MLW retreat rates of between 0.9 and 1.3m/yr. Data suggests foreshore steepening at one location but flattening at another location.	Retreat same as past trends.	▪ EA data: variable data quality but MSL rates from +0.3 to -1.6m/yr. Back of beach position shows net retreat at average rates of 0.1 to 2m/yr. ▪ SMP1 reported long-term retreat rate of 1-2m/yr. ▪ Clayton and Coventry (1986) suggested a maximum recession of 175m between Overstrand and Trimingham for the period 1885 to1985. ▪ SMP1 predicted 100 to 110m over 75 years.	Assumed cliff erosion will continue at recent rates – but with consideration of slightly increased feed as defences fail to north. Used combination of Futurecoast and EA data.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Comparison with Overstrand – Mundesley SS prediction. Also considered influence of defences at Mundesley slowing erosion along this section.	Futurecoast score: very low Massive rotational failures are common and unpredictable. Historical over 13m erosion has occurred during one event.

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
			- Overstrand to Walcott SS predicted long-term (up to 50 years) recession rates of between 0.75m/year and 2.6m/year				
Vale Road Beach Access to Mundesley	(see above)	(see above)	- (see above)	Cliff erosion assumed to be restricted by defences.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component.	Assumed cliff erosion will continue – used Futurecoast pre-defence rates plus SLR component. Consideration of effect of both reduced feed from north and potential build up updrift of Mundesley.	(see above)
Mundesley	Coast defended for much of period. Net retreat of MLW: 0.7m/yr. Foreshore steepening identified.	No change in shoreline position.	- EA data: Shows fluctuation in position. MSL rates of retreat: -0.9 to -3.2m/yr. - Overstrand to Walcott SS identified steepening of beach in west to east direction between 1885 and 1969.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	Futurecoast score: very low
Mundesley to Bacton	Net retreat of MLW: 1.0m/yr. Net retreat of cliff line: 0.9m/yr. No change in profile identified.	Retreat same as past trends.	- EA data: One profile shows accretion of both Back of beach position and MSL, the other profile shows erosion. - No direct prediction in SMP1, but estimated rates for Mundesley and Bacton of 60m to 70m and 100 to 110m respectively, for the period 1994-2068.	Assumed cliff erosion will continue but affected by limited feed from north - used Futurecoast MLW rate.	Assumed cliff erosion will continue but increasingly affected by limited feed from north – used modified Futurecoast MLW rate plus SLR component.	Assumed cliff erosion will continue but increasingly affected by limited feed from north – used modified Futurecoast MLW rate plus SLR component.	Futurecoast score: very low Impact of reduced feed due to Mundesley defences.
Bacton and Walcott	Net retreat of MLW: 1.2m/yr. Net retreat of back of beach: 0.9m/yr. Coastal position held for much of period.	No change in shoreline position.	- EA data: very variable data: some profiles suggest net accretion, others suggest net erosion. - SMP1 reported long-term erosion rates for MLW of 1 to 2m/yr.	No change in cliff position due to defences, but historical evidence suggests beach will steepen and narrow.	No change in cliff position due to defences, but beach expected to disappear.	No change in cliff position due to defences, but no beach expected.	Futurecoast score: very low
Ostend to Happisburgh	Net retreat of MLW: average trend = 0.8-0.9m/yr. Net retreat of cliff line: average	Retreat same as past trends.	- EA data: unreliable data, therefore not used. - Pre-defence rates (1886 to 1938 maps) of 0.4 and 0.8 m/year	Used Futurecoast rates.	Used Futurecoast rates plus SLR component but modified to reflect decrease in sediment	Used Futurecoast rates plus SLR component but modified to reflect decrease in sediment arriving from north.	Futurecoast score: very low

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
	trend= 0.9m/yr. Both flattening and steepening trends identified from data.		erosion reported in Ostend to Cart Gap SS. ▪ Post-defence erosion rates of 0.4 and 1.2m/yr reported in Ostend to Cart Gap SS.		arriving from north.		
Happisburgh Village	(see above)	Retreat same as past trends.	▪ EA data: unreliable data, therefore not used. ▪ Pre-defence rates (1886 to 1938 maps) of 0.4 and 0.8 m/year erosion reported in Ostend to Cart Gap SS. ▪ Post-defence erosion rates of 0.4 and 1.2m/yr reported in Ostend to Cart Gap SS.	Used Futurecoast data and observed change to assess rates.	Used Futurecoast rates plus SLR component but modified to reflect decrease in sediment arriving from north.	Used Futurecoast rates plus SLR component but modified to reflect decrease in sediment arriving from north.	Futurecoast score: low High uncertainty of coastal response post defence failure and amount of feed from cliff erosion to north.
Happisburgh Village South	(see above)	(see above).	▪ EA data: unreliable data, therefore not used. ▪ Pre-defence rates (1886 to 1938 maps) of 0.4 and 0.8 m/year erosion reported in Ostend to Cart Gap SS. ▪ Post-defence erosion rates of 0.4 and 1.2m/yr reported in Ostend to Cart Gap SS.	Erosion expected to continue at pre-defence rates – used those reported in Ostend to Cart Gap SS used.	Used pre-defence rates reported in Ostend to Cart Gap SS plus SLR component.	Used pre-defence rates reported in Ostend to Cart Gap SS plus SLR component.	Futurecoast score: low High uncertainty of coastal response post defence failure and amount of feed from cliff erosion to north.
Eccles on Sea	Data variable, but average retreat trend -= 0.5m/yr for MLW and -0.1m/yr for the beach of beach position. Coastline held for much of period.	No change in shoreline position.	▪ EA data: unreliable data, therefore not used. ▪ Happisburgh to Winterton SS reports that between 1886 and 1905 much of the coast was in a state of relative stability, but during 1905 to 1946 the whole coast eroded by approximately 0.7m/yr. ▪ UEA report 2.3m/yr retreat 1883-1906 and 0.3m/yr for 1906-1952.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow, as experienced historically.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow, as experienced historically.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow, as experienced historically.	Futurecoast score: low

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	**Prediction[5]**		**0-20**	**20-50**	**50-100**	
Sea Palling to Waxham	Fluctuating MLW position – no clear trend.	No change in shoreline position.	▪ EA data: no clear trend due to recharge. ▪ Beach recharge since 1992. ▪ (also see above)	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow despite recharge.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow despite recharge.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow despite recharge.	Futurecoast score: low
Waxham to Winterton dunes	Long term retreat trend of between 0.7 and 0.8m/yr for MLW and 0.2m/yr for back of beach position.	No change in shoreline position.	▪ EA data: Variable rates for various profiles which show both accretion and erosion trends. ▪ High chance of breach identified for Horsey from Happisburgh – Winterton Strategy Review. ▪ (also see above)	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow despite recharge.	Sea wall assumed to remain therefore no change in backshore position, but foreshore expected to narrow despite recharge.	Sea wall assumed to remain therefore no change in backshore position, but beach expected to narrow despite recharge.	Futurecoast score: low High uncertainty of offshore losses.
Winterton-on-Sea	No data for ness point, but to north: retreat trend of 1.6m/yr for MLW and 1.1m/yr for back of beach position. To south: no clear trend for MLW, but accretion of back of beach of 0.2m/yr.	Oscillation same as past trends.	▪ EA data: poor data for one profile, other suggests retreat of MSL of -7.4m/yr and retreat of back of beach position of -7.8m/yr. ▪ UEA, 1971 report accretion opposite Winterton Village at 1.1 to 1.4m/year between 1883 and 1952.	Ness position expected to fluctuate – between 1880s and last OS survey area in front of Lifeboat Station was accreting. There has since been period of rapid erosion, but area still significantly seaward of 1880s position. Combination of EA data and Futurecoast data used to estimate range.	Ness position expected to fluctuate – between 1880s and last OS survey area in front of Lifeboat Station was accreting. There has since been period of rapid erosion, but area still significantly seaward of 1880s position. Combination of EA data and Futurecoast data plus SLR component used to estimate range, but consideration of impact of changes to the north.	Ness position expected to fluctuate – but net erosion expected due to changes to the north. Estimate based on natural fluctuation rates from Futurecoast plus SLR component and understanding of how coast has changed historically.	Futurecoast score: low Large uncertainty over ness evolution and evolution of coast to the north.
Newport and Scratby	Poor data for foreshore, but cliff retreat average rate of -0.2m/yr.	Retreat same as past trends.	▪ EA data suggests a range of cliff retreat rates for 1992-2002 of 1.3 - 1.9m/yr and change in back of beach position of 1.5 to 1.7m/yr. MSL data shows no clear trend apart from at one site: erosion at 1.3m/yr. ▪ UEA (1971) reported accretion at	Erosion of dunes expected to continue – EA data used together with Futurecoast data. Area also expected to be affected by movement of Winterton Ness and restricted input from	Erosion of dunes expected to continue – EA data used together with Futurecoast data plus SLR component – but slower rates expected at Scratby where sand cliffs are present. Breach	Total loss of dune expected, but erosion of sand cliff expected – combination of EA and Futurecoast rates used, plus SLR component. Breach potential based upon Happisburgh to Winterton Strategy Review.	Futurecoast score: low Uncertainty regarding dune survival.

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
			0.4m/year between 1883 and 1906, but the trend later switched to erosion. ▪ SMP1 reported retreat rates of 0 to 0.5m/year in the north of this area, and 0.5 to 1.0m/year to the south. ▪ SMP1 predicted 30-45m erosion at Scratby up to 2068. ▪ Happisburgh to Winterton Strategy Review identified the potential for breach at the southern end of Newport	north.	potential based upon Happisburgh to Winterton Strategy Review.		
California	(see above)	No change in shoreline position.	▪ EA data pre-berm is poor, but post-berm there was no change in cliff position and an advance of MSL. ▪ SMP1 predicted 30-45m erosion at California up to 2068. ▪ (also see above)	Berm expected to continue to slow erosion – EA data used.	Berm expected to continue to slow erosion – EA data used in combination with Futurecoast plus SLR component.	Berm expected to continue to slow erosion, but to a lesser effect – EA data used in combination with Futurecoast plus SLR component.	Futurecoast score: low
California to Caister (reefs)	(see above)	No change in shoreline position.	▪ EA data shows no clear trend for the upper beach, but post-reef data shows accretion at rate of between 0.4 and 0.9m/yr. ▪ SMP1 reported an average long-term rate for MLW >2m/yr accretion.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed coastline position (cliffs/ dunes) will be held by reefs and groynes.	Assumed coastline position (cliffs/ dunes) will be held by seawall.	Futurecoast score: medium
Caister (reefs to Lifeboat Station)	Net retreat of mean low and an average rate of 1.0m/yr. Also net retreat of back of beach position at an average rate of -1.2m/yr. The foreshore shows a general steepening trend.	No change in shoreline position.	▪ EA data shows at northern end erosion of beach between 4.6 and 5.6m/yr, but accretion at southern end of frontage of dunes at average rate of 2.3m/yr. ▪ SMP1 reported an average long-term rate for MLW >2m/yr accretion.	Assumed coastline position (cliffs/ dunes) will be held by the seawall.	Assumed coastline position (cliffs/ dunes) will be held by the seawall, but beach expected to narrow as per historical data.	Assumed coastline position (cliffs/ dunes) will be held by the seawall, but beach expected to narrow as per historical data.	Futurecoast score: medium Evolution of Caister Point ness uncertain.

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
Caister to Great Yarmouth (Pleasure Beach)	Frontage defended for most of period. Net accretion trend illustrated – with apparent step change between 1960 and 1980. Average rate of MLW = 3.4m/yr, average rate of back of beach position change = 3.5m/yr.	Oscillation same as past trends.	▪ EA data shows accretion ranging from 2.4 to 5.9m/yr across beach profile. ▪ CHaMP (2003) reported that there has been an advance of High Water at a rate of 1m/year over the past decade. ▪ SMP1 reported a long-term average advance of MLW between 0.5 and 1.0m/yr. ▪ CHaMP (2003) concluded that North Denes should continue to be relatively stable over the next 30-50 years.	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall.	Futurecoast score: low Uncertainty over ness evolution. Uncertainty over impact of changing configuration of nearshore banks.
Great Yarmouth South Beach	Frontage defended for most of period. Net accretion trend for northern end of frontage: average rate of MLW = 0.3m/yr and for back of beach = 0.1m/yr. Despite this net steepening trend illustrating by foreshore. At southern end profile indicates net retreat (although fluctuating): average rate of MLW = 0.6m/yr erosion, Back of beach position = 0.5m/yr erosion.	Oscillation same as past trends.	▪ EA data shows accretion of between 0.5 and 2.2m/yr across beach profile, but data at southern end was poor.	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall, but beach expected to narrow as per historical data.	Assumed coastline position will be held by the seawall, but beach expected to disappear at southern end as per historical data.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Gorleston-on-Sea	Frontage defended for most of period, therefore little change in cliff position. Foreshore data illustrates a fluctuating	No change in shoreline position.	▪ EA data shows erosion of beach and retreat of MSL at rate between 2.8 and 3.5m/yr. ▪ Gorleston to Lowestoft SS reported that the beach was in a poor condition in the 1880s, but	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall, but beach expected to narrow as per historical data.	Assumed coastline position will be held by the seawall, but beach expected to disappear as per historical data.	Futurecoast score: low Uncertainty over impact of changing configuration

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
	trend, with both erosion and accretion since 1880s. Net change over the period is small.		there was then accretion during the early 1900s, at 2.9m/yr up until 1927. Then beach levels dropped again – possible cyclic behaviour proposed.				of nearshore banks.
Gorleston-on-Sea to Hopton-on-Sea	Net retreat of MLW at an average rate of 0.5m/yr and cliff retreat at 0.4m/yr. Foreshore shows a steepening trend.	Retreat same as past trends.	▪ EA data suggest generally stable beach with little change. ▪ Gorleston to Lowestoft SS reported cliff erosion at 0.55m/yr between 1889 and 1998, with timber revetment in place for some of period. ▪ No specific prediction in SMP1: but predictions 30 to 50m erosion for Gorleston and 60 to 80m erosion for Hopton up to 2068.	Assumed that timber revetment will continue to reduce erosion – used EA rates.	Assumed that timber revetment will continue to reduce erosion – used combination of EA and Futurecoast rates plus SLR component.	Assumed that timber revetment will continue to reduced erosion – used combination of EA and Futurecoast rates plus SLR component.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Hopton-on-Sea	Both MLW and cliff show a net retreat at an average rate of 0.9m/yr. Foreshore shows a steepening trend.	No change in shoreline position.	▪ EA data poor. ▪ Gorleston to Lowestoft SS reported long-term cliff erosion at 0.71m/yr between 1889 and 1998 but that recent surveys have indicated beach advance.	Assumed cliff position will be held by the seawall.	Assumed cliff position will be held by the seawall, but beach expected to narrow as per historical data.	Assumed cliff position will be held by the seawall, but beach expected to as per historical data.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Hopton-on-Sea to Corton	(as above)	Retreat same as past trends.	▪ EA data shows generally stable, but net retreat of cliff at average rate of -0.3m/yr. ▪ Gorleston to Lowestoft SS reported cliff erosion at 0.78m/yr between 1889 and 1998 but recent advance of MHW (1993-1998). ▪ UEA reported long-term retreat of MLW.	Assumed that timber revetment will continue to reduce erosion – used EA rates.	Assumed that timber revetment will continue to reduce erosion – used combination of EA and Futurecoast rates plus SLR component.	Assumed that timber revetment will continue to reduced erosion – used combination of EA and Futurecoast rates plus SLR component.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Corton	Low rate of cliff retreat even before defences.	No change in shoreline	▪ EA data shows net retreat of both upper beach and MSL of between	Assumed no change in cliff position due to	Assumed no change in cliff position due to	Assumed no change in cliff position due to defences, but	Futurecoast score: low

Location	Futurecoast data		Other	Prediction of shoreline change for WPM			Uncertainty
	Historical	Prediction[5]		0-20	20-50	50-100	
	Net MLW retreat at an average rate of 0.6m/yr.	position.	1.1 and 1.7m/yr.	defences.	defences. but beach expected to narrow as per historical data.	beach expected to as per historical data.	Uncertainty over impact of changing configuration of nearshore banks.
Gunton Warren	Net retreat of MLW and cliffs: 1.7m/yr and 1.6m/yr respectively.	Retreat same as past trends.	▪ EA data shows that along northern section it has been generally stable but erosion increases towards south. Rates ranged from 0.1 to 1.2m/yr.	Assumed that beach and dune erosion will continue - used EA data rates.	Assumed beach and dune erosion will continue – used combination of EA and Futurecoast data plus SLR rise component. Also considered lack of sediment feed from north.	Assumed beach and dune erosion will continue – used combination of EA and Futurecoast data plus SLR rise component. Also considered lack of sediment feed from north.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.
Lowestoft North Beach	Coastline defended for much of period. Net retreat of MLW at an average rate 1.1m/yr. Foreshore shows a steepening trend.	No change in shoreline position.	▪ EA data showed that at northern end there has been some accretion, although levels fluctuate – average rate = 0.6m/yr. Data for southern section was poor. ▪ Lowestoft Ness has eroded considerably – UEA reports 3.6m/yr in 1880s.	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall.	Assumed coastline position will be held by the seawall.	Futurecoast score: low Uncertainty over impact of changing configuration of nearshore banks.

C6 Maps (NAI and WPM)