Hunstanton Groyne Fields: appraisal of groyne effectiveness

Appraisal report

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Contents

1. Introduction

1.1 Scope of study

This study has been commissioned by the Environment Agency, but also considers the frontage managed by the Borough Council of Kings Lynn and West Norfolk (BCKLWN). The focus of the study is Hunstanton Town to Heacham frontage, which is located on the north-eastern side of The Wash.

There have been defences along parts of this frontage since the 1880s and current protection from coastal erosion at Hunstanton is provided by a promenade and seawall, whilst further south there is a combination of a gravel ridge and hard defences, with a setback earth embankment forming a secondary line of defence along part of the frontage. In addition, there is a mixture of concrete groynes and timber groynes along the frontage that are intended to retain a beach, primarily to provide a supporting defence function. Management of the groyne field falls under the jurisdiction of both BCKLWN, to the north of the Power Boat Ramp at Hunstanton, and the Environment Agency, to the south of the Power Boat Ramp. Both of these organisations manage their groyne structures differently and both would like to align their approach.

The scope states that the amount of beach material at Hunstanton beach has been reducing for a number of years, but this has reportedly become more noticeable over the past two years. It is states that the groyne field does not appear to be effective in maintaining the beach material, particularly in the northern area. The groynes are currently in a deteriorated state and would require further investment to return them to a target condition. At present BCKLWN are looking to repair and rebuild their groyne structures whereas the Environment Agency cut back their groyne structures when they become exposed. These organisations wish to ascertain whether existing beach management practices are effective, or whether alternative/supportive management practices need to be considered. If this technical assessment, finds the groyne field is no longer effective at trapping beach material or needs to be supported with a beach recharge then they will then need to assess future beach management.

This study has therefore been commissioned to consider the effectiveness of the groynes, to enable both BCKLWN and the Environment Agency to make informed decisions regarding future management of their frontages.

1.2 Approach

A desk-top study of coastal processes and shoreline change has been undertaken, drawing upon the recent Wash East Coastal Strategy (Royal HaskoningDHV, 2015) and Hunstanton Coastal Management Plan (AECOM, 2019), in addition to other available studies and information. The most recent beach monitoring data has been obtained from Anglian Coastal Monitoring (ACM) programme, to supplement information from the annual beach survey reports produced for the Environment Agency for the frontage south of the Power Boat Ramp (Jacobs, various years). A summary of current understanding is provided as Appendix A to this report. This information has been used to appraise changes in beach level and volume over time and also to understand the key drivers of change along the coast.

A site visit was undertaken in July 2021 by Kevin Burgess (Jacob's principal coastal engineer) and Helen Jay (Jacob's principal geomorphologist), accompanied by Catherine Harries (Environment Agency), Peter Jermany (BCKLWN) and Dave Robson (BCKLWN). The beaches at this time were likely to be close to their fullest state and therefore observations made may be indicative of the maximum retention of beaches by groynes. As at this time, the timber groynes along the Environment Agency frontage were substantially buried, a second informal visit was undertaken in November 2021 by Kevin Burgess to carry out further inspection of the groynes, particularly along the EA frontage. These visits have enabled a review of current defence condition, which has informed a technical appraisal of their current sediment trapping efficiency and therefore effectiveness. They have also been an opportunity to visually appraise the current composition and morphology of the beaches.

1.3 This report

This report provides an opinion on the effectiveness of the current groynes based upon our visual assessment during the site and our understanding of the coastal processes, plus any other information provided by the Environment Agency and BCKLWN. This has considered aspects such as effects of groyne design (length, height, depth - where known from as built drawings), and condition, in relation to beach width, level and sediment transport.

Appraising the effectiveness of the groynes has been approached in two ways: (1) through considering evidence from beach profile data combined with an understanding of coastal processes along this frontage, and (2) through examining the design and condition of the groynes to assess their likely interaction with sediment movement. High level alternative approaches to current management are also identified and discussed, including high level cost estimates. The report is laid out as follows:

- **Section 2** provides a site overview, including current understanding of coastal processes
- **Section 3** explains what factors have been considered in determining groyne effectiveness, in terms of their design, and summarises current condition of the groynes
- **Section 4** summarises the assessment of beach behaviour and response to management
- **Section 5** presents the appraisal of the current effectiveness of the groynes in retaining beach material, drawing upon findings from sections 3 and 4
- **Section 6** presents a consideration of options
- **Section 7** summarises the key findings and makes recommendations.

The report is supported by the following technical appendices (including full references):

A. Review of coastal processes and shoreline change

B. Review of existing groyne structures.

2. Site overview

2.1 Location

This report focuses on the concrete and timber groyne frontages managed by the BCKLWN and the Environment Agency, which stretch from the start of the promenade at the northern end of Hunstanton to the end of the timber groyne field at Jubilee Bridge, Heacham.

Along the BCKLWN frontage there are nine concrete groynes between along Hunstanton North Promenade to just south of the Amusement Arcade and 10 zig-zag timber groynes, down to the boundary with the Environment Frontage at the Power Boat Ramp (Figure 3-3). Along the EA frontage considered there are a further 31 timber zig-zag groynes; groyne markers number these 1 to 31, but for the purposes of this study these have been referred to as EA1 to EA31 (Figure 3-5).

2.2 Existing management approach

2.2.1 BCKLWN frontage

The primary risk along this frontage is from erosion; defences consist of the seawall and groynes. This frontage has been defended by seawalls since the start of the twentieth century, but defences have been substantially improved over this time period. The date of construction of the current groynes is not known; there is a record of concrete groynes being present along this frontage in the 1950s with some timber groynes evident by the 1920s. Further reinforcement and construction of groynes was undertaken in the early 1980s and it is thought that all of the current groynes have been in place since this time.

The existing policy for this frontage, as set out in the Shoreline Management Plan (Royal Haskoning, 2010) is to continue to Hold the line into the long term (2105) by holding the shoreline defences where they are now. The subsequent Wash East Coastal Management Strategy (WECMS) (Royal HaskoningDHV, 2015) recommended that the Hold the line policy should be implemented through sustaining the existing defences for the next 10 to 15 years. At that point, the Strategy identified that the most likely option is a replacement of the promenade and sea wall, but alternatives could be a rock revetment or beach recharge. It does not appear, however, that the intention of the Strategy would be to replace groynes as part of this long-term approach.

The more recent Coastal Management Plan for the Hunstanton frontage (AECOM, 2019) concluded that the preferred option is to maintain the existing defences along the frontage and in the medium to long term future sustain the level of flood protection by iteratively increasing the crest levels of the rear floodwall. This included provision for the maintenance, through refurbishment, of the concrete and timber groynes, to extend their defence life to approximately 30 years, although the basis for including the groynes is not clear from the reports.

2.2.2 Environment Agency frontage

The primary risk along this frontage is from flooding. Current defence is provided by a combination of a gravel ridge and hard defences, with a setback earth embankment forming a secondary line of defence along part of the frontage, which provides further protection to the low-lying area inland.

It is understood that up to the 1930s/1940s, the coastline between Hunstanton and Wolferton Creek was undefended (with the exception of short lengths of timber groynes and breastwork). There was, however, already an earth embankment that ran sub-parallel to the shoreline for part of the frontage; the date of which is unknown. Construction of Heacham South Beach wall, Heacham North Beach wall and Hunstanton South Beach followed. The seawalls and revetments along this stretch have been improved and extended over time, particularly in response to storm events in 1953, 1978 and 1983. The date of construction of the timber groynes is not certain. Anecdotal information suggests 1982, but photographs reportedly from 1978 infer the zig-zag groynes were already in place by time. Early OS mapping also shows short lengths of groynes were being used as early as 1904.

Due to continued issues of beach erosion it was decided in 1990 to implement a beach recharge scheme, with around 400,000m^3 of sand and gravel dredged from the mouth of the Humber placed on the beaches between Hunstanton and Snettisham. Since completion of the scheme in 1991, the Environment Agency has undertaken annual recycling of sand and gravel together with beach reprofiling works. Material is currently taken from Snettisham Scalp and placed on the eroding beaches to the north. Further nourishment was undertaken in 2005 to address issues along specific stretches of coast.

The Shoreline Management Plan policy for this frontage is to Hold the line in the short term between Wolferton Creek and South Hunstanton (Policy Development Zone PDZ2) to enable time for a sustainable long-term solution to be developed. The WECMS (Royal HaskoningDHV, 2015) also concluded that "*it is not yet possible to determine a set coastal management approach that is best for the next 100 years*." For the short term, the strategic approach is to hold the current line, through continuing the current management. This includes continued maintenance of the groynes.

2.3 Overview of coastal morphology and processes

The site lies along the north-eastern side of The Wash, within its outer reaches and is therefore influenced by both open coast and estuarine processes. Whilst The Wash is generally typified by extensive saltmarshes characteristic of sheltered, low-energy environments, the more exposed coastline of Hunstanton to Heacham is distinctly different. Here, the frontage is characterised by the dramatic Hunstanton chalk cliffs to the north to the low-lying plain of Heacham to the south, fronted by a gravel barrier, steep and narrow upper beaches consisting of gravelly sand, and lower sandflats. Outcrops of Carstone are exposed along the beaches of Hunstanton, forming a distinctive jointing pattern.

The offshore bathymetry is shallow, with the average depth of The Wash less than 10 m. Sand is the dominant subtidal surface sediment, with mud and shells in the inner channel bottoms and coarser materials around the deepest parts. The Wash features a complex series of sand banks, which lie parallel to the axis of main tidal flow and tend to separate flood and ebb-dominant tidal flows. Sunk Sand is the closest of these to Hunstanton; this extends around four kilometres from the coast. South of Heacham, there is shore-attached sand bank, known as Stubborn Sand. This feature has historically increased in size over time.

These banks act to modify both tidal flows, which flow between the banks, and waves, as they pass over the banks. As a result, waves experienced at the shoreline are less than those at the mouth of The Wash. The Wash is macro-tidal, with a spring tidal range of around 6.3 m and neap tidal range of around 3 m, and as a result tidal currents can be strong, particularly in the main channels. The central part of The Wash is flood dominated, whilst the margins are ebb-dominated but weaker, with north-eastern residual flows along the study frontage. This means that at Hunstanton and Heacham the net tidal current flows run from south to north.

The Hunstanton-Heacham shoreline is exposed to waves predominately from the north-north-east sector, but waves within The Wash can be both externally and internally generated, due to the width of The Wash. Those internally generated are typically of much shorter period and of smaller magnitude, but greater in frequency.

Storm surges are also important, with both the shape of the North Sea Basin and the funnelling effect of The Wash embayment increasing the vulnerability of this coastline to surge events. Recent events, which have resulted in significant change at the shoreline include those in 2013, 1983, 1978 and 1953. Mean significant wave height typically ranges from 0.3 m to 0.7 m (Environment Agency, 2010), but in the south-eastern Wash, strong or gale force north-east to north-west winds may produce wave heights of about 1 m, increasing to up to 2 to 3 m during severe gales.

Waves at the shoreline are typically at an acute angle to the shoreline and have the potential to drive a north to south littoral drift. Estimated rates of sediment transport along the frontage vary, due to both subtle changes in orientation and also the varying attenuation of waves across the sandbanks but previous studies suggest they may be in the region of 6,000 to 8,000 m^3/year (although these are likely to be potential rather than actual rates). Incoming waves can also be affected by the strong currents within The Wash. The wave-driven littoral transport is opposite to that generated by tidal currents but along the upper part of the beach the wave driven transport is understood to be sufficient to overcome the northward drift generated by the residual tidal currents. Conversely, along the lower beach and sandflat, northward tidal flow may become more dominant.

In terms of sediment supply, there is a significant influx of fine sediment to The Wash (fine sand, silts and clays), carried in suspension, which has led to the infilling of The Wash over time and associated growth of saltmarshes and intertidal flats. In comparison, the input of coarser sediment is understood to be much smaller, via bedload transport. The original source of the coarse sediment (coarse sand and gravels), which constitutes the beaches of the study frontage, is likely to have been erosion and subsequent onshore transport of fluvio-glacial or glacial sediments occupying parts of the deeper and outer parts of The Wash embayment and North Sea.

Contemporary inputs of coarse sediment from this source are believed to be small, but onshore movement of sand is likely, although studies of transport within The Wash has tended to concentrate on the western and southern shorelines rather than the Hunstanton-Heacham shoreline. Whilst material, in the form of cobbles of chalk and sandstone is supplied through erosion of the Hunstanton cliffs to the north, this is thought unlikely to be significant in maintaining beaches along the study frontage over the timescales considered. Breakdown of the cliff boulders will eventually provide a source of finer sediment, but not the flint gravels that are a component of the upper beaches. Currently beaches along the Environment Agency frontage are maintained though recycling (and nourishment) of sediment; without which the beaches would diminish over time.

3. Determining groyne effectiveness

3.1 General principles

3.1.1 Fundamentals of groyne design and effectiveness

Groynes are designed to slow the alongshore transport of beach sediment (generally sand and gravel), by interrupting the movement of that material within the intertidal zone and trapping it on the updrift face of the structure. A lesser known but significant original objective for introducing groynes, however, was to control the tidal currents which were believed to be the primary driver for the longshore drift of beach sediment. This was attempting to follow the same principle that had been employed in rivers to reduce current speeds along the banks by diverting the flow offshore (CIRIA, 2020).

CIRIA (2020) usefully sets out key factors with respect to the sediment trapping efficiency of groynes. It notes that where groynes are used on beaches with coarse materials (e.g. gravel) they act directly in trapping a fraction of the material moving along the shoreline. But for sand beaches, with a significant amount of suspended sediment transport, groynes also act indirectly by affecting the longshore currents containing the sand, but reducing the strength of the currents withing the groyne 'bays', creating circulatory patterns. Typically these circulations result in seaward-flowing currents along the down-drift side of each groyne (this being a potential cause of scour). The sediment trapping efficiency depends on many factors, such as the type and condition of the groynes, the amount of sediment already trapped by the groyne since installation, the amount of sediment that can overtop the groyne, the wave climate, water level and tidal range, the sediment size and the groyne dimensions (i.e. length, height, spacing) and orientation in relation to the direction of sediment transport.

The height, slope and length are critical factors in determining the trapping effectiveness of a groyne field; these should all be based upon the beach profile, noting that this will fluctuate as the beach responds to varying wave conditions. Groynes need to accommodate those fluctuations. For a sand beach, therefore, that often means a shallow slope so longer groynes to ensure that the 'toe' of the beach is within the footprint of the groyne field, but also recognising that sand beach levels can be highly variable. Shingle beaches will typically need shorter groynes at a steeper angle. Where backed by seawalls (as along this shoreline), an effective groyne field should ensure that the top of the beach is not exposed to waves, so will also ideally be above Highest Astronomical Tide (HAT) level, otherwise wave reflections off the wall can increase drawdown of the upper beach and accelerate losses.

A groyned beach also needs a regular feed of sediment to collect within the bays they form (or an existing beach to be held), Without this supply of material, any groynes are effectively redundant. For groynes to be an effective control measure, they need the process of sediment movement to be predominantly alongshore, for them to interrupt and thus intercept that movement. If for example the movement of the beach sediment is predominantly onshore-offshore, they are less likely to be effective; groynes will not prevent offshore losses as they do not act upon cross-shore processes.

Permeable groynes, such as the timber structures found on this coastline, are rare. Van Rijn (2018), notes that two main types of groynes can be distinguished: '*Groynes are either permeable or impermeable, depending on whether sediment can be transported through the groyne. The idea of permeable groynes is that they reduce alongshore currents, and thus reduce sediment transport. Permeable groynes have several advantages such as their relatively low cost and a smaller tendency to produce rip currents and currents round the end of the groyne. Another advantage is that permeable pile screens don't create such severe erosion downdrift, as sediment is transported through the groyne*.' He also notes that these are generally used on beaches which have slightly insufficient supplies of sand; the function of the groynes is then to slightly reduce the littoral drift in the inner surf zone and to create a more regular shoreline (without saw-tooth effect). These groynes act as a filter rather than as a blockade to longshore transport. It is not certain that this was the basis for the design of the timber structures found along these frontages, as there are no records of that, but does help explain how they might actually function.

CIRIA (2020) reports that the design of permeable groynes is with the aim of minimising downdrift erosion, while still stabilising the updrift beach, but it is hard to gauge their effectiveness because there is typically very little difference in beach profile either side of them. A meeting of SCOPAC (2010) on timber groynes is quite dismissive, noting that '*Permeable groynes are seen to be useless as they have little effect on drift and require a lot of maintenance*', and the only reason that some remain is the huge cost for their removal rather than them being effective in their experience.

Also relevant to the effectiveness of groynes is their materials. CIRIA (2020) provides comprehensive information on the use of timber. It identifies that the performance of timber groynes varies significantly due not just to the form of construction, but due to the timber species used, wave action and the type of sediment found on the beach. Deterioration of groyne timber is mainly caused by sunlight, mechanical abrasion, and biological attack.

CIRIA (2020) reports that a study conducted in 2018 of six sites showed that timber groyne replacement (or part-replacement) cycles varied from five years in aggressive conditions on one site, to up to 30 years on another with mild conditions, modest abrasion and no biological attack. In broad terms, SCOPAC (2010) identifies the typical residual life of a groyne on a sand beach is approximately 20-25 years, and on a shingle beach approximately six years.

The use of concrete for groyne construction is also discussed in CIRIA (2020), but noting it is difficult to make concrete as abrasion resistant as timber, and identifies the issue of concrete cracking and breakage from chloride-induced corrosion of reinforcing steel due to seawater penetration, with exposed and protruding reinforcement steel being a dangerous hazard. It notes that there are now few examples of concrete groynes remaining in the UK.

3.2 Existing groynes

3.2.1 BCKLWN frontage: concrete groynes (Groynes 1 to 9)

Groynes 1 to 9 (Figure 3-1 and Figure 3-3) consist of precast concrete piles and precast concrete planking, which is an unusual form of structure and not commonly found at other locations.

The date of their construction is also not known, but is believed to be around 1955, although there are references to the existence of six precast reinforced concrete groynes along the North Promenade wall in 1953, dating from 1943. Similarly, whilst information on the design elements of the groynes is available, the basis for their design in respect of potential sediment trapping effectiveness is unknown. Although there is no measured information, it is thought that all of the groynes were built to a similar elevation and slope.

Notably, the concrete strength and related cover to reinforcement would be considered insufficient by today's standards and the groyne elements would be expected to be reaching the end of their design working life by now.

The site inspection undertaken in 2017 for the Hunstanton Coastal Management Plan (AECOM, 2019) concluded that the groynes were in 'Fair' condition, but with notable damage. This was however focussed on the condition of the structural elements, not to be confused with an assessment of their overall functioning or effectiveness. From the recent site walkovers (2021), it was observed that the major structural issue throughout this groyne field appears to be one of overall stability rather than material degradation; in particular lowering of the beach and these would be more accurately described to be 'Poor' or even 'Very Poor'. Several groynes currently have one or more sections where there are gaps beneath the lowest planks. Previous gaps were filled as part of the remedial works in 2012, but other gaps have since appeared. In one instance (Groyne 7) the scour hole reaches a depth of up to 50 cm below the groyne underside. Several groynes are also damaged or leaning at their seaward ends due to the same foreshore lowering, for example, Groyne 6 where 3 three to 4 four bays are collapsing. The end of Groyne 5 has already been removed.

During both site walkovers, it was observed that only a little sand had accumulated in a triangle on the north sides of most groynes against the seawall, but otherwise there was little difference in beach levels either side, indicating little effectiveness in controlling alongshore sediment movement between the groynes. It is conceivable that the sand predominately deposited here is simply material that is in suspension, dropping out at the top of the tide, rather than being driven by longshore processes. The groynes have not helped to prevent further foreshore lowering either, with the Carstone exposures here similar to those seen along the cliff frontage immediately to the north.

The evidence suggests that either there is little supply of beach material to this frontage, or if there is a supply it is not building up and being retained by these groynes.

Figure 3-1 Condition of BCKLWN concrete groynes

3.2.2 BCKLWN frontage: timber groynes (Groynes 10 to 19)

Groynes 10 to 19 (Figure 3-2 and Figure 3-3) are permeable timber zig-zag groynes consisting of timber piles and walings with intermediate posts (stakes), instead of timber sheet piles or planks: again, this is a very unusual and uncommon form of structure.

The date of construction is unknown, although drawings showing 'replacement of *timber zig-zag groynes at Hunstanton*' from 1982 suggest that whilst the current structures may have been improved in this period, they may have replaced existing groynes. Similarly, whilst information on the design elements of the groynes is available from the 1980 drawings, the basis for their design in respect of potential sediment trapping effectiveness is unknown. Possible reasons include: to provide greater stability; that the zig-zag design can possibly create compartments to trap sediment, particularly at the top of shingle beaches; or that the design reduces the waves and/or currents running seaward along the downdrift side of the groyne, which would otherwise cause scour.

The site inspection undertaken in 2017 for the Hunstanton Coastal Management Plan (AECOM, 2019) concluded that the groynes were in 'Poor' to 'Fair' condition, but with notable damage. Once again, this refers to the timber elements and not to their effectiveness. From the recent site walkovers (2021), it was observed that due to abrasion, much larger gaps now exist between the posts than when constructed. Given the significant deterioration of these fundamental components of the groynes, the overall condition has to be concluded to be 'Poor' or even 'Very Poor'. In several places the walings have also been damaged, split, or lost completely. Along the seaward ends of several of the timber groynes, rock has been placed around their base to resist further erosion and prevent overturning and collapse of the supporting piles and thus overall structure.

The beach along this frontage comprises a coarse upper beach and sand lower beach. Beyond this lies a low tide sandflat. The upper beach is steeper than the lower sand beach and generally buries the root of each groyne, although this tapers northwards, and becomes absent north of Groyne 12. During the site visits, there was no differential in sand levels evident across the lower beach either side of the groynes, other than a few centimetres locally (e.g. over a couple of metres length) where larger pebbles and cobbles have become trapped in the gaps between the stakes. The evidence therefore suggests that the groynes are not having an influence on longshore transport along the upper beach.

The transition from lower beach to sandflat does, however, appear to coincide with the ends of several of the groynes (although there is no indication of transport around those ends). They may therefore be having some modest effect on alongshore currents, helping to maintain a slightly higher level of sand in their lee, albeit a limited amount.

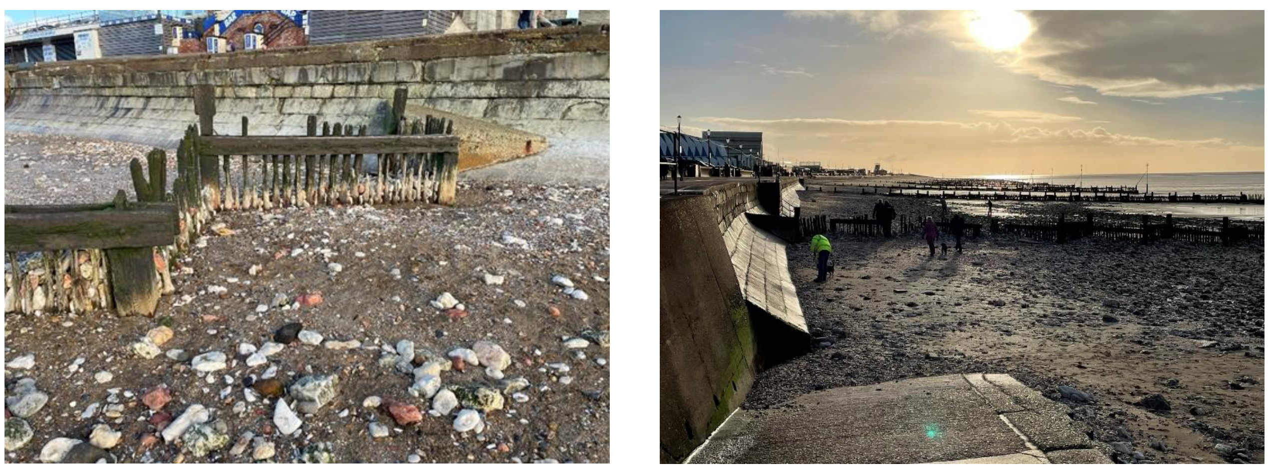

Figure 3-2 Condition of BCKLWN timber groynes.

Figure 3-3 BCKLWN drawing showing the location of the concrete groynes (Groynes 1 to 9) and timber groynes (Groynes 10 to 19) along their frontage.

3.2.3 Environment Agency frontage: timber groynes (Groynes EA1 to EA31)

For the purpose of distinction and clarity in this study, the timber groynes along the Environment Agency frontage between the Power Boat Ramp and Jubilee Road, Heacham have been labelled EA1 to EA31 (Figure 3-4 and Figure 3-5). These are also permeable timber zig-zag groynes consisting of timber piles and walings with intermediate posts (stakes), which is unusual. There are no past details available on the Environment Agency timber groynes. However, from inspection they look identical in form to those along the BCKLWN frontage directly to the north, other than varying in length. As for the BCKLWN frontage, the basis of their design is therefore not known, but the same possible reasons exist as discussed above. The timing of their construction is also uncertain: anecdotal information suggests that they were also constructed around 1982, but photographs of the Heacham frontage in 1978 indicates that some zig-zag groynes were already present at this time. The only previous study containing any information on the structures along this frontage is WECMS (Royal HaskoningDHV, 2015); although this did not include any condition assessment of the timber groynes it refers to NFCDD (the National Flood and Coastal Defence Dataset) which recorded the overall condition (2006 to 2011) as 'Good' or 'Fair'.

Observations from the recent site walkovers (2021) were that the general condition of the groynes was similar to those at Hunstanton in places, but better in others, specifically through the embayment area (Groynes EA16 to EA23), but worse on some of the more exposed areas of seawall (e.g. around Groyne EA8). In a number of places the ends of the groynes have previously failed and have been removed. Much larger gaps now exist between these posts than when constructed, and in this regard any potential trapping efficiency will be considerably reduced compared to when constructed. Given the significant deterioration of these fundamental components of the groynes, the overall condition has to now be concluded to be 'Poor' or even 'Very Poor'.

Along the northern part of the frontage, Groynes EA1 to EA12, the situation was observed to be similar to that along the BCKLWN frontage, with the transition from lower beach to sandflat appearing to coincide with the ends of the groynes. Here the groynes may therefore be having some modest effect on alongshore currents, helping to maintain a slightly higher level of sand in their lee, although this is a limited amount. South of Groyne EA12 there is simply an upper beach – very wide in the embayment area down towards Groyne EA27, and then narrower south of that promontory.

It is also notable that none of the groynes appear to be higher than the toe of the seawall, so will have little effectiveness in terms of holding a beach to a height that would help protect that structure. During the site visits, there was no differential in sand levels evident across the lower beach either side of the groynes. The evidence therefore suggests that the groynes are not having an influence on longshore transport along the upper beach.

Figure 3-4 Condition of Environment Agency timber groynes.

Figure 3-5 EA timber groynes: Groynes EA1 to EA31. Also shown are Zone 1 to Zone 4, as defined in the Beach Survey Annual Reports (e.g. Jacobs, 2020).

4. Assessment of beach behaviour and response to management

4.1 BCKLWN frontage

4.1.1 Concrete groyne frontage

Beaches along this frontage (Figure 4-1) are characterised by a steep but very narrow mixed sand and gravel beach at the base of the seawall, which is typically lies between +1 mOD and +3 mOD (referred to as 'upper beach'). This is fronted by an outcrop of Carstone and lower sand beach ('lower beach'), beyond which is a sandflat below mean sea level (referred to as 'sandflat'). Offshore of this frontage lies the nearshore sand bank of Sunk Sand.

Figure 4-1 Concrete groyne frontage, looking south.

Beach profile data covering the past ten years indicate that there has been a small but net reduction in beach volume (above mean sea level). This equates, however, to an average annual loss of less than 1,000 m^3/year, and when considering only the upper beach (above +1 mOD) the rate of loss is closer to 500 m^3/year.

Whilst along the northern half of the concrete groyne frontage, volumes have tended to fluctuate, losses along the southern half of the frontage have been progressive. Upper beach levels over the past few years have been some of the lowest recorded. This has resulted in narrowing of the upper beach, particularly in the vicinity of the Amusement Arcade. This reduction in upper beach width is also shown by the increased exposure of the Carstone platform over time, evident from aerial images.

Against this longer term trend, short term fluctuations in beach level are also recorded in the data, with changes greater at the base of the seawall than elsewhere along the profile: this is where the more mobile sediment is concentrated. Beaches along the southern part of this frontage are more volatile, again likely due to the greater volumes of mobile sand and gravel. Also observed is that typically when beach levels at the seawall are highest, the upper beach slope is steeper, whilst lower levels at the seawall are associated with a flatter beach, suggesting that there is a wedge of sediment that tends to be moved back and forth across-shore and between the groynes. This suggests that on-offshore movement of sediment may be a key process along this frontage.

Notably historical photographs show that a scarcity of beach sediment has been a feature of this shoreline in the past, including pre-groynes. An early photograph of Hunstanton from the early twentieth century (

Figure 4-2) illustrates that at this time there was no beach exposed at high tide along the promenade frontage, whilst a photograph from 1893 at low tide (https://www.francisfrith.com) illustrates widespread exposure of Carstone in front of the North Promenade.

It is understood that concrete groynes were constructed in 1943, when six groynes were present between the start of the promenade of the pier. Subsequent replacement of the groynes is believed to have been undertaken in the early 1980s. Notably, construction of the promenade and defences has created a distinct promontory along this stretch of shoreline (as illustrated in Figure 4-3).

There is little evidence from the beach profile data for either this frontage, or from along Hunstanton cliffs, that significant influxes of sediment have been moved onto this frontage from further north over the period over the past few decades. There is also an absence of beach along the base of the cliffs immediately north. At the larger scale, there is morphological evidence that sediment (assumed to be sand) is moved southwards from Holme, which has contributed to the build-up of beaches and dune growth to the north of the cliffs. It is possible that this sand could be moved further south and start to contribute to the beaches at Hunstanton, but equally this area, at the mouth of The Wash is likely to be a location where flows out the estuary dominate, which may naturally prohibit any further southwards movement of this material. From the historical photographs available, it is not, however, possible to confirm this.

Figure 4-2 Hunstanton at high tide: date of photograph not known but assumed to be early twentieth century. Source: http://www.hunstantoncivicsociety.org.uk.

Figure 4-3 Aerial image of the coast. Taken from: https://environmentagency.blog.gov.uk

The evidence from the beach profile data suggests that the existing concrete groynes are not effective in preventing the net loss of sediment from the frontage, particularly along the southern part of this frontage. They do, however, exert some limited influence on sediment movement, as evidenced by the very localised, and occasional, accumulation of sediment at the back of the beach, which is moved within the bays, both cross-shore and alongshore. Even where sediment has accumulated against the groynes, it is not in substantial volumes.

In terms of their influence when they were in better condition, no beach data for this period have been found and there is only limited information available from historical photographs (e.g. Figure 4-4), which shows the original six concrete groynes (before their replacement/ refurbishment in the 1980s). This photograph also shows exposure of Carstone at the northern end of the promenade and narrower upper beaches.

Combining these observations with the understanding of coastal processes (section 2.3), current understanding of coastal behaviour and response along this stretch can be summarised as follows:

- A key characteristic of this stretch is the paucity of sediment. This is not a new phenomenon and is likely to be related to the exposure conditions along the shoreline and lack of mechanism by which new sediment can be moved onto this frontage. Erosion of Hunstanton cliffs, whilst contributing material, is not thought to provide significant volumes of beach-building sediment. Some fine sand may be moved onto the frontage from further north or from offshore, but does not build significant beaches here.

- The frontage is exposed to externally and internally generated waves, as well as strong ebb tidal flows, which makes it unlikely for any sediment that arrives to be retained naturally along this frontage for any length of time. Tidal flows are understood to run parallel to the shoreline channelled by the nearshore bank of Sunk Sand. The situation has likely been exacerbated by the seaward extension of the shoreline position through construction of the promenade and seawalls. The existing groynes are not observed to have been effective in retaining sediment; this is believed to be predominately due to the nature of their design, rather than their existing poor condition.

Figure 4-4 Hunstanton in the 1950s. Exact date of photograph is unknown. Source: https://www.kingslynn-forums.co.uk

4.1.2 **Timber groyne frontage** (Figure 4-5)

Figure 4-5 Timber groynes along the BCKLWN frontage

Moving southwards from the concrete groyne frontage the morphology of the beach changes south of Groyne 12, characterised by a much wider upper gravelly sand beach (‘upper beach’) and lower sand beach (‘lower beach’), which transitions to a sandflat beyond the end of the groynes (’sandflat’). Beach volumes (across the whole profile) are much greater along this stretch than along the beaches further north.

The beach profile data and LiDAR indicate differing patterns of change along the frontage, as illustrated in Figure 4-6. Along the northern half of this frontage, there has been a trend of beach lowering and therefore beach sediment loss over the past 10 years. In contrast, the southern half has generally seen net gain across the upper beach.

This corresponds with the distinct change in shoreline orientation along this frontage around Groyne 12. Notably, losses across the northern half have typically been across the beach profile and contour data derived from the LiDAR show that there has been a landward translation of the beach profile (see Appendix A). To the south, the gains have predominately been across the upper beach, i.e. along the base of the seawall, although some increase in the level of the lower sand beach is also evident from the data.

Observations from the site visits indicate that the upper beach is around 35 to 40 m wide, but tapers considerably north of Groyne 12, this means that between 50 and 60 m is the groyne length is exposed for most groynes – increasing to the full 90 m for the more northern structures. Negligible height differential either side of the groynes was observed, occurring only where pebbles had been trapped in gaps between the vertical posts.

Historical aerials show that beach levels have fluctuated along this frontage in the past, and that the stretch of shoreline south of the former pier (now the Amusement Arcade), has previously experienced both very low and higher beaches. Whilst the wave-driven transport is understood to be southwards, aerials do show some accumulation of sediment on the southern side of the Power Boat Ramp on occasions, so there may be potential for material to be moved in both directions at this transition between BCKLWN and Environment Agency frontages; noting that the stretch south of the ramp is occasionally nourished using recycled sediment. Over time, the beach volumes since 2011 above mean sea level have fluctuated by around 3,000 m^3. The data suggests that the area of erosion may be progressively moving south, which may be indicative of the limited availability and, therefore, input of sediment from the frontages to the north.

Combining these observations with the understanding of coastal processes (section 2.3), current understanding of coastal behaviour and response along this stretch can be summarised as follows:

- As along the concrete groyne frontage, the beaches here are affected by both waves, predominately from the north, and northwards ebb tidal flows, which result in opposing sediment movement across the sandflat/lower beach and the upper beaches. Cross-shore movement of sediment is also believed to be of significance here. The upper coarse beaches are currently experiencing an erosional trend, which is progressing southwards, indicating lack of new sediment input from the north.

- Much of the gravel and coarse sand component that remains along the frontage is likely to be relict, with little or no contemporary natural source of fresh material. There is potential for finer sand to be moved alongshore by tidal currents and then onshore by waves, but this mechanism is not sufficient to significantly build beaches and is unlikely to contribute to the upper coarse beaches.

- By their design, the groynes will not prevent any wave-driven transport of sands, although they may influence current flows, particularly across the lower beach, allowing deposition and retention of finer sediment here.

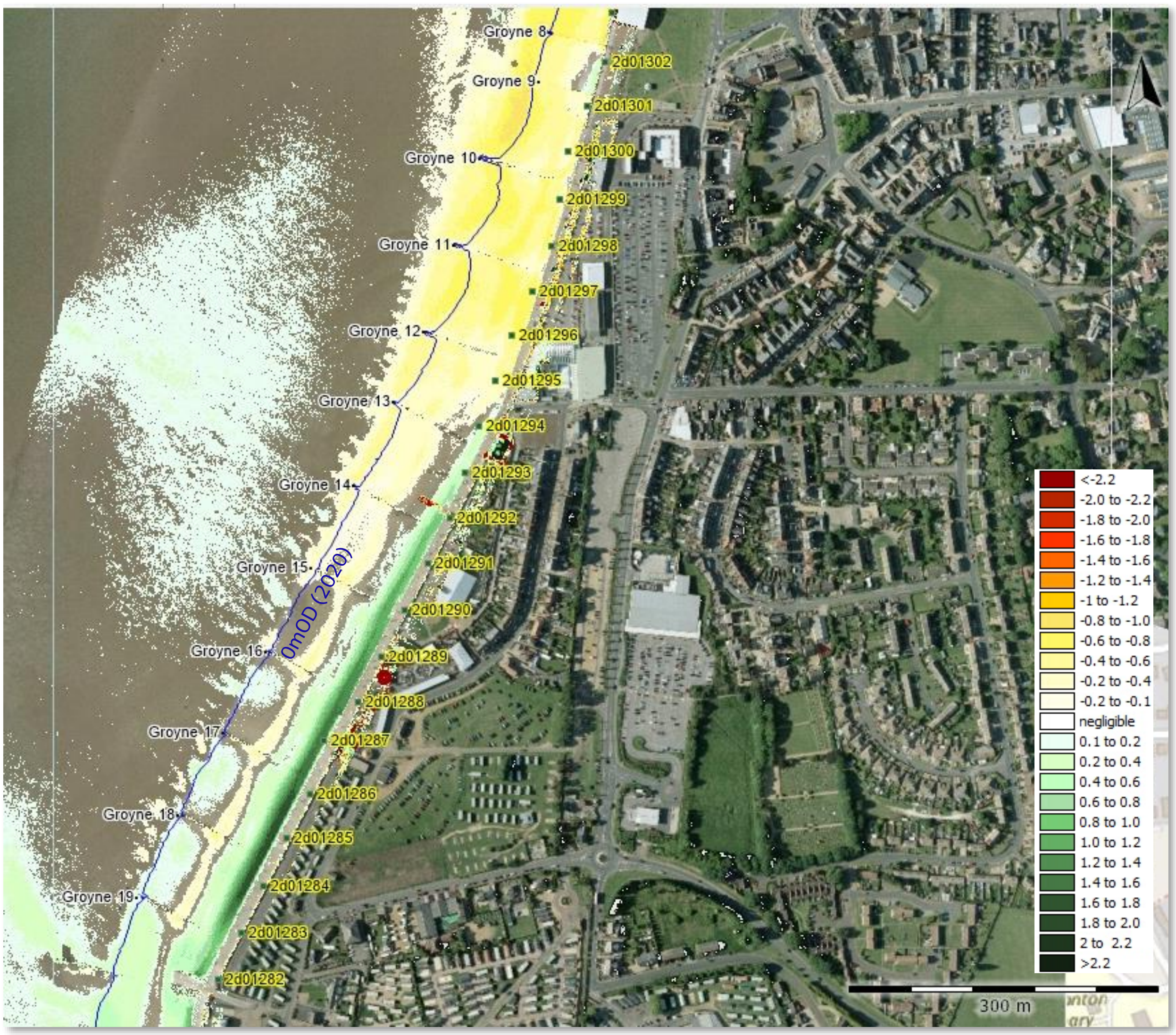

Figure 4-6 Difference plot for the BCKLWN timber groyne frontage, generated from LiDAR data from 2020 and 2011, with change in beach level in metres. (data courtesy of ACM). Negative values (green) mean that there has been a drop in level in 2020, and positive values (red and yellow) indicate an increase in level.

4.2 Environment Agency timber groyne frontage

As part of the monitoring undertaken to inform the recycling, the frontage has been divided into a number of zones: Zone 1 to 4 are within the timber groyne frontage (Figure 4-7, Figure 4-8) considered by this study, with Zone 1 starting from the Power Boat Ramp. These zones are therefore referred to in the following text.

Figure 4-7 EA timber groyne frontage (looking south from between Groyne 8, Zone 2)

Along this frontage, changes in the beach morphology and volume are complicated due to management activities, namely sediment nourishment, recycling and reprofiling.

The natural shape of the coastline also differs alongshore, with the intertidal flat considerably wider at the southern end this frontage, forming Stubborn Sand. Here (within Zone 4), the level of mean sea level lies seaward of the toe of the groynes.

At the northern end of the frontage in Zone 1, Groyne EA1 to Groyne EA4, the beaches are characterised by a upper mixed beach, which varies in width due to occasional nourishment with recycled sediment, but can extend over half way down the groynes (which are around 55 to 65 m in length Groynes EA1 to EA3, and 80 m length at Groyne EA4). Beyond this is a sandy lower beach, typically to around the end of the groynes, and sandflat. This morphology remains similar through the start of Zone 2 (Groyne EA5 to Groyne EA13), although the upper beach starts to steepen and there is some evidence to suggest that this is better sorted in places. Along Zone 3 (Groyne EA14 to Groyne EA23) and through to Zone 4 (Groyne EA4 to Groyne EA31), the beach form changes to a more distinct coarse upper beach, which transitions to the sandflat.

Longer beach level data sets are available for this frontage than for the BCKLWN frontage, with data available from 1992 at regular intervals. The early data indicate that following nourishment of the beaches in the early 1990s, there was a natural adjustment of the beaches along most of the frontage, with a shallower beach profile typically developing through lowering of the upper parts of the beaches.

Figure 4-8 EA timber groyne frontage (looking north)

The observed changes vary across the frontage, with greatest losses across the beach recorded along the central stretches between Groyne EA6 and Groyne EA18 (Zone 2 and the northern part of Zone 3 as defined in the Annual Beach Survey Reports), resulting in narrowing of the upper beach. Some profiles along the frontage indicate the occurrence of localised beach lowering, due to the formation of small pools and channels from the toe of the groynes.

Immediately south of start of the Environment Agency's frontage, at the Power Boat Ramp, there is a slight embayment, which may be slightly more conducive to retaining sediment (Zone 1; Groyne EA1 to Groyne EA4). Some accumulation of sediment occurs either side of the ramp, which may be a result of this sheltering effect. Although along this frontage the recorded changes in volume have been small and suggestive of a net accretion trend, the data show that following the nourishment in 1992 there has been notable adjustment of the beach profile, with a drop in beach levels across the upper beach but increases in beach level across the lower beach (both within and outside the limit of the groynes). The profile data suggest that there was a change in beach response around 1997-1998; which is when beach levels below mean sea level started to increase, resulting in a net flattening of the beach profile. Although beaches remain below those in 1990s, there has been fluctuation in the width and level of the upper beach over time, associated with occasional placement of recycled sediment.

Moving south, into Zone 2 (Groyne EA5 to Groyne EA13), the coastline protrudes slightly, resulting in this being a more exposed frontage. This is also where a low water channel of The Wash lies closest to this shoreline and limits the extent of the intertidal sandflat. Here, the beaches are typically narrower and steeper, and there is little evidence that material moved from the top of the beaches is being retained lower down. As a result, there has been a recorded loss in beach volume over the past few years. Notably the area of erosion has moved progressively southwards, into Zone 3 towards Groyne EA18.

Further south, along the Heacham Manor Golf Club frontage there is a deeper embayment (Zone 3; Groyne EA14 to Groyne EA23); the low dunes that have developed here are evidence of the potential for sediment retention at the back of the beach/ base of the seawall. Much of the groyne lengths are buried here, and due to the embayed nature of the shoreline, the effective length of the groynes is also reduced. It is notable that the beach line does not follow the embayed backshore alignment. At the northern end of this embayment, there has, however, been more recent erosion (as acknowledged above) and during the November site visit cliffing of the backshore dunes was also observed (Figure 4-9). Historical aerials indicate that the dunes may be a fairly recent feature (since 1999) and have experienced previous periods of growth and erosion.


Figure 4-9 Cliffing of the low dune in Zone 3

Along Zone 4 (Groyne EA24 to Groyne EA31), there has been a net drop in beach levels since nourishment in 1992, but generally since the early 2000s the upper beach has remained fairly stable, fluctuating slightly in level between surveys. The data do indicate the possible influx of sediment, which forms a small beach berm or ridge around +1 mOD, but this tends to be subsequently eroded. The intertidal area widens along this stretch and there is evidence to suggest that the sandflat is increasing in level and extent.

If the volumes of sediment added to the beaches through nourishment and recycling are ignored, calculated 'natural' beach volumes indicate a net loss across the groyne frontage over the past ten years. The losses across the beach (above mean sea level) equate to around 2,200 m^3/year, but this includes the considerable losses experienced along this frontage due to the December 2013 storm. Excluding the impact of this event, average annual losses are closer to 1,000m^3/year.

Combining these observations with the understanding of coastal processes (section 2.3), current understanding of coastal behaviour and response along this stretch can be summarised as follows:

- As along the BCKLWN frontage, the beaches here are affected by both waves, predominately from the north, and northwards strong ebb tidal flows, which result in opposing sediment movement across the sandflat and lower beach, and the upper beaches. Along the northern half of the frontage a low water channel runs close to the shoreline, but due to the growth of Stubborn Sand this is pushed further offshore to the south. As a consequence of this nearshore morphology, tidal current flows are likely to be stronger along the northern stretch. This cannot, however, be corroborated due to the lack of available data on bathymetry and tidal flows. Similarly, little can be said about the influence of any changes in bathymetry on observed beach changes.

- Patterns of observed change do, however, appear to relate to the alignment of the shoreline, that has been at least retained, or not created, through the construction of backshore defences. This has created a series of slight promontories and embayments, with the promontories typically experiencing greater losses of sediment.

- As to the north, the input of fresh sediment from natural sources is limited, although there is potential for fine sand to be moved onshore. Therefore, observed changes relate to the reworking and redistribution of sediments along the frontage.

- By their design, the groynes will not prevent any wave-driven transport of sands and gravels, although they may influence current flows, particularly across the lower beach, allowing deposition and retention of finer sediment here. Along this frontage, the influence of the groynes on tidal flows does, however, significantly diminish due to the intertidal sandflat, which widens considerably to the south.

5. Effectiveness of the existing groynes

5.1 BCKLWN frontage

5.1.1 Concrete groyne frontage

Along this frontage, the following key observations apply:

- There is very limited sediment cover at present: consisting of a very narrow (around 20 m in width) strip of upper coarser beach deposits, and a thin veneer of finer sand interspersed between the Carstone outcrops across the lower beach. There is little evidence that substantial volumes of sediment are regularly moved onto this shoreline. Although there is some evidence that fuller beaches may have been present at some points in the past, scarcity of beach sediment has been a feature of this shoreline previously, both pre- and post-groynes. As such, current effectiveness of the existing groyne structures along this frontage is limited due to the paucity of sediment available to be retained between structures.
- Construction of the promenade and defences has created a distinct promontory along this stretch of shoreline. This, together with the greater exposure to both internally and externally generated waves than elsewhere along the study frontage, makes it unlikely for sediment to be retained naturally along this frontage for any length of time, even if there were a reasonable input of sediment to the system.
- It is also probable that any sediment drawn down the beach may be moved into the low water channel that lies inshore of Sunk Sand sandbank, where it might be moved northwards by flood currents.
- Cross-shore movement of material is evident from beach level data, with loss of sediment from the upper beach. This loss of sediment is not being prevented by the current groyne structures.
- Condition-wise the groynes are considered to be 'Poor' given their overall structural integrity and potential for failure, in large part due to the stability of the in-situ piles. There are places where a few planks missing, but this make little difference to their trapping performance. There are also locations where there are gaps beneath the groynes. Due to limited availability of details on their structural design, very little can be said regarding their intended sediment trapping effectiveness.
- The elevation of these structures is also too low to be effective, with a need to retain beach material above high water if they are to be effective in front of a reflective seawall.
- Current groynes are observed to have only a very localised effect on the coarse upper beach sediment, where this forms a slightly more substantial deposit, but this is very much limited to the top few metres of the groyne length. Even where sediment has accumulated against the groynes, this is substantially lower than the height of the groynes.

On the basis of these observations, it is concluded the existing concrete groynes are currently ineffective in retaining sediment along this frontage. At present, this is due to the scarcity of sediment input to the frontage, but even when there has been sediment present in the past this has not been retained over time.

5.1.2 Timber groyne frontage

Along this frontage, the following key observations apply:

- The beaches consist of an upper beach comprising coarse sand, pebbles and gravel, which transitions to a lower sandier beach, and a fronting sandflat. Between the upper and lower beach there is commonly a covering of much coarser sediment, composed of cobbles derived from the Hunstanton cliffs. This coarse deposit is likely to be mobilised only under the most energetic wave conditions, whilst at other times it will form a fairly stable surface that is occasionally covered by sand. At the northern end of this frontage, the upper beach is very narrow and barely existent.

- The beaches contain a greater volume of sediment than those along the concrete groyne frontage, particularly south of Groyne 12. The fronting sandflat is also higher and wider than further north.
- The slope of the groynes is fairly well aligned with the slope of the lower sand beach, but the upper beach, which is composed a mix of sand and gravel, lies at a steeper slope. As a result, the upper parts of the groynes are largely buried (with the exception of the northernmost groynes 10, 11 and 12, where the upper beach is very narrow or non-existent) and therefore are currently having very little effect on any movement of sediment at the top of the beach. Where they are exposed across the lower sand beach, the lack of any differential in height either side of the groynes implies that they also are having limited effect on wave-driven alongshore transport along this part of the beach.
- The present condition of the groynes is considered to be 'Poor', although the upper parts of those south of Groyne 12 are buried and therefore not inspected. However, even in a pristine state these are permeable groynes and it is therefore assumed (as no design rationale/ details have been available) that the intention was simply to reduce the rate of sediment movement, rather than form a blockade to longshore transport. Based on the design, sand-sized sediment is likely to simply pass through the groynes.
- There has been significant abrasion of the timber groynes, which has widened the gaps between the intermediate piles (stakes), further reducing any potential effect that might have been expected. Boulders have been placed along the groynes in places; although addition of these is probably unrelated to the original design rationale.
- The pattern of change observed from the beach monitoring data indicates that whilst beaches to the north of Groyne 12 have been losing sediment and lowering, beaches to the south of Groyne 12 have generally gained sediment (as shown in Figure 4-6). As such the planform of beach has rotated clockwise over time. Erosion north of Groyne 12 is a continuation of the trend observed along the southern part of the concrete groyne frontage (Groyne 6 to Groyne 9).
- Whilst the groynes may have some very localised influence in slowing the loss of upper beach sediment along the seawall, they have not prevented the progressive loss of sediment from the upper and lower beach north of Groyne 12, due to a predominantly southwards wave-driven transport processes. Currently this sediment appears to be at least partly held up north of the Power Boat Ramp, possibly due to the change in coastal alignment created along the frontage back to Groyne 12 by the promontory created at this location and orientation of the seawall to the south.
- There is no evidence that the much coarser sediments, namely the pebbles and cobbles derived from the Hunstanton Cliffs, are noticeably affected by the groynes; although some pebbles and cobbles evidently become trapped between the stakes (intermediate posts) there does not appear to be any significant differential in height at the groynes, nor are the deposits crenulated in form, which otherwise be expected between the groynes.
- The possible influence of the groynes on tidal currents and therefore transport of finer sediments is less certain as observations indicate that along this stretch slightly higher sandy beaches may be being retained between the groynes. The origin of this material is not known; potentially it is the finer sands and silts washed out of the upper beach, or it may be being moved onshore from the offshore sandbanks and wider Wash. Previous studies have identified that tidal current flows along the shoreline are northwards during the flood tide, and across the lower beaches and sandflat these flows may become the more dominant process (as opposed to southwards wave-driven transport further up the beach). The groynes may cause a disruption to tidal flows across the beaches at mid to high water levels, reducing flow speeds and thereby both reducing erosion and potentially encouraging some limited deposition of sand on the ebb tide.

On the basis of these observations, it is concluded that whilst the groynes in their current condition may have some influence on retention of sand on the lower beach, through their effect on tidal currents, they do not appear to be affecting wave-driven longshore transport of coarser sediments along the upper beach. Although it is possible that retaining sand across the lower beach may help support the upper beach, evidence suggests that these upper beaches are losing volume, the pattern of which cannot be attributed to variations in condition of the groynes (these all being in a similar state of disrepair) and is therefore more likely to relate to their permeable design.

5.2 Environment Agency timber groyne frontage

Along this frontage, the following general observations apply:

- The morphology and beach levels vary along this frontage:
  - Along the northern part of this frontage, between the Power Boat Ramp and the embayment area (Groynes EA1 to EA15: Zones 1 and 2), the beaches typically consist of an upper beach consisting of sand and gravel, which transitions to a lower sandier beach, and a fronting sandflat beyond the groyne field. Beaches south of the Power Boat Ramp are typically lower than the beaches immediately north of the Ramp and upper beach levels decrease towards the embayment.
  - Along the central stretch the alignment of the shoreline forms an embayment (between Groyne EA16 and Groyne EA23; Zone 3), and here the beaches are much higher and wider. This is also where low dunes have developed along the base of the seawall.
  - To the south to the end of the timber groynes frontage (i.e. Groyne EA24 to EA31; Zone 4), the morphology changes slightly with a more distinctive pebble and gravel upper beach fronted directly by a widening intertidal sandflat, i.e. the sandier lower beach is absent.
- The observed patterns of change also vary alongshore:
  - Between the Power Boat Ramp and the embayment area (Groynes EA1 to EA15),beaches north of Groyne EA5 have been stable or accreting slightly, but moving towards the slight promontory, at the start of the embayment, there has been net loss of sediment. This is where the lowest beach levels are currently recorded. At the time of the November site visit, the roots of the groynes were exposed in the vicinity of Groyne 12 and Groyne 13 and the upper beach was not sufficiently high enough to cover the capping beam above the toe piles.
  - Along the central embayed stretch, the upper beaches are higher and wider and there is evidence that this stretch has been conducive for sediment accumulation, demonstrated by the development of low dunes at the back of the beach. However, the beach profile data shows that there has been a recent trend of erosion, which has progressively moved southwards. In contrast, beaches at the southern end of the embayment have continued to grow.
  - South of Groyne EA24 (Zone 4), the key change has been growth and expansion of the intertidal sandflat over time, particularly post 1997.
- As along the BCKLWN timber groyne frontage, there has been significant abrasion of the timber groynes, where exposed, which has widened the gaps between the intermediate piles (stakes). Given the significant deterioration of these fundamental components of the groynes, the overall condition has to be concluded to be ‘Poor’, although the upper parts are typically buried and therefore not inspected. However, even in a pristine state these are permeable groynes and it is therefore assumed (as no design rationale/ details have been available) that the intention was simply to reduce the rate of sediment movement, rather than form a blockade to longshore transport. Based on the design sand-sized sediment is likely to simply pass through the groynes. As observed along the BCKLWN timber groyne frontage, the state of the groynes does not significantly vary alongshore, although it appears that some groynes have been shortened over time, which may be due to their failure.

- The slope of the groynes is fairly well aligned with the slope of the lower sand beach, but the upper beach lies at a steeper slope. As a result, the upper parts of the groynes are largely buried and therefore are currently having very little effect on any longshore movement of sediment at the top of the beach. Where they are exposed across the lower sand beach, the lack of any differential in height either side of the groynes, as also observed along the BCKLWN timber groyne frontage, implies that they also are having limited effect on wave-driven alongshore transport along this part of the beach.
- The lengths of the groynes do not appear to have a significant effect: a comparison of beach levels within Zone 2, between the shorter groynes EA9 and EA10 and longer groynes EA11 and EA12, did not reveal any notable increase in beach width or level. This was also evident from observations made during the site visits: the ends of the groynes are exposed and there is believed to have been previous issues with groyne stability at the ends of these structures.
- Cross-shore adjustment of the beaches is also evident from the data; again this does not appear to be influenced by the groynes.
- As along the BCKLWN timber groyne frontage, the possible influence of the groynes on tidal currents and therefore transport of finer sand sized sediments is less certain as observations indicate that sand may be being retained between the groynes, within Zones 1 and 2. The origin of this material is not known; potentially it is the finer sediment washed out of the upper beach, or it may be being moved onshore from the offshore sandbanks and wider Wash. Previous studies have identified that tidal flows along the shoreline are northwards during the flood tide, and across the lower beaches and sandflat these flows may become the more dominant process (as opposed to southwards wave-driven transport further up the beach). The groynes may cause a disruption to tidal flows across the beaches at mid to high water levels, reducing flow speeds and thereby both reducing erosion and potentially encouraging some limited deposition of sand on the ebbing tide.
- Within Zone 4 (Groyne EA24 to Groyne EA31) the widening of the sandflat is unrelated to the groynes, and is a continuation of a trend of growth of Stubborn Sand, which has been ongoing since the 1870s, based on historic Admiralty Chart data. Both here, and in Zone 3 (Groyne EA14 to Groyne EA23), where there is a much wider intertidal flat, any influence of the groynes on tidal currents will be significantly less, due to shallower water depths and distance from the main channel.

On the basis of these observations, the following can be concluded regarding the effectiveness of the existing groynes:

- Along the northern stretch of shoreline (Zones 1 and Zone 2: Groyne EA1 to Groyne EA13) the groynes in their current design and condition may be helping to retain a lower sand beach, through their effect on tidal currents, but do not appear to be affecting wave-driven longshore transport along the upper sand-gravel beach. The change in shoreline orientation at the Power Boat Ramp, possibly combined with the effect of the ramp structure and associated outfall pipe, appears to have a greater impact on sediment accumulation than the adjacent groynes. Whilst it is possible that by retaining sand across the lower beach helps hold the upper beach, evidence suggests that upper beaches, particularly along Zone 2 and northern half of Zone 3, are losing sediment, which cannot be attributed to variations in the condition of the groynes (these all being in a similar state of disrepair) and is therefore more likely to relate to their design.
- Along the central stretch, the embayment area, many of the groynes are currently buried and therefore have little to no influence on sediment movement across the upper beach. Previous accumulation of sediment in this area is more likely to be attributable to the embayed shape of the coast. More recent data suggests, however, that the erosion experienced within Zone 2 is progressively moving southwards. The effective length of the groynes is less here and some sediment does appear to be moving beyond the ends of the groynes, across the mouth of the embayment.

- Further south, in Zone 3 and Zone 4 (Groyne EA14 to Groyne EA31), any effect of the groynes on tidal currents is likely to be significantly diminished (and probably virtually non-existent) due to the wider intertidal area along this stretch. The low water channel also lies further offshore here. However, there equally appears to be very little impact of the groynes on any wave-driven sediment transport across the upper beach.

6. Consideration of options

Based upon the findings presented in sections 3, 4 and 5, this section summarises the assessment of:

1. Whether the groynes are of any benefit in retaining beach material in their current design (presuming groynes were at target condition)

2. Whether they would be effective if their design was altered, and

3. If groynes are of limited or no benefit, then what approaches may potentially retain sediment on the beach.

Where relevant, the potential impacts of climate change on the effectiveness of these structures has also been noted.

In respect of points 2 and 3, identification of other options has also considered the primary benefit of providing a beach along each frontage, and therefore the potential of including additional beach nourishment within those options has also been appraised.

Across the BCKLWN frontages, previous studies and proposed management indicate that beaches are not contributing significantly to the defence function, with that to be provided in full by improvements to the walls and promenade. So, the main justification for holding beaches here is for amenity purposes, and in that respect the aspiration is for sandier beaches, not pebbles, cobbles and gravel.

Across the Environment Agency frontage, however, the beach clearly has a significant defence function, and is considered part of the flood defence system in combination with the seawalls. These beaches also fulfil an amenity function and important for the local tourism economy.

6.1 BCKLWN concrete groyne frontage

6.1.1 Re-instating or altering existing groynes

For all of these options, the groynes would need to be completely reconstructed, as the existing structures and their elements are no longer suitable – in particular the new structures would need to extend much deeper to address the foreshore lowering that has occurred and a much more robust design will be needed for the main piles to avoid similar deterioration and failure.

In respect of the effectiveness of the present configuration, however:

- if the groynes were simply reinstated to the same profile and length, it is not likely that these would have an effect under current sediment regime due to the paucity of sediment arriving at the beaches at this location.
- if the groynes were reinstated to the same profile and length, <u>and</u> the beach nourished with sand, this sediment is still likely to disappear, as has occurred previously with this arrangement.

For these reasons, there would seem little benefit in investing further in maintenance and repair of the existing structures (other than for health and safety reasons as this may be less expensive than wholesale removal).

To improve <u>the potential</u> for any beach retention the concrete groynes would certainly need to be higher; extending to an elevation enabling a beach to exist to above high water and minimise any wave reflection off of the seawall. For a sand beach slope, these would also need to be considerably longer to accommodate the full beach profile, which, from observations here, is relatively flat for the naturally occurring grain size. However, it is considered that:

- If the groynes were made higher or longer it is still unlikely that these would have an effect under the current sediment regime, due to the absence of sediment naturally arriving at the beaches at this location.
- If the groynes were made higher or longer, and the beach nourished, there is potential for more of the imported sediment to be retained (dependent on the design), although they would still not prevent the onshore-offshore movement of sand which appears to be a prevailing process, so it is expected that the groynes bays would still eventually become denuded of this additional sediment over time.
- An alternative of renourishing with a coarser sediment (e.g. large gravel) might be a more effective way to provide some beach, however (i) this is contrary to the aspiration here to create a sand beach and (ii) would significantly increase the levels of abrasion making the structures vulnerable to more rapid degradation and thus having a much shorter life expectancy.

In summary, none of these options are considered likely to be effective for the retention of a beach along this frontage. Consequently, assessing the impact of climate change on their effectiveness is immaterial.

6.1.2 Alternatives

With no groynes present, it is unlikely that anything beyond the current narrow veneer of mixed beach deposits would be present for much of the time along the top of the beach; which would be a return to the position at the turn of the twentieth century and not that dissimilar to today's situation.

If the existing groynes were removed (e.g. for health and safety reasons) and not replaced, but beach nourishment were placed here, it is considered that:

- Sand nourishment, to provide a beach of the nature aspired to for recreational purposes, is not expected to remain. Although the groynes are considered ineffective in their present form, their removal also does nothing to improve sand retention along this frontage. Therefore, this sand will be mobilised and removed over time in the same manner described above.
- An alternative of renourishing with a coarser sediment (e.g. pebbles and cobbles) which is less readily mobilised may remain much longer. However, as already noted, this is contrary to the aspiration here to create a sand beach for recreational and amenity purposes.

The impact of climate change on either of these approaches would be to simply hasten the movement of this sediment from the frontage through greater wave energy resulting from deeper water due to sea level rise.

As presented in section 6.1.1, simple groynes are not likely to be an effective form or beach control along this stretch of shoreline. Rock groynes can provide greater attenuation of wave energy, improving the retention of sediment, but the issue of lack of supply persists. Furthermore, any cross-shore removal of sand would not be addressed, even with beach recharge which would also be required. To attempt to counter this potential loss, these structures would need to be higher and much longer than the existing groynes to accommodate the full beach width. It is probable that they would actually need to extend even further seawards beyond the toe of the beach to intercept alongshore currents that are thought responsible for removing sand, and require a headland configuration to help control and influence wave activity within each bay.

These will essentially be large rock headland structures rather than 'groynes' however, effectively 'locking in' the renourished beach as far as possible. This will also be considerably more expensive (detailed developed of this concept would be required to provide an estimate of costs). In this situation it would be necessary to totally redesign the groyne field (supported by detailed modelling) rather than simply assuming these sit along the alignments of the existing structures. Designing to accommodate the impacts of climate change would also therefore need to form part of any further appraisal.

6.2 BCKLWN timber groyne frontage

6.2.1 Re-instating or altering existing groynes

For any of these options, the groynes would need to be mostly if not completely reconstructed, as many of the existing elements are heavily degraded and beyond the end of their effective life. In particular, new intermediate posts would be needed throughout, most walings would require replacement, and the remaining residual life of each king pile will require close examination. Certainly many of the latter will no longer be sufficiently embedded as the groynes ends have become subject to failure where beach levels have lowered. Changes would also need to be made to the timbers used in their construction, although abrasion will remain an ongoing matter for continual maintenance.

In respect of the effectiveness of the present configuration, however:

- If the groynes were simply reinstated to their original condition, and same profile and length, little change in current beach retention effectiveness is expected as their current poor functioning is not thought to be a direct result of their existing condition, but a consequence of their design, exacerbated by limited natural sediment supply.
- If groynes were reinstated to the same profile and length and the beach was recharged with imported sand, more material is likely to remain on the lower beach for a while but little will change in respect of their retention efficiency, as the groynes would remain as permeable structures and the situation would likely return to one similar to that today.

For these reasons, there would seem limited benefit in investing further in maintenance and repair of all of the existing structures. However, those forming the four or five bays towards the southern end of this stretch (i.e. directly north of the Power Boat Ramp) are potentially helping to influence current flows and thus helping a little with lower beach sand retention. It may therefore be worth reinstating some of the intermediate posts along these if remaining elements are sound, if this could be done relatively inexpensively, simply to help maintain the status quo whilst longer term decisions are made.

With respect to altering the size of these groynes, it is considered that:

- If the groynes were made longer, there could be potential for more sand to be retained across the lower beach; although this may be limited by the volume of sediment being naturally moved onto the beaches. It is also notable that there have already been stability issues with foreshore lowering at the end of the groynes, which reinforces this point. It is therefore considered unlikely that this would significantly improve retention of beach material across the upper beaches.
- If the groynes were made higher, little if any improvement to either the upper or lower beach would be expected due to the permeable nature of the groynes and the understanding (based on observations) that the groynes are not acting as effective barriers to wave-driven longshore transport.

In summary, none of these options is considered to be particularly effective for the retention of a fully developed beach along this frontage. The nature of these structures means they do little to intercept alongshore sand movement, or control on-offshore movement; they only serve to influence tidal currents and help with modest sand deposition.

Even the possible influence on helping to retain some sand on the lower beach would be diminished by the effects of climate change, with higher water levels and resultant reduction in wave attenuation leading to greater mobilisation of fine sediments. Consequently, alternative approaches would need to be considered.

6.2.2 Alternatives

An alternative to the current permeable groynes would be to consider impermeable structures, i.e. fully planked timber panels similar to more common traditional groynes. But, given the relatively low rates of alongshore movement of the upper coarser beach, and the strong on-offshore movement of the lower beach sand component, these are unlikely to make a significant difference to beach building along this frontage.

As discussed in section 6.1.2, rock groynes can provide greater attenuation of wave energy, improving the retention of sediment, but would not address the issue of a lack of sediment supply. Through suitable design they may help to reduce, but would not prevent, the cross-shore removal of sand so might have limited effectiveness even with beach recharge. A more effective approach may be to consider the wider plan shape and effect that the changes in shoreline orientation already have upon beaches throughout this area, and in particular the effect that the promontory at the Power Boat Ramp appears to have.

A preferable approach rather than groynes may therefore be to create a more stable (and wider) embayment between two larger rock headland structures. This might include extending the Power Boat Ramp promontory seaward at one end (but still providing access to the vessels using this facility), constructing a similar structure further north, e.g. in the vicinity of Groyne 10 to Groyne12, and constructing some intermediate shore-parallel reefs to better address on-offshore sand movement. This would, however, be very expensive and more detailed development of this concept would be required to provide an estimate of costs.

Another alternative is a mega-renourishment, i.e. similar to the Bacton Sand Engine, and it is understood that other sites are being sought to trial this concept. This would differ from a traditional beach nourishment and involve placing a considerable volume of dredged sand on the frontage, with the knowledge that this will be redistributed over time. But it could provide a substantial recreational beach and additional protection for the immediate future (the estimated life of the Bacton scheme is 20 years). Groynes would be immaterial with respect to this approach. It is also possible that the level of additional protection provided by the mega-nourishment might defer by a few years the need for, and associated costs of, some of the seawall and promenade upgrades currently planned. Depending upon the behaviour of the placed sand this may also benefit both the concrete groyne frontage and the Environment Agency frontage.

Considerable and comprehensive assessments of this approach, including extensive modelling and monitoring of the beach, nearshore and wider Wash area, would be critical to determine the likely timeframe of its effectiveness, costs, and importantly any potential implications of the redistribution of the sediment particularly across the environmentally sensitive sites within The Wash.

Given the diversity of all the above suggestions, and the requirement for more detailed assessment of any of them, each would need to be appraised at the time of development with respect to the impacts of climate change over their anticipated lifespan (notably higher sea levels and potentially larger waves).

6.3 Environment Agency timber groyne frontage

6.3.1 Re-instating or altering existing groynes

For any of these options, the groynes would need to be mostly, if not completely, reconstructed, as many of the existing elements are heavily degraded and beyond the end of their effective life. In particular, new intermediate posts would be needed throughout, many of the walings would require replacement, and the remaining residual life of each king pile will require close examination. Changes would also need to be made to the timbers used in their construction, although abrasion will remain an ongoing issue, requiring continual maintenance. It is assumed here that the present practice of beach recycling continues.

In respect of the effectiveness of the present configuration:

- If the groynes were simply reinstated to their original condition, and same profile and length, little change in current beach retention effectiveness is expected as their current poor functioning is not thought to be a direct result of their existing condition, but a consequence of their design, exacerbated by limited natural sediment supply.

In terms of the actual effectiveness of these groynes, however, this does vary, with some groynes possibly exerting an influence over the lower sand beach, whilst others are probably redundant, as described in section 5.2. Therefore, intervention may be worth considering for some of the structures, for example (but not exclusively) groynes EA8 to EA10, but not others, for example (but not exclusively) groynes EA17 to EA25.

For these reasons, there may also be some benefit in investing further in maintenance and repair of some of the structures to help maintain the status quo whilst longer term decisions are made.

In terms of altering the size of any of the existing groynes:

- If the groynes were made longer, this is unlikely to change present upper beach retention effectiveness significantly.
- If the groynes were simply made higher, but to the same design, little (to no) improvement to either the upper or lower beach would be expected due to the permeable nature of the groynes and the assumption (based on observations) that their design is not acting to provide an effective barrier to wave-driven longshore transport.

The possible influence of the existing structures on helping to retain some sand on the lower beach along the northern part of this frontage would be reduced by the effects of climate change in future, with higher sea levels and resultant lesser wave attenuation being conducive to greater mobilisation of finer sediments. The bigger issue here, however, would relate to the reduction in flood defence standard unless the seawall was raised, or a much more substantial beach could be provided to reduce exposure to wave overtopping. The current groyne structures will not address that, and therefore broader alternative approaches will probably need to be considered.

6.3.2 Alternatives

Consideration of options here need to reflect the variations in conditions and alignments along this frontage with distinct areas each having different characteristics.

With respect to the northernmost section, the suggestion within section 6.2.2 to consider a larger headland structure at the Power Boat Ramp as part of an alternative approach along the BCKLWN frontage would also have potential implications for this area. The influence on the lower beach area to the north should be matched by an influence to the south, as well as providing additional sheltering from waves along this stretch. A similar principle of headlands in the vicinity of Groynes EA14 and EA27/EA28, where other promontories already exist, may also be worth further consideration, to assist in improving the overall plan form of the shoreline by aiding retention of lower beach sand.

Although as noted in section 6.3.1 raising the existing groynes is not likely to make any notable difference to upper beach retention, this might be improved in places if the landward sections were replaced with higher impermeable structures, i.e., fully planked timber panels rather than the intermediate post arrangement, or preferably rock. Replacement groynes would need to be raised higher than the present structures; these are currently lower than the toe of the seawalls which means they are not effective in holding sediment to the elevation necessary to prevent its exposure. This could be important for overall stability of sea defences from groynes EA1 to EA16 where the toe of the wall is already visible and could therefore become vulnerable to undermining. The intended purpose of these would be to provide improved retention of the upper coarser beach material against wave-induced alongshore transport. To achieve that, it may also be necessary to consider a recharge or recycling of a coarser gravel-sized material, with placement at the top of the beach within these bays.

Given the diversity of all the above suggestions, and the requirement for more detailed assessment of any of them, each would need to be appraised at the time of development with respect to the impacts of climate change over their anticipated lifespan (notably higher sea levels and potentially larger waves).

A final option which may be undertaken in conjunction with any of the above, or in its own right without any dependency on beach control structures, is to review modifying the current recycling regime. Variations to this may include how much material is placed, where it is placed, and even when it is placed. Restrictions with respect to the extraction of this apply, so may be limiting factors, but a review of the optimal use of this and scope for obtaining any other material (and potentially a change in sediment size), might be timely. This practice will most definitely be affected by climate change and it would be prudent to begin to understand that now, so that any decisions regarding the future management approach can be appropriately informed.

Furthermore, if a decision to implement a mega-nourishment on the BCKLWN frontage were taken (see section 6.2.2), this could have beneficial implications for the management requirements along the Environment Agency frontage, which would need to be taken into account.

7. Summary and recommendations

The conclusion of this study is that the groynes present along this frontage are largely ineffective in their current state and would have limited effectiveness even if rebuilt to an improved standard.

The concrete groynes are situated in an area where the nearshore tidal channel runs close to the shore and there appears to be a notable lack of any natural sediment supply onto that part of the frontage. However, even with an input of sand here, e.g. through a renourishment, it is considered unlikely that this sand would be successfully retained by a groyne field similar to that presently found here.

Although the design rationale is unknown, the unusual permeable nature of the timber groynes makes it highly unlikely that these were built with the expectation of retaining sand and gravel moved alongshore by wave action, even if there were a regular natural supply. Some of these timber groynes may have an influence on tidal currents and help to retain a small amount of sand on the lower beach, particularly in the vicinity of the Power Boat Ramp, but there is no evidence that they have much influence on the alongshore movement of the upper beach. In fact, the size and shape of the upper beach against the seawalls appears to be dictated more by the alignment of those walls and the creation of some slight promontories and embayments.

This lack of effectiveness also means that, overall, there is no indication that any of the groynes are doing any harm (other than maybe some elements needing attention for health and safety reasons), but there is limited justification for investing further in their maintenance or refurbishment.

If beaches are to be provided, then more effective options will be to manage these frontages differently from the present. Alternative options include larger and different structures to control the waves and currents that affect the stability of the beach. But the absence of natural supply onto the frontages will almost certainly also require the nourishment of those beaches with material imported from elsewhere, and an acceptance that the retention of that will be finite, with further recharging required in the future. Other options to consider are to recharge without structures (e.g. mega-nourishment on the BCKLWN frontage), or to rebuild the upper beaches with a coarser sized sediment along the Environment Agency frontage.

These are, however, high-level observations and require more detailed appraisal to determine whether they could be suitable as there are other considerations to be taken into account; for example, safe public access along the beach and around any new structures, and the requirements of other beach users (e.g., sailing clubs, anglers etc). In particular it will be important to assess the environmental implications of any of these options. Further outline technical development would also be needed to better inform the likely costs for these and establish any economic justification for considering them further.

In the meantime, it may also be beneficial to review and potentially refresh the Beach Management Manual (last updated in 2014) for the Environment Agency frontage, taking into account more recent information to confirm design beach requirements and inform future recycling campaigns.