SMP7 Policy Review Study at Bawdsey, Suffolk

East Suffolk Council

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Important note

This report has been prepared exclusively for East Suffolk Council (formerly Waveney District Council) and no liability is accepted for any use or reliance on the report by third parties

1. Scope of study

This study has been commissioned by Coastal Partnership East (CPE), which incorporates the following local authorities; North Norfolk District Council (NNDC), Great Yarmouth Borough Council (GYBC), Waveney District Council (WDC) and Suffolk Coastal District Council (SCDC) (the last two now combined as East Suffolk Council).

As lead authority for the Suffolk Shoreline Management Plan (SMP 7), East Suffolk Council is working with the Environment Agency (EA) and other stakeholders to review Shoreline Management Plan (SMP) policy at East Lane, Bawdsey, where current policy may need revision.

As part of this process, Jacobs have been commissioned to undertake some high-level assessments for consideration by the Client Policy Review Group (CPRG) and to enable local officers to make a recommendation as to whether existing policies should remain or be updated. The CPRG comprises the Environment Agency (EA), Natural England (NE), Suffolk County Council (SCC), the Water Management Alliance (WMA), on behalf of the East Suffolk Internal Drainage Board and community representatives, including Bawdsey Coastal Partnership.

At East Lane, Bawdsey (SMP policy unit HOL16.5) the driver for reviewing any need for a policy change is the development of further studies and new research that challenges some of the assumptions regarding coastal processes operating on this section of coast, which underpinned the existing SMP policy. In addition, the investment required to sustain the current SMP policy of Hold the Line has increased significantly.

Potentially viable management approaches have been considered for this policy unit HOL16.5 (and part of policy unit HOL16.4), considering the SMP policy options of Advance the line, Hold the Line, Management Realignment and No Active Intervention. A high-level assessment has also been undertaken of the possible environmental, social and economic impacts of such approaches, based upon existing information. This report does not, however, make any recommendations on the need to change existing SMP policy and the high-level appraisals are not intended to replace a Strategic Environmental Appraisal (SEA) or Water Framework Directive (WFD) assessment, which may need to be undertaken as required at subsequent phases depending on the way forward (see below).

This is the first of three phases to consider policy review:

Phase 1 (this report): Identify and assess potentially viable approaches to management	High-level review and assessment to provide a baseline appreciation of aspects that are key to identification of a viable policy, with a focus on implementation measures, concluding with a presentation of findings to the CPRG. Informed by this high-level assessment the CPRG can conclude a preferred way forward, i.e. whether to pursue any policy change and what the nature of that change might be.
Phase 2: Environmental assessments of phase 1 outputs	Further detailed assessments, including more detailed environmental appraisals to be undertaken as required to fully appraise the proposed policy change, including formal engagement with statutory consultees required as part of that process.
Phase 3: Public consultation, adoption and dissemination	Upon completion of necessary studies, the proposals will be subject to wider consultation, to review and agree the policy changes. Following this, and taking responses into account, the policy change process can be finalised accordingly.

The following sections consider:

- the existing situation (section 2),

- appraisal of the SMP policy, including a review of assumptions made during the SMP and the new information available since the SMP (section 3),
- future management approaches (section 4).

Appendix A provides more details on coastal processes and shoreline change, based upon a review of the SMP and a range of studies undertaken both pre and post the SMP. This has been supplemented by a high level appraisal of historical maps and beach profile data collated as part of the Anglian Coastal Monitoring Programme.

Appendix B provides details on the baseline conditions at the site, considering environmental, social and economic considerations, which have then been appraised against the viable policies.

Appendix C includes cost information for the various implementation measures considered.

2. Existing situation

2.1 Location

Policy unit HOL16.5 (East Lane) lies to the south of Orford Ness within Hollesley Bay. The SMP recognised that the unit lies within a larger management area, known as HOL16, which stretches between the apex of Orford Ness and a location referred to as Bawdsey Hill. However, in terms of process interactions the SMP referred to a wider policy zone (PDZ6) stretching between Orford Ness and Cobbold's Point on the Felixstowe frontage (Figure 2).

Policy unit (PU) HOL16.5 is defined by the beginning and end of the built defences (at the time of the SMP): extending in front of the Martello Tower (Martello Tower W) at the start of Bawdsey cliffs, in the south, to the boundary between the two northern-most irrigation ponds to the north. However, since the SMP it has been necessary on four separate occasions to further extend defence works to the north, beyond the management unit boundary, encroaching approximately another 340 m into Hollesley Bay (Policy unit HOL 16.4).

2.2 Current policy

The Shoreline Management Plan covering the frontage, SMP7, was completed by Royal Haskoning in 2010. The overall intent of the plan for management area HOL16 is to "*manage the supply and distribution of sediment along the coast, so as to maintain both Shingle Street and the agricultural value of the area in a sustainable manner, supporting existing habitat development and adaptation*". This would involve managing the configuration of the whole of Hollesley Bay but "*in a manner allowing and supporting the mobility of sediment along the frontage, while maintaining and allowing a roll back of the wide shingle beach." Integral to this was seen to be maintaining East Lane as a "control point in the system*". Also key to this was the understanding that within Hollesley Bay, the angle of the bay was in "net equilibrium", such that under north to east wave conditions material would progress south, whilst under south easterly wave conditions there would be northward drift.

It was, however, recognised that the long term sustainability of East Lane was uncertain. The SMP therefore recommended ongoing monitoring and monitoring as part of the current scheme at East Lane recognizing that there was "*the possibility that policy would need to be revised in the light of this monitoring. Any revision of policy would take account of potential damages*". The following policies were defined for HOL16.5 and adjacent units (Figure 1):

SUMMARY OF SPECIFIC POLICIES

Policy Unit		Policy Plan			
		2025	2055	2105	Comment
HOL 16.1	Orford Beach	NAI	NAI	NAI	Maintain supply to south.
HOL 16.2	North Weir Point	MR	MR	NAI	Potential need to manage changes in estuary.
HOL 16.3	Shingle Street	MR	HTL	HTL	Manage periodic loss of width to beach.
HOL 16.4	Hollesley Bay	MR	MR	MR	Allowing rollback of the front line shingle beach defence.
HOL 16.5	East Lane	HTL	HTL	HTL	Maintain control of drift.
HOL 16.6	Bawdsey Hill	NAI	NAI	NAI	Maintain supply to the south.

Key: HTL - Hold the Line, A - Advance the Line, NAI – No Active Intervention
MR – Managed Realignment

Figure 1 Summary of policies, taken from the SMP (Haskoning, 2010).

Figure 2 Taken from SMP7 (Royal Haskoning, 2010) showing East Lane, Bawdsey policy unit (HOL 16.5) and where it sits in the wider coastal setting.

2.3 Existing defences

Figure 3 and Table 1 below summarises the current defence structures, broken down into sections running south to north. Along almost all of the defended frontage there is no longer access for inspection as the defence toe is permanently submerged (Figure 4). Consequently, access for regular maintenance is also difficult. At the northern end of the defences, erosion of the beach has resulted in exposure of the underlying London Clay (Figure 5).

This is based upon observations (from the defence crest) during site visits in June 2017 and December 2018 and information provided by the Environment Agency.

Table 1 Description of current defences (see Figure 3 for location of sections)

Section	Approximate length	Details
1	280 m	Rock armour revetment built around 2008 – one of first examples of 'partnership funding' approach. All looks in good condition, as would be expected just 10-15 years on.
2	130 m	Built in late 1990s/ 2000, this was first length of 'emergency works' carried out at the point. Comprises a steel sheet piled wall with a concrete capping beam. Since then, some rock armour has been placed in front to prevent toe scour failure. That rock is not as high as adjacent sections and does get overtopped at times.
3	250 m	Rock armour revetment fronting old wall, built around 2005/06. Rock all looks in good condition, as would be expected. No signs of movement so likely to currently be in reasonable condition at the toe.
4	50 m	This is the end of the old 'Quilters Wall' (as shown on Ordnance Survey map 1920). A WW2 Pill box marks end of this wall. Work initially required to backfill with rock behind. Rock armour (7 tonne) added in front of it around 2011 to protect toe. That has held up well but is now collapsing behind wall.
5	85 m	New rock armour revetment, added around 2011. Looks sound at present.
6	80 m	Further extension of defences necessary in 2014/15. Also rock armour revetment.
7	50 m	Further extension carried out around 2015 – driving a wall of steel sheet piles, with armourflex mattress above as emergency works. Quickly scoured out in front and rock had to be added to the toe soon after (2016) to prevent failure. This section is in poor condition and although not failed there is an area where the rocks have started to slip (probably due to insufficient size and extent).
8	125 m	Another extension (circa 2016) of new rock armour revetment along the front line of the existing embankment. This is currently in fair condition other than approximately 25 m where the rock has slipped (possibly due to foreshore lowering) and there has been some erosion of the clay bank. Works are due to start to address that, but these will potentially use up all that remains in the existing rock stockpile.

To the north of the current defences, along Policy Unit HOL16.4, the primary protection is the shingle barrier beach, which is backed by a continuation of the earth embankment in HOL16.5 (Figure 6).

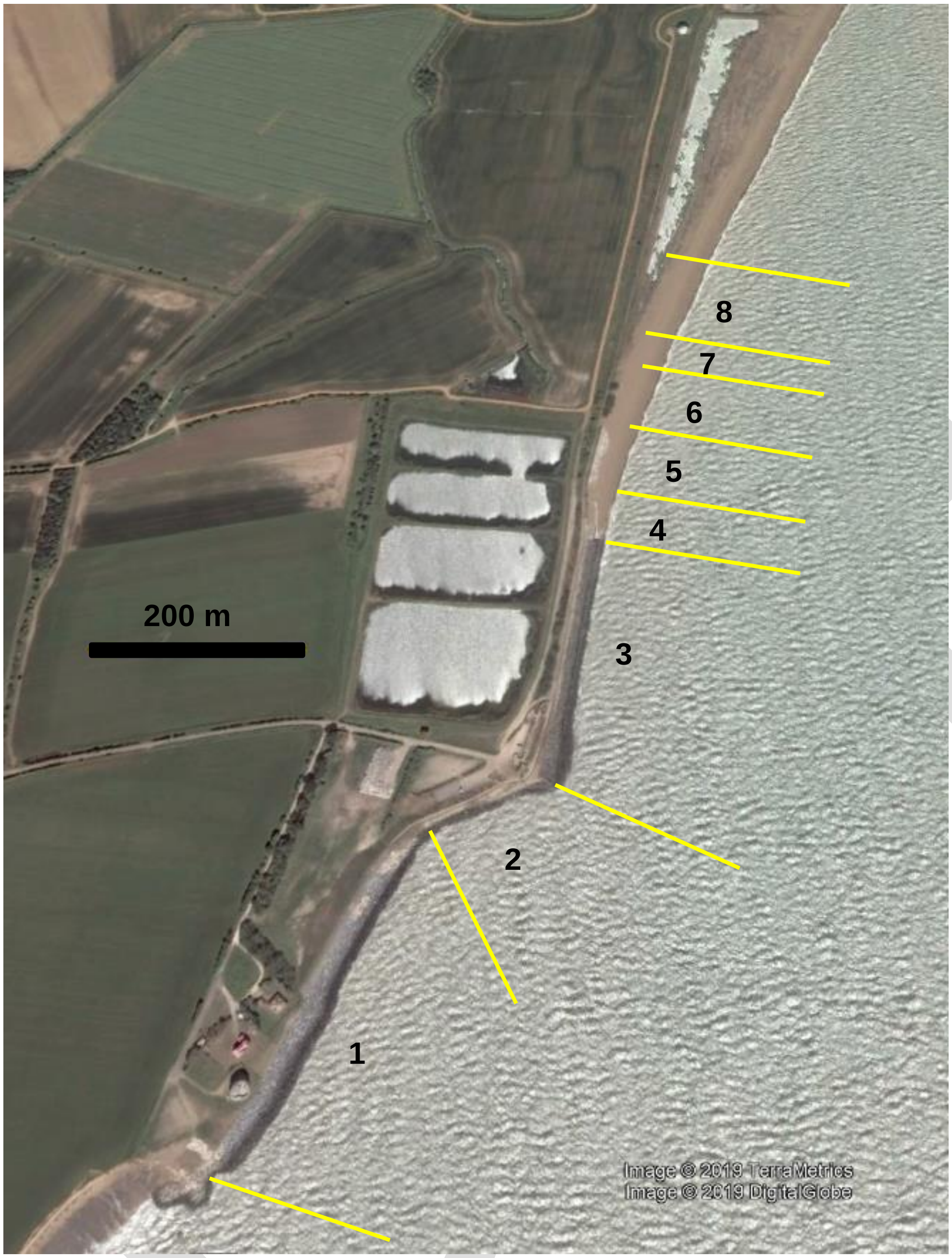

Figure 3 Sections of current defences, as described in Table 1.

Figure 4 Looking north from East Lane towards Shingle Street. Taken June 2017.

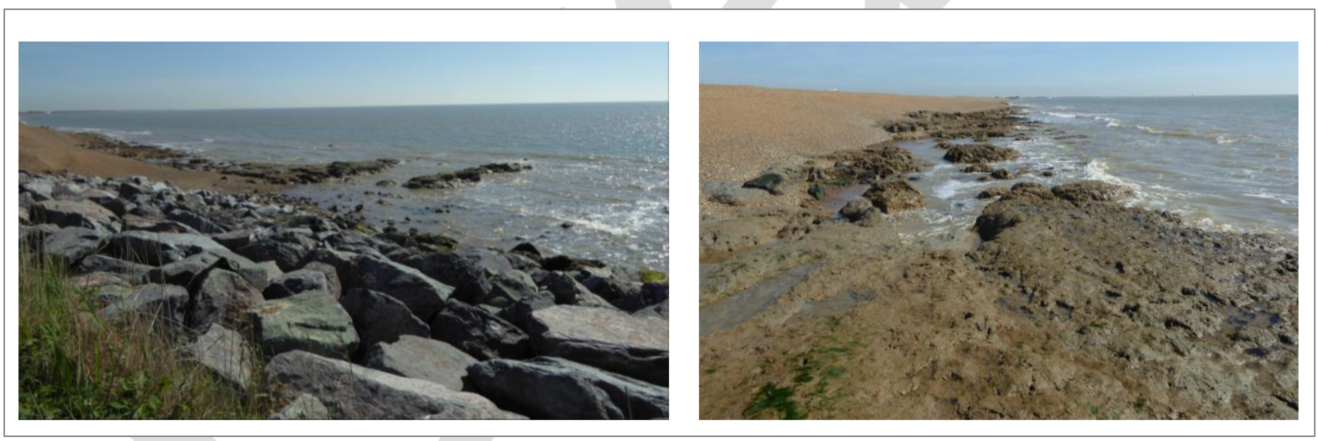

Figure 5 Exposure of underlying London Clay at northern end of East Lane defences. Taken June 2017.

Figure 6 Shingle bank and backing embankment north of East Lane. Taken December 2018.

3. Appraisal of the SMP policy

3.1 The basis of the SMP policy

The current SMP policy is Hold the Line for all three epochs at East Lane (HOL16.5) and Managed Realignment along Hollesley Bay (HOL16.4). The overall intent of the policy is as follows:

'The intent in management of this area would be to manage the configuration of the whole of Hollesley Bay but in a manner allowing and supporting the mobility of sediment along the frontage, while maintaining and allowing a roll back of the wide shingle beach. To achieve this it would be necessary to maintain East Lane as a control point in the system.'

The SMP does not discuss potential implementation measures to deliver these policies but provides significant discussion of the principles behind the policy. This is critical information given the current review of policy and also informs the possible implementation options that could be considered.

To assess how the shoreline might behave and respond in the future, the SMP discusses three possible scenarios: an 'unconstrained' scenario and two baseline scenarios of 'no active intervention' and 'with present management'.

(1) Unconstrained scenario

The unconstrained scenario assumes that all defences are instantly removed, which differentiates it from the no active intervention scenario where defences would gradually fail but continue to have a residual impact for some time. However, in the SMP discussion text it is not clear whether the scenario assumes defences are removed or that defences had never been built.

The SMP states that '*if East Lane had not been defended there would have been significant erosion at this point forcing the whole of Hollesley Bay to retreat*' and that '*in the absence of East Lane, the downdrift control point of the bay would be the higher ground of Bawdsey Cliffs'*. This assumes that some form on control point would continue to exist at the northern end of the bay (North Weir Point). In considering where the shoreline position could lie under this unconstrained scenario, the SMP applied both extrapolation of erosion rates derived from monitoring data and equilibrium bay theory.

Key conclusions reached by this work, relevant to the current study, are:

- '*without East Lane the indicated readjustment of the bay impacts over the full extent of Hollesley Bay, affecting the Shingle Street frontage'* and
- '*As material is subsequently released from the Shingle Street sink, this would tend to move south with little retention along Hollesley Bay due to the transient control imposed by the southern headland'*.

The SMP does, however, introduce some uncertainty into how the shoreline would respond under this scenario, through the following statements:

- '*At Shingle Street there would still be occasions when changes in the configuration of the mouth moves the northern point of the bay south, due to the greater retention of sediment at this northern end. Associated with this would be a period of reduced sediment supply over the bay as a whole and greater erosion at the southern end.'*
- '*The sudden natural change in orientation at this southern point* [southern headland formed by Bawdsey cliffs] *might, however, induce the development of a ness, locally holding material at the corner and releasing this sporadically to the coast to the south.'*

(2) No active intervention

Under this scenario it was assumed that the northern section of the East Lane promontory would fail during the second epoch (20 – 50 years) but that over the longer term the coast would adjust as for the unconstrained scenario. Based on this the SMP concluded that:

- *'the control of the bay is progressively shifted south and west. The bay opens up and gradually, as the Shingle Street frontage works through cycles of change, the trend will be for gradual retreat of the coast'*
- *'This is likely to result in erosion affecting the community of Shingle Street.'*
- *'At East Lane …the properties and Martello Tower would be lost within the next 10 years'* (without further works undertaken now)
- *'Over the bay as a whole, the shingle bank would be weakened and would be regularly overtopped. The retreat of the shingle bank would eventually be squeezed against the defence embankment behind.'*
- *'There would eventually be some equilibrium restored so that sediment could travel through to Bawdsey Cliffs to the south. The regular flooding of the low lying land would create a large expanse of saltmarsh or mud flat.'*

(3) With present management

A key process assumed by the SMP under this scenario is that at some point material held within the banks at Shingle Street will be released and moved southwards, reducing the issues currently faced.

Under this scenario the SMP considered two possibilities regarding defences at East Lane: (a) defences remain long enough to benefit from an increased supply of sediment due to the breakdown of the spit at Shingle Street or (b) defences along the northern section of East Land promontory are allowed to fail before this occurs. Under (b) the response would be as for the no active intervention scenario.

In developing the SMP policy a number of assumptions were made, building upon the scenarios discussed above:

- The defences at East Lane are critical to maintaining Hollesley Bay – the SMP states that the '*East Lane defence system* (retains) *the natural defence of the whole bay, with direct flood defence to the southern section and coast protection to the collection of properties and the Martello Tower'* and *'This headland controls the shape of Hollesley Bay and acts to regulate sediment moving south'.*
- Hollesley Bay is in dynamic equilibrium – the SMP states that '*Over Hollesley Bay, the angle of the bay is in net equilibrium. Under north to east wave conditions material will progress south. South easterly wave conditions can cause northerly drift. Over the Bawdsey cliff section the drift is on average to the south with relatively high rates. Here, as with Hollesley Bay, there can be northerly drift due to waves from the south but with lower rates*.'
- The defences at East Lane also control erosion to the south – the SMP states that the defences '*impose a significant downdrift control of the shoreline to the north and more locally act as an updrift headland to the coast to the south*'.
- Material is able to bypass East Lane promontory – the SMP states that '*Subject to the amount of material built against East Lane, this has the potential to overspill to Bawdsey Cliffs and down across the Deben*'.
- A key issue has been the recent retention of shingle at Shingle Street – the SMP states that '*At present and potentially over the last 20 years, a greater extent of the shoreline sediment supply has been held within the North Weir banks and the ness in front of Shingle Street. This has tended to limit the sediment build against East Lane and restricts material passing to the Bawdsey Cliff section*'.

The SMP recommends a policy of Hold the Line, with the following justifications:

- '*The promontory …* [acts] *to retain sediment within the bay, sustaining the beach, the defences, and the shingle comprising part of Orfordness-Shingle Street SAC*.'
- *'To the south of east Lane there has been increased erosion locally. This is as a result of the promontory but also in response to the retention of material at Shingle Street. At the entrance to the Alde/Ore works through its cycle, sediment will be released to Hollesley Bay. This flow of sediment will effectively re-establish the width of the beach at the southern end of the bay (to the north of East Lane) and will then overspill to the south. East Lane in this respect acts as a dam allowing the bay to the north to fill before allowing a supply of sediment to the south.'*
- *'Hold the Line at East Lane … allows for natural realignment within the bay to the north, with the possibility of limited intervention at Shingle Street in response to the cyclic nature of sediment loss and accumulation.'*

3.2 Review of new evidence

A full review and collation of previous studies is included in Appendix A: this has looked at a range of studies that have been undertaken since the SMP but also includes key reports that pre-date the SMP. To support this, a high level evaluation of the most recent beach profile data has also been undertaken to appraise recent changes in the beach morphology and levels.

In terms of shoreline behaviour and consideration of how it may change in the future, a number of key factors can be recognised:

- At a large scale, the Suffolk coastline is receding, driven by rising sea levels. Formation of the indented beach at the start of the century resulted in emergence of East Lane as a headland. Construction of linear defences augmented this position and prevented cliff retreat that would otherwise have occurred. Continued retreat has meant that exposure along East Lane headland has continued to increase leading to loss of shingle under higher energy conditions and exposure of the underlying London clay platform (see Figure 5). It is also likely that the defences themselves are adding to the issue by potentially increasing the offshore flux of sediment.
- The most recent beach profile data indicate that at the southern end of Hollesley Bay the zone of erosion has been gradually progressing northwards. This has been accompanied by growth of the ness at Shingle Street and also a southward shift in the ness position. South of East Lane, in recent years there has been significant erosion in the vicinity of Martello Tower W, although some stability appears to have been reached; however, beach losses further south suggest erosion could become an issue in the near future along this stretch. Along the Bawdsey Manor frontage, beach levels continue to fluctuate, with no net trend of change evident.
- Beach data shows that where beaches are eroding, the beach face is retreating in a parallel fashion, and it is only once a critical width is reached that rollback occurs, but at this point the barrier is significantly reduced in volume and is relatively quickly lost.
- Superimposed on the observed changes along the foreshore, studies have also revealed changes in the nearshore banks (e.g. Burningham and French, 2016), which suggest that some of these features have moved northwards and onshore, potentially affecting ebb and flood tidal flows.
- Offshore waves are bi-modal, with a large majority of waves approaching from either a north-easterly direction or from the south to southwest. As these waves move inland, they become modified by the various bank systems including those associated with the estuaries.
- 'Wave shadow' zones to the south of Orfordness have been recognised (Burningham and French, 2016; HR Wallingford, 2016) which means that waves from the north become blocked and the importance of waves from the south increases. Reports using recent modelling of nearshore conditions and evidence from beach profile data, also suggest a recent shift to a predominance of northward drift, which has been used to explain current issues (Burningham and French, 2016; HR Wallingford, 2016); however, this may be an oversimplification of the situation and does take account of controls at the mouth of the Alde-Ore. Since rollback of the beach system occurred at the start of the century, an indented beach north of East Lane has developed, which now seems disconnected from the beach system to the south. This means that any shingle moved northwards at East Lane is not replaced; equally any southward drift of shingle does not seem to be retained by the beaches and may be lost offshore, due to exposure conditions at the headland. Extension of defences has added to this issue, as they lie to seaward to enable any beach to be retained here.
- Together with waves, tidal currents are a key process in influencing shoreline change. The changing form of Orfordness spit from an elongate continuous barrier to a series of trailing banks is believed to be a key control on the supply and distribution of shingle within Hollesley Bay. There appears to be a link between the length of the spit and the size and position of the ness at Shingle Street, as first determined by Cobb (1957) and Carr (1986). The exact relationship is uncertain and would require further study but is likely to be a combination of:
    - changes in the direction and force of tidal flow in and out of the mouth of the Alde-Ore estuary: when the spit is a contiguous barrier flows are forced parallel to the coast possibly dispersing deposited shingle quicker whilst once the spit breaks down, the flow is more perpendicular to the coast and Carr (1986) also suggested potential for bifurcation of flows through the banks.

- changes in the extent of protection afforded by the spit – different orientations may create variations in the wave shadow zones identified by Burningham and French (2016). This may mean that as waves from the northeast and east are reduced or eliminated, there is no wave-driven mechanism for shingle within the ness to be moved southwards, which is effectively minimising sediment feed to the south.
- changes to wave regeneration due to refraction along the landward edge of the spit, which has potential to drive northward transport of shingle from Shingle Street and may also play a role in sustaining the ness.
- changes in the rate, volume and deposition of shingle to Shingle Street – Steers suggested that break down of the spit in the 1890s released a vast quantity of shingle; however, estimates by Orford (2017) and evidence from beach profiles indicates that the ness feature is continuing to grow and may be larger now than previously. Beach monitoring data illustrate the arrival of material onshore and its subsequent movement up the beach profile. The location where this shingle is moved onshore may therefore be a key factor in how it is subsequently moved.

Figure 7 illustrates understanding of shoreline behaviour based on the review of available studies, whilst Figure 8 present a hypothesis of how the behaviour north of East Lane may respond to changes in Orfordness spit.

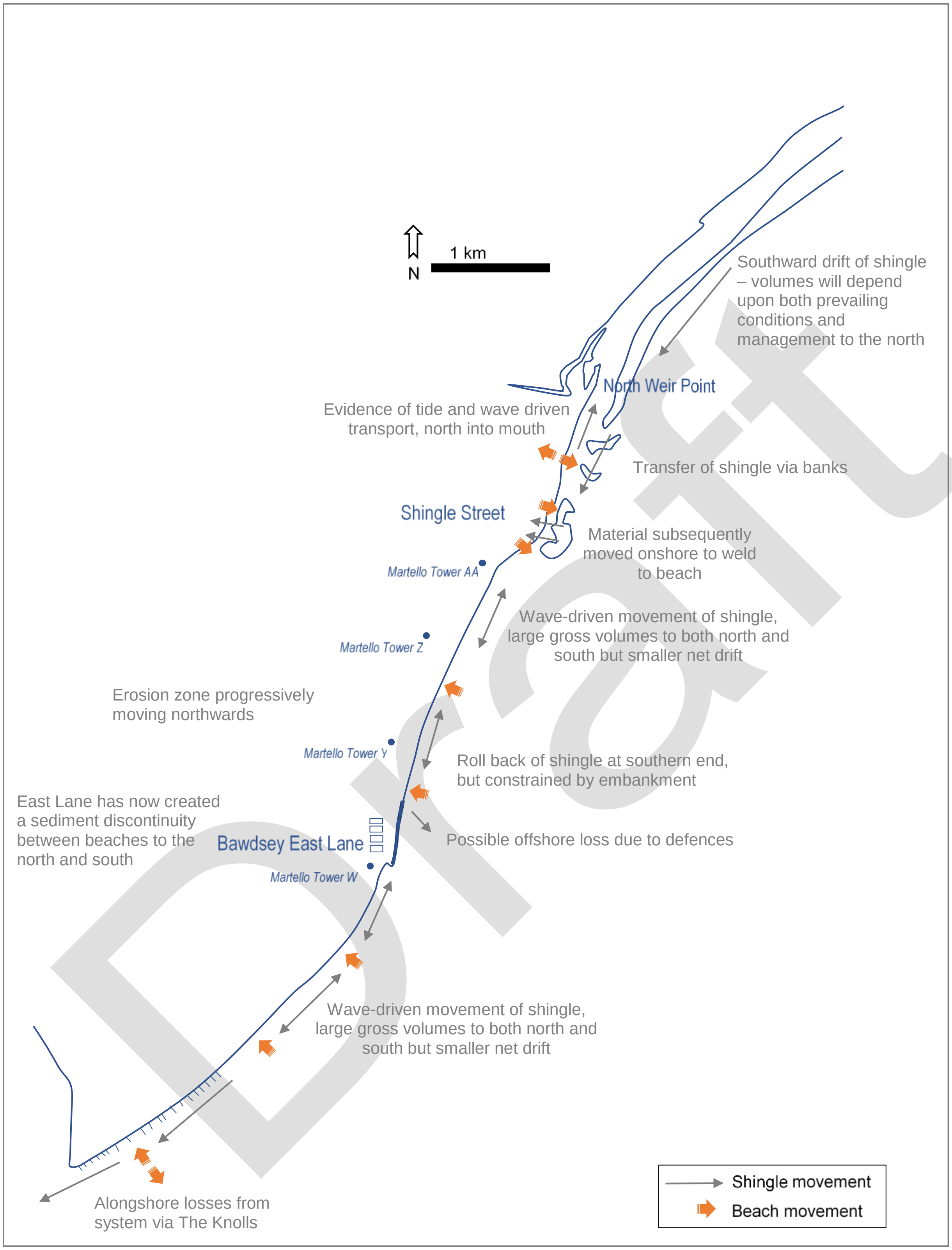

Figure 7 Conceptual understanding of coastal behaviour, based on a review of available studies.

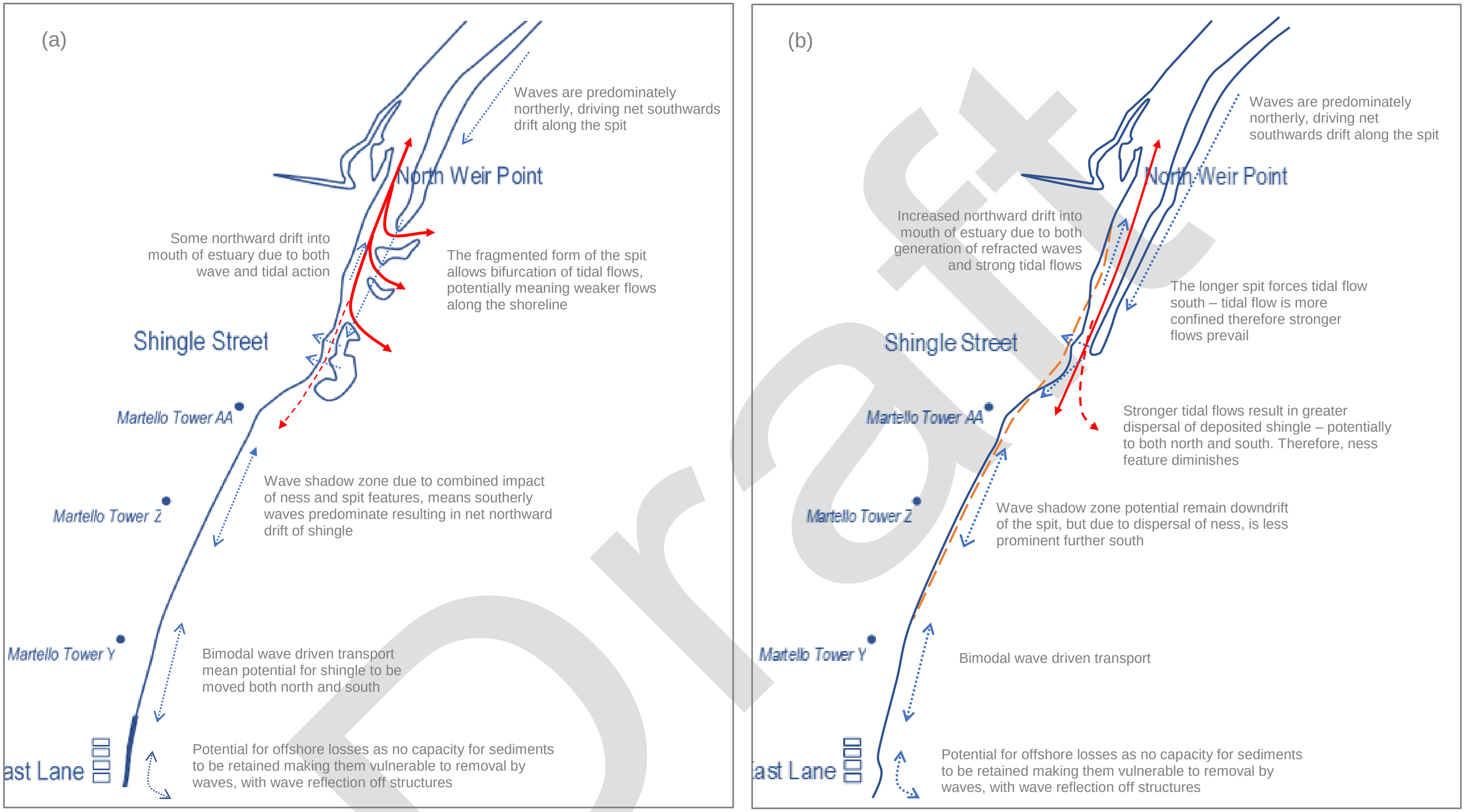

Figure 8 Possible change in coastal dynamics north of East Lane that could result from changes in Orfordness spit. (a) shows the current situation whilst (b) illustrates a possible shoreline response (indicated by the orange dashed line) should the spit elongate as it has done in the past.

3.3 Review of SMP assumptions

The SMP made a number of critical assumptions, which underpin the preferred options presented. These are discussed below, based upon the review of available evidence presented in Appendix A and summarised in the previous section.

1) The defended hard point at East Lane is critical to the position of the whole shape of Hollesley Bay and stability at Shingle Street

This appears to arise from early work, predating the SMP, which was used to justify the need for continued investment at East Lane. It is based upon equilibrium bay theory which assumes that a stable bay will form between two fixed control points: East Lane being the downdrift control point and the estuary entrance (North Weir Point) the updrift control point.

A key question here is the applicability of equilibrium bay theory along this frontage. Whilst East Lane is currently maintained as a static promontory, the same is not true for the northern control point. Although the mouth of the Alde-Ore has lain approximately opposite Hollesley since the late 1700s, the position and width of North Weir Point and the estuary mouth vary significantly on annual to decadal scales (Pye, 2014), with the length of North Weir Point varying by over 2.5 km (Carr, 1986).

Equilibrium bay theory is also predominately driven by wave processes; however, there is evidence that tides play a significant role in the sediment dynamics particularly at the mouth of the estuaries.

Finally, as various studies have concluded, this is a highly complex and dynamic system. Not only is there a bi-modal offshore wave regime, but nearshore conditions are also affected by bed features, the changing position of Orfordness Spit, which reportedly both protects the shoreline, but also has the potential to regenerate current and waves along its shoreline edge and the variation of tidal flows. This means it is difficult to confidently apply theoretic models to explain changes in form.

2) The defences at East Lane are effective in retaining material in Hollesley Bay

This statement relates to a statement in the SMP, which refers to East Lane as a ‘dam’ to sediment.

Evolution of the shoreline since the early 20th century, which also coincides with the introduction of defences at East Lane, has resulted in the shoreline has becoming more indented over time. It appears that beaches became stripped of sediment between 1880s and early 1900s making them less resilient to prevailing waves and enabling barrier rollback. It is likely that this would have occurred even if groynes had not been present but the landward rollback of the shoreline between Shingle Street and East Lane appears to have accentuated the headland at East Lane. The groynes may have contributed to this situation by affecting sediment connectivity, but succeeding maps show that despite the groynes, the cliffs here subsequently retreated. It is highly likely that if linear defences had not built in response to this cliff erosion, the coastline to the south of East Lane would have naturally realigned further.

Although Mott Macdonald (2015) suggested that the recent build up of sediment immediately south of East Lane (in the vicinity of Martello Tower W) is evidence that material is being moved around East Lane,other reports (such as Orford, 2017, Barber, 2017 and Burning and French, 2016) conclude that it is unlikely that material is currently bypassing East Lane.

As well as inhibiting longshore transport, it is also possible that they are currently promoting the loss of sediment seaward. Mott Macdonalds (2015) also acknowledge this issue, noting the “*unnatural angle between the natural beach extending northwards ….. and the Bawdsey coastal defences*”, but this does not appear to be explored further to explain why shingle might be depleting here. The report suggested is that the narrowing, lowering and erosion of the beach immediately to the north of the defences is due to “*a reduction in supply to the north to replenish losses, or a (temporary) reversal in the net sediment transport direction*.” This ignores the possibility that there is possibly just insufficient space to accommodate a beach due to the squeeze between the deeper water and the defence line. Under more natural conditions erosion of a backshore would create a more indented shape which could help retain a beach; however the alignment of the embankment and extension of defences to protect the embankment means that the beach effectively can not roll landwards and is instead lost.

Sediment losses here may also be the result of deepening conditions at the toe of the defences resulting in increased sediment mobilisation and transport due to larger waves closer inshore. Beach profile data show a progressive northward extension of erosion from East Lane and there appears to be very little material arriving along the frontage between the end of the defences and the northern end of the lagoons. The data suggest that once the beaches reach a critical width, there is increasing potential for barrier roll back. Prior to this material is simply stripped from the beach face, resulting in parallel recession.

3) A net northward trend of sediment movement in recent years has depleted sediment at the southern end of Hollesley Bay

Beach profile data show that there has been a progressive northward extension of the erosion zone for the period of data available (from 1991/2). Shingle is being stripped from the beach face resulting in linear retreat of the beach, with little evidence of rollback or onshore movement of shingle, until a critical beach width is reached.

Recent wave modelling (HR Wallingford, 2016 and Burningham and French, 2016) using 30 years hindcast data seems to indicate a predominance of net northward driven transport, which has been used to explain this erosion trend. It should be noted, however, that the data indicates high gross rates of both north and south drift, whilst the net drift volumes are considerably lower.

The beaches north of East Lane now seem disconnected from the beach system to the south, which means that any shingle moved northwards at East Lane is not replaced from shingle from the south. Southward drift is still likely to occur but shingle does not seem to be retained by the beaches and is likely to be lost offshore at East Lane, due to exposure conditions at the headland. Conversely, when there is a northward drift, material moves towards Shingle Street. That means the material at the southern end is moved away from the embankment, but is not replaced, resulting in erosion.

The ness at Shingle Street is continually growing at present; this growth is thought to be connected to changes in the Orfordness Spit, rather than simply a net increase in sediment moved northwards. The growth is effectively restricting the amount of sediment that is moved southwards. Therefore the depletion of sediment at the southern end of Hollesley Bay is likely to be due to a combination of factors.

4) Insufficient shingle to extend across longer bay frontage if defence at East Lane was removed

Historical maps from the 1880s show that a continuous beach did originally exist across the frontage; although mapping of clay exposures along sections of Bawdsey cliffs suggests that the shingle cover may have been variable and certainly the mapping shows that the beaches south of East Lane have always been fairly narrow. It is believed that the beaches north and south of East Lane have been disconnected in terms of sediment exchange since the start of the century.

Although as Barber (2017) reported, there has been no detailed analysis of beach volumes across the frontage, there are significant quantities stored at Shingle Street and evidence that this store is growing year on year. Gains here are believed to be much greater than losses across the rest of Hollesley Bay (e.g. Orford, 2017). A key question, however, is whether this sediment is likely to become released and distributed. Based on previous studies it is believed that the interaction of waves, tides and evolution of Orfordness spit are primary controls on the ness at Shingle Street. If Carr's (1986) cycle is correct (see Appendix A), then redistribution of this material southwards may only occur if the ness lengthens considerably and regains a form similar to its position in 1812 and 1885, or conversely retreats to a position similar to the 1920s. The spit has not taken these extreme forms since these dates and it is unknown whether it will, given changes further north. In more recent years, the spit has been more stable in terms of extent.

In conclusion, assumptions upon which the current SMP policy is based should be challenged, based upon new evidence and observations of recent change.

4. Future management

4.1 Policy options

Since the development of the SMP there have been two notable changes that impact the SMP policy:

1) the implementation of works to achieve the HTL policy have encroached 340 m north of the policy unit boundary into HOL16.4 (where the SMP policy is managed realignment);

2) the SMP identifies the East Lane headland as crucial to retaining shingle within Hollesey Bay; however, recent observations suggest that there is not a build-up of shingle at the southern end of the bay and instead narrowing and deepening has been occurring at the junction, and the zone of erosion has also been extending northwards.

Although this scope of this review is policy unit HOL16.5 (East Lane Bawdsey), encroachment of defences into HOL16.4 and the future need for further extensions means that a policy boundary change may need to be considered as part of the policy review. HOL16.5 and HOL16.4 jointly provide coastal defence to the flood risk area beyond and also the current justification for the hold the line policy at East Lane is its influence on the stability of Hollesley Bay to the north (HOL16.4) and Shingle Street beyond (HOL 16.3). Therefore, for this review, we have considered both HOL16.5 and the southern section of HOL16.4 – referred to HOL16.5(b) in this report. The northern boundary of this unit does, however, depend upon the approach taken.

There are four SMP-level policy options to consider: Advance the line (ATL), Hold the line (HTL), Managed realignment (MR) and No active intervention (NAI) (see Table 2).

Advance the line is rarely applied and is not considered to be applicable here, where exposure is already an issue.

Table 2 SMP options

SMP option	Definition of option	What this means for the study frontage
Hold the line (HTL)	By maintaining or changing the standard of protection. This policy includes works carried out in front of the existing defences to improve or maintain the standard of protection provided by the existing defence line, or works to the back of existing defences (such as building secondary floodwalls) where they form an essential part of the current coastal defence system.	This is the current policy and management practice at East Lane and although not the policy for the adjacent unit of Hollesley Bay, it has been applied here due to works to extend the armouring works along the line of the embankment. There are a number of measures that could deliver a Hold the line policy: linear defences, such as revetment or seawall, and approaches that involve maintaining a beach, which would contribute to the defence system through reducing wave exposure of the backshore. The latter can include measures such as shingle nourishment or the introduction of control structures, such as groynes and breakwaters.
Managed realignment (MR)	By allowing the shoreline to move backwards or forwards, with management to control or limit movement (such as reducing erosion or building new defences on the landward side of the original defences).	Implementation of this policy along Hollesley Bay policy unit and the flood risk lengths of East Lane policy could involve: (a) breaching the existing defences to allow tidal incursion and building new flood embankments much further inland to both limit the extent of that inundation risk and create new intertidal habitats or (b) realigning the defence assets landwards to allow the beaches at the shoreline to respond more naturally. This policy could also include removing defences, rather than allowing them to fail, as under no active intervention.
No active intervention (NAI)	No investment in coastal defences or operations.	This policy is implemented through a 'do-nothing' approach. The rock revetment or earth embankment would not be maintained, although most sections of that are likely to remain intact for several years and would not be expected to fail in the short term. Similarly, the embankment along Hollesley Bay would be maintained or repaired if it becomes exposed and damaged, for example due to loss of beach. The southern end of the bay,

SMP option	Definition of option	What this means for the study frontage
		between the present termination of the rock at East Lane and Martello Tower Y, is the most vulnerable and it is probable that future storms will result in a breach forming through the bank at some point in the future, resulting in inundation of a large area. Although there will be significant implications of a No Active Intervention approach, the consequences of this need to be considered and will be used as a baseline against which other approaches are evaluated.
Advance the line (ATL)	By building new defences on the seaward side of the original defences. Using this policy should be limited to those policy units where significant land reclamation is considered.	The policy refers to situations where the whole defence line is moved seawards, for example to reclaim land for development or other purpose and does not include approaches such as beach recharge (which are effectively hold the line). This policy option is rarely applied (there are only 2 such instances across over 1500 policy units throughout England and Wales) and is not considered to be applicable here, where exposure is already an issue.

To deliver policies of hold the line and managed realignment, various measures could be implemented; these are discussed in the section below.

The appraisal has also taken note of previous appraisals undertaken since the SMP by Mott MacDonald (2015) and Barber (2017). Mott MacDonald (2015) considered a series of options:

- Sustain – patch and repair operations plus a sediment recharge programme from donor sites to maintain/sustain sacrificial beach cover to resist erosion pressures. This was considered to be high risk, as there is no guarantee the recharge will remain in place.
- Extend Revetment – continue existing revetment for approximately 150m further north.
- Beach – extend revetment (as above) plus groynes and sediment recharge to north (and south).
- Breakwaters – one or two shore parallel structures offshore of East Lane.
- Managed Realignment – set back existing defences, plus recharge of beach. It is noted that the type of Managed Realignment presented in Motts (2015) referred to only one approach (based upon schemes such as Medmerry and Steart), rather than others such as simple realignment of flood embankments providing space for the shoreline to adapt.

Whilst Barber (2017) reviewed various studies and concluded that 'natural' erosion to either side of the East Lane promontory has resulted in a shoreline orientation, relative to waves which maximises the alongshore movements of sand and shingle, which are currently considered to be in a northward direction.

He suggests works to re-orientate the shoreline would reduce alongshore movement. To address this, his proposed option is to reshape the East Lane promontory by introducing several Y-shaped rock structures of varying length, and shingle nourishment. It was suggested this would improve wave energy dissipation and result in a reorientation of the shoreline, which, when combined with shingle recycling, could result in the southern end of Hollesley Bay advancing seaward.

4.2 Potential implementation measures

4.2.1 Hold the line

Both linear structures and measures to develop a beach have been considered. Application of these measures would be different for the two frontages HOL16.5 and HOL16.4(b).

HOL16.5 (East Lane) - maintain/improve the present rock revetment

The existing revetment structures should remain for a number of decades (into epoch 2) with relatively limited work required to maintain and improve them. However, along this frontage works to undertake minimal maintenance, for example to repair displacement of rocks due to storm damage, will be extremely difficult, and expensive due to existing conditions. Access and capability will almost certainly require the use of specialist marine-based plant and is not something that the EA or LA would be able to undertake themselves.

More significant works, such as placement of additional rock/concrete armour units, would also be necessary to ensure these structures are sufficient to provide defence into epoch 3 and it is possible that such works could be required earlier, within 20 to 30 years. These additional works would involve considerable cost.

Taken forward for further appraisal.

HOL16.5 (East Lane) - develop a beach

Benefits of this approach along this frontage are that a beach would reduce wave exposure along the existing defences and reduce the risk of overtopping and undermining and would also help provide a conveyor of shingle from north to south around the headland. However, due to current exposure conditions, it is unlikely that attempts to develop and maintain a beach here would be effective without significant intervention: headlands and promontories are not usually conducive to beach retention, protruding seaward of the adjacent shorelines and generally into deeper water. As a consequence, they have more exposure to larger waves and thus higher energy conditions that will typically quickly remove any sediments present there. An indicator of this is the absence of any shingle there now in what is otherwise a 'sediment-rich' environment.

Measures to develop and retain beach material would therefore need to include beach control structures, such as (a) groynes or (b) rock breakwaters.

a) Groynes

Given the deep water at this location, and the high level of volatility that shingle here will experience as a result of the aforementioned conditions, these would need to be substantial and protrude some considerable distance seaward. It is likely that rock groynes would be a more viable option than timber groynes; although timber was traditionally used to build groynes, a key issue with timber groynes is the high rates of abrasion of the timbers caused by continually mobile shingle, which is one reason why rock has become more commonplace material for groyne construction on this type of beach. As well as being expensive, other consequences are:

- the protrusion of those structures compared to the adjacent natural shorelines may themselves act as a terminal barrier to the movement of shingle from Hollesley Bay onto this frontage, so groyne bays will need to be artificially nourished and likely re-nourished to replace losses;
- they would likely result in a complete barrier to any southward shingle transport that does remain down onto the Bawdsey Manor frontage and Deben Knolls.

b) Rock breakwaters

Shore-parallel breakwaters are an alternative form of beach control, which would overcome the above terminal effects. These structures tend to be more effective where there is a high incidence of shore-normal waves; however along this headland frontage waves can reach the shoreline at quite acute angles, from north or south, so likely to still result in considerable volatility behind the structures, and potentially concentrating stronger current flows which again will not be conducive to shingle becoming stabilised along this frontage. These structures would need to be constructed further offshore in deeper water and of sufficient height to influence the propagating waves under high water level conditions and would therefore involve higher costs that rock groynes.

Not taken forward for further appraisal due the technical difficulty and extremely high cost of providing defences large enough and deep enough to be successful in retaining sediment at the headland. It is also anticipated that frequent re-nourishment would also be required to maintain beaches.

HOL16.4(b) (Hollesley Bay south) - further extension of the rock revetment

Since 2014 there have been three extensions of the rock revetment northwards into Hollesley Bay. Sections of this are poor and require improvement, but otherwise the general nature of this structure would be the basis for any continuation of a linear defence along the existing embankment line. Works would probably need to be extended as far as the next Martello Tower (Martello Tower Y) (approximately 400 m) in the near future and further extension could be required if the beach depletes further to the north.

At the southern end of this unit there could be similar access issues as described for HOL16.5 (see above).

Taken forward for further appraisal.

HOL16.4(b) (Hollesley Bay south) – develop a beach

The purpose of providing a beach along this length would be to provide the primary defence to the earth embankment against direct attack from waves. Measures to develop and retain beach material may require beach control structures and might also include regular nourishment or recycling, with or without those structures. (a) to (d) below discuss various measures.

a) Beach nourishment

One approach to strengthening the existing shingle ridge will be to introduce more beach material to the foreshore, regularly re-nourishing the beach. The key issue here appears to be one of retaining shingle at the southern end of Hollesley Bay. Given the dynamic nature of beach along this frontage and the underlying long-term trend of sea bed deepening, it may be difficult to keep pace with the rate of shingle movement and it is therefore quite likely that nourishment would be needed on a very regular basis.

This approach will be highly intensive and will require great flexibility on timing and volumes. The quantities of shingle required to implement this measure would be considerable. Combined with the frequency of operation this may mean that the use of locally derived material, for example from Shingle Street, would not be environmentally acceptable. Consequently, shingle may have to be imported, i.e. sourced from offshore dredging, both for the initial campaign and subsequent operations. This would increase costs and require additional studies to identify a source of suitable material.

b) Groynes

As described above, measures to develop and retain beach material would probably need to include beach control structures. One approach would be to introducing groynes to try and stabilise shingle being naturally moved along the shoreline by littoral processes (rather than undertaking any initial nourishment operations). As discussed above, rock rather than timber is more likely to be a viable option. However, the effectiveness of groynes is not guaranteed, as attempts to hold the beach in its present location south of the Martello Tower would need to extend into deep water which would result in more expensive structures and it less likely a beach would be retained, due to the exposure conditions.

c) Rock breakwaters

Shore parallel rock breakwaters are an alternative to groynes. The choice of groynes or breakwaters is not simply an aesthetic or economic choice but is dependent upon the prevailing wave conditions. Key issues at this location are progressive clay erosion of the seabed leding to deeper water, greater exposure, and the need for large structures. Further discussion on these structures is provided in Motts (2015).

d) Build a single ‘terminal groyne’ at northern end of present revetment

A further option is to build a ‘terminal’ structure at the current interface between beach and revetment to trap shingle that is transported southwards before it is ‘lost’ along the East Lane frontage and potentially removed from the littoral system altogether. That structure may take a similar form to the northernmost Y-shaped groyne proposed by Barber (2017) - see below. However, one potential issue is whether material would be moved away from this location during periods leaving the embankment exposed.

(a) (beach nourishment) is likely to require considerable volumes of shingle to be successful and would also be costly – therefore this has not been taken forward.

(b), (c) and (d) have been taken forward for further appraisal.

HOL16.5 and 16.4(b) - alternative approach (Y-shaped groynes)

An alternate approach presented by Barber (2017) was to modify the coastal processes at East Lane by reshaping the shoreline. This involves introducing a series of six Y-shaped rock groynes of varying length, combined with a shingle nourishment (and future recycling) operation. The intention would be to create a series of pocket beaches (albeit not in all bays) and advance the shingle beach line locally in Hollesley Bay.

It was suggested that by this improving wave energy dissipation and re-orienting the shoreline that the southern end of Hollesley Bay could be advanced seaward.

The scope of this study is not to examine that proposal in detail, but some observations are as follows:

- The report makes some good and accurate observations on the lack of knowledge and understanding of certain processes operating on this shoreline.
- It is not entirely clear whether the proposals are expected to enable shingle to move south naturally from Hollesley Bay to the Bawdsey Cliff frontage, or not. It is possibly that these proposals would not improve that situation compared to the current arrangement and could actually exacerbate it.
- The report notes that there are a number of further studies and fieldwork required to support any design of this nature. Notably some questions that would require addressing include:
    - The proposed Y-shaped groynes appear to extend up to 120 m from the present shoreline at the northern end of the present rock revetment. Whether the beach within Hollesley Bay could be advanced by such a distance, and in deeper water, to align with this, is not certain.
    - Stability of the shingle within the bays is not certain.
    - The southernmost structure is situated approximately 400 m south of the end of the present works and extending approximately 100 m seaward. It is not certain whether this may create another downdrift shadow and locally accelerated erosion (as has occurred previously directly to the south of the current defences).
- This approach is referred to in the report as “managed realignment”, but that is different from the definition of that generally applied in SMPs.
- The report appropriately notes that any estimate of costs can be only speculative at this stage. But comparisons on costs are made with the Hopton scheme in Norfolk. However, the seabed levels at Bawdsey are considerably lower than those at Hopton when the works there were constructed, and the tidal range is greater than at Hopton. Consequently, much higher structures, requiring much more rock, would be required here. Furthermore, the Hopton scheme did not require any beach nourishment, which would be required here, and this material would be shingle (whereas Hopton is sand), the nourishment or recycling of which is considerably more expensive than similar operations on sand shorelines.
- If the quantity of shingle to be recycled is considerable, then it is questionable whether this would be permissible and therefore likely to be necessary to import this shingle from another source, most likely offshore dredging. The costs associated with shingle nourishment and recycling could therefore be significantly higher than assumed in that report, which is thought to be based upon shingle extracted from the Shingle Street area.

Not taken forward for further appraisal. This would be a very high cost option, particularly given the need to undertake nourishment. Shingle Street was suggested as a source area, but it is unlikely that this would be environmentally acceptable, therefore importing shingle would need to be considered. There are also considerable uncertainties regarding the successful application of such as scheme. On this basis, this option has not been explored further.

4.2.2 Managed realignment

As managed realignment approaches will have implications across both units, these have been looked at together. In both cases the flood defence is formed by the construction of new clay embankments covered by turf. These would be similar to that currently found at the back of the beach through Hollesley Bay, although the height and footprint may vary depending upon the levels to be provided, quality of the construction material, ground conditions and proposed use (e.g. for access).

Four types of managed realignment have been considered: (a) construction of a new embankment inland (termed wetland creation scheme), (b) construction of new embankment along a realignment slightly inland of current embankment, (c) natural shingle barrier management and (d) removal of defences.

(a) Wetland creation scheme

This would comprise a large-scale realignment, involving the construction of new embankments extending some distance inland.

These schemes are frequently construction with a purpose of also creating new intertidal or wetland habitats, with a range of elevations that allow wet and dry areas to form and provide some diversity within the site. The nature of the area (e.g. saline or brackish) could also depend upon the natural evolution of the shingle beach, which may form a barrier across the entrance which is occasionally overwashed or could allow a permanent inlet to exist.

The new embankment positions can be determined by any number of factors, including the location of the properties and infrastructure the scheme is designed to protect, the presence of higher ground which provides a natural boundary, any objectives for such a scheme to create a certain amount of new habitat (if that is a requirement), and the acquisition of the land that is to be used. Materials for construction of the new flood embankments is all sourced from the site, with cuts made to form new channels or deeper water areas.

One of the flood risk management benefits of such an approach is that the embankments are situated some distance from the sea and exposure to wave attack. Consequently, they are much less vulnerable to being breached, and generally less expensive to construct than defences at the shoreline.

Taken forward for further appraisal.

(b) Construct realigned embankment

A much less extensive form of managed realignment would be to relocate the existing earth embankment behind the beach to a new position that allows the beach to behave naturally and enabling roll-back. The ideal alignment under this arrangement would be one where the embankment line was sufficiently set back that the beach in front of it could move dynamically for the next several decades without that movement being constrained.

One of the key issues to the south of the Martello Tower is the lack of space for a healthy beach shape and profile to stabilise, with deeper water seaward and the change in embankment alignment that exists there. If the embankment were reoriented along this southerly section of Hollesley Bay, it would initially allow a similar beach width and plan form to develop similar to that seen further north. It is thought probable that this could build naturally with littoral transport moving shingle along the shoreline from Shingle Street. With the set back position there would be better beach retention as the impact of the current funnelling effect created by the present configuration would be significantly reduced.

One further consideration is the cost of providing any surface protection – the less exposed the embankment the less requirement for any protective covering. It is possible that some light protection is necessary at this location, but the shingle will attenuate much of the wave action.

Taken forward for further appraisal.

(c) 'Natural' shingle ridge management

Whereas the beach nourishment and control structures measures presented previously seek to 'hold the line' by keeping the beach in its present position, other forms of beach management are also possible.

A managed realignment approach would involve allowing the beach to behave naturally, with minimal intervention to repair breaches if and when they occurred (although experiences elsewhere, such as Salthouse and Clay on the North Norfolk coastline have observed these to naturally self-heal). To accommodate this, however, would require removal of the existing earth embankments that would constrain this movement and see the depletion and loss of the shingle over time, losing this natural barrier to potentially constant inundation (which would be the consequence of No Active Intervention).

The beach would need to be able to 'roll back' to continually find its equilibrium position for natural stability. There is no guarantee that a new non-maintained barrier, left to roll back naturally, will maintain constant volume and crest height, and there would need to be an acceptance of an increase in risk to properties below extreme sea levels. With this approach there is therefore a need to introduce flood management adaptation measures to provide that protection at the local level.

Not taken forward for further appraisal. This approach would not, however, be compatible with either Hold the line or Managed realignment at HOL16.5. Roll back adjacent to the hard point would lead to a discontinuity and a weak spot where breaching would become inevitable.

(d) Removal of East Lane defence structures

Managed Realignment also applies to situations where defences are actively removed. If a different approach to management of this shoreline is considered, perhaps to provide a better functioning natural system that may also benefit areas to the south, then this may be something that is undertaken to achieve that change (noting that under a No Active Intervention policy these structures would remain at least in part for several decades).

This would be a significant undertaking, requiring specialist marine plant to be able to access and remove parts of these structures. However, the structures are primarily constructed of rock, which can be recycled, so removal costs might be offset by the reuse or sale of the materials for other projects.

Taken forward for further appraisal.

4.3 Approaches

As this SMP Review has identified the need to look at both policy unit HOL16.5 and the southern part of HOL16.4 (HOL16.4(b), there are various combinations of the SMP policy options that could be considered; these are referred to as approaches.

Table 3 screens these and identifies approaches to be taken forward for further appraisal (section 5).

Table 3 Combinations of policy options considered and taken forward for further assessment.

Policy option		Taken forward for further assessment?		Implementation
HOL16.5	HOL16.4(b)			
NAI	NAI	Y	For baseline purposes only (Approach 1).	Do nothing - no further work to maintain or repair defence assets; nor would they be replaced if failed.
HTL	HTL	Y	Taken forward as Approach 2.	Along HOL16.5 the most suitable measure to Hold the line is likely to be to maintain/improve the present rock revetment. Along HOL16.4(b) there are three possible measures: (a) further extension of the rock revetment, (b) introduction of rock groynes or other control structures or (c) a combination of (a) and (b):
HTL	NAI	N	The potential for breach along Hollesley Bay and resultant flooding of the hinterland area would undermine the justification for continuing to hold the line at East Lane, apart from the short stretch at the southern end of East Lane.	
HTL	MR	Y	Taken forward as Approach 3. This is the current SMP policy for epochs 2 and 3.	Along HOL16.5 to maintain/improve the present rock revetment is likely to be the most appropriate implementation, with refurbishment of the terminal end of the revetment would require refurbishment. To the north, there are two viable options: (a) build new flood embankment some distance inland and enable wetland creation or (b) realign the existing embankment a smaller distance inland:
MR	HTL	N	There would be little benefit of combining these two options as this would not address the exposure issues currently experienced.	
MR	MR	Y	Taken forward as Approach 4.	This would involve active removal of the rock revetment along East Lane (HOL16.5) and set back and the realigned defence lines ((a) or (b) from

Policy option		Taken forward for further assessment?		Implementation
HOL16.5	HOL16.4(b)			
				Approach 3) would also need to extent to connect to the area of high ground to the south of East Lane.
NAI	MR	N	Failure of defences at East Lane would result in a potential breach at the northern end and resultant flooding of the hinterland area. A more appropriate approach would be for MR in both units (as considered above) to ensure continued flood protection.	

5. Appraisal of approaches

Figures at the end of this section illustrate the approaches considered at this phase.

For each approach this section sets out the implementation measures considered viable and the physical impact on the shoreline and associated technical issues, considering anticipated shoreline response, resultant change in the coastline form and potential technical implications of this.

The impact on the wider coastal environment and the interests it supports have then been appraised under the following themes:

- Biodiversity, geology and geomorphology features
- Water and hydromorphology
- Historic environment and landscape
- Communities, economy and material assets

These appraisals draw upon previous studies and further detail is provided in Appendix B. It is not intended that these would fulfil the requirements of a Strategic Environmental Appraisal (SEA) or Water Framework Directive (WFD) assessment: these would need to be undertaken at a later phase if the CSG decide to pursue a policy change.

Each table includes indicative costs – further details are included in Appendix C.

5.1 Approach 1 No active intervention (both units)

Implementation
Do nothing - no works will be undertaken throughout the policy unit. Even without maintenance, the rockworks along much of the East Lane frontage (HOL16.5) would be likely to remain intact for several more years, well into Epoch 2 of the SMP, providing continued protection to the few properties at the southern end which are at risk of coastal erosion. Eventually they would suffer damage and their effectiveness would reduce, ultimately failing and no longer providing that protection. However, that may not occur until the latter part of Epoch 2, or possibly Epoch 3. There are some sections of rockwork north of East Lane point that are in a poorer condition than mentioned above and could fail sooner, but inundation via a breach along the south Hollesley Bay (HOL16.4b) frontage is thought likely to occur earlier.
Potential impacts
Although defences along East Lane would remain for some time and continue to function as an effective defence, continued loss of beach at the northern end of the defences would expose the earth flood embankment north of the recently placed rockwork at the southern end of this unit to direct wave action resulting in increased erosion, overtopping and ultimately leading to a breach. The orientation of this bank relative to the natural beach orientation is believed to be preventing sufficient shingle build up and retention here to provide the necessary protection. This is a high risk within the next 5 years. This would allow sea water inundation of the low-lying hinterland. In the longer term the breach could widen and become more permanent, depending upon supply of shingle from the north, which would have a wider impact on the environment. The defences along East Lane would continue to deteriorate increasing the risk of breach here and also the re-establishment of cliff erosion. Assuming little change to the wider system to the north, there is a risk that this frontage would continue to receive limited sediment, with the majority of sediment being held at Shingle Street ness. The presence of the embankment is also likely to prevent any natural beach reforming to seal such a breach, so this would be semi-permanent at best. In the longer term the impacts are likely to be become more widespread, with the potential for the breach to widen due to flows into and out of the breach. Along Shingle Street, there is likely to be little impact for several years and the situation here will continue to be governed by changes in the Orfordness spit and the input of shingle from the north. Longer term, the

impact of a wider and more permanent breach could have farther reaching effects, but there is high uncertainty regarding the nature and impact of these impacts. Further south, for some time the situation is likely to continue as present, with shingle volumes continuing to fluctuate exposing some sections of cliff to erosion. Changes along this stretch are more likely to be sensitive to changes in management within this unit, rather than HOL16.5 and 16.4.	
Biodiversity, geology and geomorphology features	Designated sites in this management area are Alde-Ore Estuary SSSI, AldeOre Estuary Ramsar/SPA, Orfordness and Shingle Street SAC and Alde-Ore & Butley Estuaries SAC. To the south of East Lane lie the Bawdsey Cliffs SSSI and the Deben Estuary SSSI, Ramsar and SPA. In the long term, a more naturally functioning coast may ultimately be beneficial to the overall objectives of the environmental designations, however there will be localised changes as a result of a breach. There is a high risk that lagoons at the southern end of the frontage will be lost as a result of shoreline recession, but it should be recognised that there is no process by which these could be naturally recreated further inland, e.g. through rollback, so this should not be considered a loss due to coastal squeeze. It is thought unlikely that the situation at Shingle Street is will change as a direct result of a change in management, at least in the short to medium term, therefore here continued accumulation may continue. Orford (2017) noted that the development of perennial vegetation at the ness does not appear to be keeping pace with the relatively rapid development of the gravel ridges, which may cause some concern, but this is part of the natural dynamism of the environment. There is also potential for new natural lagoons to be created as material is moved onshore from the interconnected banks of Orfordness spit. Longer term changes are more difficult to predict, given the complexity of this coastal environment. Further south, limited impact on Bawdsey cliffs is anticipated in the short to medium term, although there is potential for increased erosion, given recent observed beach losses, which could actually enhance the SSSI through increased exposures. Similarly processes affecting the Deben Estuary are not anticipated to be affected until the longer term, as the defences at East Lane will continue to affect longshore connectivity for some time.
Water and hydromorphology	It is anticipated that in the short term there will be more frequent overwashing where the ridge breaches, but this is not likely to have a significant impact on the local waterbody. In the much longer term, a permanent and wider breach will mean waves are able to penetrate new areas, which could have implications on the tidal flows and sediment transport and distribution. This is an area of high uncertainty and further appraisal would be necessary to improve understanding of potential consequences. Of key importance are the groundwater aquifers upon which agriculture on the Suffolk coast is dependent. There is a potential risk intrusion of salt water into freshwater aquifers.
Historic environment and landscape	Martello Towers Y (Hollesley Bay) and W (south of East Lane) are at potential risk of loss within the short to medium term. The risk to Towers Z and AA are more likely to be governed by changes to the north than management of this unit. In the longer term, the Grade II listing at East Lane car park will be at risk. There are a number of non-designated archaeological sites and monuments along the study frontage, floodplain and further south that may be affected due to erosion and flooding. Further south, direct impacts of a change in management are not anticipated until the much longer term. Failure of defences will have a detrimental impact on the landscape, although ultimately in the very long term, a more naturally functioning coast could be beneficial to some objectives of the AONB and Heritage Coast. Access along the coast would, however, be compromised by a permanent breach forming.
Communities, economy and material assets	Initially, there is likely to be increased inundation of the agricultural fields, which would have a localised impact on productivity. Once a breach occurs flooding would become more widespread, affecting both agricultural land and isolated

	properties within the low lying area. Saline intrusion and loss of irrigation ponds would also have a wider impact on farming. Hinterland flooding would also result in access routes being cut off, this would have an impact on Shingle Street properties and holiday rentals in the area. There could also be a wider scale impact on sewage works and pumping station, affecting the functioning of this facility. As discussed above, directs impacts south of East Lane are not anticipated until the longer term, therefore changes here, including to Bawdsey Manor and the Radar museum are more likely to be affected by management changes in their specific management unit. Longer term impacts are very uncertain.

Costs
None (although it is noted that there may be costs associated with health and safety requirements)

5.2 Approach 2 Hold the line (both units)

Implementation

Hold the line – undertaken works to continue to minimise the risk of coastal flooding and erosion along the existing defence alignment.

Along HOL16.5 the most suitable measure to Hold the line is likely to be to maintain/improve the present rock revetment.

Along HOL16.4(b) there are three possible measures: (a) further extension of the rock revetment, (b) introduction of rock groynes or other control structures or (c) a combination of (a) and (b):

a) further extension of the rock revetment along the embankment line: if recent extensions are indicative of requirements then it could be necessary to go as far as the Martello Tower Y within the next 10 years. Although this will then reach a position where the embankment orientation and beach line are likely to be more stable, this rockwork could require further northward extension by Epoch 3, possibly much sooner during Epoch 2 (this would depend on effects of climate change, rate of clay loss on the seabed, patterns and rates of shingle movement south from Shingle Street).

b) introduction of rock groynes or other control structures: the intention would be to retain more shingle along this stretch, reducing its susceptibility to removal under differing wave conditions and thereby retaining a buffer in front of the embankment. This would be a costlier option and would require more detailed design to reduce the risk of accelerating erosion at the end of the defences.

c) An alternative would be the combination of (a) and (b) such as constructing a terminal structure.

Potential impacts

The intention would be to continue to hold the existing alignment of defences such that there would be no adverse impacts on the hinterland area for as long as the defences are maintained. Through undertaking these works, there would be a disruption of sediment exchange with the beaches south of East Lane; this would represent a continuation of a situation that is believed to have existed for up to a century.

Biodiversity, geology and geomorphology features	Orford (2017) concluded that Orfordness SAC is not currently being detrimentally affected by southern losses, given that new areas of shingle growth at the ness represent a natural dynamic changing environment which more than covers the losses elsewhere and this situation would continue. There would be a direct loss of habitat due to construction of new defences under all 3 options, but under (b) there is potential for beaches to be retained, albeit under a heavily managed approach. In the long term management of defences may not

	be sustainable, although use of rock means that defences could theoretically be moved and reused if required enabling some flexibility. Under both options it is likely that the lagoons would still be lost (but see comment in approach 1 above regarding coastal squeeze).
Water and hydromorphology	There will be a short term, temporary impact on the coastal water body during construction of new defences. As the purpose of the implementation measures is to prevent a breach, inundation of the hinterland would be avoided and therefore risks of saline intrusion should be minimised.
Historic environment and landscape	As the purpose of this approach is to prevent a breach, inundation of the hinterland would be avoided and the Martello Towers would remain protected. There could, however, be impacts on non-designated features along the beach. Construction of additional defences, particularly under (b), may not be compatible with the AONB objectives and would require further consideration.
Communities, economy and material assets	As the purpose of this approach is to prevent a breach, inundation of the hinterland would be avoided and hinterland assets and agricultural land would remain protected from coastal erosion and flooding. The irrigation ponds would also remain protected, with implications for wider agriculture. There could be restricted coastal access along the beach, particularly under (b) and this would need further consideration.
Costs	
Cost range depending upon measures implemented in HOL16.4b, but are likely to be over £14 million (including 60% optimism bias).	

5.3 Approach 3 Hold the line (HOL16.5) with Managed realignment (HOL16.4)

Implementation

This combination of policy options is the current SMP policy and involves works to continue to maintain defences along East Lane but looks to realign the defence to the north.

Along HOL16.5 to maintain/improve the present rock revetment is likely to be the most appropriate implementation. However, with a managed realignment approach to the south, the terminal end of the revetment would require refurbishment. The options for that could be (i) importing more rock to provide that or (ii) reducing the length of the present works and reusing that same rock to construct this feature and undertake the remedial repairs required at other spots along the existing revetment.

To the north, there are two options for Managed realignment, both of which are considered viable: (a) build new flood embankment some distance inland and enable wetland creation or (b) realign the existing embankment a smaller distance inland:

a) build new flood embankment some distance inland to ring-fence an area where breaching and inundation could occur: wetland creation. This option would be considerably cheaper (in the long term) and provide a more sustainable flood defence to properties and other infrastructure. A key impact and cost would, however, be the loss of agricultural land. The actual extent of this realignment could be designed to suit needs (the alignments shown on the illustrations are schematic only to give an impression of one possible extent). It would also be appropriate (either at the outset or over time) to remove the remainder of the existing embankment, to allow the dynamic shingle barrier beach to form and behave naturally along the seaward edge of this new area, otherwise that would deplete and potentially be lost.

b) realign the existing embankment to provide ‘accommodation space’ for the beach to realign and potentially build between the north end of the existing revetment and the Martello Tower Y. The beach should accommodate a better alignment, and the termination of the revetment would itself form a ‘trap’ to reduce losses of shingle offshore and retain any southward drift of shingle. This approach would not, however, prevent recession and in the future it would be necessary to build a new embankment line further inland, so that the beach can roll back in an unconstrained fashion to provide the primary buffer against waves and surges, whilst the embankment provides the ‘back up’ line of defence against extreme water levels. Realignment of the shoreline may affect sediment drift patterns along the frontage although as discussed earlier material may continue to be retained at Shingle Street, meaning the southern end of the frontage is likely to continue to recede faster than adjacent frontages.

Potential impacts

The intention would be to continue to hold the existing alignment of defences at East Lane, but provide a new defence along a recessed alignment to the north such that coastal flood and erosion risk to the hinterland area would continue to be minimised, albeit across different areas to today. As for Approach 2, through undertaking these works, there would be a disruption of sediment exchange with the beaches south of East Lane; this would represent a continuation of a situation that is believed to have existed for up to a century.

Biodiversity, geology and geomorphology features	The intention for MR along 16.4 (b) is to allow the dynamic shingle barrier beach to form and behave naturally along the seaward edge of this new area. In at the least the short to medium term, impacts on the SAC would therefore be less than under Option 1 or 2. As beach recession would continue, as part of the large scale trend of regression along the Suffolk coast, there would continue to be fluctuations in coastal shingle and unless there is a change in the wider scale processes within Hollesley Bay it is likely that the southern end of the bay will continue to retreat as material is retained at Shingle Street ness. As such it is considered likely that the lagoons would be lost (but see comment in approach 1 above regarding coastal squeeze). As concluded by Orford (2017) new areas of shingle growth at the ness represent a natural dynamic changing environment which more than covers the losses elsewhere and this situation would be expected to continue and possibly improve as any losses offshore due to the defences should be reduced by allowing a more indented coastline to form, which should improve retention of shingle along the southern beaches. Allowing set back would also ensure a more functioning shingle barrier system to develop which would be more resilient to future changes, including climate change and accelerated sea level rise. Option (b) could bring wider benefits by allowing some wetland development and enabling greater flexibility in the barrier system, whilst option (a) would mean smaller changes from present and the possible need for additional works in the future or barrier management.
Water and hydromorphology	As the purpose of the approach is to manage the risk of coastal flooding, inundation of the hinterland would be avoided and therefore risks of saline intrusion to areas behind defences would be minimised.
Historic environment and landscape	As the purpose of the approach is to prevent a breach, inundation of the hinterland would be avoided. However, construction of new embankments may impact on buried archaeology within the flood plain. Design of alignments would need to take account of continued protection to the Martello Tower, particular Y, whilst Martello Tower W should remain protected. Under (a) Impacts on the landscape are likely to be small, but there is potential for enhanced landscape under (b).

Communities, economy and material assets	At the wider scale, as the purpose of the apporach is to continue to manage risks from coastal erosion and flooding, inundation of the hinterland would be avoided and assets would remain protected. However both options would result in a loss of agricultural land along the coastal strip – the extent of which under (b) would depend upon the exact alignment chosen.
Costs	
A wetland creation approach (a) would involve costs of over £14 million, whilst realigning the embankment (b) is likely to range between £10 and £12 million (including 60% optimism bias).	

5.4 Approach 4 Managed Realignment (both policy units)

Implementation	
This would involve active removal of the rock revetment along East Lane (HOL16.5) and set back and the realigned defence lines would also need to extent to connect to the area of high ground to the south of East Lane. As for Approach 3, there are two options for Managed realignment, both of which are considered viable: (a) build new flood embankment some distance inland and enable wetland creation or (b) realign the existing embankment a smaller distance inland.	
Potential impacts	
The potential impacts of this approach are highly uncertainty given the potential for wider scale effects on how the system functions. Further studies would be required to appraise this. Impacts will also depend upon the realignments chosen.	
Biodiversity, geology and geomorphology features	In the long term, realigning the shoreline would create a more naturally functioning coast that may ultimately be beneficial to the overall objectives of the environmental designations. The intention would be to continue to manage coastal erosion and flood risks to the hinterland so impacts would be along the beaches. As for approaches 1 to 3, there is a high risk that lagoons at the southern end of the frontage will be lost as a result of shoreline recession. In the longer term, there could be a change in which the whole system functions, which may mean redistribution of shingle currently held within Shingle Street ness – this could bring both benefits and disbenefits in terms of the designation sites. It is likely that there could be increased erosion of Bawdsey cliffs at least initially, which could enhance the SSSI through increased exposures. Longer term, redistribution of shingle along this frontage, could however mean wider beaches and reduced exposure. Impacts on areas further south are very uncertain, as a new coastal alignment would ultimately develop and both benefits and disbenefits are possible.
Water and hydromorphology	At the wider scale, the risks of coastal flooding will continue to be managed, therefore the risk of saline intrusion to areas behind defences would be minimised. However, the necessary realignment would mean a loss of the irrigation ponds, which if not relocated would have wider reaching impacts.

Historic environment and landscape	It is possible that the required alignment could mean the loss of Martello Towers Y and W; these would depend upon the realignments chosen. As for Approach 3, construction of new embankments may also impact on buried archaeology within the flood plain. There would be a significant change in the coastal landscape, but once established it is possible that a more naturally functioning coast could be beneficial to some objectives of the AONB and Heritage Coast. Access along the coast could be impacted and the car park at East Lane would be lost if not realigned.
Communities, economy and material assets	At the wider scale, as the purpose of the approach is to continue to manage risks from coastal erosion and flooding, inundation of the hinterland would be avoided and assets would remain protected. However, all options would result in a loss of agricultural land along the coastal strip – the extent of which would depend upon the exact alignment chosen. In the longer term there could be impacts on assets downdrift such as Bawdsey Manor and the Radar museum, but this is very uncertain.
Costs	
Both a wetland creation approach (a) realigning the embankment (b) could involve costs of between £7 and 9 million (including optimism bias). Note that costs would be reduced to (a) £10 to 12 million and (b) £7 to 9 million, if removal of the defence were delayed.	

5.5 Discussion

Along the current defences at East Lane, there is little need to do any significant work along much of the existing East Lane structures in the near term other than a couple of areas which require improvements, notably lengths 2 and 7 as shown in Figure 3, section 3). Options to apply other measures here are therefore not required for the purpose of short-medium term stability (e.g. the next 20 years); only if the intent to so somehow alter the overall shore alignment and movement of sediment (as per Barber, 2017 proposal), or to attempt to hold some form of beach along that frontage. Approaches to both are however (a) highly uncertain over success, and (b) extremely expensive.

However, if East Lane point is to be held into the longer term, then it is highly likely that some further works would be necessary to provide the stability required. This will be most likely because of the deepening of the seabed in front of the defences together with rising sea levels, combining to create even deeper water that would allow larger waves to break onto the defences. That increases the risk of failure through (a) greater destabilising forces displacing rocks from the revetment (b) scour at the toe resulting in some slippage of the revetment and further increasing the possibility of displacement, and (c) higher overtopping eroding the crest and backface of the protected bank leading to failure and destabilising behind the revetment.

In these cases, then seeking to reduce that risk by holding a beach along the base of the revetment would be a positive option, However, as above that is considered likely to be problematic and extremely expensive compared to other options. The alternative would be to make significant improvements to the existing revetment by adding larger rock to the slope, extending the toe, and increasing the height. This will also be a major engineering construction operation and extremely expensive.

To address the risk of flooding north of the existing revetment, one option is to continually extend the defences northward to address the risks posed to the unprotected earth embankment each time beach material is depleted. This is a continuation of the practice adopted over the last ten years. There is every likelihood that this will need to extend to at least the next Martello Tower Y well before the end of the next SMP epoch, quite possibly much sooner. With deepening of the seabed and this material being forced seaward under northerly conditions, it is unlikely that any beach will form in front of the rockwork, further reducing the length of the Hollesley Bay shingle ridge and removing shingle from the shoreline sediment system.

A second option would be to terminate the seawall construction where it is and seek to maintain the beach at this point, for example building groynes. This may be successful but will also be expensive. With ongoing shoreline recession, it will also become more and more difficult to retain the shingle so is not necessarily a sustainable longer term approach. A variation on this is a single terminal groyne structures, however, under southerly wave conditions, that area would become depleted as there is no drift from south, so it is still likely that some form of protection will need to be added to the rear embankment.

A large scale managed realignment in Hollesley Bay is a suitable approach to provide more robust and sustainable flood protection to properties and infrastructure inland, but may not be widely popular. Other options involve realigning the shoreline along the southern end of Hollesley Bay. It is clear that the beach is constrained south of the Martello Tower Y by the seaward orientation of the rear earth embankment, being squeezed between that and the gradually deepening foreshore. Re-positioning that length of the embankment to an alignment on the same orientation at the embankment north of the Martello Tower Y would immediately relieve that pressure and give the space for a similar beach profile and width to develop.

Given the significant uncertainties associated with larger scale realignment of the coastline, a possible way forward would be to address the immediate issue of the potential risk of breach along this frontage for the least cost. This would give a period of time (around 20 years) to continue to monitor change and undertake further modelling and appraisal studies to improve understanding of coastal change and investigate managed realignment options.

Figure 9 Approach 2 - Hold the line in both policy units

Figure 10 Approach 3a Hold the line (HOL16.5) with Managed realignment (HOL16.4) through wetland creation.

Figure 11 Approach 3a Hold the line (HOL16.5) with Managed realignment (HOL16.4) through a realigned embankment. Note that a variation at the southern end could be considered.

Figure 12 Approach 4a Managed realignment in both units through wetland creation in HOL16.4.

Figure 13 Approach 4b Managed realignment in both units through a realigned embankment in HOL16.4.

Appendix A. Overview of coastal processes and shoreline behaviour

A.1 Introduction

Whilst the intent of this report is to support of the review of SMP policy at East Lane (SMP policy unit HOL16.5), to understanding shoreline behaviour it has been necessary to consider the wider coastline. The policy unit sits within a much larger coastal system, the limits of which are difficult to define due to the high sediment connectivity along the Suffolk and Norfolk coastlines. For the purpose of this SMP review, attention has been focused on the slightly wider frontage that lies between the mouths of the Alde-Ore and Deben estuaries but it is recognised, however, that controls on behaviour extend much further, particularly to the north of Alde-Ore.

This dynamic shoreline has been the subject of various studies over the past few decades, from the observations made by Steers in the 1920s, to the most recent considerations by Barber (2017), Orford (2017) and HR Wallingford (2016). These have been reviewed to gain an up to date understanding of shoreline behaviour and response.

No new modelling or analysis has been undertaken as part of this study, which is beyond the scope of the current phase, instead the focus has been on reviewing the evidence gathered by others in the context of what this tells us about appropriate management of this coastline in the future. To support this, a high level evaluation of the most recent beach profile data has been undertaken to appraise recent changes in the beach. Historical maps have also been reviewed (available to view on-line at https://maps.nls.uk/).

A.2 Evidence used

A.2.1 Previous studies

A1 summarises the reports reviewed as part of this study, from the most recent to the oldest. Although the focus has been on studies since the SMP, key reports that pre-date the SMP have also been included.

Table A1 Synopsis of previous reports used

Report	Produced for	Summary
Alde-Ore Estuary: Modelling Report (HR Wallingford, 2018)	Tidal Lagoon Power (TLP) and East Suffolk Internal Drainage Board (IDB)	This study looks at potential realignment sites within the Alde-Ore estuary and includes modelling to investigate potential impacts on water levels, flood extends and wider estuary morphology.
Bawdsey Engineering Study - Phase 1 (Barber, 2017)	Bawdsey Coastal Partnership	This report examines a selection of 23 previous reports on the shoreline around Bawdsey with the objective of providing a collated definition of coastal process influences on beach behaviour over the frontage and identifies gaps in the work undertaken to date. Also presents a view on the likely appropriate form of future shoreline management for the area.
Geomorphological Advice to Natural England in respect of	Natural England	The specific focus is on geomorphology and its role in supporting valuable coastal habitats

East Lane (Suffolk) coastal changes and their impact on Shingle Street Barrier (Orford, 2017)		within Orfordness Special Area of Conservation (SAC). The report presents an initial high-level analysis of shoreline changes over the last 150 years to support a wave-sediment cell perspective that can help to explain Shingle Street Barrier and its accretional ness (Shingle Street Ness) in terms of fluctuating long-term (multi-decade) southerly drift as against the more recent short term (sub-decade) northerly drift. The role of beach rotation is also discussed in the context of the temporal changes in shoreline position along Shingle Street.
An Economic and Environmental study of the value of coastal defences in the Bawdsey Coastal Partnership area (Bawdsey Coastal Partnership, 2016)	Bawdsey Coastal Partnership	The aim of the report was to improve understanding of the assets and local economy at risk from coastal erosion and flooding. It provides baseline information on key assets and includes an appraisal of the potential mechanisms and consequences of defence failure.
Bawdsey - Coastal Process Assessment (HR Wallingford, 2016)	The Crown Estate	The aim of this study was to improve knowledge of the coastal processes at East Lane, Bawdsey and its immediate surroundings in order to help inform a coastal management option appraisal for the frontage. The report includes: a desktop review of past shoreline, analysis of profile and seabed changes, a wave assessment to derive a set of nearshore time-series and numerical modelling of shoreline evolution to investigate how the longshore shingle transport and the plan-shape of the beaches are likely to change in the future.
Shoreline - Shoreface Dynamics on the Suffolk Coast (Burningham and French, 2016)	The Crown Estate	In support of consideration of the feasibility of ‘sand engine’ super-nourishment scheme by The Crown Estate this study provides a regional analysis of the behaviour of the entire Suffolk shoreline and the adjacent shoreface at high spatial resolution. It includes analysis of historical shoreline change, sediment budget analysis and wave modelling, which has been used to derive longshore transport flux.
Bawdsey Manor Coastal Protection - Preliminary Option Assessment (Royal Haskoning, 2016)	Jackson Civil Engineering	The report provides an option assessment for coastal protection options at Bawdsey Manor, Suffolk, to the south of the study frontage, and includes a summary of the key coastal processes at the frontage, based on previous studies, review of surveys and observations during the site visit.

The Alde-Ore Estuary Plan (AOEP, 2016)	Alde and Ore Estuary Partnership	Presents the strategic plan for managing the estuary in the future.
Coastal Processes Study: East Lane, Bawdsey (Mott MacDonald, 2015)	Environment Agency	This report examines the causes and consequences of past and recent coastal erosion and coastal management in the vicinity of East Lane, Bawdsey, Suffolk and provides a brief review of the contemporary coastal erosion problems at Bawdsey and the chronological sequence of coastal protection measures implemented to offset erosion since the early 1900s.
Geomorphological and hydrodynamic assessment of future flood defence management options at Hazlewood Marshes, within the wider context of the Alde and Ore Estuary (KPAL, 2014)	Alde and Ore Estuary Partnership	This consider the potential geomorphological and hydrodynamic consequences of several management options for Hazlewood Marshes, within the Alde-Ore estuary. Although most of the analysis is focused on the inner estuary, some information relates to the mouth of the estuary.
Deben Estuary Plan (Stage 2) (Black and Veatch, 2013)	Environment Agency	This report summarises flood risk management appraisal work undertaken on the Deben Estuary to inform the Deben Estuary Plan; and presents strategic recommendations regarding options for managing flood and coastal erosion risk, including a No Active Intervention (NAI) scenario.
Suffolk - Coastal Trends Analysis (Environment Agency Shoreline Management Group, 2011)	Environment Agency	This reports on data from the Anglian Coastal Monitoring programme, updating the previous 2007 Suffolk Coastal Trends report to incorporate data up to and including summer 2010 with trends recalculated to reflect this new data.
East Lane Bawdsey Cliff recession study (Halcrow, 2011)	Waveney District Council	This report specifically investigates the acceleration of erosion of Bawdsey cliffs, to the south of East Lane, Bawdsey, considering possible mechanisms for the observed change in erosion rates.
Bawdsey - Beach morphology report (Environment Agency Shoreline Management Group, 2010)	Environment Agency	This report considered the frontage from Shingle Street to Bawdsey Manor and analysed 10 beach profiles between 1991 and 2010, aerial photographs and the condition of defences.
Shoreline Management Plan SMP7 (Royal Haskoning, 2010; approved 2012)	Suffolk Coastal District Council, Waveney District Council and Environment Agency	As part of the development of the SMP policies, a coastal process study was undertaken. This considers, using evidence form previous studies: to consider (1) the broad scale background to the coast, discussing the interaction between the coastline, the underlying geology and the

		nearshore area and (2) local scale shoreline processes, including information on water levels, waves, sediment movement, coastal change and principal control features. The report also provides an estimate of future erosion based on the above information.
Hollesley to Bawdsey Sea Defences -Environmental Statement (Posford Haskoning, 2003; amended by Halcrow, 2005)	Environment Agency	Provides an environmental appraisal of the preferred implementation options for East Lane.
Bawdsey Manor implementation report (Royal Haskoning, 2003)	Suffolk Coastal District Council	Provides advise on the implementation of the Holesley to Bawdsey strategy along the Bawdsey Manor frontage. Appraises different options, based on previous studies of shoreline behaviour.
Hollesley to Bawdsey Sea Defences - East Lane detailed appraisal (Posford Duvivier, 2000)	Environment Agency	This report pre-dates the SMP and it is likely that evidence from this was used in developing the SMP baseline understanding. It comprises the EA's submission got approval of defence works and East Lane and considers various options.
Hollesley to Bawdsey Sea Defences - Coastal process report (Posford Duvivier, 2000)	Environment Agency	This report pre-dates the SMP and it is likely that evidence from this was used in developing the SMP baseline understanding. The purpose of this report was to examine the coastal processes and long term morphological trends along the Hollesley to Bawdsey frontage, and in doing so to review the findings of the first SMP covering the frontage: the Lowestoft to Harwich SMP (Halcrow, 1998).
Orfordness GCR site report (May, 2007)	Joint Nature Conservation Committee	Provides a geomorphological description of Orfordness, based upon a review of previous papers. Includes a synopsis of historical change of the spit, up to 1985.
The estuary of the River Ore, Suffolk: Three decades of change in a longer-term context (Carr, 1986)	-	This paper describes changes at the mouth of the River Ore from 1956 to 1985 based on annual topographic and hydrographic surveys. It includes a conceptual mode to explain the mechanism by which the distal end of the Orford spit breaks up and its influence on the adjacent shoreline of Shingle Street.
Shingle Street: Suffolk: a brief geographical introduction (Cobb, 1956)	-	This paper describes observations of change along the Shingle Street coastline and offers possible explanations for the evolution of the

		coastline here, between the earliest Ordnance Survey mapping and 1957.
The Suffolk Coast: Orford Ness (Steers, 1927)	-	This paper describes observed changes which have taken place along the Suffolk Shore between Yarmouth and Aldeburgh, focussing on the evolution and structure of Orford Ness.

Appendix A, Table 1

A.2.2 Historical maps

A high level examination of historical maps of the study frontage has been undertaken to appraise the analysis presented in previous reports.

Although there are maps of the area dating back to the time of Henry VIII, these are commonly schematic and can only provide an indication of the general nature of the coast. Slightly more reliable maps were produced in the 1700s and Steer (1927) considered these in his appraisal of how Orfordness has evolved over history. The first edition of the Ordnance Survey maps was produced in 1805, with a revision in 1856, but it is not until 1888 when the first six-inch maps was produced that the level of detail becomes equivalent to today's mapping.

The maps have been used to review changes in the coastline over time, but no GIS analysis has been undertaken at this phase. Maps have been viewed on-line from https://maps.nls.uk/.

A.2.3 Monitoring data

Beach level data along the coast is collected as part of the Anglian Coastal Monitoring Programme. Data dating back to 1991 is available for a number of locations, at roughly one kilometre intervals, but additional data for intervening areas is available from 2007/2009. The latest survey available is August 2018.

A visual analysis of the data has been undertaken at this stage to appraise the key changes in the beach morphology. This has included data for the area stretching from North Weir Point (north of Shingle Street) to the River Deben: see Figure A1 for profile locations.

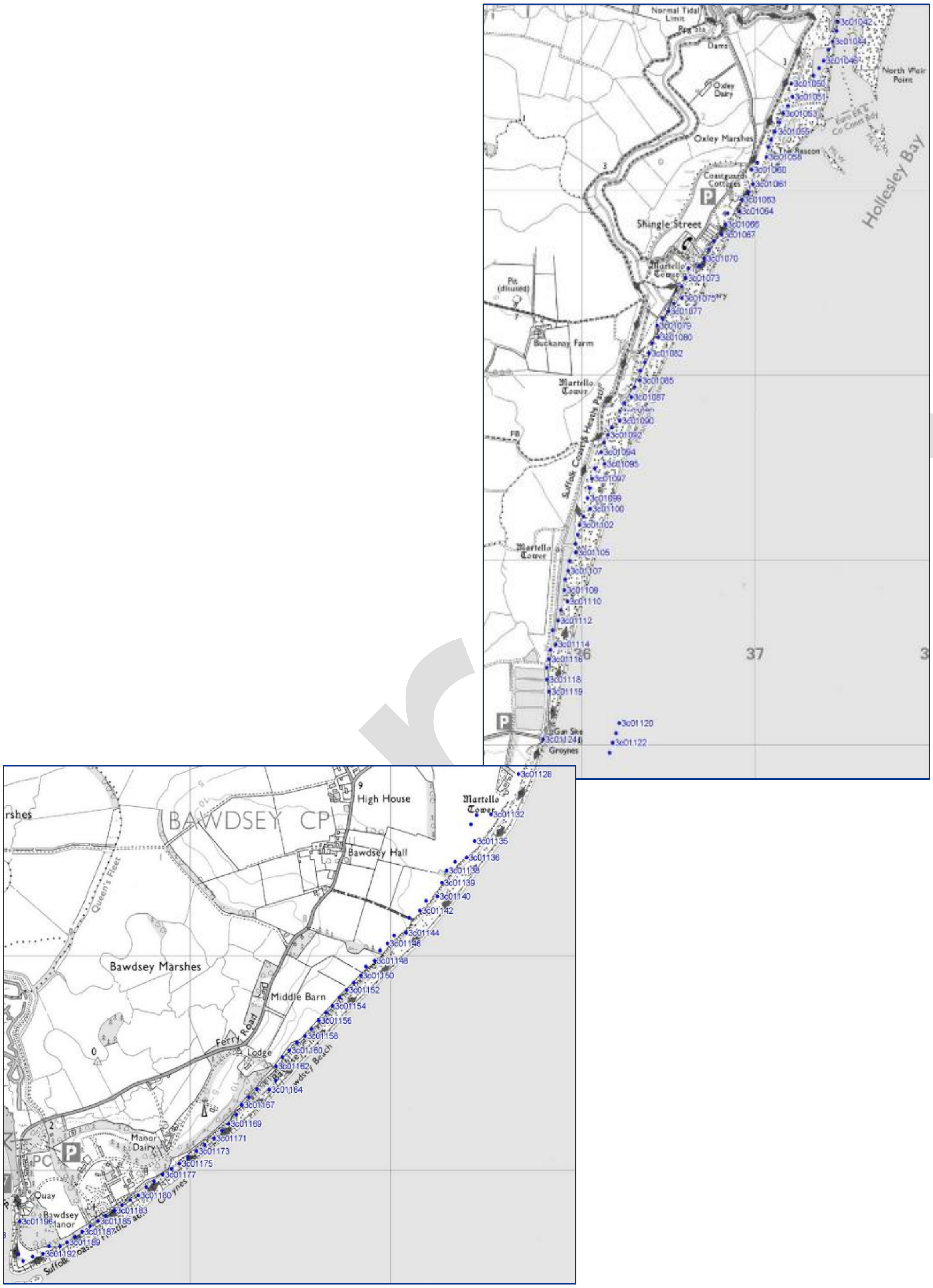

Figure A1 Environment Agency beach profile locations: note that only selected profiles have a full or partial data set: some only have data from 2011 and 2017. Profile location names have also changed over time.

A.3 Collation and review of evidence

A.3.1 Introduction

The dynamic nature of this coastline and of the wider Orfordness system is highlighted in all of the previous studies and with this dynamism inherently comes a residual uncertainty in terms of: the key drivers of change, interactions of these various drivers and the superimposed human interference on these processes. One of the more recent appraisals by Barber (2017) highlights this uncertainty and recommends a number of additional studies to fill gaps in knowledge. Whilst accepting these gaps in understanding, the aim of this policy review is to consider how management of this coast should best be undertaken, based on the evidence available. This section therefore sets out to identify areas of agreement and disagreement within the literature in order to build up a picture of shoreline behaviour and response.

A.3.2 Historical change

Usually an understanding of how the coastline has evolved in the past can give an indication of how it is likely to respond in the future: this depends upon identifying a trend of change or alternatively a cycle of change.

At the very basic level the underlying geology of an area sets the baseline for future change. Steers (1927) describes this coastline as an example of a 'submerged low coast' formed during the last ice age. The solid geology of the region is soft, locally consisting of London Clay and Red Crag (a shelly sand deposit (Daley and Balson[1]), making it easy erodible. However, the relatively resistance of these two materials has resulted in local variations in the rates of erosion. London Clay is relatively more resistant to erosion than the overlying Red Crag, therefore headlands have tended to form where London Clay crops out above mean sea level, whilst shallow bays formed where weaker crags are exposed allowing the formation of marshes in these lower lying areas (Halcrow, 2011). Bawdsey was formerly known as 'Baldhere's island' and the elevated area to the south of East Lane would have originally formed a semi-island surrounded by marshland. Early maps also show that even prior to defences this stretch formed a slight promontory along the coastline.

It is not known when a barrier beach started to form along the Hollesley Bay shoreline or whether it existed prior to the extension of Orfordness southwards, which progressively deflected the mouth of the River Alde southwards, as early maps do not depict this level of detail, but it is likely that erosion of Bawdsey Cliffs would have contributed some beach materials over time (contributions from the cliffs are discussed later). Previous studies do agree, however, that maps from the early 1500s to the late 1700s provide unquestionable evidence for the development of Orfordness and southward extension of Orford Spit (e.g. Steers, 1927; Burningham and French, 2016).

Pye (2014) concludes that that the mouth of the Alde-Ore has lain approximately opposite Hollesley since the late 1700s, although the position and width of North Weir Point and the estuary mouth vary significantly on annual to decadal scales. He also reports that a survey by Trinity House in April 2014 shows that the estuary mouth had moved by around 80 m north compared to its position in 2012, concluding that this demonstrates the difficulty in appraising whether the estuary itself is in morphological equilibrium. These variations in the width and position of North Weir Point, which defines the distal end of Orford Spit, were examined in detail by Carr (1986): from the literature examined this appears to be the most comprehensive analysis of change undertaken, although it only considers change up to 1985 (see Figure A2).

Carr describes how the main channel of the River Alde has changed in alignment over time from shore-normal (in 1958) to shore-parallel, associated with the development of the Orfordness spit and connected shoals, and builds upon earlier work by Steers (1927) and Cobb (1956). His observations were summarised by May (2007) (see Figure A3), which illustrates a 'cycle' of change, although Carr highlights that this 'idealised cycle' may be

[1] Daley B., Balson P. (1999) British Tertiary Stratigraphy. Geological Conservation Review Series Volume: 15. Joint Nature Conservation Committee.

interrupted by events such as storms and that as the maps and charts used are only snapshots in time, phases of the spit development may not be represented.

Carr (1986) questioned earlier assumptions regarding the regularity in the cycle; for example, work by Cobb (1957), which reported periods of growth lasting around 100 years, followed by retreat based on observations that the spit reached a maximum length in 1811 and again in 1893. Instead he recognised that even over short time periods, accretion of the distal end of the spit was very irregular, ranging from no change between 1956 and 1957 to 80 m between 1962 and 1963. This is similar to conclusions regarding the Knolls at the mouth of the Deben reported in Royal Haskoning (2003, 2016), which state that within the Knolls there is not a regular cycle of growth, collapse and regrowth, but instead they evolve in an unpredictable manner, affected by changes in tidal flows, water levels and storms.

A key observation made by Carr (1986) was that during periods when Orfordness spit has extended south, the Shingle Street shoreline has experienced recession, suggesting that a minimum width of the river mouth is maintained. This has also been reported by others. There is also evidence to suggests that the regrowth of the spit takes place along the same alignment each time, with no obvious migration of the spit landwards, based upon the discovery of peat south of the spit (Carr, 1986; May, 2007).

Pye (2014) suggests that this natural variation in mouth reflects the interaction of waves and tides in controlling alongshore and onshore-offshore sediment transport. Carr (1986) was, however, unable to define a direct link between annual wave climate and annual growth of Orfordness spit. He did note, however, that the 1953 storm did not cause a breach, suggesting that a critical state has to be reached before a breach can occur. Cobb (1957) suggested that the most southerly location of the spit has been opposite Martello Tower Z at the southern end of Shingle Street, whilst the most northerly known location since 1811 was reportedly in 1912 (Posford Duvivier, 2000); the distance between the two locations is more than 2.5 km, as shown on Carr's (1986) maps (see Figure A2).

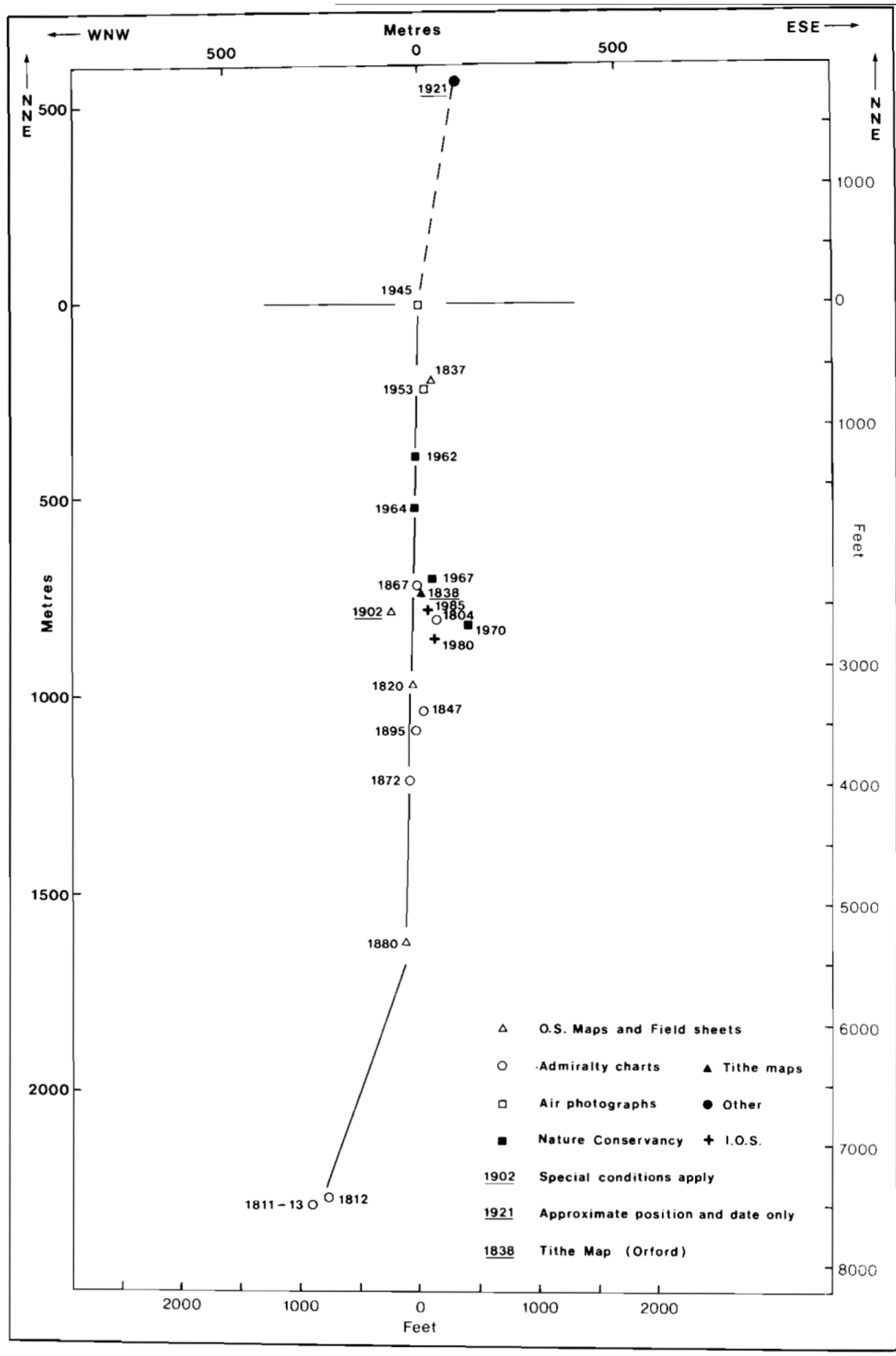

FIG. 8.

North Weir Point: distal point 1804–1985 showing variation in length but consistency in orientation. Note the clustering of dates close to the mean position and the apparent variability in growth rates from time to time. The latter are largely determined by the disposition of the contemporary banks and shoals.

Figure A2 Carr's figure (1986) showing the change in length, but not orientation, of North Weir Point between 1804 and 1985, based on a variety of sources.

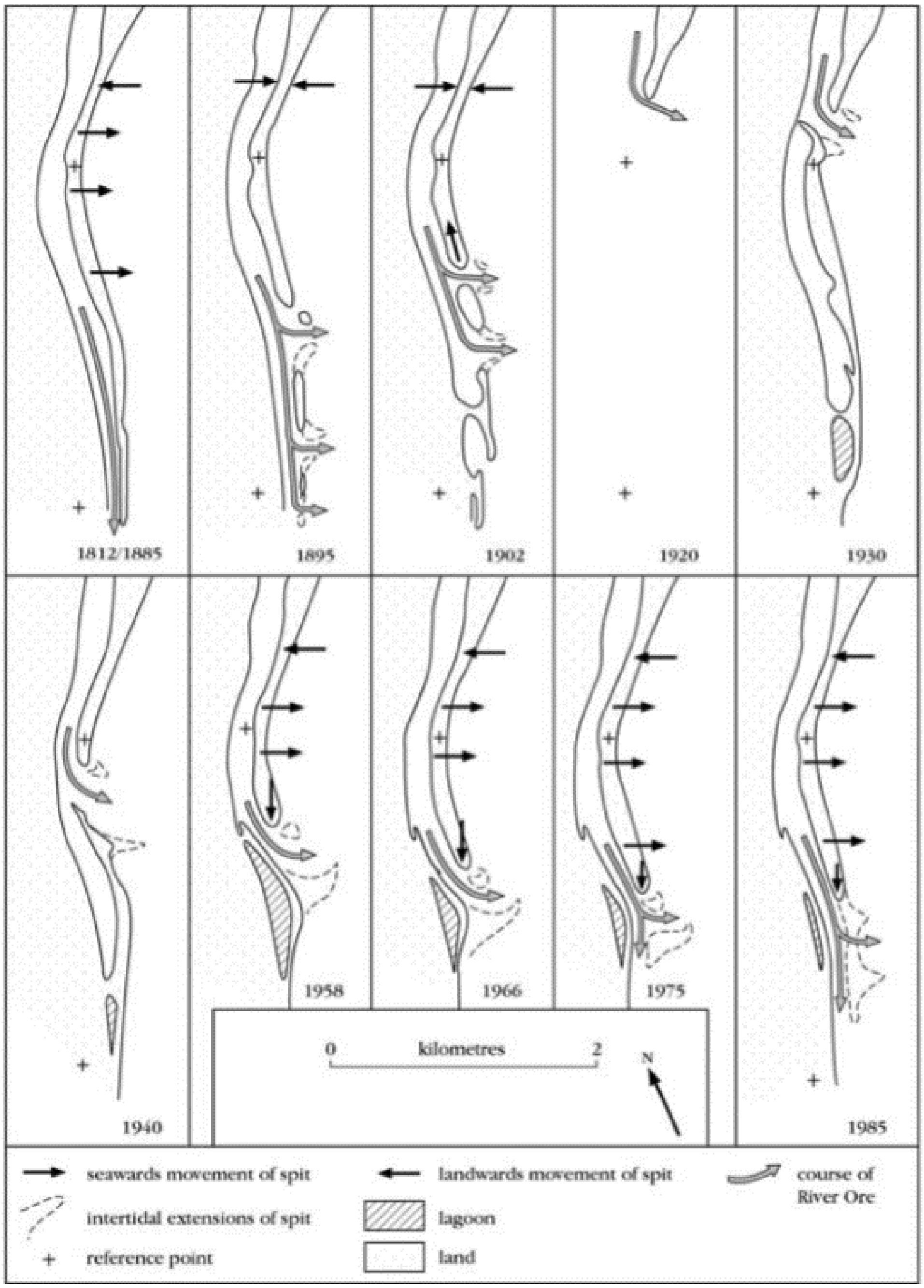

Figure A3 Figure 6.44 from May (2007) showing historical changes in the position of distal features at Orfordness (after various authors, mainly Carr, 1965; and Green and McGregor, 1988.)

Whilst Carr's work focused on the spit, the most recent work looking at shoreline changes along the rest of the study frontage has been undertaken by Burningham (reported in HR Wallingford, 2016) and Burningham and French (2016). This has involved mapping shoreline position from historical maps and more recent aerial photographs and is included here as Orford (2017) raises some uncertainty in the plotted shoreline position, given the range of map and aerial sources used and the fact that this is usually related to mean tide or spring high tide. The data remains useful in providing an indication of trends of change in the beach face, but fails to capture the more complex roll back process and cross-shore changes which are more revealing regarding coastal change along this shoreline. It is also evident within HR Wallingford (2017) that this has led to some misinterpretation of the data as presented.

Shoreline mapping data from Burningham were also used by HR Wallingford (2016) to appraise changes to the south of East Lane, who conclude that south of East Lane, beaches have gone through phases of advance and retreat but that recession has been the dominant trend, with recent surveys indicating the most landward shoreline position over the past 130 years (**Error! Reference source not found.** A4).

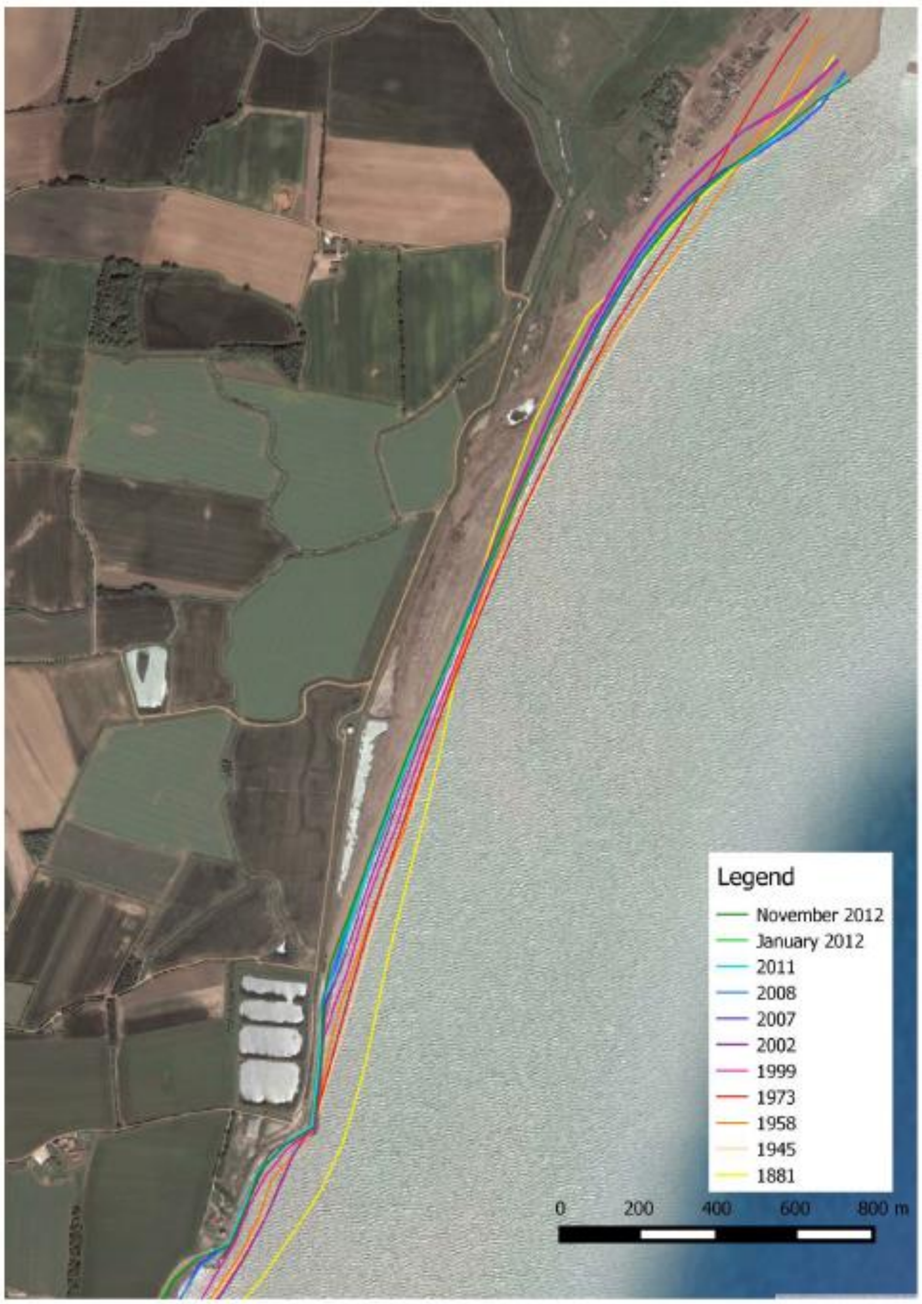

Figure A4 Taken from HR Wallingford (2016) – Mapping of shoreline position change by Burningham.

Based on the shoreline position mapping, both HR Wallingford (2016) and Orford (2017) discuss evidence for rotation of the shoreline between North Weir Point and Shingle Street. This contrasts with earlier conclusions by POsford Duvivier (2000) and the SMP2 (Royal Haskoning, 2016) that Hollesley Bay was in net equilibrium. HR Wallingford (2016) refer to a '*seesawing of the coastline around a hinge point in the centre of Hollesley Bay … with beach sediment transferring from one end of the frontage to the other'*, whilst Orford (2017) proposes that changes along the coast could possibly be explained by a regime driven by beach rotation defined as '*where two controlling headlands act as boundaries to an oscillating beach alignment which rotates on a central pivot between the headlands*'. Whilst a comparison between the mapped 1881 and more recent shoreline positions would support the concept of a rotating coast, this rotation is not so apparent when comparing post 1945 data sets, which tend to show a simple retreat along most of the shoreline, albeit more pronounced in the south, whilst at the northern end there has been accretion associated with the ness feature.

An examination of the historical maps also reveals that historically there has not simply been erosion of the shoreface, but that between 1888 and 1928 there was a significant change in whole beach system with the shingle ridge rolling inland by up around 100 m in places enveloping hinterland areas. In response a new, more formal, embankment was constructed at the rear of the barrier beach, which remains in situ today.

Mapping from this period seems to indicate that it was between map editions from 1888 and 1902 that a critical change in shoreline behaviour occurred. The 1888 maps show that at this time there were no defences along the East Lane frontage and that a continuous beach was present linking Hollesley Bay to the Bawdsey cliffs frontage and southwards to the River Deben. To the north of East Lane, the maps show vegetation at the back of the beach suggesting a very stable system.

In contrast, the OS map from 1902 shows that at this time the beaches north of East Lane were severely depleted and there is evidence of overwashing indicated by the presence of debris fans inland of the barrier beach. By this point, groynes had been constructed at East Lane, which suggests that diminishing beaches had prompted their construction, in order to reduce erosion of the cliffs. Subsequent roll back of the barrier beach north of East Lane indicated by the 1928 map led to the emergence of East Lane as a headland, which has remained the situation up to the present day.

Over the same period, beaches to the south of East Lane indicate a slightly different pattern of behaviour. In 1888, the mapping indicates that shingle beaches were present along the frontage, but formed only a narrow strip along the frontage south of the beacon, with mud patches exposed on the foreshore. By 1902, although beaches immediately south of East Lane diminished, there is some indication that the upper beaches further south may have improved slightly and there is no indication of any cliff erosion. There is a difference in the position of mean low water, which could indicate steepening of the beach profile, but this may simply reflect a change in mapping technique. By the following map edition (1928), there had been retreat of the cliffs south of East Lane and also beaches diminished further south resulting in retreat of mean high water. The only area to have improved by this period is the Bawdsey Manor frontage.

A number of studies have also analysed beach profile data sets, which include data back to 1991, to appraise recent beach change. The most recent of these was the work undertaken by HR Wallingford (2016), which looked at beach profiles for the period 1992 to 2015. This reported that the beaches immediately north have been eroding, with the zone of erosion extending northwards over time, whilst the central part of the bay shows some stability. From this HR Wallingford (2016) concluded that north of East Lane the data indicates a movement of beach sediment northwards from East Lane, accumulating at or just south of Shingle Street. Whilst south of East Lane the profile data seems to suggest a net southward transport trend leading to erosion south of the defences at East Lane, which is maintaining beaches further south at Bawdsey Manor.

To review this, as part of this appraisal, a high level appraisal of beach profile data has been undertaken. From this, a number of key observations have been made for the coastline north of East Lane:

- From the data, there is little evidence of any onshore rollback of the shingle barrier – instead recession has been through erosion of material from the beach face, resulting in a parallel retreat of the face over time. The only exception to this was observed immediately north of East Lane. Here the data shows that once the shingle barrier reaches a critical width, shingle can be moved onshore enabling some rollback of the crest. This process is illustrated below (Figure A5).

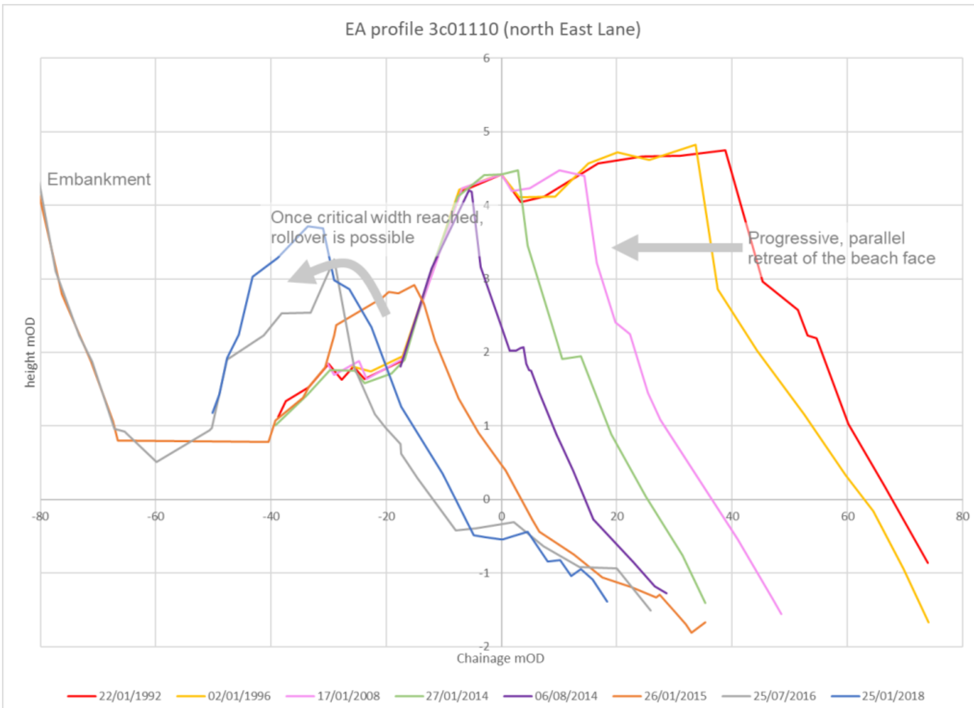

Figure A5 Selected profile data for EA profile 3c01110, just north of East Lane.

- Between East Lane and the northern end of the lagoon, all beaches show recession over time, with removal of shingle from the frontage face. Erosion has progressively moved northwards and the latest data suggest that profiles 3c01096 and 3c01095, just to the south of Martello Tower Y are starting to show signs of net recession.

- The data for this stretch of coast also indicates beach ridges present landward of the barrier crest, indicating a potential sediment pathway, but there is no evidence that this material is moved onshore. In contrast, further north, the data indicates that beach levels fluctuate over time indicating sediment fluxes, with shingle both moving into and out of the frontage. The changes recorded at profile 3c01100, which lies at the northern end of the lagoons illustrates a change in behaviour that has occurred around 2014 (see Figure A6). The data show that between the start of the data set in 2009 and 2014, the beach fluctuated in level with evidence that this frontage received shingle which was then pushed onshore to build the beach on occasions. A change in net trend occurred around 2014, when there was erosion across the frontal face of the barrier. Since this time the net trend has been for recession through erosion of the frontal face resulting in a reduction in beach width and there is little evidence of the frontage receiving any sediment influx.

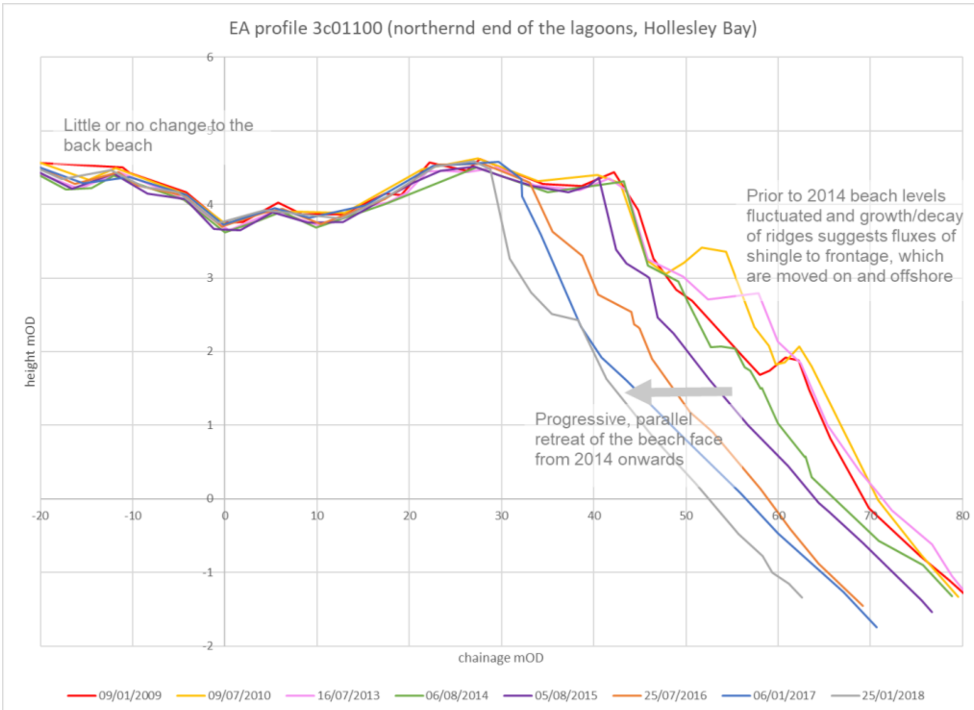

Figure A6 Selected profile data for EA profile 3c01100, at the northern end of the lagoons, Hollesley Bay.

- Between Martello Towers Z and AA (Shingle Street), north of profile 3c1093, the beaches are dynamic and exhibit periods of growth and retreat, suggesting both supply and removal of shingle from this area. The beaches generally indicate net accretion, at least since around 2014. Prior to this, it is more difficult to identify a net trend.

- The beach north of Martello Tower AA, along the Shingle Street frontage, to The Beacons, indicate a more variable development, with distinct periods of growth and recession. Unfortunately, there is only one profile location where data is available from 1992 (profile 3c1070). Although this location indicates a net advance of the coast over the time period available (1992 to 2018), with development of new beach ridges, within this there have been periods of retreat/no net change. This, and other profiles, along this stretch do indicate a period of net growth since 2011. Beach profile 3c01064, which lies closer to The Beacon illustrates how material arrives in the nearshore zone, moves onshore and becomes welded to the beach face (Figure A7).

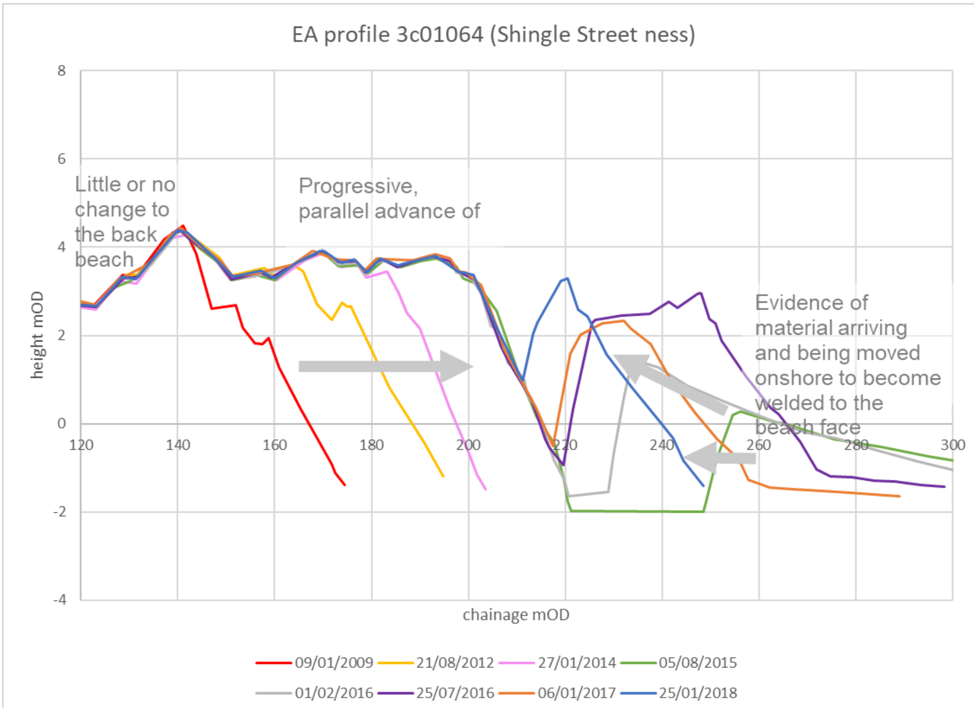

Figure A7 Selected profile data for EA profile 3c01064, between Shingle Street and The Beacon.

- North of The Beacon, Shingle Street, the pattern of change is more irregular. This is the main area of the ness and is extremely dynamic. The longer profile data sets (3c1058 and 3c1050), indicate periods of net gain and loss of material from the beach. Most recently, between 2011 and 2018 there has been net loss of material, with shingle being stripped from the beach face. Profiles to the south indicate growth but there is no data for the beaches to the north, therefore it is difficult to define the fate of this shingle. Profiles along this stretch do, however, illustrate the onshore movement of material with shoaling of the subtidal recorded within the data.

To the south of East Lane, variable trends of change can be observed from the beach data, with three distinct areas of change evident:

- Between East Lane and Bawdsey Hall (profiles 3c01128 to 3c01143) there has been cliff erosion, with greater erosion over the data time period in the north that to the south, with over 30 m retreat of the cliff to recorded at profile 3c01132 (in the vicinity of Martello Tower X) between 2009 and 2013. Since 2013 there is been limited further cliff erosion recorded and there is evidence that the beach at this northern end has built up. As the cliff has retreated it has exposed the London Clay platform, which has created accommodation space for beaches to be retained. Notably, the beaches further south continued to erode up to 2014. Halcrow (2011) undertook a detailed review of the changes here, with additional analysis undertaken by Mott Macdonalds (2015). Halcrow attributed the accelerated erosion of the cliffs south of East Lane in part to the artificial lowering/ damage to the clay shore platform possible due to engineering works in 2009, with the construction of the breakwater. The profile data reveals unusual features in the exposed platform which may correlate with this observation, but further analysis would be necessary to confirm this as an erosional cause. The cliffs were also observed by Halcrow (2011) to be particularly active where water seepages were evident.

- In contrast, data for the cliffs south of Bawdsey Hall to Manor Diary (profiles 3c01144 to 3c01176) indicate that there has been progressive beach loss resulting in narrowing and increasing exposure of the cliff toe. The northern-most profile (3c01144) shows cliff erosion between 2014 and 2015, following a period of diminishing beaches (see Figure A7). This location shows that the cliffs remained stable between 2015 and 2018, but beaches continued to drop resulting in further cliff erosion in 2018. The only other profile to show cliff erosion is 2c01172, near the beacon. As elsewhere beaches have been receding since 2011 (which is the start of the record here), with initially some retreat of the cliff toe in 2016, but the most recent data (August 2018) indicating recent cliff top retreat.

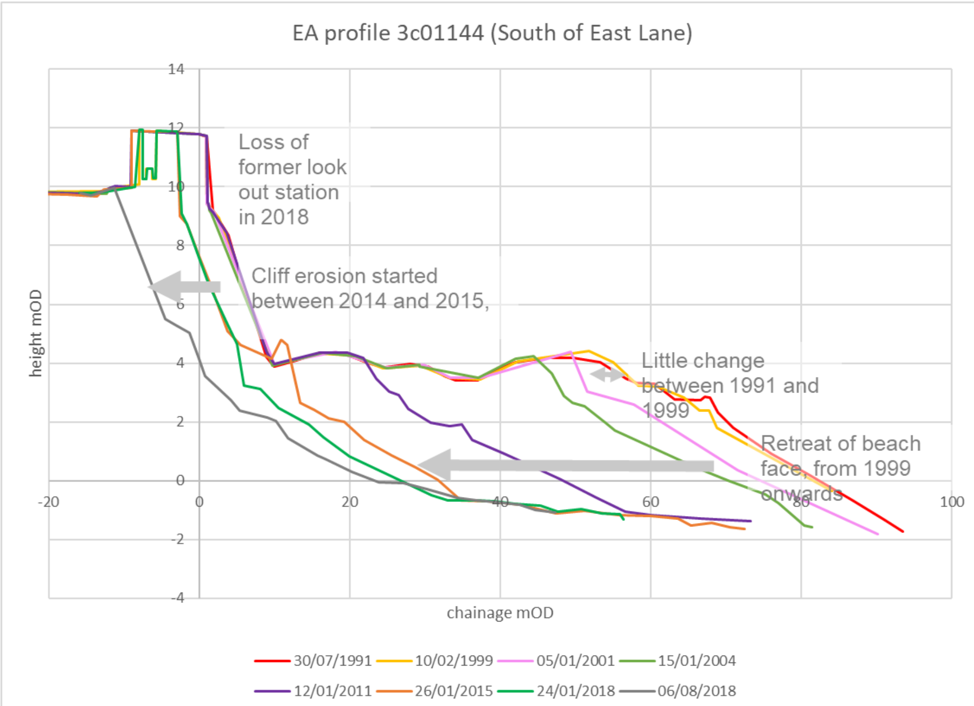

Figure A8 Selected profile data for EA profile 3c01144, south of East Lane

- South of Manor Diary (profiles 3c01176 to 3c01194), the data sets indicate very volatile beaches which have both gained and lost sediment over time. Beach levels here have fluctuated by over 2 m over time, with a change in width of up to 20 m. It is noticeable, however, that current beach levels are generally the lowest in the data record (which in places dates back to 1991) and that since 2014 beaches along this stretch have commonly been lower than previously.

From the studies appraised, there does not appear to have any detailed appraisal of changes in volume within the coastal system, which was also concluded by Barber (2017), and the study by HR Wallingford (2016) states that the balance between the gains of shingle from the north and losses to the south is highly variable and difficult to both measure and predict, due to the episodic nature of the transfer of sediment across the mouths of the Alde-Ore and Deben estuaries.

As part of his appraisal, Orford (2017) did undertake some very high level calculations of likely changes, in order to assess possible impacts on the SAC of beach losses at East Lane. He estimated that the increase in areal extent on the Shingle Street Ness has been 3 to 4 times the loss at East Lane, such that SAC gains at Shingle Street Ness significantly outweigh losses at the southern end of the frontage. This also indicates that erosion at East Lane has not been the primary contributor to accretion at Shingle Street.

Historical mapping and beach profile data only capture the visible part of the beach, but the influence of nearshore features has been recognised by previous studies, including the early studies by Carr (1986), who highlighted the possible role of the nearshore banks in protecting Orfordness spit until it extended beyond their influence. There are a number of seabed features which have the potential to affect the study area, namely

Cutler Bank, Whiting Bank, Bawdsey Bank and also Shipwash, Inner Gabbard Bank and Outer Gabbard Bank, which lie further offshore (see Figure **Error! Reference source not found.**).

HR Wallingford (2016) refer to analysis of bathymetric charts by Burningham and French (2009), which covers the period 1840 to 1990. From this, they conclude that there is some evidence to suggest that the Cutler Bank, which lies offshore of the Deben, has moved offshore and lowered. There has also been a possible offshore movement of Whiting Bank, which lies offshore of Hollesley Bay, but no change in depth. HR Wallingford tentatively suggest that these changes may have increased wave energy along the frontage. However, they were unable to find evidence of differences in the nearshore that would lead to differential erosion and accretion along the beaches near East Lane.

More recent analysis of the surveys by Burningham and French (2016) concludes that the seabed around Shipwash has lowered, but with evidence that the bank itself has accreted, possible indicating reworking of sediment eroded from its margins. The same project also reports that Bawdsey Bank has accreted, but over a more substantial area, including a large region to the north of the bank. The authors suggest that this is likely associated with the opposing ebb (north-flowing, between the banks) and flood (south-flowing, around the banks) tidal currents. The key conclusion is that substantial accretion within the north part of this system and erosion to the south has resulted in the northward shift of the whole system. This has also resulted in the banks also moving closer to the shoreline – around 600-800 m in the case of Whiting Bank.

There does not, however, appear to have been any analysis or modelling of how these banks could affect shoreline processes and behaviour within the study frontage, but there is potential that they could affect both tidal flows within the area and also the nearshore wave regime.

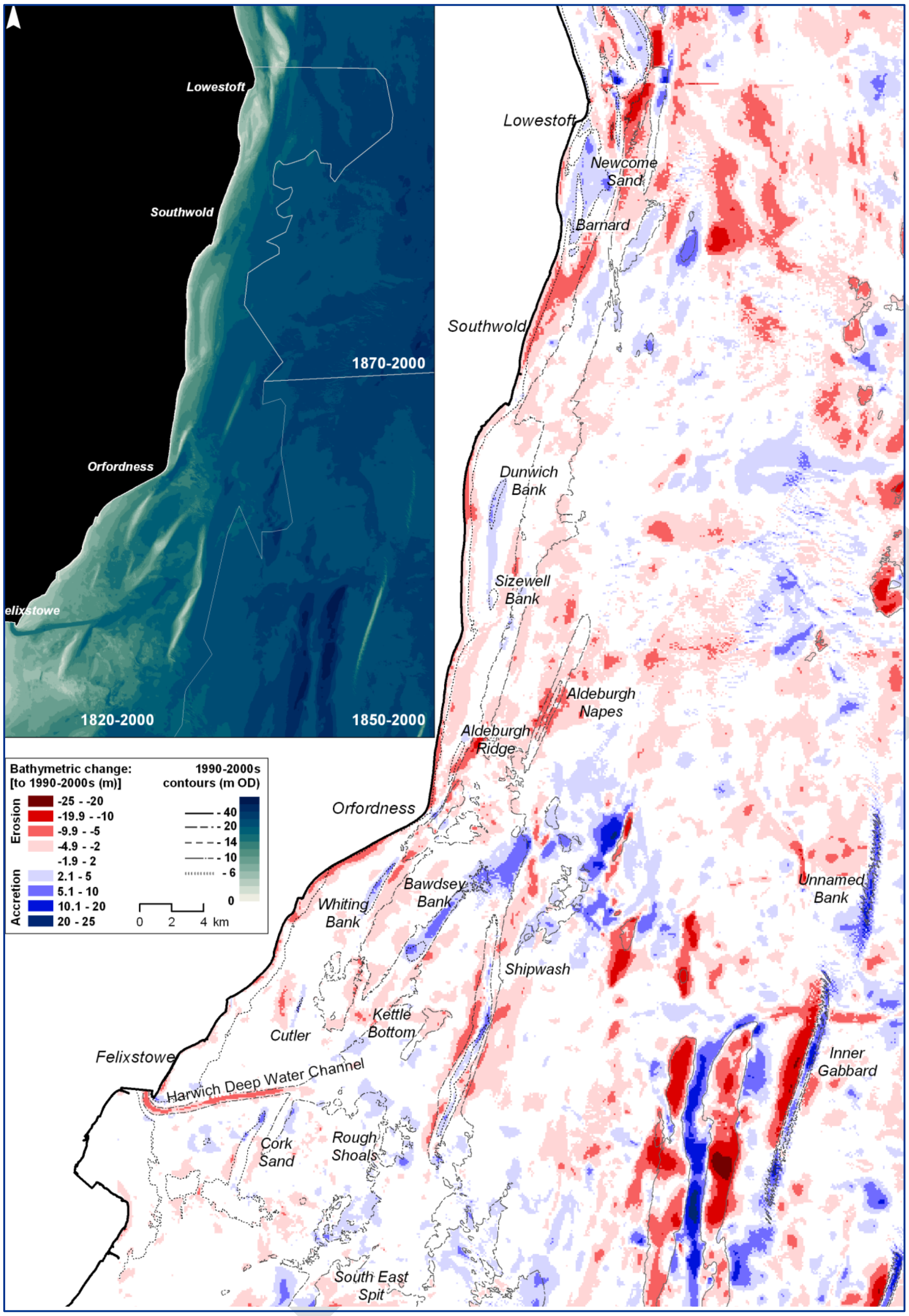

Figure A9 Taken from Burningham and French (2016) (Figure 2.18) which shows the distribution of banks across the wider Suffolk area and the net change in bathymetry between the earliest (1820s-1850s) and the most recent (1990s) surveys. The Inset map shows the extent of each early survey used.

A.3.3 Controls and drivers of change

A.3.3.1 Tides

The coast is meso-tidal with a spring tidal range of 2.8 m at Orford Haven to 3.1 m at Bawdsey; the tidal range increases from north to south (reported in Royal Haskoning, 2016).The SMP2 (Royal Haskoning, 2010) suggests that along the coast tidal flows nearshore are relatively ‘low’ and typically from the north-east to south-west on the flood and the reverse on the ebb; Posford Duvivier (2000) reported average tidal velocities of 1.0m/s during a spring tide, with ebb evolocities around 0.1m/s greater than flood velocities. However, at the mouths of the estuaries, the constrained nature of flow means higher velocities result and a study by Black and Veatch (reported in Pye, 2014) reported values of 1.63 m/s at the mouth. The threshold velocity for 10 mm shingle in the absence of waves is around 1.5m/s (see Barber, 2017).

The earlier studies by Cobb (1956) and Carr (1986) both noted the potential for tidal currents at the mouth to move shingle northwards into the estuary and Cobb records that “*there is, however, a very strong current in this particular estuary, reaching speed of 6 knots* (3.1 m/s) *on the full flood, which is northward, and it would seem that this is the force which moves the shingle after waves have lifted it not suspension. An underwater survey … produced direct evidence of some shingle movig along the bottom beneath the strongest current*”. Pye (2014) does, however, report that near the estuary mouth ebb velocities are greater than the flood tide velocities which restricts any tidally-driven movement of shingle further into the estuary.

Barber (2017) noted that there was little discussion within the literature regarding tidally-driven transport of shingle along the open coast where flows are lower, but highlights the potential for sediment mobilisation through wave agitation and subsequent transport by tidal flows, which would mean that shingle would be able to be moved by much lower currents then if wave agitation was ignored.

A.3.3.2 Waves

Offshore wave data is available from Met Office hindcast models, with the most recent study by HR Wallingford (2016) obtained offshore data from Met Office European hindcast model, for a point around 45 km southwest of the study frontage. The data set covering the period 1980 to 2015 indicates that the waves approach predominately from the north, north-east and south-west. Analysis of this offshore data set by HR Wallingford indicates that the largest waves tend to approach from the south-west (Figure A10). This broadly concurs with data obtained by previous studies and indicates that the offshore wave climate is bi-modal. From their analysis of wave conditions around the Suffolk coastline, Burningham and French (2016) also concluded that the key driver of coastal wave conditions is the strongly bi-modal wave direction climate in which around 85% of waves approach from either a roughly northeasterly or a roughly southerly direction.

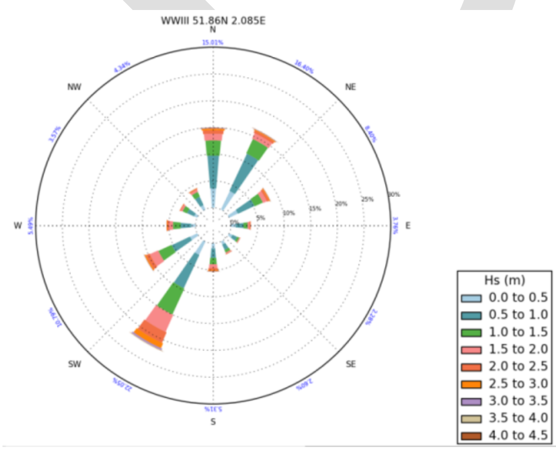

Figure A10 Offshore wave rose generated from hindcast Met Office data. Taken from HR Wallingford (2016)

However, various studies recognise that the nearshore banks and wider nearshore area significantly influence nearshore wave direction. From the studies reviewed, there is only one mention of any nearshore wave monitoring; HR Wallingford refer to a wave buoy at Bawdsey, which is part of the WaveNet, Cefas' strategic wave monitoring network for the United Kingdom. Data for this site are available for 3 years (2006 to 2009). All analysis of nearshore wave climate has therefore been based upon transformation of offshore waves inshore. Various studies have undertaken wave transformations including Posford Duvivier (2000), Halcrow (2005) and most recently HR Wallingford (2016) and Burningham and French (2016).

The report by Posford Duvivier does not include inshore wave roses, but inshore wave roses produced by HR Wallingford (2016) (Figure A11), derived from offshore data covering the period 1980 to 2015, indicate that along the entire length of shoreline between the River Deben and North Weir Point, there is almost an absence of waves from the north to north east sector. HR Wallingford (2016) correlate this phenomenon to both the protection afforded by Orfordness from waves from the north-east and the strong refraction of waves from offshore to inshore. It is noted, however that correlation of the model has been with monitored data from south of East Lane, where protection from north-east waves would be expected. Within their report, Burningham and French (2016) also refer to wave shadow zones.

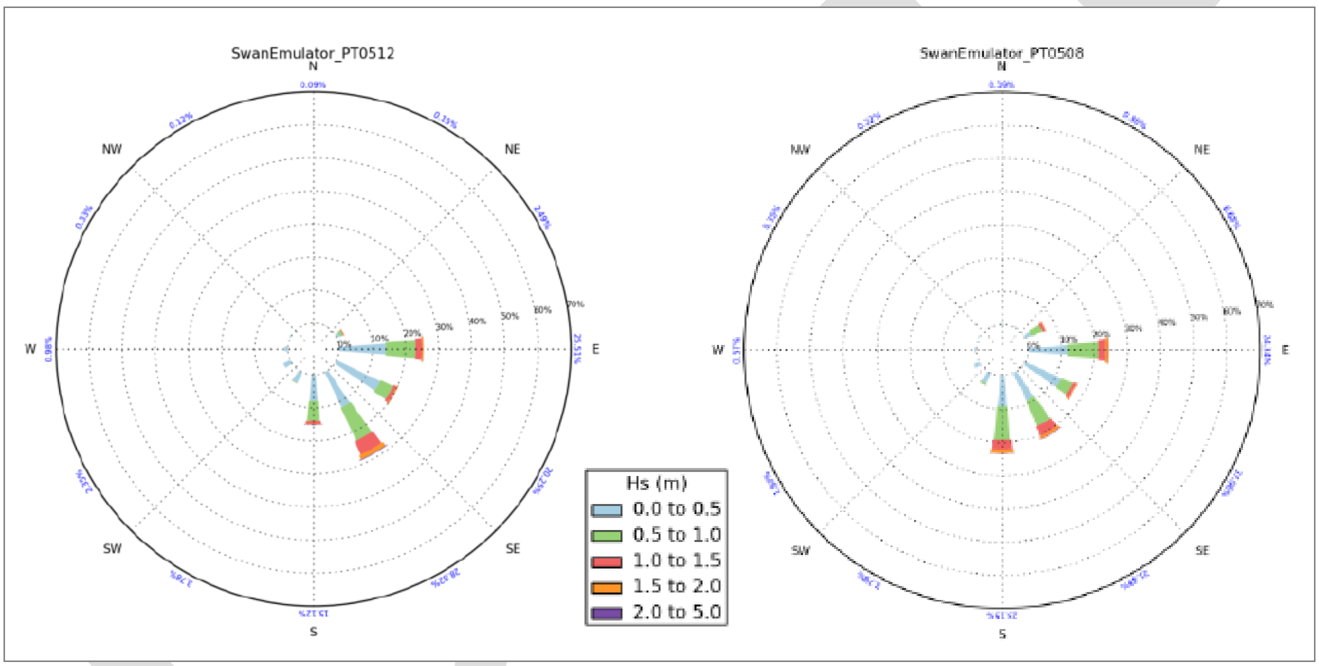

Figure A11 Inshore wave roses for Shingle Street (PT0512) and South of East Lane (PT508), taken from HR Wallingford (2016)

A.3.3.3 Wave-driven longshore transport

There have been various studies looking at potential sediment drift rates along the frontage and the SMP2 (Royal Haskoning, 2010) provides a synopsis of data up to 2010. Based on this, the SMP2 concluded that net drift along the frontage is from north to south, although north to east wave conditions will move material south, whereas south-easterly waves can cause northward drift. This concurs with the work by Posford Duvivier (2000) which determined that along Orford Ness spit the drift was almost exclusively southwards, north of East Lane there was potential for limited amounts of both northward and southward transport of sediment, whilst to the south of East Lane the trend changed again to almost exclusively southwards transport.

The SMP concluded that the patterns of sediment movement are therefore sensitive to wave conditions, with north-easterly conditions mobilising the whole coast and resulting in a southwards drift of sediment, but a more segmented movement of material during waves from any other direction. This southward net trend of movement concurs with studies undertaken prior to the SMP and reported in the Southern North Sea Sediment Transport Study (HR Wallingford, 2002). It also aligns with Steer's understanding of sediment movements in 1926, based on geomorphological evidence at the time.

More recent studies by HR Wallingford (2016) and Burningham and French (2016) have, however, questioned this transport regime. Using their modelled inshore wave data, HR Wallingford (2016) derived potential longshore transport rates based upon the CERC formula but including a coefficient to accommodate shingle rather than sand beaches. Their key conclusions are that whilst estimated gross rates are very high, between 86,000 to 133,000 m^3/ year, net rates are modest, between 10,000 to 45,000 m^3/ year and that, with the exception of the Bawdsey Manor frontage, the average annual net drift is northwards (Figure A12). They also propose that a drift reversal exists along the Bawdsey cliffs. The report goes on to conclude that since 2012, the profile data indicates a movement of beach sediment northwards from East Lane, accumulating at or just south of Shingle Street which is linked to a recent change in the direction of longshore beach sediment transport within Hollesley Bay from southwards to northwards, particularly since summer 2013.

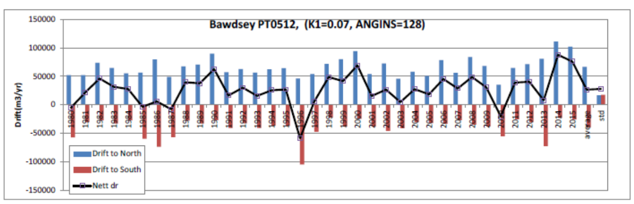

Figure G.1: Potential longshore drift from 1980 to 2015. Point PT0512 (S of Shingle Street)

(a)

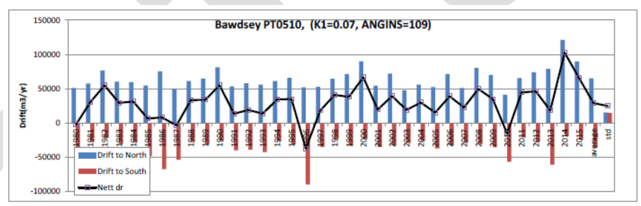

Figure G.3: Potential longshore drift from 1980 to 2015. Point PT0510

(b)

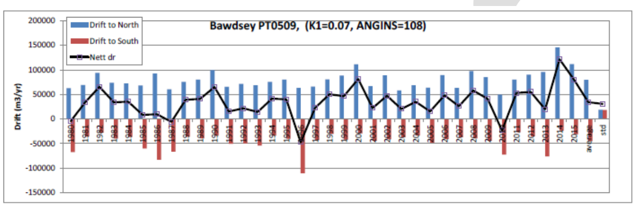

Figure G.4: Potential longshore drift from 1980 to 2015. Point PT0509 (East Lane)

(c)

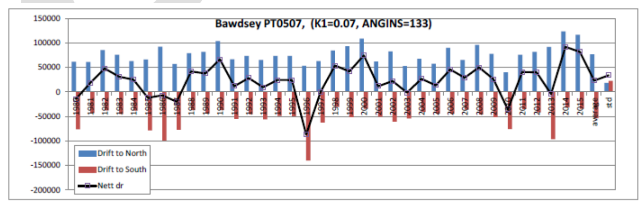

Figure G.6: Potential longshore drift from 1980 to 2015. Point PT0507

(d)

Figure A12 Potential longshore drift for various locations along the study frontage determined by HR Wallingford: (a) south of Shingle Street, (b) in the vicinity of the lagoons north of East Lane, (c) East Lane and (d) Bawdsey cliffs. Taken from HR Wallingford (2016).

In their study, Burningham and French (2016) used SWAN Cycle III version 41.01 model to consider the generalised pattern of wave energy variation and its effect on potential sediment transport along the coast, based on a composite bathymetric datasets ranging from 1982 to 2006 and offshore wave data from 2009 to 2016 (West Gabbard offshore Met Office dataset). They found that the effect of shoreline protrusions in creating shadow zones under high angles of wave approach was particularly evident south of Orford Ness. Their conclusion was that along the study frontage the net flux is harder to resolve, due to smaller gross southward and northward transports than elsewhere along the Suffolk coast, but that there appears to be northward sediment movement at Shingle Street, between Bawdsey and East Lane and just south of the Deben inlet (see Figure A13).

Burningham and French (2016) also considered the sensitivity of the coast to interannual variability in waves: comparison of the 2010 and 2011 wave climates with the combined 2009-2016 wave rose showed that 2010 experienced more north-easterlies and 2011 more southerlies than average. Analysis of the 2010 and 2011 climates indicated that the southern part of Hollesley Bay was sensitive to changes in the dominance of north-easterlies to southerlies, but the northern part of the bay was less so, with northward drift shown to remain dominant.

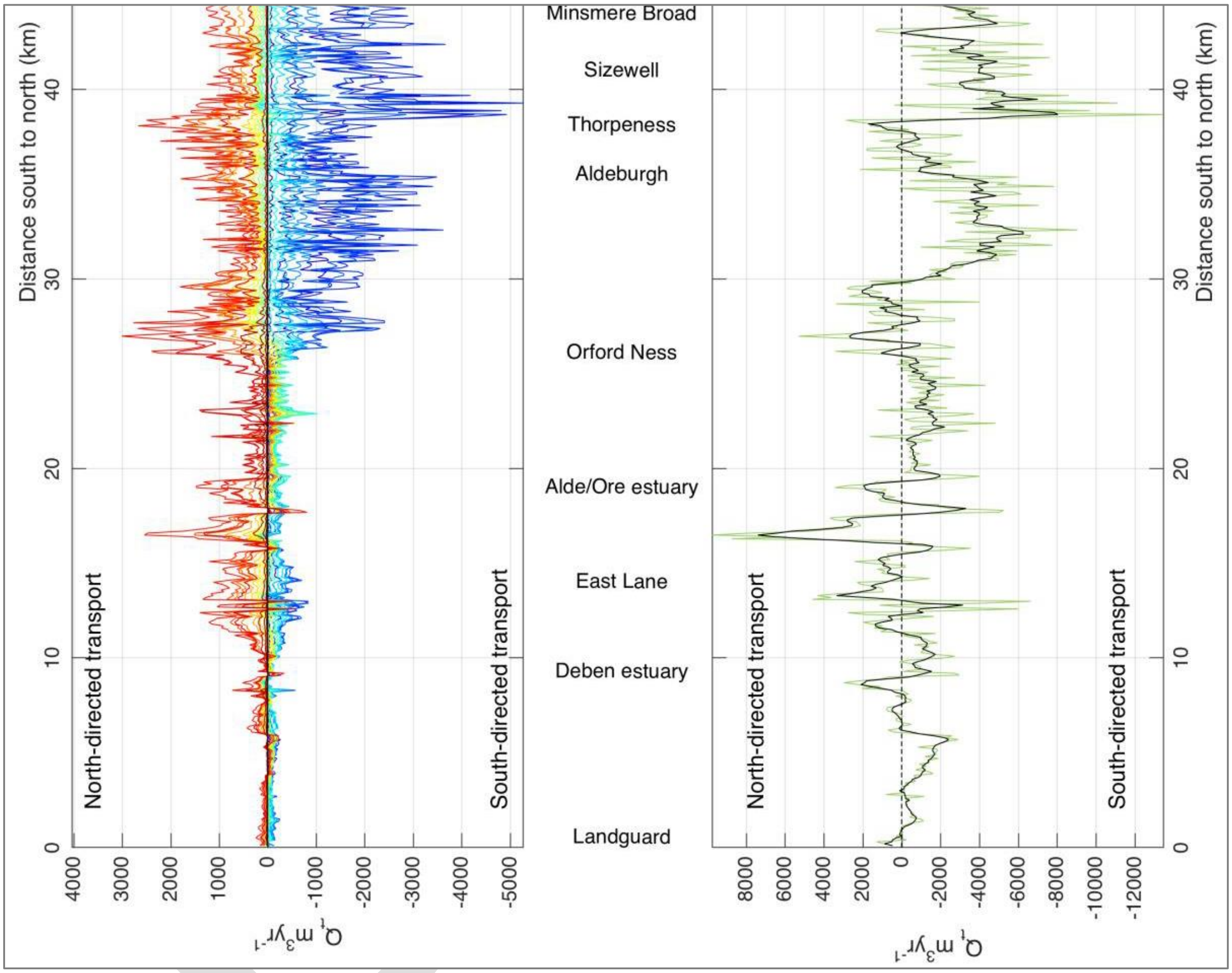

Figure A13 A portion of Burningham and French's Figure 4.9 showing computed potential longshore transport for coarse gravel (*d50* = 25 mm): a) longshore transport rate (annualised m³ /year) b) net transport rate for these conditions.

There is some disagreement within the various studies, regarding the potential for sediment to move around East Lane. The SMP2 (Royal Haskoning, 2010) described East Lane as a 'dam' which allows the bay to the north to fill before allowing a supply of sediment to the south, but suggests that if material builds against East Lane it has the potential to overspill to Bawdsey Cliffs and down and across the Deben. Although it does state that sediment has been held up at Shingle Street and within the North Weir Point banks, which have reduced the availability of sediment to bypass the frontage. Whilst Mott MacDonald's coastal process study (2015) proposed that a sudden appearance of coarse beach sediment south of East Lane is indicative that sediment is still able to move south around East Lane promontory.

However, in contrast, Orford (2017) concludes that '*There seems to be very little possibility of beach gravel transport around this protection (East Lane defended frontage) on a scale sufficient to maintain the contemporary position of the southern end of the Shingle Street Barrier*.' Based on this, Orford concludes that any northward feed to the ness at Shingle Street must be through cannibalisation of shingle within the barrier beach itself; although this is not substantiated by any additional analysis.

In support of this conclusion, from analysis of supratidal sediment stores, Burningham and French (2016) conclude that the on-going extension of defences at East Lane has established a discontinuity of the coastal sediment system. They were unable to find evidence of any overlying clastic/non-cohesive sediment in the lower foreshore/nearshore in the vicinity of East Lane from which they concluded that the sediment pathway between the south end of the Shingle Street barrier and the north end of Bawdsey Beach is weak, if not non-existent.

A.3.3.4 Sediment stores and sinks

In terms of sediment supply to the coast, there is general agreement within the literature that material enters the study frontage from the north from Orfordness. Transport onshore from the offshore banks is considered unlikely: the reports conclude that as Whiting, Bawdsey, Shipwash and Cutler Banks are formed of sand and crushed shell and therefore not considered to be a source of shingle to the beaches (EA coastal morphology report, cited by Barber 2017; HR Wallingford, 2016). Although there is limited data on seabed sediment, HR Wallingford (2016) conclude that as seabed surveys along beach profile lines indicate only mud and sand and there are no notable accumulations of shingle, this is evidence that there are no significant offshore losses of gravel. This does not, however, take account of the possibility that any loss of shingle is more likely to become strewn across the surface of the London clay rather than form discrete accumulations.

At the northern end of the study frontage, Pye (2014) reported the potential for wave-driven sediment transport northwards between Shingle Street and Barthorp's Creek along the western shore of the lower estuary, due to regeneration of refracted waves on the estuary side of the banks that lie at the estuary mouth (Pye, 2014). The significance of this movement is not, however, defined by Pye, but does concurs with much earlier work by Cobb (1957), which also reported the potential for northward drift of shingle into the estuary, as a result of combined wave and current action.

To the south of the study area, there is agreement that sediment leaves the study frontage via the banks across the mouth of the Deben, 'The Knolls', and that once material has crossed the river mouth and onto the Felixstowe Ferry frontage there is no transport mechanism enabling it to return northwards. However, the mechanism and frequency of movement is less clear. Posford Duvivier (2000) concluded that there is a constant southward movement of sediment across the mouth, supplemented by periodic releases of material from the banks. However, Royal Haskoning (2003, 2016) report that within the Knolls there is not a regular cycle of growth, collapse and regrowth, but instead they evolve in an unpredictable manner, affected by changes in tidal flows, water levels and storms. From their review of previous studies, Barber (2016) suggests that volumes required to maintain the Knolls over a 20 to 30 year period may actually be very little and that that '*the substantial beach along Bawdsey Cliffs could supply the episodic movement of sediment south onto the Knolls for several decades*'.

There is dispute within the literature regarding the significance of sediment supply from the Bawdsey cliffs. HR Wallingford (2016) refer to the BGS 2006 report, which considered cliff composition along the Anglian coastline. Bawdsey cliffs are described as Red Crag overlying London Clay. According to Daley and Balson[2] (1999), the Red Crag at Bawdsey comprises shelly sands. At the base is a discontinuous lag deposit containing flint, phosphorite and quartz pebbles. The BGS report estimated that the cliffs could contribute 25 to 30% coarse sediments, with a potential to contribute around 5000 m^3 of coarse sediment per metre retreat. On this basis HR Wallingford (2016) suggest the cliffs are a more important contributor to the beach system than previously

[2] Daley B., Balson P. (1999) British Tertiary Stratigraphy. Geological Conservation Review Series Volume: 15. Joint Nature Conservation Committee.

assumed. Halcrow (2011) in contrast state that the London Clay and Red Crag formations are dominated by clay to sand sized materials, and with the exception of a very thin and discontinuous flint gravel bed at the contact between the two formations, there is very limited supply of coarse beach building material. They concluded that as the cliffs erode the majority of material is transported away and a very small proportion remains in the beach.

A.3.3.5 Future shoreline behaviour

All previous studies acknowledge uncertainty regarding future shoreline behaviour and response, even under scenarios of no change in management.

The SMP2 argues that an increase in flow in and out of the Alde-Ore Estuary has the potential to destabilise North Weir Point, which could result in the breakdown and release of sediment through the tidal delta and bank system. But if tidal flows decrease this could result in the spit and bank system to move closer to the shoreline and increase the sediment supply and mobility across Shingle Street frontage. However, the SMP goes on to conclude that whilst locally significant to Shingle Street it is unlikely that changes in flows within the Alde-Ore would be unlikely to affect the overall sediment supply, just the timing and regularity. This seems to ignore the wider influence that the spit has on shoreline behaviour across the whole frontage down to East Lane.

HR Wallingford (2016) concluded from beach planshape modelling (albeit this modelling was not successful in predicting shoreline change within Hollesley Bay), that in terms of sensitivity to climate change, changes in wave direction have the greatest influence on beach changes. The study also suggests that the direction of drift may reverse naturally, leading to a return of shingle to the southern end of the bay and the need for any scheme to be able to adapt to variations in the wave climate is highlighted by Barber (2017).

Orford (2017) also considered the capacity for future change. He highlighted that it depends upon the balance between southward and northward dominance of net drift and the degree to which the Alde-Ore estuary mouth system would continue to provide protection to the adjacent shoreline. From this, he concluded that there was high uncertainty in predicting future shoreline response.

All studies concur that changes in management would have a significant impact on the shoreline behaviour and evolution although there is some variation in the arguments presented.

Posford Duvivier (2000) looked at the potential influence on transport rates if East Lane was realigned around 50 m landward. From this they concluded that more sediment could pass East Lane but that once it has passed there would be less force driving sediment further south, so erosion to the south would reduce slightly, with material being fed from the north of East Lane. In contrast, the SMP2 (Royal Haskoning, 2010) suggested that without the artificial headland at East Lane, material would still be held up at Shingle Street, but the control point at the southern end of Hollesley Bay would be Bawdsey Cliffs, 750 m south. It was concluded that this would significantly reduce the shingle width to north within Hollesley Bay, but with the probable development of a ness at the northernly section of Bawdsey Cliffs. There was little explanation, however, of the drivers of the ness development.

Given the narrow nature of the beaches at the southern end of the frontage, more recent studies conclude that there is a high risk of breach in the near future (e.g. BCP, 2016). Barber (2017) reports that previous studies present a general view that if existing defences were breached this could have a significant effect on alongshore movement of shingle and consequences for the shoreline to the south of any breach (based on an assumption of net southward drift of sediment). This assumes that the volume of shingle available to protect the bay will either remain the same or reduce, such that level of protection would also reduce, and assumes a net northward drift occurs and Shingle Street remain a sediment sink. The BCP report also suggested that effects of changes along this shoreline could be felt much wider, at Aldeburgh and possibly Southwold, although impacts were not quantified.

In his study specifically looking at managed realignment within the Alde-Ore Estuary, Pye (2014) considered the possible wider implications of a change in management; he concluded that unless managed realignment was undertaken on a very large scale it would be relatively unlikely that it would result in widening of the mouth. Two reasons were given for this: (1) the constraints imposed at the mouth by wave and tidal processes which transport sediment towards North Weir Point and into the estuary mouth and (2) current velocities at the mouth are already very high such that even large-scale increases in tidal prism are unlikely to make a significant difference to the mobility of shingle in the mouth area. HR Wallingford (2018) have also looked at three possible managed realignment sites within the Alde-Ore estuary: two in the vicinity of Havergate Island (Boyton marsh and Gedgrave marsh) and one further upstream towards Slaughden (Iken marsh). None of the sites was predicted to have a significant effect on the wider estuary morphology, with changes in currents anticipated to be localised to the breach locations.

A.4 Summary

Offshore waves are bi-modal, with a large majority of waves approaching from either a north-easterly direction or from the south to southwest. As these waves move inland, they become modified by the various bank systems including those associated with the estuaries. Wave shadow zones to the south of Orfordness have been recognised (Burningham and French, 2016; HR Wallingford, 2016)), whilst the potential for regenerated waves inland of the Orfordness spit has also been suggested (Pye, 2015). Potential drift along this shoreline is therefore both to the north and south, with evidence that different net direction may have predominated over different periods in time; the most recent data indicating a net northward drift at present.

Tidal currents also play an important role in shoreline evolution, with extremely high flows at the estuary mouths, but lower shore-parallel flows along the open coast. However, even these lower flows when combined with wave agitation, have the potential to transport shingle sized sediment. There has been limited investigation, however, into the significance of tidal currents in affecting shoreline behaviour along the study frontage.

The combination and interaction of factors above has resulted in an extremely dynamic coastal environment which has undergone significant morphological change in the past. Reports using recent modelling of nearshore conditions and evidence from beach profile data, suggests a recent shift to a predominance of northward drift, explains current issues of erosion at East Lane (Burningham and French, 2016; HR Wallingford, 2016); however, this may be an oversimplification of the situation.

The study frontage sits within a larger coastal system which has been experiencing net recession over centuries. Analysis of changes across the Suffolk coast by Burningham and French (2016) shows that 89% of the Suffolk coast has experienced a reduction in beach width since the late 19th century, accompanied by net steepening (although local variations exist). There are, however, local variations in this pattern of net recession. Historical mapping indicates that prior to defences being constructed in the early 20th century, the higher land at East Lane formed a slight bulge in the coastline; this can be attributed to higher elevations of London Clay along this frontage, which is more resistant to erosion than the overlying Red Crag. At the start of the 20th century, there was sediment connectivity between the shorelines north and south of East Lane and a continuous beach existed along the frontage; although there is evidence to suggest that the beaches to the south of East Lane were narrow even at this time and that the distribution of shingle was not consistent across the frontage, either spatially or over time.

There appears to have been a critical change in shoreline behaviour at the start of the 20th century, when beaches between Shingle Street and East Lane appear to have been stripped of sediment; the contrast is clearly shown by Ordnance surveys maps from 1888 and 1902. Given the scale and speed of the change it is considered highly unlikely that this can be attributed to the construction of groynes at East Lane, which also corresponds to this period, and it is likely that groynes were constructed to address an existing issue of narrowing beaches at East Lane. However, the groynes are likely to have locally exacerbated the problem, particularly at the southern end of Hollesley Bay, by reducing sediment connectivity along the frontage. In contrast, to the south of East Lane, the beaches in front of Bawdsey cliffs are shown to be full at this time.

The cause of this change in behaviour is uncertain and there is no earlier mapping data to confirm whether this had occurred previously. It does, however, correspond to a significant change in the form of Orfordness Spit and development of the ness feature at Shingle Street. At the time of the earlier map edition of 1888, the spit was near its maximum length, but by the 1902 map, it had become breached in several places and its distal end was located 850 m further north. Steers (1937) suggested that a storm in 1897 resulted in "*great quantities which were cut off from the spit …* (and) *… were thrown on to that already existing at Shingle Street*". Cobb (1956), however, attributed the breach of the spit to a storm in November 1893. What is not possible to determine, however, is whether the erosion of the beaches predates this, was a result of a particularly stormy number of years, or was the result of material being held up at Shingle Street. A note in Steers (1957) regarding a large storm in 1895 which caused significant damage at Slaughden, may be evidence that of a series of stormy winters during this period.

Subsequent maps shows that significant rollback of the barrier followed, effectively forming the indented beach planform present today within Hollesley Bay, as shown on the 1928 map. In response new embankments were constructed inland; these currently define the landward margin of the beach. By 1928, there had also been accretion of beaches south of Shingle Street, forming a series of lagoons (as recorded by Cobb,1956), suggesting significant movement of shingle southwards. It was noticeable, however, that the beach accretion during this period only extended as far south of the Martello Tower Y at the northern end of the lagoons. Cobb also, observed, however, that there was evidence of shingle also moving north of Shingle Street. He concluded that once material is moved across the estuary from North Weir Point onto the Shingle Street side of the estuary "*the material divides, some of it being taken northwards by combined wave and current action and some it is continuing to move south*".

Mapping and analysis of change from the 1920s to the 1970s by Cobb (1957) and Carr (1986), records a general trend of recession along the Shingle Street frontage, with accretion further north along The Beacons, resulting in the loss of the beach lagoons recorded by Cobb, which broadly corresponds with net growth of the Orfordness spit. From his observations, Cobb (1957) proposed that the accretion at The Beacons was 'starving' the beach to the south. Neither reports specifically mention the beaches further south so it is not clear how the areas around East Lane were changing over this time period.

The most recent data indicate that at the southern end of Hollesley Bay the zone of erosion is gradually progressing northwards. This has been accompanied by growth of the ness at Shingle Street and also a southward shift in its position. The current distal end of Orfordness spit is around 1.5 km north of its position in the 1880s and around 600 m north of its position in the 1980s, when Carr made his observations. The last data sets recorded by Carr from the 1980s showed a slight recession in the spit compared to the 1970s and this trend appears to have continued. There are currently several distinct trends of behaviour within Hollesley Bay: beach recession to the south of the lagoons, which is progressing north; growth of the ness at Shingle Street and extension of the feature south since 2014, and variable behaviour north of Shingle Street, where onward movement of shingle is evident.

South of East Lane, the beaches, apart from along the Bawdsey Manor frontage, have remained fairly narrow since the earliest Ordnance Survey maps, although local variations in shingle cover are indicated by the mapping. Despite volatile beaches, the net change across the Bawdsey Manor frontage has been very little over time, although defences have been in place in some of this time. Further north, comparison of historical maps indicates there has historically been cliff erosion along the frontage, increasing in a northward direction towards East Lane, resulting in a net change in shoreline orientation over time. Significant erosion has occurred in the vicinity of Martello Tower W, although some stability appears to have been reached; however, beach losses to the south suggest erosion could become an issue in the near future along this stretch. Since the emergence of East Lane as a headland at the start of the century, behaviour of the beaches south of East Lane appear to have been disconnected from those to the north of East Lane.

Superimposed on the observed changes along the foreshore, studies have also revealed changes in the nearshore banks (e.g. Burningham and French, 2016), which suggest that some of these features have moved northwards and onshore potentially affecting ebb and flood tidal flows.

In summary, an amalgamation of available information therefore presents a complex pattern of change, with several influencing factors:

- The changing form of Orfordness spit from an elongate continuous barrier to a series of trailing banks is believed to be a key control on the supply and distribution of shingle within Hollesley Bay. There appears to be a link between the length of the spit and the size and position of the ness at Shingle Street, as first determined by Cobb (1957) and Carr (1986). The exact relationship is uncertain and would require further study but is likely to be a combination of:
    - changes in the direction and force of tidal flow in and out of the mouth of the Alde-Ore estuary: when the spit is a contiguous barrier flows are forced parallel to the coast possibly dispersing deposited shingle quicker whilst once the spit breaks down, the flow is more perpendicular to the coast and Carr (1986) also suggested potential for bifurcation of flows through the banks.
    - changes in the extent of protection afforded by the spit – different orientations may create variations in the wave shadow zones identified by Burningham and French (2016). This may mean that as waves from the northeast and east are reduced or eliminated, there is no wave-driven mechanism for shingle within the ness to be moved southwards, which is effectively starving downdrift areas.
    - changes to wave regeneration due to refraction along the landward edge of the spit, which has potential to drive northward transport of shingle from Shingle Street and may also play a role in sustaining the ness.
    - changes in the rate, volume and deposition of shingle to Shingle Street – Steers suggested that break down of the spit in the 1890s released a vast quantity of shingle; however, estimates by Orford (2017) and evidence from beach profiles indicates that the ness feature is continuing to grow and may be larger now than previously. Beach monitoring data also shows the arrival of material onshore and its subsequent movement up the beach profile. Where this shingle is moved onshore may be a key factor in how it is subsequently moved.
- At a large scale, the Suffolk coastline is receding, driven by rising sea levels. Formation of the indented beach at the start of the century resulted in emergence of East Lane as a headland. Construction of linear defences cemented this position and prevented cliff retreat that would otherwise have occurred. Continued retreat will have meant that exposure along this headland has continued to increase leading to loss of shingle under higher energy conditions and exposure of the underlying London clay platform. It is also likely that the defences themselves are adding to the issue.
- Beach profile data indicates that there is movement of shingle along the coastline, but it is difficult to ascertain the direction of travel from this data. Both northward and southward movement is likely, given the bimodal nature of the offshore waves but wave modelling seems to indicate a predominance of northward driven transport. The reasons for this are uncertain, as is likelihood of this trend continuing. In combination with changes in the north of the bay this may partially explain the northward progression of erosion from the southern end of Hollesley Bay. Since rollback of the beach system occurred at the start of the century, an indented beach north of East Lane has developed, which now seems disconnected from the beach system to the south. This means that any shingle moved northwards at East Lane is not replaced; equally any southward drift of shingle does not seem to be retained by the beaches and may be lost offshore, due to exposure conditions at the headland. Beach data shows that the beach face is retreating in a parallel fashion, and it is only once a critical width is reached that rollback occurs, but at this point the barrier is significantly reduced in volume and relatively quickly lost.

Appendix B. Environmental, social and economic considerations

B.1 Information used

This section draws upon information contained within the SMP and more recent appraisals including:

- Bawdsey Coastal Partnership (2016) An economic and environmental study of the value of coastal defences in the Bawdeys Coastal Partnership area.
- National Character Area profile: 82 Suffolk Coast and Heaths, produced by Natural England
- Alde and Ore estuary Partnership Estuary Plan, 2016

The discussion below includes both the local (HOL16.4 and HOL16.5 frontages) and wider area. Due to the governing coastal processes which mean that sediment transport between Orfordness and the study frontage is uni-directional, i.e. north to south, it is not likely that management of the study frontage would affect any features along Orfordness or frontages further north. Therefore, the wider area only includes area to the south, to Felixstowe including the flood risk zone defined by the Environment Agency.

B.2 Biodiversity, geology and geomorphology features

Much of the study frontage is designated as part of the wider system, namely the Alde-Ore Estuary Ramsar site, Orfordness – Shingle Street SAC, Alde-Ore SPA and Alde-Ore SSSI. The boundaries of these sites are coincident, with the southern boundary located at the tip of East Lane promontory (in line with the southern end of the irrigation ponds). Orford Ness is also an internationally important nature reserve (Orford Ness NNR), with an RSPB site on the norther side of the River Alde at Havergate (Havergate Island & Boyton Marshes).

The Alde-Ore Estuary is a designated Site of Special Scientific Interest (SSSI), first notified in 1949 and extended at the last revision in 1992. The site stretches along the coast from Bawdsey to Aldeburgh and inland to Snape. It includes Orfordness, Shingle Street, Havergate Island, and the Butley, Ore and Alde Rivers. The site contains a number of coastal formations and estuarine features including mud-flats, saltmarsh, vegetated shingle and coastal lagoons which are of special botanical and ornithological value, and the shingle structures of Orfordness and Shingle Street are of great physiographic importance.

The adjacent estuarine and intertidal habitats are designated separately as the Alde, Ore and Butley Estuaries SAC. The Alde/Ore Estuary together with the shingle ness is also designated as a Ramsar site and SPA. The site comprises the estuary complex of the rivers Alde, Butley and Ore, including Havergate Island and Orfordness. There are a variety of habitats, including intertidal mudflats, saltmarsh, vegetated shingle (including the second-largest and best preserved area in Britain at Orfordness), saline lagoons and grazing marsh (JNCC, 2008b). The site supports nationally-scarce plants, British Red Data Book (BRDB) invertebrates, and notable assemblages of breeding and wintering wetland birds. It has been estimated that the area supports 20,000 seabirds feeding, roosting and nesting, including populations of redshanks and lesser blacked-backed gulls.

Annex 1 Habitats recognised at this location are as follows:

- Annual Vegetation of Drift Lines (H1210) - drift-line vegetation occurs on the sheltered, western side of the spit, at the transition from shingle to saltmarsh, as well as on the exposed eastern coast. The drift-line community is widespread and comprises sea beet Beta vulgaris ssp. maritima and orache Atriplex spp. (Natural England, 2005).
- Coastal Lagoons (H1150) - these have developed in the shingle bank adjacent to the shore at the mouth of the Ore Estuary. Salinity of the lagoons is maintained by percolation through the shingle, although at high tides sea water can overtop the shingle bank. The fauna of these lagoons includes typical lagoon species, such as the cockle Cerastoderma glaucum, the ostracod Cyprideis torosa and the gastropods Littorina saxatilis tenebrosa and Hydrobia ventrosa. The nationally rare starlet sea anemone Nematostella vectensis is also found at the site (Natural England, 2005).

- Perennial Vegetation of Stony Banks - coastal shingle vegetation outside the reach of waves - the Orfordness site as a whole supports some of the largest and most natural sequences in the UK of shingle vegetation affected by salt spray (Natural England, 2005). Pioneer communities with sea pea Lathyrus japonicus and false oatgrass Arrhenatherum elatius grassland occur

Conservation objectives are to maintain or restore:

- the extent and distribution of qualifying natural habitats,
- the structure and function (including typical species) of qualifying natural habitats, and
- the supporting processes on which qualifying natural habitats rely (Natural England, 2014).

A single SSSI unit covers the study frontage (unit 33), from the Alde River to the boundary of the designation at Bawdsey. This was last assessed in 2013 and condition defined as 'unfavourable - no change': this is a change from the previous condition in 2009 of 'unfavourable - declining'. Whilst the the Coastal Geomorphology, Coastal Lagoons & Vascular Plants features were all found to be Favourable, the vegetated shingle features were deemed to be in 'unfavourable - no change' condition due to '*failing targets on species composition and recreational pressures being unresolved*'. Other pressures on the site were recognised as follows:

- Erosion of the foreshore in the south of the unit, with the seawall preventing roll back of shingle.
- Significant constraint on natural function placed in the unit by rock revetment.
- Lagoons between shingle ridge and seawall being squeezed.
- Trampling damage with several areas devoid of any vegetated substrate within the habitat as a result of anthropogenic activities (anglers, walkers, recreational beach users); areas particularly affected include. The southern end of Unit (East Lane), the route from southern end of Shingle Street village to shore, and the route from main Shingle Street carpark to shore.

To the south of East Lane lies Bawdsey Cliffs SSSI. This 2 km stretch of cliffs is of great geological interest for its exposures of Red Crag. It is currently in favourable condition. The key management principle for coastal geological sites is to maintain exposure of the geological interest by allowing natural processes to proceed freely, although active management of coastal geological sites is often only necessary when human activity has interfered with natural rates of erosion.

Further south lies Deben Estuary SSSI, Ramsar and SPA. The Deben is notified for for its populations of overwintering waders and wildfowl and also for its extensive and diverse saltmarsh communities. Several estuarine plants and invertebrates with a nationally restricted distribution are also present.

The nearshore and offshore zones are covered by the Outer Thames SPA, Southern North Sea Marine Protected Area (and candidate Special Area of Conservation/Site Conservation Interest), and Orford Inshore proposed Marine Conservation Zone (pMCZ):

Outer Thames SPA (classification date 31/10/2017)

The SPA lies along the east coast of England in the southern North Sea and extends northward from the Thames Estuary to the sea area off Great Yarmouth on the East Norfolk Coast (JNCC, 2017a). It is classified for the protection of the largest aggregation of wintering red-throated diver (Gavia stellata) in the UK, an estimated population of 6,466 individuals, which is 38% of the wintering population of Great Britain. It also protects foraging areas for common tern (Sterna hirundo) and little tern (Sternula albifrons) during the breeding season. It includes both the beach area and offshore zone.

Southern North Sea Marine Protected Area (designated candidate Special Area of Conservation/Site Conservation Interest (cSAC date: 30/01/2017, SCI date: 12/12/2017).

Located to the east of England, this site stretches from the central North Sea (north of Dogger Bank) to the Straits of Dover in the south, covering an area of 36 951 km^2 (JNCC, 2017b). The majority of this site lies offshore, but it does extend into coastal areas of Norfolk and Suffolk. A mix of habitats, such as sandbanks and gravel beds, are included in the site. The Southern North Sea cSAC has been identified as an area of importance for harbour porpoise. This site includes key winter and summer habitat for this species and covers an area over 3 times the size of Yorkshire, making it the largest cSAC in UK and European waters at the point of designation in 2017.

Orford Inshore proposed Marine Conservation Zone (pMCZ)

This site covers an area of approximately 72 km² and lies approximately 14 km offshore from the shoreline. The Orford Inshore site is dominated by habitats composed of subtidal mixed sediments. These sandy, gravelly sediments are important as nursery and spawning grounds for many fish species including Dover sole, lemon sole and sand eels. Colourful species of burrowing anemones can be found within the sediment, alongside sea cucumbers, urchins and starfish. Several nationally important shark species are found within the site, including the small spotted catshark. The area is also important for foraging seabirds and harbour porpoise are often spotted passing through.

B.2.1 Water and hydromorphology

The study frontage lies within the Suffolk waterbody (coastal) (ID GB650503520002), which is defined as "heavily modified", with moderate ecological status and good chemical status.

The Alde River lies within the Alde & Ore transitional waterbody. The Alde & Ore transitional waterbody is defined as "heavily modified" with moderate ecological status and good chemical status.

Of key importance to the areas are also the groundwater aquifers. Agriculture on the Suffolk coast is dependent on the maintenance of a freshwater supply from groundwater aquifers. Abstraction and storage of freshwater upon the lower marshes also allows use of the higher land around the estuary. The delivery of this supply is threatened by intrusion of salt water into freshwater aquifers and from the loss of boreholes at risk from erosion.

B.3 Historic environment and landscape

There are four Martello Towers within policy units HOL16.4 and HOL16.5 (AA at Shingle Street, Z near Buckanay Farm, Y at the northern end of the lagoons and W south of East Lane - X was destroyed); these are all Scheduled monuments and Grade II listed buildings. Other listed buildings along the study frontage are: the Battery Observation Post, East Lane car park (Grade II) and Tower House.

Further afield, Bawdsey Manor Registered Parks and Garden (Grade II) lies to the south of East Lane, there is also a number of buildings and structures associated with Bawdsey Manor that are Grade II and II* listed, including the Pulhamite Cliff structures.

There are a number of non-designated archaeological sites and monuments along the study frontage, floodplain and further south. A number of these relate to historic sea defences or remains associated with military activities, such as WW2 pillboxes, strong points, anti-tank ditches, pill boxes and the gun emplacement at East Lane. To the south of East Lane is the former site of RAF Bawdsey, which is considered the home of British Radar and was an important site during the Cold War; this site contains a number of buildings and structures. The area also contains significant evidence of human occupation, including prehistoric and Bronze Age finds within Bawdsey cliffs, Bronze Age barrows and ring ditches, and medieval and post-medieval evidence of farming practices.

The whole coast lies within the Suffolk Coast and Heaths Area of Outstanding Natural Beauty (AONB) and Suffolk Heritage Coast (designated in 1973). The landscape character and special qualities of the Area of Outstanding Beauty are set out in the AONB Management Plan 2013- 2018. http://www.suffolkcoastandheaths.org/assets/AONB-Management-Plan-20132018.pdf. Unlike the AONB, Heritage Coasts are defined rather than designated so they are not statutory. Heritage coasts are protected through development control and the National Planning Policy Framework (March 2012) states that local authorities should: 'maintain the character of the undeveloped coast, protecting and enhancing its distinctive landscapes, particularly in areas defined as heritage coast, and improve public access to and enjoyment of the coast.'

The study frontage is also included in the Suffolk Coastal and Heaths National Character Area (NCA). NCAs are areas that share similar landscape characteristics and NCA Profiles are guidance documents to inform decisionmaking. The profile for the study frontage includes the following Statements of Environmental Opportunity (SEO) which have particular relevance to management of this coast:

- SEO 1: Manage the nationally significant coastal landscapes, ensuring that coastal management decisions take full account of landscape, environmental and visual impacts as part of an integrated approach working with coastal processes. Improve people's understanding of the process of coastal change.
- SEO 2: Manage the components of characteristic productive agricultural landscapes to benefit food production, biodiversity and soil and water quality. Promote sustainable farming practices that are able to adapt to changing agricultural economics, the considerable challenges of climate change and water availability.

B.4 Communities, economy and material assets

A key economic activity in the area is agriculture, comprising arable marsh and grass marsh and well as high value vegetable crops (Bawdsey Coastal Partnership, 2016). Vital to the productivity of the land is the need for irrigation. Associated with future management of the coast, there are therefore a number of risks associated with agricultural activity in the area:

- Direct loss of agricultural land due to erosion
- Saltwater ingress resulting from failure of existing defences or seepage through any future embankments
- Loss of irrigation ponds – whilst these are potentially replaceable, sufficient time would be required to ensure this is undertaken prior to any change in defence.

The area is sparsely populated, with larger settlements at Bawdsey, Alderton and Hollesley and smaller communities at Bawdsey Quay, East Lane and Shingle Street. Approximately 35 to 37% of houses in the area are second homes or holiday lets (Bawdsey Coastal Partnership, 2016). There is a prison at Hollesley, which includes around 330 inmates (Bawdsey Coastal Partnership, 2016). There is very little commercial property at risk, consisting of farm buildings at Buckanay Farm and Oxley Dairy, which lie in the flood risk area inland of Hollesley Bay, and Bawdsey Manor (south of HOL16.5) (Bawdsey Coastal Partnership, 2016). Note that since the report by Bawdsey Coastal Partnership in 2016, Bawdsey Manor has now been purchased by PGL (opened 2018) as an adventure centre.

The Suffolk coastline is a popular tourist destination, with visitors attracted to the coast by the natural beauty of the landscape and seascape and the wildlife it supports. There are holiday cottages at Shingle Street and Oxley Dairy. Local visitor attractions in the area also include the Suffolk Punch Trust and the Radar Museum at Bawdsey. The adjacent Deben and Alde-Ore Estuaries are also important centres for recreational water use.

There are a number of roads within the flood risk area, some of which are the only access routes to properties. There is also an Anglian Water sewage works and pumping station (Bawdsey Coastal Partnership, 2016).

Appendix C. Cost estimates

The following tables shows the activities associated with each implementation measure considered (Table C1) and combined costs for each management approach taken forward (approaches 1 to 4) (Table C2). The costs for alternative approaches considered are also shown in Table C3.

Costs have been broken down into:

1) initial costs, which considers implementation during remainder of SMP epoch 1 (up to 2025) and
2) further costs, which considers implementation to the end of epoch 2, up to 2055.

Note that some approaches may have a low initial cost but a considerable ongoing commitment, resulting in a high whole life cost, whilst the converse can also be true.

These potential costs are illustrative only and therefore where a range of costs might exist with any particular implementation measure, an 'average' of that range has been used and shown in the table.

Rates used to develop the costs presented in this report have been collated from a range of sources, including a number of previous strategies and schemes, and some published reports. It must be emphasized however that they are only indicative; the implementation measures assessed here have not been developed to outline design level, and considerable variations exist in the characteristics of different schemes that will have a bearing on their cost. Four key material considerations apply and with respect to those it is to be noted that:

- rates for rock and for earth embankments are primarily based upon typical costs per linear metre from schemes elsewhere
- rates for using locally sourced shingle costs are based upon the average costs from local experience of recycling to Slaughden
- rates for imported shingle are based upon the costs regularly experienced on other 'large' dredging and beach nourishment scheme

Taking account of the generic nature of the information and broad level of the options presented here at this initial assessment level, a factor commonly referred to as 'Optimism Bias' (OB) has been applied to the costs in each case. OB is a recognised and accepted contingency that is included to take account of uncertainties and a range of items that fall outside of the primary costs, such as lesser ancillary works, temporary works required during construction, uncertainties over actual volumes required, additional investigations and surveys, dealing with unsuitable ground conditions, on-costs such as design fees, modelling, other unforeseen or changeable factors such as increases in cost rates, material supply issues etc. Research into this has determined that at SMP level, OB should be set at 60%.

Ultimately, the level of costs estimated at this stage of assessment may be subject to considerable change once further information becomes available and development of options takes place. There have also been no factor increases applied at this stage for future climate change, which may see more intensive activities or higher levels of damage and thus repairs, particularly in epoch 3 when changes in coastal processes and other demands on resources (materials and finances), may see greater costs increases that affect the viability of some approaches.

The costs presented here are, however, sufficient to provide an order of magnitude expectation for each implementation measure and thus, importantly, enable a relative comparison to be made between those different management approaches, particularly through to 2055.

Table C1 Activities assumed for each implementation measure

Implementation measure	Initial works (epoch 1 to 2025)	Future works (epoch 2 to 2055)
No active intervention		
Do Nothing	*Investigations and studies to inform approach*	None
	No activity	Actions for Health and Safety
Hold the line		
Linear Structure (rock revetment) along HOL16.5 (East Lane)	*Investigations and studies to inform design*	
Assuming continuing to defend until epoch 3	Repair and improve currently weak areas of the existing revetment *(will require importing new rock armour)*	Additional rock/armour to bolster and improve revetment stability and elevation
		Strengthen (add) new rock toe structure
Repair & maintain ahead of medium-longer term MR	Repair and improve currently weak areas of the existing revetment *(assume reuse of existing rock armour)*	None (other than removal - see Measure 9)
Develop a Beach along HOL16.5 (East Lane)	*Investigations and studies to inform design*	
(a) Rock Groynes or (b) Offshore Breakwaters	Construction of new rock structures	Post-storm damage repairs (reposition rocks)
	Repair and improve currently weak areas of the existing revetment (will require importing new rock armour)	Post-storm damage repairs (reposition rocks)
+ nourishment	Importation of shingle to nourish frontage (assume Shingle Street)	Regular re-nourishment of shingle to maintain beaches
	If shingle has to be obtained from offshore dredge site costs would be significantly higher	Nourishment from dredged shingle source
Linear Structure (extended rock revetment) along HOL16.4	*Investigations and studies to inform design*	
	Import rock/armour to build new revetment structure as far as Martello Tower	Post-storm damage repairs (reposition rocks)
Develop a Beach along HOL16.4 (Hollesley Bay)	*Investigations and studies to inform design*	General maintenance and repairs to earth embankment
Beach Nourishment	Initial major campaign to place shingle along beach (assume sourced from Shingle Street)	Regular re-nourishment of shingle to maintain beaches
	If shingle has to be obtained from offshore dredge site costs would be significantly higher	Nourishment from dredged shingle source

Rock Groynes or Offshore Breakwaters	Construction of new rock structures	Post-storm damage repairs (reposition rocks)
Terminal Structure	Construct new long rock groyne	Post-storm damage repairs (reposition rocks)
+nourishment	Initial major campaign to place shingle along beach (assume sourced from Shingle Street)	Regular re-nourishment of shingle to maintain beaches
	If shingle has to be obtained from offshore dredge site costs would be significantly higher	Nourishment from dredged shingle source
Reconfigured Defence Line	*Investigations and studies to inform design*	General maintenance and repairs to earth embankment
Y-shape groynes	Construct new Y-shaped rock groynes	Post-storm damage repairs (reposition rocks)
+ Renourishment	Initial nourishment along HOL16.4 (assume sourced from Shingle Street)	Regular re-nourishment of shingle to maintain beaches
	Initial nourishment along HOL 16.5 (assume sourced from Shingle Street)	
	If shingle has to be obtained from offshore dredge site costs would be significantly higher	Nourishment from dredged shingle source
Managed realignment		
Wetland Creation	*Investigations and studies to inform design*	
HOL 16.4 only	Create creeks and construct new inland embankments	General maintenance and repairs to new embankments
	Breach existing embankment	
	Improve terminal end of rock revetment *(use existing rock from revetment)*	Post-storm damage repairs (reposition rocks)
HOL 16.4 & HOL 16.5	Create creeks and construct new inland embankments	General maintenance and repairs to new embankments
	Breach existing embankment	
Realigned Embankment	*Investigations and studies to inform design*	
HOL 16.4 only	Construct new clay embankment	General maintenance and repairs to new embankments
	Remove existing embankment	
	Additional material for protective cover layer on seaward side if required	
	Improve terminal end of rock revetment	Post-storm damage repairs (reposition rocks)
HOL 16.4 & HOL 16.5	Construct new clay embankment	General maintenance and repairs to new embankments
	Remove existing embankment & irrigation ponds	

	Additional material for protective cover layer on seaward side if required	
Natural' Shingle Ridge Management	*Investigations and studies to inform design*	
	Remove existing embankment & irrigation ponds	Emergency response to address breaches (recycle shingle and reinstate barrier beach)
	Local flood risk management adaptation measures	Maintain local adaptation measures
Removal of East Lane defence structures	*Investigations and studies to inform approach*	
	Removal of rock, concrete walls and sheet piling	None

Table C2 Indicative costs for approaches 1 to 4 identified in the main report.

Approach			Implementation measures		Initial cost	Future costs (to 2055)	Total with 60% OB
	HOL16.5	HOL16.4	HOL 16.5	HOL 16.4			
1	**NAI**	**NAI**	Do nothing	Do nothing	£0	£0	**£0**
2a	**HTL**	**HTL**	Maintain/ improve revetment	Extension of revetment	£4-6 Million	£4-6 Million	**£14-15+ Million**
2b	**HTL**	**HTL**	Maintain/ improve revetment	Introduction of rock groynes or other control structures	£4-6 Million	£4-6 Million	**£14-15+ Million**
2c	**HTL**	**HTL**	Maintain/ improve revetment	Construction of terminal structure	£4-6 Million	£4-6 Million	**£14-15+ Million**
3a	**HTL**	**MR**	Maintain/ improve revetment	Wetland creation	£4-6 Million	£4-6 Million	**£14-15+ Million**
3b	**HTL**	**MR**	Maintain/ improve revetment	Realigned bank	£2-3 Million	£4-6 Million	**£10-12 Million**
4a	**MR**	**MR**	Immediate defence removal	Wetland creation	£4-6 Million	< £1 Million	**£7-9 Million**
4b	**MR**	**MR**	Immediate defence removal	Realigned bank	£4-6 Million	< £1 Million	**£7-9 Million**

Table C3 Indicative costs for alternative approaches considered.

Approach			Implementation measures		Initial cost	Future costs (to 2055)	Total with 60% OB
	HOL16.5	**HOL16.4**	**HOL 16.5**	**HOL 16.4**			
	HTL	**HTL**	Y-shaped groynes (Barber, 2016)		> £10 Million	£2-3 Million	**£14-15+ Million**
	HTL - MR	**MR**	Delay revetment removal	Wetland creation	£4-6 Million	£2-3 Million	**£10-12 Million**
	HTL - MR	**MR**	Delay revetment removal	Realigned bank	£2-3 Million	£2-3 Million	**£7-9 Million**
	MR	**MR**	Immediate defence removal	Natural beach (+adaptation*)	£2-3 Million*	< £1 Million*	**£5 Million***

** Adaptation costs have not been included.*