Unit C Initial Assessment Technical Report on Findings

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Technical Report on Findings

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1 Introduction

1.1 Background

The Wash East Coastal Management Strategy (WECMS) 2015 (Environment Agency, 2015) covered the frontage between Hunstanton Cliffs and Wolferton Creek on the Norfolk coast of The Wash, and divided this area into three distinct units (Figure 1-1): Unit A (Hunstanton Cliffs) and Unit B (Hunstanton Town), both at risk of erosion, are under the responsibility of the Borough Council of King's Lynn and West Norfolk (BCKLWN); Unit C (South Hunstanton to Wolferton Creek) is at risk of flooding and the Environment Agency is responsible for coastal flood defence.

Figure 1-1 Strategy unit boundaries and features along the frontage

This initial assessment is only considering management practices in along part of Unit C, primarily between Hunstanton Power Boat Ramp and Snettisham Scalp (Figure 2-1).

Management of flood risk throughout Unit C is implemented through a combination of hard defences (seawalls), soft defences (dunes) behind a sand/shingle upper beach and maintaining the beach ridge where necessary through annual recycling of sand and shingle recovered from Snettisham Scalp. Twice in the past, beach recharge has also been carried out, with material dredged from offshore put onto the beaches. An earth embankment forms a secondary line of defence which provides further protection against flooding to the area inland.

The current approach to management of flood risk here is defined in WECMS (2015) and the beach recycling operations are based upon the Beach Management Manual (BMM) which was significantly updated in 2014 (Environment Agency, 2014). A further revision was made in 2023 (Environment Agency, 2023a) but primarily to acknowledge Natural England's asset to continue following environmental review in 2022 rather than amending the technical criteria for the operations.

The most recent Business Case for the ongoing recycling works, and a potential additional beach recharge, was produced in 2016 and covers a period up to 2031, subject to ongoing monitoring and review (Environment Agency, 2016).

1.2 WECMS trigger points

WECMS confirmed that the current approach to flood risk management (i.e. beach recycling activities and maintenance of existing defences) remained sustainable from a social, environmental and economic perspective, but only if enough funding continues to be available. Subject to those conditions being met, this was expected to be the preferred approach at least at to the point when the hard defences at the northern end are likely to need to be replaced (expected around 2045). Decisions could be triggered by one of three developments:

- if funding (from any source) for continued defence management becomes insufficient,
- if the environmental impacts of defence management become unacceptable, or
- if the frequency of flood evacuations becomes unacceptable.

The WECMS identified that regular reviews would be undertaken to reassess the approach in relation to triggers and decision points, supported by the continuation of the current monitoring regime. This includes monitoring of the beach itself, beach ridge and dunes to inform recycling activities, and inspections and maintenance of the defences.

A high-level review of such triggers was undertaken as part of this initial assessment which found that:

- Environmental impacts of defence management are still acceptable. There is currently a requirement for a review of environmental monitoring activities to be undertaken every 5 years. The last one undertaken in 2022 was based on extensive monitoring of sediments, invertebrates, sand dunes and scalp vegetation and waterbirds, and showed no direct evidence of significant direct ecological impacts from individual past engineering and major renourishment works, nor from the recurring annual beach sediment recycling activities. However, observations of the dune and Scalp ecology raise concerns about potential future change of the vegetation communities (Environment Agency, 2022).
- Frequency of flood evacuations is still acceptable. Evacuation notices have only been issued very few times over the Strategy period.
- Funding (from any source) may have become insufficient. In light of potential changes to the physical environment and new information in terms of costs for beach recharge activities, this initial assessment was commissioned by the Environment Agency to identify whether this trigger has (or not) been reached.

1.3 Reasons for this assessment

Further assessment undertaken as part of the Business Case produced in 2016 assumed that a further beach recharge would be required from 2023 onward.

The Business Case estimated that a "mini- recharge" would cost approx. £2.5m, but more recently obtained quotes indicate that this will cost closer to £5-£8m. This is above the overall financial approval of £5.4m for both the 15 years of recycling and the mini recharge. These estimated costs are three times the estimated project value and fall outside of the approved spend for the project. A new appraisal process would need to be undertaken and initial assessments indicate that the necessary funding would not be granted through the Flood Defence Grant in Aid[1] process.

[1] This funding is obtained through government and uses nationally consistent Treasury Green Book Guidance

The need for a beach recharge could also be triggered by changes in the physical environment. This initial assessment also investigated potential changes in beach behaviour, in particular whether the sand and shingle placed during the annual beach recycling campaigns has been lost (and if this is the case, why)within weeks of placement rather than providing the longer-term protection envisaged. There have also been concerns over volume of material arriving at Snettisham Scalp (the source of the recycling) being insufficient for the annual campaigns.

The other issue that brought about this assessment is the landward migration of the dune system towards the properties at the south end of Heacham. This movement was not accounted for in the WECMS, but could potentially initiate a change to the decision points if environmental impacts or number of evacuations become unacceptable.

Consequently, questions arise over whether any of those triggers are being reached, i.e., whether the current recycling approach remains technically sustainable, whether a beach recharge is now required, whether recharge would still be affordable at current rates, and whether any changes to existing practices may need to be considered.

Although the decision point is a financial one, the basis for that is the technical requirements that now exist to provide flood risk management. This initial assessment is therefore focussed upon the physical changes and technical activities that might be necessary to address those, these determining the levels of expenditure that would then be necessary.

1.4 Scope of assessment

This is an initial assessment of the magnitude of any issues using existing available information, not a full review of all options or management strategy. In doing so, the following have been examined:

- Is the recycled material now being lost more rapidly and what are the potential reasons for that?
- Is annual beach recycling still an effective and sustainable approach to flood risk management for Unit C?
- Is a beach recharge required?
- What changes to the approach to flood risk management might be required or considered?

The purpose of an initial assessment is to establish whether a trigger point is being approached and, as such, solely to provide additional technical data to assist and inform decisions on any next steps, not making recommendations on what is required or offering a fully detailed analysis at this stage. Consequently, no environmental assessments, nor engagement with third parties have been carried out at this initial, purely technical assessment stage.

1.5 Structure of this report

This initial assessment is structured around answering the above questions and set out as follows:

- Section 1 provides background and introduction to this report;
- Section 2 contains a brief overview of shoreline characteristics, risks, and their management;
- Section 3 presents a review of the Beach Management Manual and present beach management practices;
- Section 4 provides the assessment of recent changes and explores the reasons for those;
- Section 5 considers the effectiveness and sustainability of annual beach recycling as an approach going forward;

- Section 6 reviews whether further beach recharge is a requirement or not at this time, or a potential option for the future;
- Section 7 offers a potential approach to future risk management in the near term, drawing upon the other assessments undertaken and reported on as part of this study;
- Section 8 provides a very high level update to the costs and benefits outlined in the 2016 business case;
- Section 9 summarises the conclusions of this initial assessment and sets out recommendations for next steps.

These sections are supplemented by three appendices containing some further information in support of the findings of this report

- Appendix A provides a review of risks, also summarising details from WECMS;
- Appendix B contains a review of the Beach Management Manual and its application;
- Appendix C presents an overview of the coastal processes.

2 Location details

2.1 Overview

This assessment covers the area currently managed by the Environment Agency, from the Power Boat Ramp to the end of the Snettisham Scalp (Figure 2-1). This has previously been considered with reference to a number of 'zones' along the frontage, which are used again in this report and shown on the figure below. The whole frontage (from Zones 1 to 15) is backed by a secondary flood defence in the form of a grassed earth embankment set back a short distance.

Figure 2-1: Frontage (Unit C) with the Zones marked on there and showing the secondary bank (in orange location approximate).

The entire area between the shoreline and the secondary embankment is low lying and thus at potential risk from flooding; and indeed was flooded extensively in 1953 and again more recently in 1978, as shown in the Figure 2-2 below. For context, extreme water levels (present day) for 1:50 year and 1:1000 year events are approximately +5.20mOD and +5.70mOD respectively.

Property interests in the area are predominantly associated with recreation and tourism, consisting of a mixture of residential/holiday properties and caravans, with associated business amenities and infrastructure at Heacham and Shepherd's Port. The area between these is largely unoccupied. Unit C also has significant ecological interest with international designations (Ramsar Site, SPA and SAC) and national designations (SSSI) largely due to the over-wintering wildfowl. Residential areas and other businesses are found on the landward side of the secondary embankment at Hunstanton, Heacham and Shepherd's Port, with a golf course and arable farmland in between.

The sea defences have been developed since the existing natural defence failed catastrophically during the storm surge in 1953. The sea defences were breached again in 1978 causing water damage to the caravans between the two defence lines (more significant damage was caused by the wind blowing caravans over) (Figure 2-2). Local reports would indicate that the presence of the secondary embankment restricted the extent of flooding which would otherwise have cause similar widespread damage to the 1953 floods, but flood depths increased likely due to the insufficient drainage capacity of the area between the embankment and the ridge..

On 5th and 6th December 2013, high astronomical tides were accompanied by a storm surge driven by a deep low pressure system tracking from the North Atlantic Ocean north of the United Kingdom. This event affected all of the North Sea coastlines of Europe, including The Wash East frontage. In some locations, this storm resulted in the highest water level ever recorded, exceeding the 1953 event. Despite the high water levels causing some localised breaching, the waves were not significant which resulted in relatively low damages. There was no injury or loss of life, but there was some damage to caravans and disruption of services to the dwellings at Shepherd's Port.

Figure 2-2: Flooding from 1953 and 1978.

2.2 Characteristics and risk management

The frontage has previously been divided into zones for management and monitoring purposes, each having slightly different characteristics. Those within the bounds of this initial assessment (Zones 1 to 13) are described below, together with a brief description of how risk is managed within each. More detail on the level of risks associated with all of these frontages, including previous assessments of the standards of protection afforded by each, is provided in Appendix A.

2.2.1 Zones 1 to 4

This frontage extends between the Power Boat Ramp and Jubilee Road in Heacham and is characterised by a concrete seawall built along the line of former dunes, which no longer exist. The Environment Agency continues to maintain this frontage under its permissive powers.

The beach fronting the wall is generally low, in particular through Zones 1 and 2 to the south of the power boat ramp where the wall alignment continues to form a promontory. The exception to this is Zone 3 where the wall sets back and a wider and higher beach has developed. A mixture of properties and caravans are situated on low land immediately behind the wall.

Although annual recycling has taken place here to provide additional beach material, this has not been a requirement in recent years unless inspection of the seawall has noted any exposure of the sheet piling at the toe greater than approximately 0.5m.

Unconventional timber groynes are located along the full length of the wall. These are not effective in holding any upper beach material, although their design would suggest this was not the intent. These were more likely intended to interact with tidal currents to limit landward migration of nearshore channels.

2.2.2 Zone 5

The seawall terminates at Heacham Jubilee Road, with Zone 5 located between there and South Beach Road. This length is characterised by a wider and higher beach than that to the north, with a ‘narrow’ upper ridge/dune at the top. The rear of this is immediately backed by an access track and caravan park.

Cliffing of the ridge occurs from the northern end towards the centre of this zone but is currently addressed through placement of recycled beach material on an annual basis.

2.2.3 Zones 6 and 7

Zones 6 and 7 extend between South Beach Road and 100m south of the last holiday home. This frontage is mostly comprised of sand dunes behind a wide beach. The primary issues here are the properties affected by a perceived roll back of the dunes onto those properties, coupled with local lowering of the dunes in places by some property owners to open up the view to the sea.

Although recycling of beach material to Zones 6 and 7 rarely occurs (a small volume once only in the past decade), this area together with Zone 5 was the recipient of over half of the material imported during the last recharge operation in 2005.

2.2.4 Zone 8(a)

The majority of the long length of shoreline in Zone 8 is characterised by a wide upper beach and wide dune system behind. There is little sign of any risk of breach along this section and recycling has not been required along this frontage.

2.2.5 Zone 9 (including Zones 8b and 10a)

There is a second seawall centred around Zone 9, 'Heacham Dam'. This is a large embankment (or built over former dune) armoured with a concrete block mattress. This structure is a considerable distance from any developments but thought to have been constructed over a previous timber structure possibly at a former low spot in the dunes where the now re-routed river may have previously discharged.

This structure now protrudes some distance seaward of the natural dune line either side, and very little sand or shingle is able to stabilise and form a beach in front of this. This protrusion contributes to erosion of the natural dunes either side, which has become the main focus of recycling operations in recent years to prevent outflanking and breaching. Significant cliffing occurs here, in part due to the height of the material placed during those operations which is subsequently cut back by wave action.

A modest volume of material was also provided to these areas as part of the 2005 recharge operation.

2.2.6 Zone 10(b)

Zone 10 is another natural frontage, although the 'dunes' here are uncharacteristically low and flat. There is little evidence of cliffing and this zone has not recently required management through recycling, although it will likely benefit from some of the updrift operations (placement of material Zones 8b, 9 and 10a).

2.2.7 Zone 11

To the north of the beach access point at Shepherd's Port, Zone 11 extends approximately 400m fronting the beach car park. This high and narrow shingle beach ridge is largely unvegetated (except on its landward side) and appears to protrude seaward and thus sit seaward of what might be expected to be the natural shore alignment. Extensive cliffing does occur here, and this zone is a regular recipient of beach recharge on an annual basis.

Zones 11 and 12 were also recipients of a sizeable portion of the 2005 beach recharge.

2.2.8 Zone 12

Zone 12 fronts Shepherd's Port, where there are a mixture of caravans, holiday homes and residential properties as well as a sailing club. This zone is mostly characterised by a lower but wide beach, backshore and low dunes. Other than on one occasion in the past decade, Zone 12 has not required management through recycling of additional beach material, although it would likely benefit from material placed updrift in Zone11.

2.2.9 Zone 13

Zone 13 is Snettisham Scalp, where beach material typically accumulates as part of a sand and shingle spit formation and is the area from which beach material for the annual recycling is taken.

There have been concerns in recent years whether sufficient material is reaching this area to be removed and thus enable the annual recycling to take place.

2.2.10 Secondary embankment

Behind these frontages, a grassed earth embankment extends from the start of Zone 2 through to Zone 13 (and further beyond). This forms a secondary defence against flood risk to land and property landward of this structure. Again, the Environment Agency continues to maintain this frontage under its permissive powers.

3 Beach management practices

3.1 The Beach Management Manual

The latest version of the 'Beach Management Manual' (BMM) was produced in 2014. This provides the overall criteria and direction for scheduled and unscheduled maintenance to be carried out along the frontage and states that the output from annual monitoring and survey work is intended to provide the data for the planning of the annual recycling works.

The BMM states that the basis for the beach management approach is "the greater the volume of material on the upper beach, the greater is its capacity to withstand a storm and hence secure the defences", i.e. resisting being breached by extreme waves and water levels.

Further pertinent details as they exist within the BMM are outlined below, noting that no further technical details beyond these are contained therein.

3.1.1 Scheduled Maintenance as stated in the BMM

3.1.1.1 Timing

Ideally the beach profile would be optimised at the start of the winter or "storm" season, however levels remain relatively high into the start of winter with insufficient material deposited on the Spit for recycle use. This situation can quickly change from mid to late winter when action is more likely to be necessary and material becomes available. This has led to the carrying out of recycling works in early to mid February - the latest practicable time which enables work to be completed before 15th March each year (excepting emergency and safety works) to comply with the working arrangements agreed with Natural England and RSPB.

3.1.1.2 Extraction

Beach material should be mainly recovered from the shingle Spit at Snettisham Scalp (Zone 13) although in certain years material may be available from Zone 3. Shingle removal from the Spit is not to exceed deposition.

3.1.1.3 Placement

The necessary volume is governed by beach slope, crest level, crest width and rear slope, with the crest level providing protection against wave overtopping and wash out from the rear. To achieve the required standard of protection (which is not stated in the BMM or anywhere else that can be located) the following criteria are to be applied when beach recycling is undertaken:

- Seaward slope of 1 in 13
- Crest level of +6.35mOD
- Minimum crest width (at +6.35mOD) of 5m

With respect to the crest width, these criteria apply to a recycled material which has a sediment characteristic generally similar to the existing beach material.

3.1.2 Unscheduled Maintenance as stated in the BMM

3.1.2.1 Emergency works

Typically, emergency works would be required should any areas of beach erosion encroach into the crest width thus leaving the sea defence in an endangered state. Repair works should be carried out to reform the beach profile.

3.1.2.2 Public safety works

"Cliffing" of the shingle ridge may occur. This may lead to inconvenience and more importantly, make public access to the beach a safety hazard. Ideally cliffs greater than 0.5m high but certainly greater than 1m high should be dealt with urgently. The BMM also states that the recommended action is to collapse the cliffing from the top at a slope of 1 in 1, or as adjudged to be safe as opposed to filling by pushing material up the beach.

3.2 Recent practice

Actual recycling practices do not now really follow the actions prescribed in the BMM, in large part because needs appear to have changed since it was produced in 2014.

The volumes and locations of actual recycling operations over the past decade are shown in Table 3-1 below, with all material placed during recycling having been obtained from Zone 13. Operations all occur during the period between late January and early March.

Table 3-1: Beach recycling volumes per zone

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 14	Zone 15
2012	2,090	0	0	143	1,551	0	0	3,597	0	0	0	0	0	0
2013	2,970	0	0	0	1,518	0	0	2,321	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	2,988	1,900	1,010	1,720	165	630	0
2015	2,233	0	0	0	0	0	0	0	176	44	0	0	0	0
2016	0	0	0	0	488	488	0	2,240	0	420	0	0	0	0
2017	345	0	0	0	480	0	0	3,915	0	855	480	0	0	0
2018	0	0	0	0	294	0	0	5,432	266	266	280	0	0	0
2019	0	0	0	0	1,134	0	0	4,004	105	105	2,240	0	42	0
2020	0	0	0	0	1,302	0	0	3,780	84	84	490	0	28	0
2021	0	0	0	0	588	0	0	3,556	210	210	1,456	0	28	0
2022	0	0	0	0	1,120	0	0	3,262	623	623	0	0	140	0
2023	0	0	0	0	84	0	0	3,486	273	273	2,002	0	252	0

The primary driver for annual beach recycling in the BMM was to achieve the minimum profile criteria. However, and with the caveat that available data currently only extends up to 2022, the annual beach survey reports, together with some additional analysis carried out for this study, all indicate that this has not really been an issue. In fact, in none of the years since 2014 were those minimum criteria not met in Zones 5, 8b, 9, 10a, or 11, i.e. where all of the recycling activity takes place. To provide some context, in Zone 11 the width of the beach ridge at level +6.38mOD has been narrow but still 8-10m at its narrowest point, in Zone 5 the actual width of the beach ridge at level +6.38mOD is regularly 18-20m.

The only places where the criteria were not met were a few profiles in Zones 10 and 12, where recycling activity does not take place, but even in those locations (generally being the same 5 or 6 profiles every year), that they do not actually fall far short of compliance, with the 5m width being achieved at levels never lower than +6.10mOD but mostly between +6.20 and +6.30mOD, and those two zones are also characterised by wider dune belts, so more resilient to breaching.

Activity in recent years has instead all been largely focussed in three areas, the main one being to resist outflanking of Heacham Dam (Zone 9 but also including the very southern end of Zone 8 (referred to in this report as ‘8b’) and very northern end of Zone 10 (referred to in this report as ‘10a’). Substantial volumes have also been placed in Zone 11, Snettisham Beach car park. The third area has been at the northern end of Zone 5, immediately south of the concrete seawall. Much of this activity appears to be addressing cliffing. Some localised reprofiling is also carried out during the annual campaigns at the discretion of the on-site team. This is not due to any disregard of the BMM by the operations team, but rather working within the very real constraints of making the best of what material (quantity and quality) that can actually be extracted for use, within the relatively short operating window and timescales available to them, to address where the perceived risks are from on-site observations.

Nonetheless, the question of whether existing operations remain appropriate and sustainable, and indeed whether the requirements of the BMM ought to be reconsidered, are points that ought to be addressed and are discussed later in this report. A more detailed examination of the criteria and application of the BMM is also provided in Appendix B.

4 Assessment of recent changes

The first part on this Initial Assessment was to understand why the recycled material is now perceived to be lost more quickly after placement. This included assessing whether the coastal processes over the last 3 to 5 years had changed, which could explain the more rapid removal of beach material following beach recycling.

The beach levels prior to beach recycling and the condition of the wave climate and water levels before and after recycling campaigns will help inform the review of current management practices, including beach recycling, beach reprofiling, and seawall maintenance, to build an understanding whether those are still effective along the frontage.

As part of this assessment, a detailed analysis of beach profiles and beach volumes (using beach topographic data) has been undertaken after 2014, i.e. after the most recent update to the Beach Management Manual (BMM), with an assessment of the averaged volumes between two time periods:

- 2015 to 2018: considering the period between the implementation of the updated Beach Management Manual (BMM) and anecdotal evidence of quicker losses following recycling campaigns.
- 2019-Present: considering the period between anecdotal evidence of quicker losses following recycling campaigns and present day.

Beach levels and beach volumes changes have then been correlated with changes observed in wave climate and water levels (over the same two time periods) and also summarised below. A detailed description of the methodology and results can be found in Appendix C.

4.1 Nature of change

The main conclusions for each zone are described below, and these have been structured considering the zones with the biggest changes observed relative to material loss and recycling activities (Zone 5, Zone 9 including Zones 8b and 10a, Zone 11 and Zone 13), and then zones with dune roll-back issues (Zones 6 and 7). The results and discussion on the other zones in within Appendix C.

4.1.1 Zone 5

Zone 5 is the zone with the greatest losses of beach volume observed since 2014 across all zones along the frontage, although the greatest losses seem to have occurred up to 2018 (Figure 4-1), since when volumes appear to have stabilised more. Whilst a loss of sediment has also been observed between 2019 and 2022, this was less significant than the previous period, having occurred mainly around and immediately above HAT (5m recession of HAT between 2019 and 2022).

Evidence from beach profile analysis (Figure 4-2) demonstrates that cliffing seems to have always occurred (evidenced by a comparison between the 1998 and 2022 surveys); the perception of cliffing occurring more often along this frontage (as suggested by anecdotal evidence) may be enhanced due to a higher dune crest over time (up to 2m higher since 1998). With a higher dune crest, but no rolling back, the whole beach profile is also becoming steeper over time.

Therefore, although beach levels and volumes are now lower than between 2015-2018 period, they were already in decline and, indeed, do not seem to have become any worse since 2019. In addition, cliffing was already occurring in Zone 5 pre-2019, but due to a higher dune crest, it may have appeared worse since.

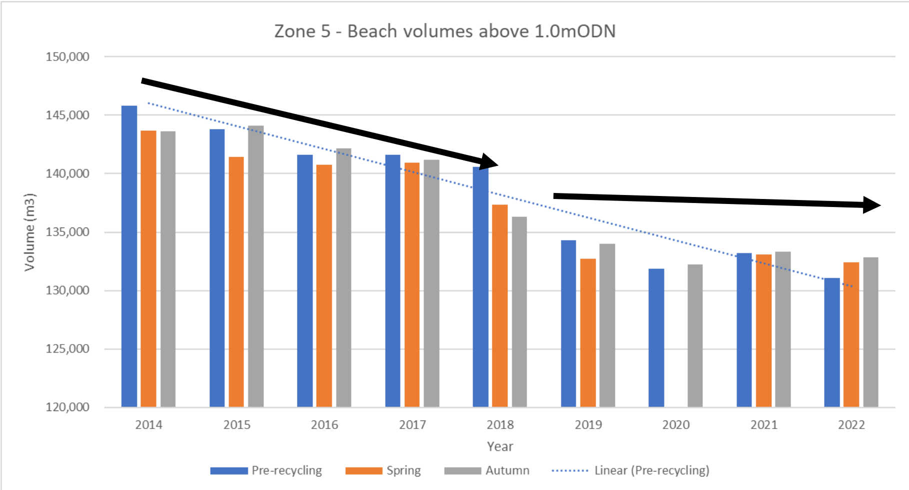


Figure 4-1: Beach volumes within Zone 5 above 1.0mODN comparing pre-recycling, Spring and Autumn survey campaigns since 2014. The black arrows indicate a greater loss of material up to 2018, with a decrease in erosion rates up to 2022.

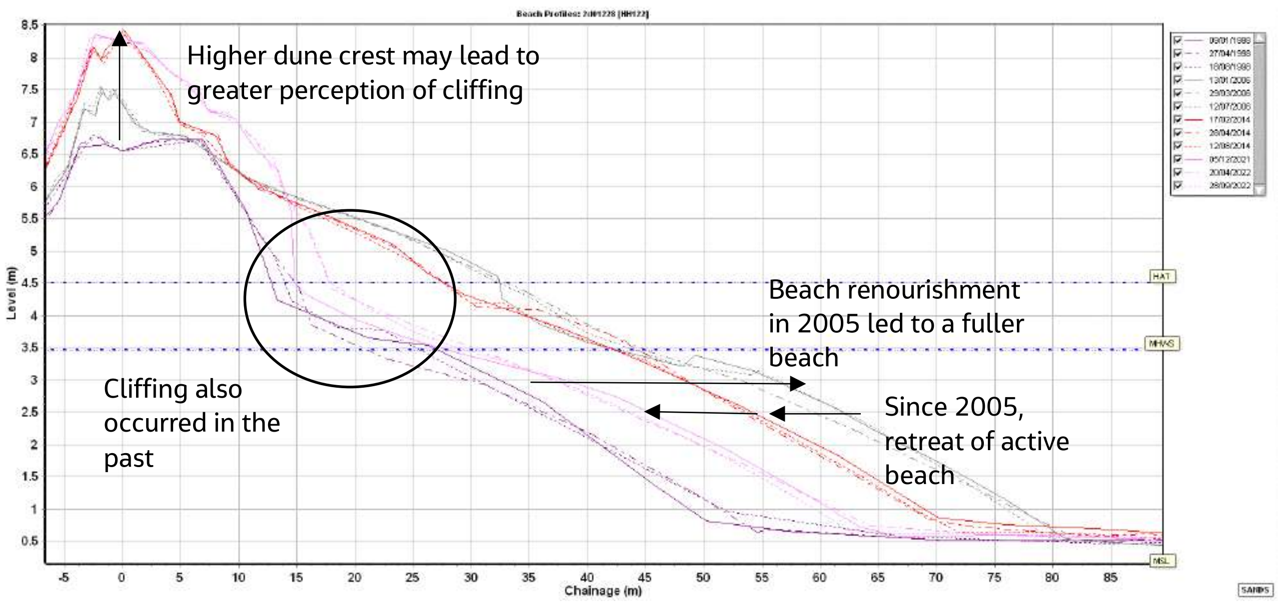


Figure 4-2: Profile 2d01228 within Zone 5. Comparison between pre-recycling, Spring and Autumn surveys for 1998, 2006, 2014 and 2022.

4.1.2 Zone 9 (including Zones 8b and 10a)

Although Zones 8 to 10 extend over 2.5km, the majority of recycling occurs in the vicinity of Heacham Dam (located mostly in Zone 9). Evidence from beach profile analysis does confirm this understanding, with recycled material placed between within approx. 250m of the southern section of Zone 8 and approx. 280m of the northern section of Zone 10.

The effect of beach recycling is clearly observed with Spring volumes higher than pre-recycling volumes (Figure 4-3). A drop from Spring to Autumn indicates that the material continues to move from here throughout the year. In addition, a gradual increase in beach volumes along this frontage, at least since 2016, suggests that beach recycling is likely to have a positive effect in maintaining, and indeed increasing, beach volumes over time. Since 2019, therefore, the beach along the recycled area seems to be accumulating material, albeit mostly below Mean High Water Spring (MHWS) (Figure 4-4).

Similarly to Zone 5, cliffing was observed both pre and post 2019 (Figure 4-4); however, this might be accentuated here because the beach recycling material is placed much higher on the edges of the Dam than the surrounding natural dunes, which then leads to higher cliffing in this zone, of around up to 3m in places.

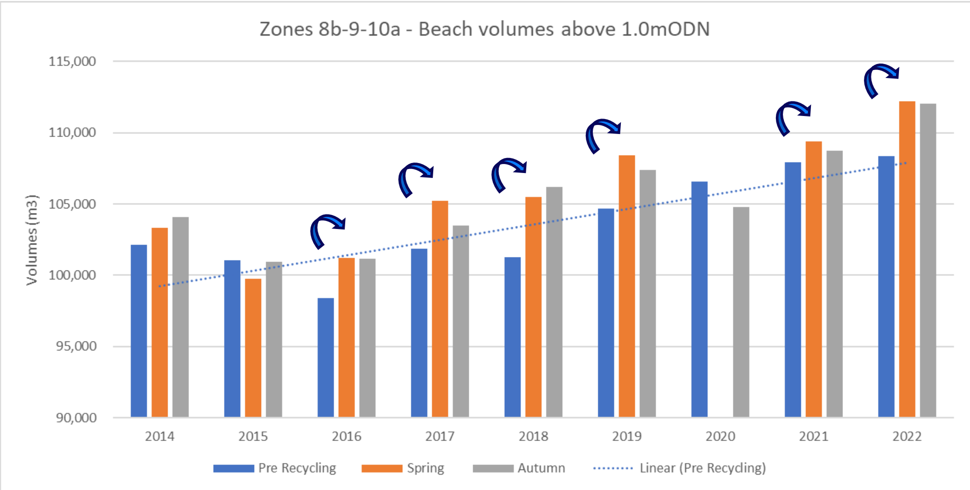


Figure 4-3: Total beach volumes (above 1mODN) for Zones 8b, 9 and 10a combined, considering pre-recycling, Spring and Autumn surveys. The arrows indicate the increase in beach volume following beach recycling

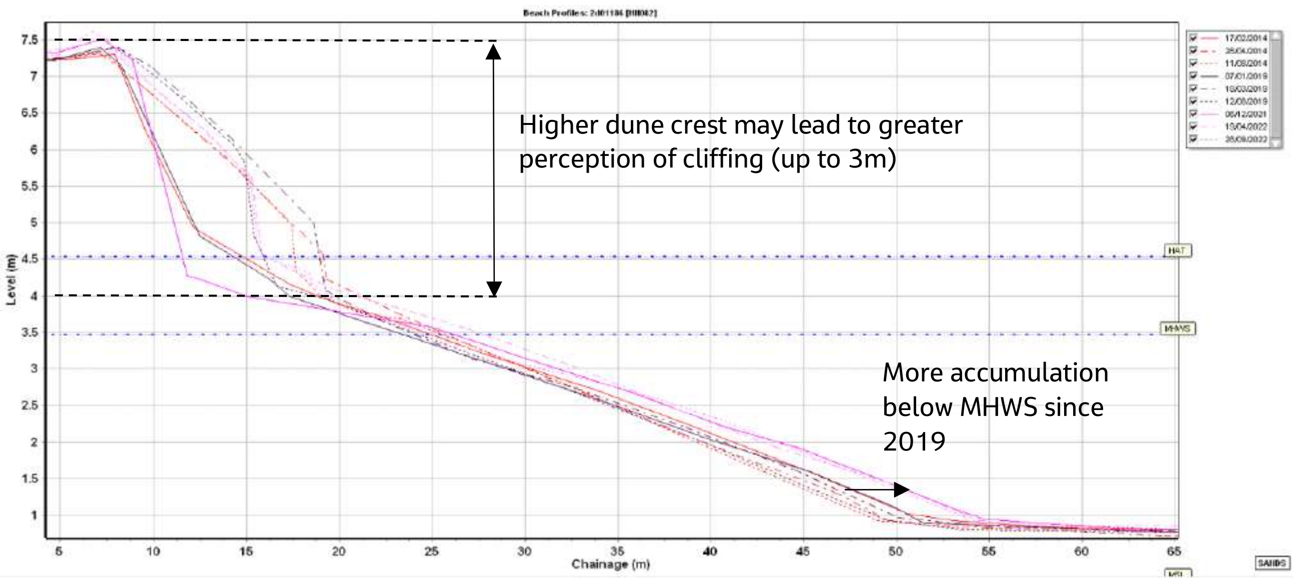


Figure 4-4: Example of profile analysis in Zone 9 along profile 2d01186 showing profile change between the pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.

4.1.3 Zone 11

A steady year-on-year reduction in beach volumes seemed to have occurred at least since 2014 but, similar to Zone 5, since 2019, beach volumes seem to be generally stable (Figure 4-5). Evidence from beach profiles (Figure 4-6) show that, in general, the active beach between 1m and 5mOD has retreated at least 5m between 2014 and 2019, but with minimal change since.

The upper beach around and above HAT, however, is the area that has showed most changes since 2019.

Whilst the crest of the dune ridge has been the same height since 2014, the dune face around 6mOD showed a seaward movement of around 3m since 2019, leading to a steeper and higher cliff (of around 1.5m in Dec 2021). It is important to note, however, that cliffing did occur between 2015-2018: the Feb 2017 survey in Figure 4-6 shows a cliff of around 1m high.

Therefore, similar to Zone 5, most of the changes in terms of beach volumes and levels along Zone 11 occurred between 2015-2018, and these do not seem to have become any worse since 2019. In addition, cliffing was already occurring in Zone 11 pre-2019, but due to a steeper dune face, cliffing may have worsened at the bottom of the dune toe (around HAT).

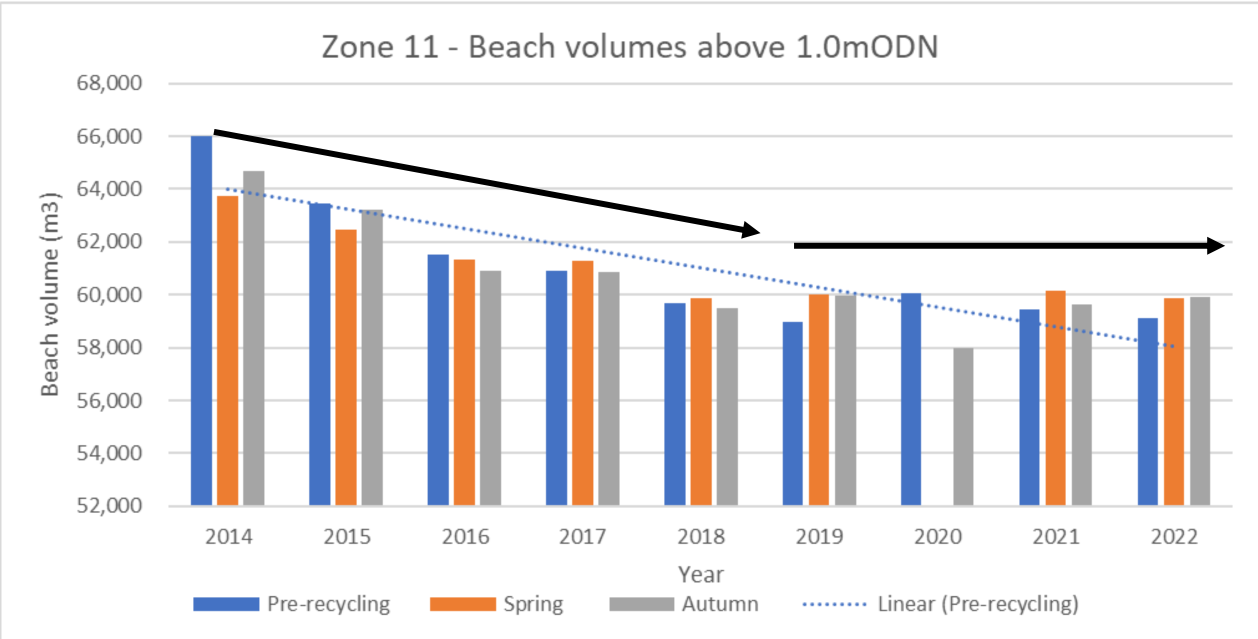


Figure 4-5: Total beach volumes (above 1mODN) for Zone 11, considering pre-recycling, Spring and Autumn surveys. The black arrows indicate a greater loss of material up to 2018, with a stabilisation up to 2022.

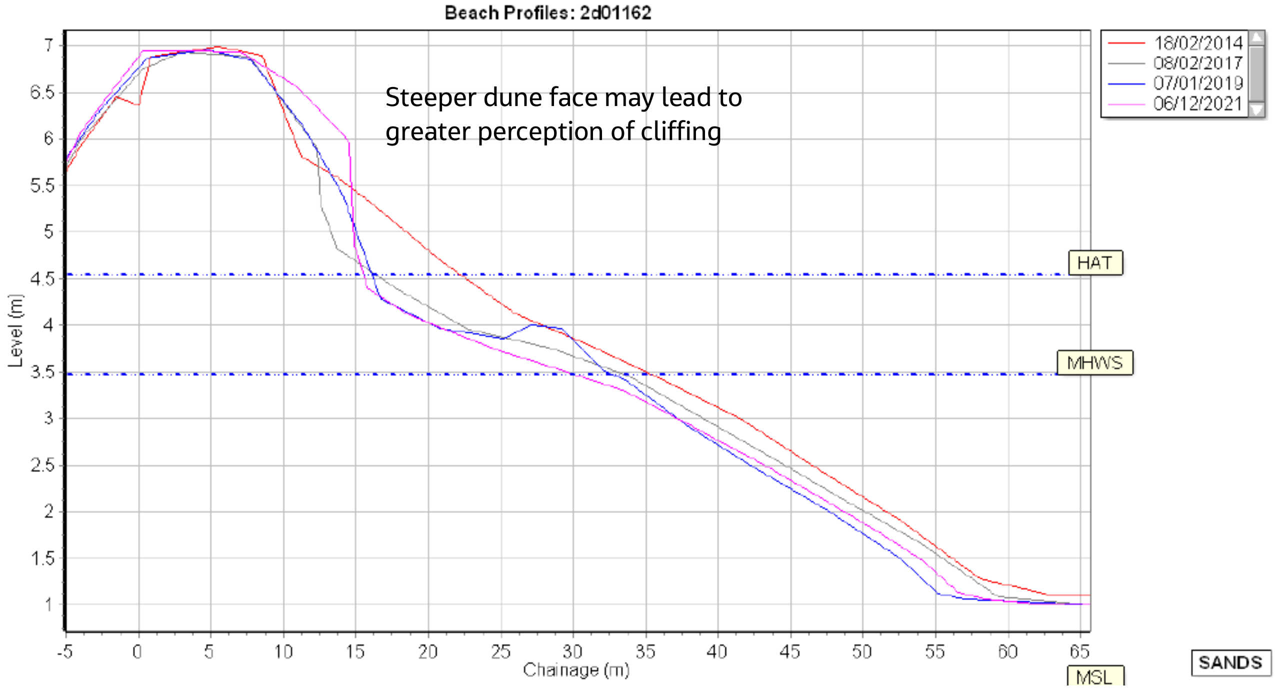


Figure 4-6: Profile 2d01162 within Zone 11, showing beach topographic surveys between 2014 and 2021. (Dec 2021 represents the pre-recycling survey of 2022)

4.1.4 Zone 13

Since 2014, there has been a steady year-on-year accretion of material along this zone, especially up to 2019, as observed in Figure 4-7. Overall volumes in 2022, however, are slightly higher than volumes in 2014. Of notice is the fact that, following extraction of beach material (observed by the drop in volumes between pre-recycling and Spring surveys), there is a recovery of beach volumes by Autumn (marked by the dark blue arrows - Figure 4-7) following by a further accumulation of material by the next pre-recycling survey (light blue arrows - Figure 4-7). This is also evidenced by the beach profiles (Figure 4-8), which showed a general seaward movement of the active beach between 1.5m and 3.5mOD of around 5m. This demonstrates that enough sediment has been reaching the scalp to at least recover the material extracted for recycling.

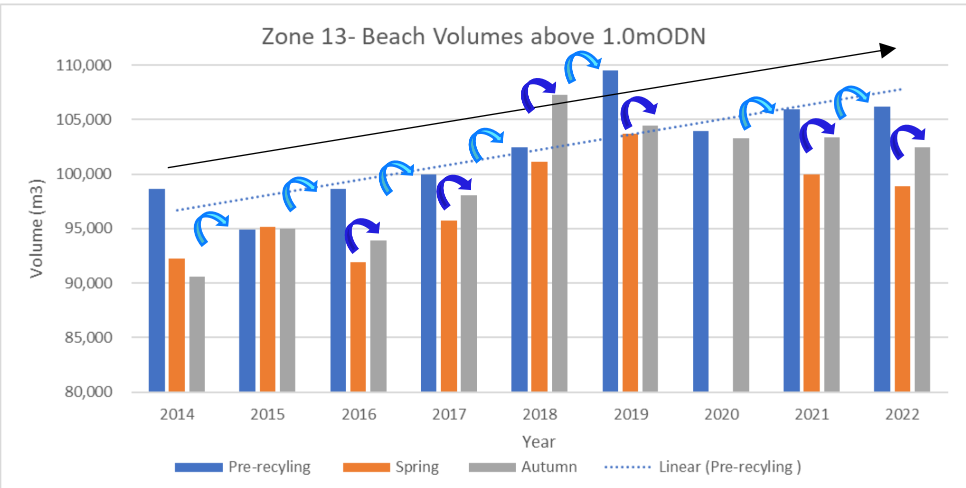


Figure 4-7: Total beach volumes (above 1mODN) for Zone 13, considering pre-recycling, Spring and Autumn surveys. The black arrow indicates a general trend of accretion within this zone. Following extraction of beach material there is a recovery of beach volumes by Autumn (dark blue arrows) following by a further accumulation of material by the next pre-recycling survey (light blue arrows).

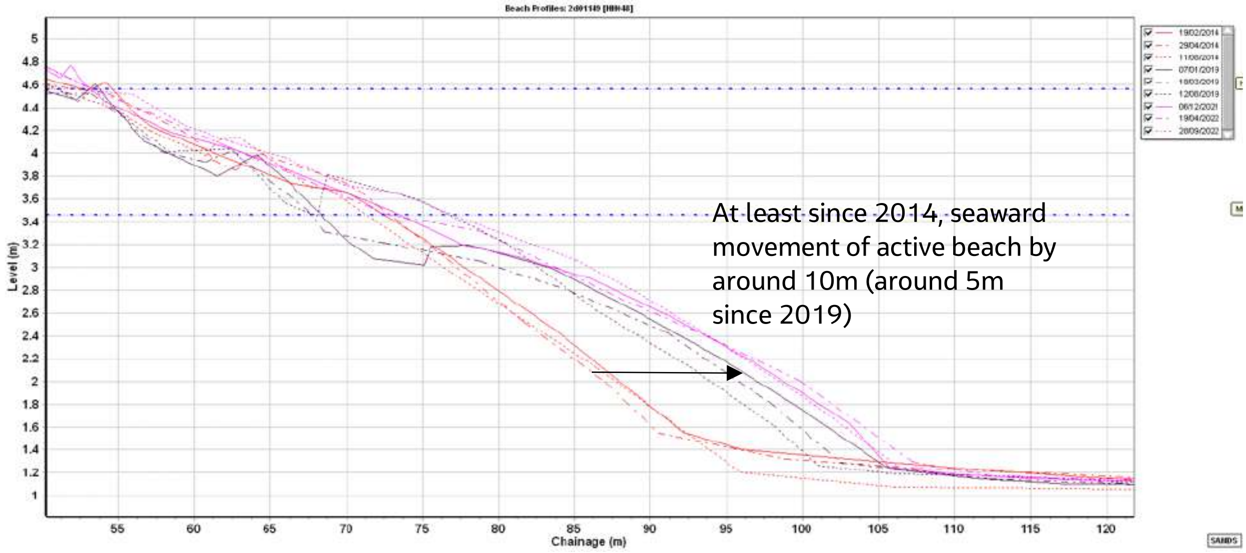


Figure 4-8: Profile 2d01149 within Zone 13, showing profiles in 2014, 2019 and 2022.

4.1.5 Zones 6 and 7

Within this area, beach volumes have been fluctuating over time (Figure 4-9), which can be partially correlated to the recycling regime in Zone 5. No material was placed in Zone 5 in 2014 and 2015, which could be related to the decrease of overall beach volumes in Zones 6 and 7 up to 2016. A subsequent increase in beach volumes up to 2021 correspond to recycling resuming in Zone 5 and more material being placed both in 2019 and 2020.

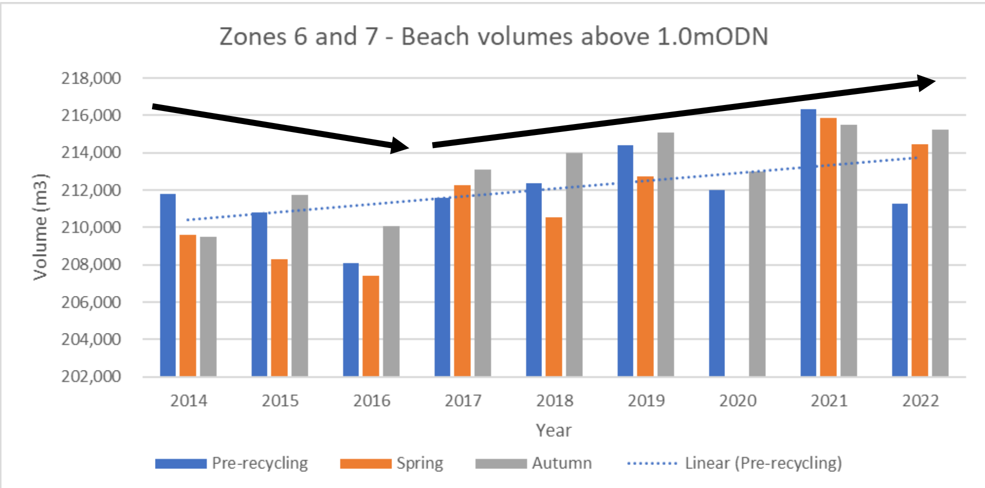


Figure 4-9: Total beach volumes (above 1mODN) for Zones 6 and 7, considering pre-recycling, Spring and Autumn surveys. The black arrows indicate general trends within these zones.

Evidence from beach profiles (Figure 4-10) showed that beach renourishment in 2005 had a positive effect in making the beaches along the northern section of this area fuller.

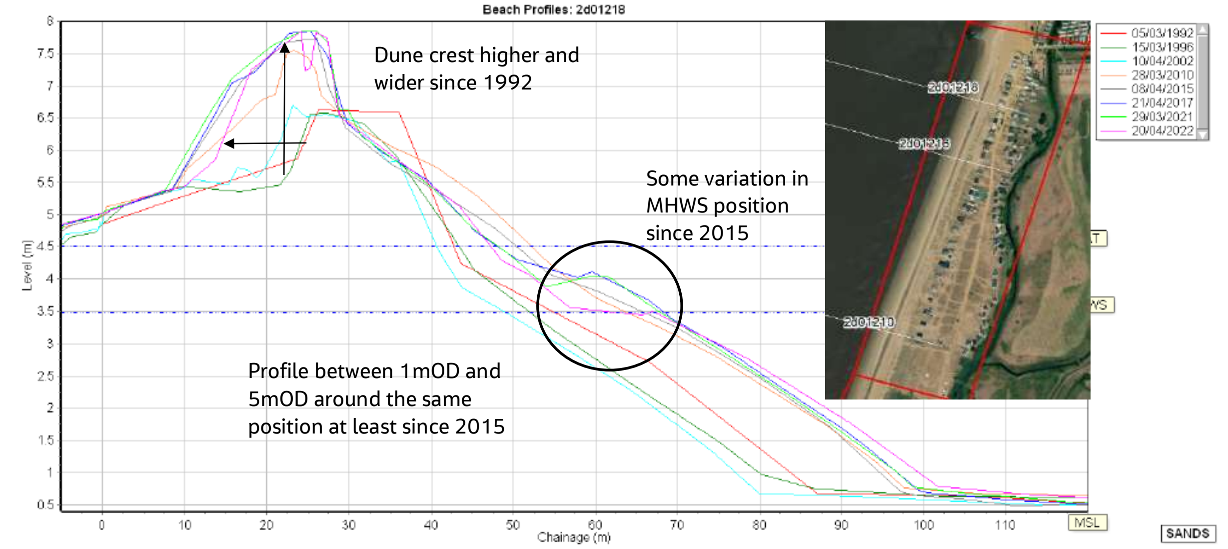
Between 2014 and 2022, the active beach along Zones 6 and 7 at the northern section between 1mOD and 5mOD (Figure 4-10a and b) has been relatively stable at the same position, with some variation in the position of MHWS throughout the period. At the southern section of this area, the active beach between

1mOD and MHWS showed a year-on-year seaward movement (Figure 4-10c), with a similar pattern of variation in MHWS position and a more stable upper beach around HAT.

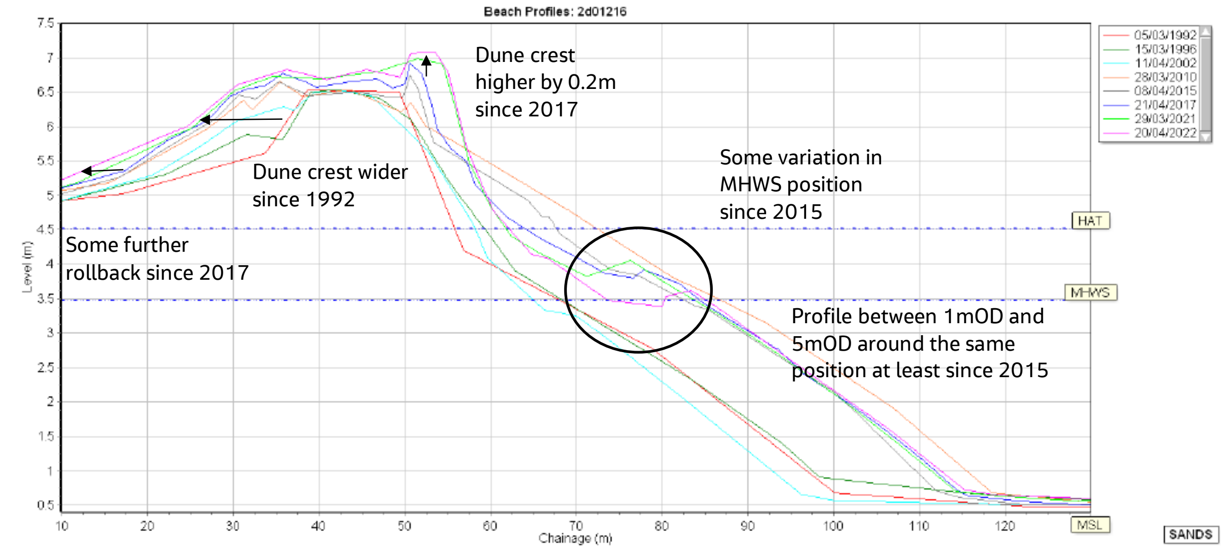
In addition to general changes along the beach described above, the dunes located at the back of this beach has shown signs of growth and roll back. Anecdotal evidence from local residents stated that this issue started after the last beach renourishment campaign in 2005. However, evidence from beach profiles (2d01218, 2d01216 and 2d01210 - Figure 4-10a, b and c, respectively) showed that the overall general position of the dune crest seems to be stable since 2001, but increasing in height by around 1.5m between 2001 and 2022. Accumulation of sediment both at the back and at the front of the main dune ridge has been ongoing since at least 1992 when records began, with an increase in dune ridge width of around 10m. Whilst evidence from beach profile analysis does show a spike in accumulation and widening at the landward side of the ridge after the last beach renourishment in 2005, this process of dune rollback is likely to have natural causes and likely to have started much earlier, at least since 1992. Zones 6 and 7 seem to have a good retention capacity as the dune ridge width increase seemed to have been partially influenced by the beach renourishment.

More specifically since 2019, dune crest height and ridge position has shown very little change compared to the period between 2015-2018 along most of Zones 6 and 7. The exception to this is at the central area of this zone around profile 2d01216 (Figure 4-10b): since 2019 dune crest has increased around 0.2m here with some further accumulation of material at the back of the dunes, which could partially explain the current issue with wind-blown sand into the seaside properties. At the time of writing, there is no information to categorically conclude whether this rollback will continue in the future, but this is a natural tendency on most coasts of this nature which see increasing sea levels and higher wave exposure, so is more likely than not to occur.

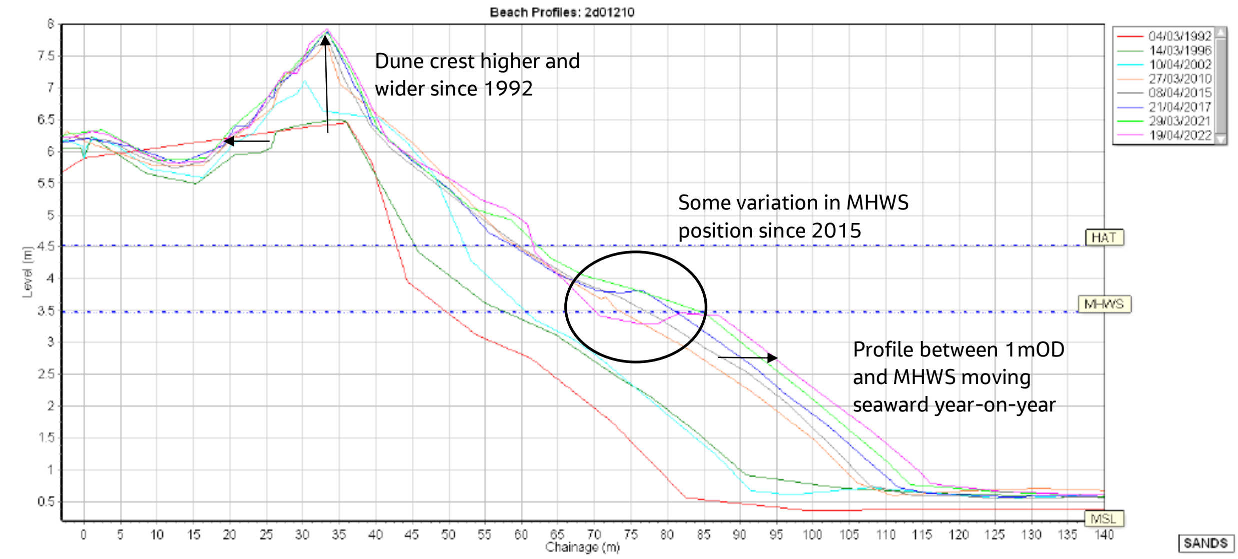
Overall, beach volumes have increased since 2017 along Zones 6 and 7, with a localised increase in dune crest height and accumulation of sand at the back of the crest since 2019 (mostly at the central section of this zone). Along most of the frontage, dunes seem to be stable in both position, height and width since 2019 but the reason for this is unknown.



a) Profile 2d01218



b) Profile 2d01216



c) Profile 2d01210

Figure 4-10: Beach profiles a) 2d01218, b) 2d01216, and c) 2d01210 along Zones 6 and 7

4.2 Correlation with hydrodynamics

Assessment has been undertaken to look at any changes in wave activity, tides and surges during and immediately after the recycling period to identify any potential changes in recent years.

Wave records were analysed for the period between pre-recycling and spring surveys each year, with exception to 2016, 2017 and 2018 due to wave data gaps. In addition, interannual periods were also reviewed between October-March and April-September to identify any variances within and throughout the years.

During the period 2015 to 2018, between pre-recycling and Spring surveys, the period showed an equal dominance of NE and SW waves, with more frequent waves of 0.5-1m. Maximum wave period did not exceed 10 seconds. It is important to note, however, that no waves were analysed between 2016-2018 due to data gaps.

Between pre-recycling and Spring surveys, a shift in wave dominance was observed from NE to SW in 2019-2020. There was a high percentage occurrence of waves between 1.5 and 2m and period of around 8 seconds from the SW over this period, with some extreme waves (but low frequency) of around 3m from NE.

From 2021-2023, NE waves became once again slightly more dominant than SW waves, with highest waves 2-2.5m and high periods of around18 seconds. There was a high percentage occurrence of wave period less than 6 seconds from both NE and SW and <8s from NE.

Table 4-1 shows the occurrence of high surges/water level events throughout the year. Pre-2019, high surges/ water level events used to occur between October and February, but more often in January and February (which was the case for 2016, 2017 and 2019) pre-recycling campaigns. There has been only one surge in 2017 which occurred between pre-recycling and spring surveys, albeit small and spanning a couple of hours only. However, post-2019, high surges/water level events occurred a bit later in the year, between March and April, i.e. after the recycling campaigns (which was the case for 2020, 2021 and 2023), in addition to winter (Jan-Feb) events. These events occurring later in the year could be responsible for more variation in beach profiles over the year/seasons.

Table 4-1: High surges/water level events (above 0.80m) occurrence throughout the year from 2015 to 2023 (2018 excluded due to no data availability). The red box shows more high surge events in Spring from 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2015										x	x	x
2016	x	x										x
2017	x	x								x	x	x
2019	x											x
2020	x			x				x	x		x	x
2021	x	x		x							x	
2022	x	x									x	
2023			x									

Therefore, the analysis indicates a shift in wave dominance from NE to SW from 2019-2020, together with a more frequent occurrence of extreme water level events in March/April from 2019/2020 onwards. This could, therefore, partially explain the quick loss of material following beach recycling campaigns. Changes in wave pattern could also have some impact on the ridge along the dunes frontage, as a variation on the position of MHWS was observed. Whilst a NE wave dominance has been resumed in the period between pre-recycling campaigns and spring, it is currently unknown whether more severe storms (from extreme water levels) are from now on more likely to occur in March/April, as opposed to the winter months pre-2019.

In addition, there seem to have an interannual shift of more SW dominated waves in the winter and more NE dominated waves in the summer observed post 2014, although it is not possible to determine at this stage whether the is a permanent change in the wave climate. However, this may be the reason why more sediment is currently reaching the Scalp earlier in the year than pre 2019 albeit volumes did not change.

4.3 Overall changes to coastal processes and conclusions on recent changes

Through the analysis undertaken above it is possible to draw conclusions and answer the question posed asking why the recycled material is being lost more quickly after placement?

In general terms, the assessment of recent changes in coastal processes found the following:

- **Beach profiles and volumes are not generally that much different along the frontage over the last 3-5 years than before.** Zones 5 and 11 were the only zones to show a consistent loss of beach volume since 2014, but this was more significant between 2014 and 2018.
- **In terms of how material moves along the coast, cross-shore transport seems to play an important role in shaping the beaches along this frontage, more than the longshore transport.** Most of the beach material is only relocated both to the upper and/or lower beaches, with only very little (if any) being lost offshore, which demonstrates that cross-shore sediment transport seems to play an important role in sediment transport along this frontage, and it has always been, at least, since 2014.
- **Cliffing did occur over the last 3-5 years, but also did occur previously.** Whilst cliffing has been observed in a number of zones (i.e. 5, 9 and 11), both anecdotally and through the beach profile analysis, it has frequently occurred in the past, pre-2019. More recently, however, the higher ridges at the back of the beach make the cliffing seem more pronounced than previously.
- **Beach recycling activities have been occurring within the same zones** since 2014 (Zones 5, 8 to 11), with beach recycling volumes placed at each location roughly the same since 2019 (and 2014).
- **Material reaching the Scalp seem to be constant, recovering from previous sediment extractions.** Beach volumes at the scalp do seem to recover and have even been slightly increasing over time, leading to the conclusion that longshore drift is still effective in transporting the material mostly southwards. What has been observed, however, it that beach material has been reaching the scalp earlier in the year than previously.
- **However, material is potentially being moved more quickly along this frontage due to the incidence of large storms events immediately after beach recycling operations.** A greater incidence of large storms in the time period directly after recycling activities is likely to be the reason why cross-shore sediment transport processes seem to be more evident in relocating sediment across the beach quickly after beach recycling, followed by beach material reaching the scalp earlier in the year over the last 3-5 years.

In conclusion, the recent changes in sediment transport over the last 3-5 years do not seem to represent an overall change in terms of sediment transport along this frontage since 2014. Instead, the same ongoing (since 2014) processes seem to simply be happening more rapidly (i.e. material is being moved earlier than pre-2019), which only represents a change in general timing between material placement and movement, rather than an overall reduction in the performance of coastal processes or adequacy of the current operations along the frontage.

5 Effectiveness and sustainability of annual beach recycling

5.1 Background

The question of whether annual beach recycling still and effective and sustainable approach to flood risk management for Unit C has two parts. The first is whether the operations and principles outlined in the Beach Management Manual of 2014 are still appropriate; the second is whether beach recycling as an approach can in principle still be an effective and sustainable part of ongoing risk management.

In addition to the commentary provided in this section, more discussion on risks and the application of the BMM/recycling practices is provided in Appendices A and B respectively.

5.2 Present management actions

5.2.1 Recycling

As mentioned in Section 3, the criteria of the BMM have been largely achieved since 2014, although the recycling may have had very little to do with that for the majority of the frontage. It might be argued that if the works to address cliffing in Zones 5 and 11 had not taken place there could have been a breach, but there is little evidence to indicate that would have been the case in that time.

The volumes that have been placed in Zone 5 for example have been modest, largely dealing with cliffing, and given the actual berm width of 18-20m here compared to the 5m criteria at level +6.38mOD, it is very possible that this would have continued to provide the expected standard of protection without recycling each and every year.

There is perhaps a stronger argument in Zone 11 where the shingle ridge is narrow (under 10m at level +6.38m in places) that this might have narrowed further without recycling, with larger volumes placed here since 2019 appearing to have at least temporarily arrested the retreat of the beach here that was ongoing in the preceding years. In respect of ongoing sustainability of this however, there is a need to consider that one of the main factors creating the risk here is the seaward prominence of this zone, which is therefore likely to continually lose any material that is placed there.

Likewise, recycling at Heacham Dam might be effective in reducing the risk of outflanking in any year at the moment (although annual profile data does not necessarily indicate the ridge is less than the BMM criteria) but this will not continue to be sustainable forever as the actions are again too far seaward for natural retention and thus any material placed there is inevitably going to be removed relatively quickly each and every year. This is likely to be worsened by Sea Level Rise (SLR) in the future, as greater water depths (hence greater waves during storms) will be able to reach further inland on the beach profile than present day.

Although WECMS suggests that a stopping recycling could result in the rapid failure of the shingle ridge within 3 or 5 years (those reports vary), there is no information therein to substantiate those estimates or the basis upon which they are made. WECMS did consider the standard of protection being provided by the shingle ridge at the time, which were generally 2% (equivalent to a 1 in 50 year return period storm) at best or lower, so it must also be assumed that those time estimates would also only apply to the occurrence of storms with a magnitude up to but not exceeding those same return periods. On that basis, 3 to 5 years does seem a rather pessimistic estimate, which ought to be reassessed. Equally, the actual return period that might be provided by the BMM criteria being met also ought to be assessed, as this is not currently identified anywhere.

5.2.2 Cliffing

The other factor to consider is the approach to deal with cliffing. This is typically dealt with at the moment through the recycling operations, placing fresh material or in some cases some reprofiling of the beach, to build up against the cliff. This is not however the approach originally intended in the BMM, which recommended "*collapse the cliffing from the top at a slope of 1 in 1, or as adjudged to be safe …. this should reduce the tendency for recurrence as opposed to filling by pushing material up the beach*".

Adopting the approach from the BMM could be more effective and sustainable than presently undertaken. This would negate the need for additional material to be brought to those locations, which is then quickly removed, or reprofiling the beach, which waves and tides will quickly return to its more natural position.

5.2.3 Sourcing

The sustainability of the practices at Snettisham Scalp are perhaps more critical due to the lesser volumes sometimes available during the short working window available to the operations team. Rather than material just being obtained from the upper beach (which is the material sought for recycling to other 'upper beach' locations), some material now has to be skimmed off the mudflat area on the lower beach. By its nature, this is likely to have a much finer sand sized grading that means when placed elsewhere will either be more mobile, or if mixed it further widens the overall grading matrix which could lead to even greater propensity towards cliffing.

Overall, the present recycling will have some effectiveness but is perhaps limited and indeed it could be debated that the present recycling operations are not actually needed each and every year. That would provide more time and opportunity for material to build up at Snettisham Scalp and in turn might ensure that the material that can be sourced, when actually needed, is of a more suitable quantity and grading.

5.3 The Beach Management Manual

5.3.1 Beach height and width

Although 'minimum profile criteria' for intervention are identified in the BMM, the actual basis for these cannot be found so is undefined, nor can the standard of protection believed to be provided by this be identified. Those criteria include having a beach slope of 1 in13 and a minimum berm width of 5m at a level of +6.35mOD (since modified to +6.38mOD). For context, it should be noted that the design level of +6.35mOD is nearly 2m higher than the extreme astronomical tide level (Highest Astronomical Tide – HAT =+4.52mOD), and is in fact higher than the predicted 1:10,000 year extreme water level (+6.10mOD).

These details appear to originate from the contract for placement of the 2005 recharge, so the design would have most likely also made allowances for draw down from that profile during a storm, or more likely potentially several successive storms, and allowances for some annual losses. In addition, the contract included tolerances so the profile could have actually been 0.15m less than the specified widths and levels.

These seem exceptionally high-performance standards to try to achieve and, given the aforementioned factors that go into a beach recharge design, surprising that these placement criteria are those also being expected from annual recycling operations.

5.3.2 Beach slope

The specified beach slope of 1 in 13 would have again been set by the contract for measurement, rather than the ultimate beach slope to be achieved to fulfil the performance criteria, acknowledging a beach will immediately respond to the subsequent wave and tidal conditions and reprofile to a natural equilibrium shape. That itself will, and does, vary along the frontage as the prevailing conditions are not identical.

It is unlikely that this would be expected to be the natural profile that would then be expected to exist and thus form the basis for design (and thus threshold performance) calculations. Consequently, the reason for the recycling having to achieve this profile rather than one that would be closer to a natural equilibrium is questionable.

5.3.3 Beach material

The BMM refers to the recycled material as expected to have a sediment characteristic generally similar to the existing beach material, which would appear to also be similar to that which was specified for the 2005 recharge works. However, the very wide and bi-modal nature of that beach grading is considered to be a primary reason why cliffing occurs on this beach. This also means that it compacts very well due to the wide grading reducing porosity, loosely 'cementing' it together and, when eroded by wave action at the top of the beach, stands up vertically, forming "cliffs". Consequently, it should be no surprise that cliffing continues to occur with application of the BMM requirement.

5.3.4 Application and re-assessment

The present recycling operations no longer appear to be driven by the outcomes of the surveys, and indeed it might be argued that in most years the recycling requirement as presented in the BMM probably did not exist. In fact there were no winter surveys in 2023 or 2024 for the operations team to refer to, so action had to be planned without those.

Consequently, it is difficult to categorically conclude whether the requirements of the BMM are effective and sustainable, as they have not really been implemented. Notwithstanding that, those criteria in the BMM appear quite onerous and in some cases could result in actions which are inadvertently counter-productive if the natural behaviour of the beach is interrupted too much. It is therefore recommended that some re-evaluation of those criteria is carried out and the BMM updated accordingly if the present approach to flood risk management is to remain (see Section 7 for alternative approaches).

As a minimum it would in any case we prudent to reassess the current beach profiles to establish the standard of protection being provided (noting the existing calculations are for the beach levels back in 2012) maintaining this as part of any future monitoring for action trigger levels. In addition, it would be helpful to calculate the standard of protection the existing 'design' profile would provide and also the size of beach required to provide any agreed minimum standard.

Any review of the BMM should also consider alternatives to annual sourcing of material from Snettisham Scalp, including less frequent removal and other locations along the frontage.

5.4 An option for future management?

Beach recycling can remain an effective approach to flood risk management for Unit C although the sustainability of removing material from Snettisham Scalp, whilst remaining possible and within the conditions of the BMM and WECMS, might be questioned and might also become more problematic with time.

Therefore, consideration needs to be given to whether the application of the beach recycling could be improved and refocussed, potentially in conjunction with other measures to contribute to flood risk management to Hunstanton, Heacham and Shepherd's Port in particular.

Along with the recommendations above to revisit the criteria and direction provided by the BMM, those potential improvements for future management have been outlined in Section 7.

6 Is a beach recharge required?

6.1 Background

The 2016 business case for works to cover the subsequent 15 years to 2031 includes for a potential small recharge (estimated to be around 50,000m^3), where additional sand/shingle is sourced from offshore dredging, to top up the beach at some time between years 6 (2023) and 15 (2030).

The undertaking of this top-up recharge would depend on:

- The need identified through monitoring,
- The availability of sufficient Partnership funding, and
- Environmental acceptability (as demonstrated through environmental assessment that will be necessary to support an application for a Marine Licence).

This would seek to maintain the height and profile of the shingle ridge but not include work to increase the ridge height and profile to accommodate future climate change.

6.2 Assessment

Based upon present size of the beaches, performance of the present recycling campaigns and risks already discussed, there is little to suggest that a recharge is necessary at this time to achieve requirements.

The driver for any recharge might therefore be only as a more sustainable and potentially environmentally preferable alternative to sourcing material from Snettisham Scalp, although at this point in time this is not yet shown to have reached a point at which that cannot continue if required, in particular if recycling requirements can be reduced in the future (see Section 7 on future approaches).

6.3 An option for future management?

Although not required at present, the question remains whether this might be undertaken over the coming years, as per the business case. To consider this, reference is also made to the previous campaigns in the 1991 and 2005 as these may provide insights to whether sand and shingle from recharging will remain or not, where it might be placed, and what sort of beach material might be required.

6.3.1 Previous experience

The assessment of groynes report (Jacobs, 2021) identified that monitoring data indicated that, following the 400,000m^3 recharge placed on 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. Focussed mainly on the northern sections where the seawall is located, monitoring data also showed that following that recharge there was a 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 2005 recharge delivered between 195,000m^3 of new material to Unit C (EA, 2016). Records of placement volumes are not available, although it is reported that this was all placed in Zones 5-8. However, monitoring volumes from approximately 2 months later the following indicate that around half of that could be found in Zones 5 to 7, around 15% in the vicinity of Heacham Dam (Zones 8 and 10), and roughly a quarter in Zones 11 and 12. Overall the beaches appeared to have increased in volume by approximately 150,000m^3, leaving the remaining 45,000m^3 unaccounted for, which could mean some of that was rapidly drawn down onto the flatter beach below MSL, which would be consistent with the observations made regarding the original recharge in 1991.

Comparing recent beach volumes from 2022 with those at the start of 2006 (i.e. immediately following the November 2005 recharge), the following observations can be made:

- Zone 5 – remains higher than pre-recharge, although approximately half that additional volume has since been removed.
- Zones 6, 7 and 10 – remain a similar size to that following recharge, i.e. no net loss of the renourishment and small net changes are within the natural variability of these beaches.
- Zone 8 – has gained material, more than recharge would have contributed here or updrift, so growth in no small part to natural drift processes moving material from other frontages.
- Zones 11 and 12 – approximately 2/3rd of that added to Zone 11 has moved off but balanced by a similar accumulation in Zone 12.

What is also notable is that, although there has been some redistribution of recharge along the frontages, there has not been any significant growth in the deposition of material at Snettisham Scalp in subsequent years as a result.

6.3.2 Lessons from experience

Previous experience would suggest that if a recharge takes place, then a reasonable proportion of that material will likely stay on the beaches, although some losses (maybe 25%) might be expected to occur quite quickly.

But, as has been noted, although this material may stay on the beaches within those zones, it is not necessarily at the top of the ridge where it is required, as in both previous recharge campaigns material has been drawn down onto the lower part of the slope. So, this does not necessarily make much difference to the achievement of 5m width at +6.35mOD.

It is also very possible that the recharge material may have a tendency to move away from the current problem areas (Zones 5, 8b, 9, 10a and 11) onto other areas where it is not actually required, because the issue in those problem areas does not appear to be lack of supply (as they have been recipients of recycling), but a lack of capacity to retain material at those locations.

Therefore, how effective a small (50,000m^3) recharge would be, is highly debateable.

Finally, if recharge material were to have a similar material grading distribution to previous campaigns, it is also highly likely that cliffing would still occur due to those characteristics.

6.3.3 What would be required

If a recharge campaign were to still be contemplated, then it is recommended that a full re-design should be carried out rather than simply replicating previous campaigns if this is to be effective. Re-evaluation of the design profile should be based upon more recent methods and knowledge than appear to have been available for the 2005 campaign or indeed used for the 2014 BMM.

Altering the beach sediment grading might be considered, including for example whether a coarser and less mobile material such as shingle should be used, or a less widely graded range of sand and shingle imported to reduce cliffing. However, availability of local offshore sources may be a constraint, and bringing in material from further afield could result in much higher costs.

Existing knowledge of the coastal processes and existing behaviours is useful but not currently enough to adequately predict the effectiveness of a recharge scheme. Introducing new material would require assessment that will integrate existing shoreline behaviour with the predicted behaviour of that addition.

More analysis and potential modelling would be recommended to design and predict shoreline response throughout the whole frontage with confidence, particularly if changes to the sediment type and profile were to be introduced.

Consideration would also need to be given to the technical challenges of undertaking a beach recharge along this frontage, which ultimately would have both environmental and financial implications. The beach profiles show a very shallow foreshore which will limit the available draft for delivering material by most marine plant directly to the beach. That could require the material to be delivered offshore and transferred to the beach which would be considerably more expensive due to the need to use pipelines or barges and could have detrimental impacts on designated sites. Delivery by land is also challenging due to inadequate roadworks for the terrestrial plant along the whole frontage.

7 Future approach to risk management

7.1 Background

Although WECMS necessarily includes options for do nothing and would involve adaption, these are not included in this initial assessment.

In this section the focus is on potential modifications that might be considered to the management of flood risk within the area bounded by the secondary embankment. These are in principle still in line with the strategic approaches discussed in WECMS.

The approaches outlined here are intended as considerations to be implemented sooner rather than later and during the remainder of the period covered by the existing business case (to 2031), in particular as consideration ought to be given to modifying the present beach recycling regime. This is with a view that these measures would then have continued applicability beyond that date, subject to funding and other approvals, although moving further forward the approaches to flood risk management to this area will require broader strategic re-evaluation in the context of ongoing climate change and response of the shoreline to those effects.

Other approaches, such as extending seawalls throughout or introducing extensive beach control structures have also been reviewed at a high level, but discounted due to the considerable expense associated with them as well a number of technical and environmental limitations and consequences of those. As such, those approaches have not been developed further for reporting on at this initial assessment stage.

7.2 Secondary embankment

It is expected that any future approach to flood risk management will include maintaining the secondary embankment as a flood defence to minimise the risk of inundation to land and property landwards of that structure. It is important to note that although that the presence of the secondary embankment significantly restricted the extent of the 1978 flooding, which could otherwise have caused similar widespread damage to the 1953 floods, local reports would indicate that flood depths/durations in areas seaward of this were greater than might have been experienced without that bank. Therefore, some further consideration to post-storm drainage in this area might be warranted as part of any future assessment.

Previous studies and anecdotal reports indicate that it is likely this structure is both high enough and sufficiently robust to provide a good standard of protection, but should be subject to more detailed assessment as part of any ongoing strategy where this is an integral part of the flood risk management system.

It is unlikely that any changes to management of the frontline shingle ridge would result in exposure to waves of any significance, due to the distance back from the shore and elevation of the land in between. However, were changes made that might increase that risk anywhere, then local armouring (no more than concrete block mattress or similar) could be added at any potentially exposed locations.

7.3 Compartmentalisation

WECMS considered compartmentalisation with cross-banks and increased emphasis on the role of the secondary embankment. Sub-options included cross-banks or similar to ensure that the weaker defences at the Country Park and at the saline lagoons do not increase the risk of flooding of the properties and caravan sites 'through the backdoor'. Compartmentalisation with cross banks was considered important for sub-options where different sub-units have differing SoPs as it could influence flow routes between sub-units and therefore influence risk.

This initial assessment considers that the concept of cross-banks should be given further consideration as part of improving the technical and environmental sustainability of the present approach of recycling material from Snettisham Scalp, by reducing the necessity of that on an annual basis and ensuring capacity of material is there if and when it is critically needed.

To maximise the potential benefit and minimise costs (by reducing management efforts along the shoreline itself), any cross-banks ought to focus on negating the flood risk associated with the areas of greatest risk and requiring most recycling at present (Zones 8a, 9, 10a and 11).

Any cross-banks would extend from the present shoreline back to tie in with the secondary embankment (Figure 7-1). At Heacham, the location of any cross-bank would most likely be at the southern end of Zone 7 (location A in Figure 7-1) to prevent the back-door flood risk to all properties, although a comparison of the costs and benefits with a much shorter cross-bank at the boundary between Zones 5 and 6 (location B in Figure 7-1) would be required to confirm any alignment. At Shepherd's Port, the obvious location for a cross-bank is along the south side of Snettisham Beach car park (location C in Figure 7-1) given the beach ridge in Zone 11 is one of the higher risk areas and most difficult to sustainably hold. This would provide protection against back-door flooding to all other properties and facilities to the south.

If this approach to compartmentalise flood risk into three broad areas is adopted, other opportunities for more sustainable management exist, as outlined below. It is important to note, however, that consideration would be required in terms of land drainage to avoid increasing flood depths/durations at both Heacham and Shepherd Port should the shoreline defences be breached.

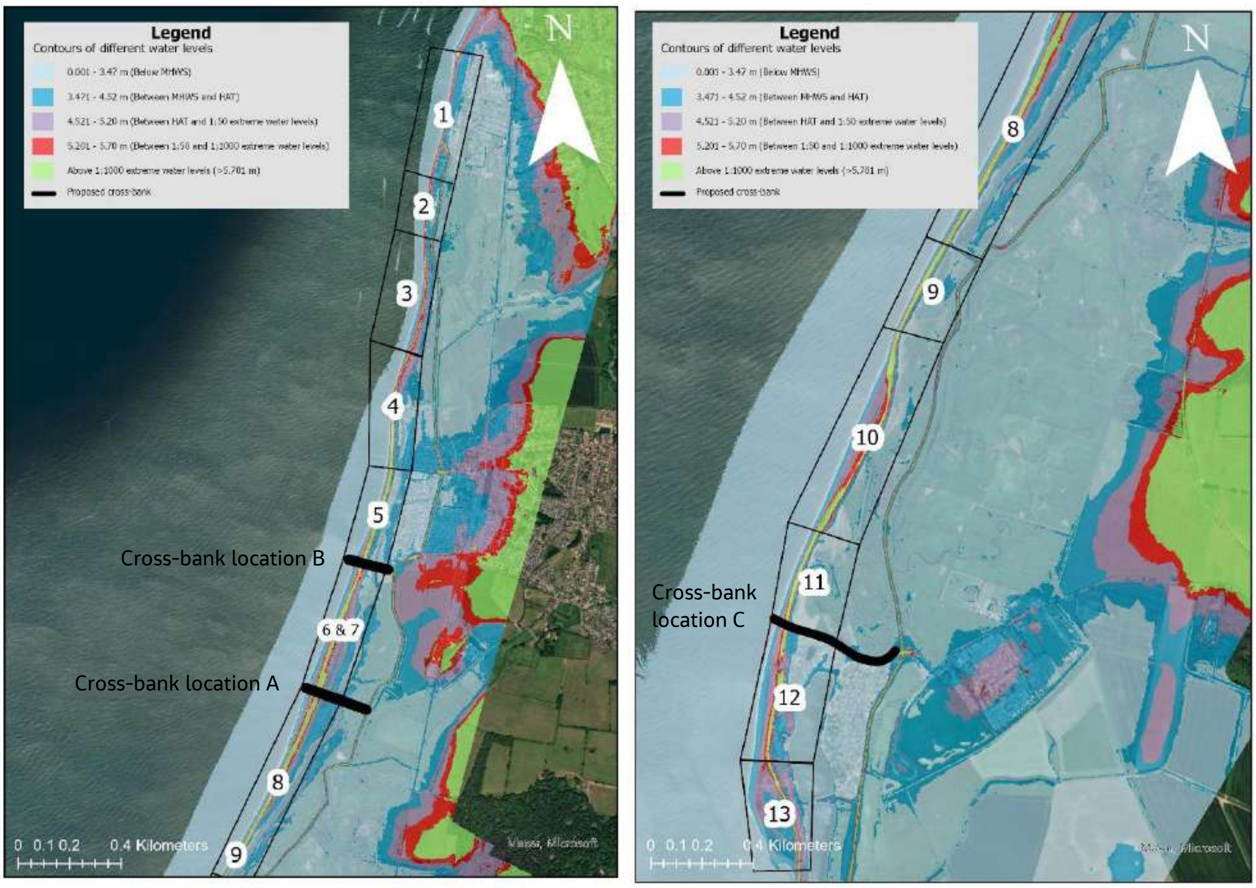


Figure 7-1: Potential location of cross-banks

7.4 Zone-by-Zone considerations

7.4.1 Zones 1 to 4

Continuing with the existing management approach of maintaining the seawall would seem most appropriate in the immediate term; WECMS predicted this to be of sufficient structural integrity to last until 2040 or beyond. Should the risk of undermining materialise, then approaches to bolster the seawall might include placing rock armour at the toe given the difficulty of holding a beach at this location.

It ought to also be noted that if works were to be undertaken in Unit B (Hunstanton) that involved beach nourishment, or large headland structures, those might also provide some benefit to the northern part of Unit C either through additional sand or shingle being transported downdrift or some sheltering effect. However, those would need to be evaluated as part of a wider strategic approach and not considered further within this report.

Zone 5 (Heacham)

Beach management operations appears to have been reasonably effective here up until now and might continue to do so, although its impact is clearly only temporary at present, with repeat works still required in most years along the northern and central sections.

The ideal solution would be to allow some roll back of the dune at the northern end, to attain a more natural alignment, but that would mean allowing it to spill over onto the access track which is most likely unacceptable at present. However, there would still be a discontinuity in alignment between this and the end of the seawall in Zone 4 which may become increasingly vulnerable to breach, particularly as some eddying of currents does seem from observation to contribute in part to erosion here.

Another option might be to extend the seawall from Zone 4 into Zone 5, but this may simply just push the ‘problem’ further along to the new termination point. Rather, if any structural intervention were to be considered, it might be preferable to construct a small protective headland here designed to shelter and stabilise any sand placed here, also acting as an upland control point to the beach beyond. This would need careful technical consideration and would also have greater cost implications than other alternatives.

The preferred option might therefore be to look at continuing with recycling but locally modify the existing approach. That could, for example, focus on just using narrower-graded coarser material that is less prone to draw down and cliffing, to reduce the losses and frequency of operations. This might also be sourced more locally, e.g. from Zone 8 rather than Zone 13 but agreement would need to be sought from Natural England and RSPB to alter the existing donor site. Preventing foot traffic through the dunes would also be strongly recommended to help maintain their integrity and resistance to storm damage.

Zones 6 and 7 (Heacham South Beach)

An approach to consider in these zones is dune restoration and management. Unlike other areas, the key issues here appear to be sand blowing over onto properties as well as one or two instances of householders cutting through the dunes to improve their view of the sea.

The latter simply has to be stopped as this presents a significant increase in risk of breaching and flooding over a wider area at the south end of Heacham.

The former could however be reduced by active dune management and in particular preventing trampling of the dunes by people. The extent of footpaths through these has significantly depleted vegetation, which in turn results in less wind-blown sand being trapped within the dunes, and more sand from within the dunes being eroded by the wind, with this material being moved back onto properties instead.

The first recommendation is to help re-establish vegetation and improve the SoP provided by these dunes by fencing them off and preventing public access to them. This would have to include access from each individual property, although they are each the direct beneficiaries of this so will hopefully support that. If access over the dunes is required, rather than via the main South Beach access point, then it should be limited to 2 or 3 selected location and facilitated by raised boardwalks at those locations.

The second recommendation, where the dune is currently in poor health such as at the northern end and where private owners have lowered it, is to encourage growth through placing and trapping some additional sand from recycling seaward of the existing main dune ridges. It is already evident that some embryonic growth is occurring a few metres down the beach, with vegetation apparently establishing relatively quickly, and this could be mimicked. This may help the dunes here to widen and by doing so further bolster the resistance to breaching.

Although recycling here has almost never been required since the last recharge campaign, should it ever be needed then that would be the most appropriate management measure going forward.

It is important that these dunes are able to reprofile naturally of their own accord if they are to provide a healthy natural flood defence to Heacham. In the future, if/when the dune system migrates inland it is possible that the number of evacuations would increase and/or amounts of sand entering properties become unmanageable. But this approach may offer a transitional solution in the meantime.

7.4.2 Zone 8(a)

Although there is currently limited risk of any breach through these dunes and no action taken anyway, if cross-banks were built to ensure that any breaches could not result in flooding at Heacham or Shepherd's Port, the no further management actions along the shingle ridge would ever be necessary here. There is also a substantial reservoir of beach building material stored within the dunes in this zone, so any erosion that did occur would have a potential beneficial effect in supplying beaches downdrift and potentially reducing flood risk to Shepherd's Port in particular.

7.4.3 Zone 9 (including 8b and 10a)

If cross-banks were constructed to south of Heacham and north of Shepherd's Port, there would be little need to continue the very considerable annual recycling to prevent outflanking here of Heacham Dam. This is an activity which is considered to be unsustainable due to the 'unnatural' alignment of the shoreline created by this structure, meaning that all the fresh beach material placed here every year is almost certainly always going to be removed during the following weeks and months. Extending the dam north or south would simply shift the problem at the terminal ends with it, so is not a solution.

With cross-banks, any risk to properties from outflanking would be eliminated, with only non-developed areas of land at any potential risk from inundation. It would in fact be advantageous to then remove the dam structure altogether to return this to a more naturally functioning coast; in principle it should reform to be similar to the remainder of Zones 8 or 10. Given this is believed to be a former low spot, it may be that some dune enhancement might be undertaken here to assist that formation develop.

Removal may also generate materials for reuse, in particular the armour block mattresses which could be relocated if desired on the seaward face of the secondary embankment if there were concerns over wave exposure, or materials from here might be used in the construction of the cross-banks.

7.4.4 Zone 10(b)

There is little need for active management of this frontage now, and that would become the permanent position going forward if potential flood risk to Shepherd's Port (or Heacham) arising from any future breaching here was restricted by other measures such as cross-banks.

7.4.5 Zone 11

The problem with the beach ridge in Zone 11 is that it is not sustainable in its present position and wants to naturally be further landward. Consequently, continuing to build up the seaward face of this is not going to be effective.

An alternative and preferable approach from a technical and environmental perspective would be to build up the rear face of this ridge instead, i.e. along the edge of the car park, and allow the seaward face to naturally reshape. In this way the beach and ridge here can reprofile without breaching and form a more robust natural barrier cutting into the new material, which should then require little if any recycling on a regular basis in the future. Indeed, if a cross-wall was to also be built as suggested, and the barrier could behave more naturally (which would then mean it would be likely to repair itself as observed elsewhere such as Cley and Salthouse), that need for recycling could become redundant.

Zone 12 (Shepherd's Port)

No action likely to be required, but could be managed with same plan as now, i.e. to recycle to here if ever necessary. In fact the proposed approaches presented for other zones to the north, and the potential build up in Zone 12 to the south, could see beach volumes increase here and further reduce any direct flood risk.

Zone 13 (Snettisham Scalp)

Through the above approaches, it would be expected that the annual recycling requirement reduces substantially, and more material is thus able to accumulate at the scalp and enable the spit formation to evolve more naturally. The lesser removal from the scalp would also enable a larger reservoir of sand and shingle to build up if ever needed for a more substantial campaign in critical areas following any significant storm event in the future (subject to the existing consents and approvals still being continued).

This could have wider beneficial influences by further sheltering/enabling more material to reach, downdrift Zones 14 and 15. Growth of the spit could also help to promote further growth of the beaches and dune vegetation immediately to the north, in Zone 12.

8 Update to costs and benefits

8.1 Background

The original Outline Business Case (OBC), EA 2016, was based upon works to be carried out over a 15-year period up to 2031, which included for annual recycling together with a one-off small scale beach recharge around 2023/2024. However, costs of recharge have escalated dramatically since and the purpose of this assessment is to examine that possibility and establish whether an economic trigger may have now been reached and to also reassess the affordability of works going forward.

Within this re-appraisal new options have not been looked at, but an update of the 2016 assessment with latest information was undertaken to establish how that affects those baseline assumptions, and then re-calculated the economics for the present day (2023/2024) to assess affordability of any works going forward for the remainder of the appraisal period.

8.2 Updated information

8.2.1 Damages/Benefits

In reviewing the OBC and WECMS, which provided much of that information for that business case, it is apparent that some adjustments needed to be made to better represent the potential benefits that might be achieved through the undertaking of the intended works, as those considered assets that lie landward of the secondary embankment which would no longer expected be at risk under a do-nothing scenario at least throughout the remainder of the appraisal period.

In summary, the main adjustments that needed to be made to the damages/benefits arising from the proposed works included in the OBC are some reductions in the number of residential properties, holiday parks, agricultural land and critical infrastructure. These adjustments result in total damages of just over £48 million, compared with previous calculations in the OBC of £74 million, and these changes are reflected in the values that follow further below.

8.2.2 Costs

The costs of the annual recycling have in fact to date been only approximately 70% of that assumed in the OBC. In terms of beach recharge, up-to-date estimates were sought in 2022/2023 from two leading contractors well experienced in providing this type of works. These show that the costs of recharge will now be between £5-8 million, compared with £2.4 million assumed in the OBC. These changes in assumed costs are also reflected in the values that follow below.

8.3 Adjustment to 2016 economic business case

With the benefit of actual information now available in respect of costs and benefits, the economic calculations undertaken in the 2016 OBC have been repeated for the preferred scheme (annual recycling plus a one-off recharge).

These calculations show a reduction in the benefit-cost ratio (BCR) from approximately 6.1 to 2.9, with a reduction in the GiA value from above £1.8million to £1.4 million. There is an increase in the external contributions required from just under £3 million to just over £6 million.

8.4 Updated economics for present day 2024

To consider the affordability of doing something to see the planned management of flood risk through to the end of the original appraisal period (2031), the costs and benefits have all been updated to 2023/2024 prices. In all cases the potential GiA is calculated to be approximately £2.6 million.

The initial case considered whether continuing with the plan to deliver a recharge at the newly estimated prices is feasible, concluding that an external contribution of over £5.2 million would need to be found to deliver that.

The next case considered whether a continuation of present recycling remains affordable, concluding that the present levels of expenditure remain within the bounds of what is currently affordable. In fact, it could be possible to provide GiA for a more intensive campaign of works up to a value of approximately £275,000 in any given year, if that became necessary.

The third and final case considered what might be affordable as a one-off scheme cost should any alternative approaches to provide the same level of flood risk management be explored. This concluded such a scheme would be unlikely to attract more than approximately £2.25 million of GiA (beach recycling being one of them). Other contributions would need to be obtained should the size/scale of any proposed works exceed that.

8.5 Conclusions

Although the costs of recharge have increased substantially, it is fortunate in that the technical assessment does now suggest that planned recharge is not likely to be required. Had that been the case, then an economic trigger would have probably been reached as that would have necessitated raising at least £5 million in external contributions.

In terms of what is affordable, it is clearly possible to continue with the present annual recycling operations through to 2031, even potentially increasing expenditure on that in any given year if necessary. However, as has been discussed elsewhere, the technical effectiveness and environmental sustainability of simply continuing that in its current form, is perhaps questionable.

Alternatively, if other approaches to provide the same level of flood risk management were to be explored, as discussed in Section 7, those might potentially attract GiA up to a level of approximately £2.25 million. However, if that were to be explored, then options that extend beyond 2031 would most likely be extended to 2045 based upon the estimated lifespan of the current seawall which would be the next decision point for major investment. Consequently, a complete review of the potential benefits would also need to be undertaken.

Indeed, it is important to note that to ensure the total amount of GiA that could potentially be obtained, a full review of the damages and benefits is required for a number of reasons. This is to more accurately reassess the numbers and values of the assets at risk, to reassess the standards of protection now being afforded to the area (potentially higher than previously assumed, hence the lack of need for the recharge), and also consider other components now available for the FCERM guidance 2021, such as environmental enhancement and carbon costs and benefits. Account would also need to be taken of the improvements of any scheme might provide, or not, i.e. to the standard of protection and thus whether risks to assets are simply being maintained at the same levels, or being actively reduced by any scheme.

Further benefits would need to be included, such as detailed carbon assessment, potential environmental enhancement (if dune management is included), SoP updates, AAD assessment and full review of all benefits in this area, seawards of the secondary embankment.

9 Summary and conclusions

In respect of the questions posed for this initial assessment, the findings are:

- Due to the relatively healthy state of the beaches over recent years, the decision points set out in WECMS to have to review the management approach due to environmental or evacuation triggers have not been reached to date. There Is though concern that the financial decision point could now be triggered due to a two-to-three fold increase in costs for planned beach recharge. However, the current state of the beaches means that recharge is still not required at present.
- But this situation remains contingent on the beach remaining healthy, and also that no storms occur that exceed the standard of protection being provided and result in a breach. Therefore, should circumstances arise that could require beach recharge in the coming years, this would now fall short of the approved funding limits, so the trigger will have been reached and reconsideration of management approach would then be necessary. The potential effectiveness of the scale of that planned recharge is also questioned and alternative measures may now need to be considered.
- Although removal of recycling material is perceived to be much more rapid in recent years, and the material available for recycling has reduced, overall, the beaches are not diminishing, although they are reprofiling. In addition, Snettisham Scalp is not smaller in volume, although the material has become spread over a larger area.
- However, some of the placed material might have been moved away from the top of the beaches a little more rapidly due to recent changes in storm activity, the continuance of which is unknown, and also possibly due to the grading of material being sourced becoming finer.
- Along most of Zones 6 and 7, the seaward and landward movement of the dune ridge seem to have improved the stability of the dune system (and likely Standard of Protection) against flooding. Further analysis is, however, required to confirm this.
- The dune ridge along the Heacham frontage shows accumulation and growth over time, at least since 1992. Although this may have been partially influenced by various beach renourishment campaigns, the cause for this is likely natural. Whilst the ridge has been stable in recent years, properties behind the ridge may be impacted by this accumulation if it continues in the future.
- Beach recycling has now altered in nature from that anticipated at the time of the BMM in 2014, with some shift in focus onto different areas, in part due to much of the frontage already meeting the minimum profile requirements. The effectiveness and sustainability of some of those current practices is however now questioned, particularly around Heacham Dam. Elsewhere, it is not evident that the recycling operation is required every year.
- Overall, the beaches are not diminishing in volume, although they are reprofiling with some of the placed material being drawn down from the upper to lower beach area a little more rapidly due to recent changes in storm activity. In addition, Snettisham Scalp is not smaller in volume, although the material has become spread over a larger area. If the recycling operation was not undertaken every year it is also possible that Snettisham Scalp could be given more recovery time.
- Elsewhere, directly to the south of Heacham sand has continued to accumulate behind the crest of the ridge towards the line of properties situated there, and will likely continue to do so. Again, measures to better manage that particular frontage could help alleviate that issue in the immediate term.
- Notwithstanding that, beach recycling can still be effective and sustainable, but the current practice and direction provided by the BMM do need to be reconsidered. This should include consideration of other changes to the way in which flood risk is managed to Heacham and Shepherd’s Port.

It is recommended that the following steps are now considered:

- Re-calculate the actual standards of protection being provided today by the shingle ridges, noting the current calculations are now based upon the state and profile of the beach over 10 years ago, which have since changed.
- Revisit the basis for the BMM criteria, including calculations to restate the operational beach profile and standard of protection provided by that, triggers for action, and any modifications to be made to material sourcing, placement and remedial works.
- Develop recommendations for improvements to flood risk management to an outline design stage, including updated economic costs and benefits assessments.
- Revisit and improve details on triggers for decision making as part of a full Strategy review along this frontage, ensuring triggers are cleared defined and measurable.

10 References

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Appendix A. Review of Risks

A.1 Background

To help consider the questions of whether the existing recycling is effective, whether recharge is now needed, and what alternative management approaches might be, the actual risks along each frontage have been reviewed based upon the data and information now available to us.

This makes reference back to work undertaken for WECMS, although it must be noted that those are now up to 10 years old and in particular with the shingle ridge will reflect the size and shape of the feature at that time, which may have now changed. As such, these should be updated with latest data if this project develops beyond initial assessment stage or in making any revisions to the Beach Management Manual (BMM).

A.1.1 Zones 1 to 4

The main risks across Zones 1 to 4 are associated with performance of the seawall and any potential for it be breached by one of three mechanisms: overtopping, structural deterioration, or undermining. The wall currently appears to be in reasonable condition and not at any immediate threat of failure through degradation, with WECMS considering it to have a life expectancy of 25-30 years (from 2015). Large storms could mean overtopping causes some localised flooding directly behind, but unlikely to be that widespread without a breach forming. Extreme overtopping could however lead to instability of the rear face of the wall and breach potential.

Analysis undertaken for WECMS (RHDHV, 2012) considered the Standard of Protection (SoP) provided by the seawall, primarily considering the risks from water overflow or wave overtopping. Throughout, the crest height of the defence comfortably exceeds predicted water levels with a 0.01% AEP (a 1:10,000 year return period event). In respect of wave overtopping, the assessment determined that the SoP was comfortably better than 5% (a 1 in 20 year event), and for the most northern section (Zone 1) where there is no secondary embankment, comfortably better than 2% (a 1:50 year return period).

Any risk of undermining and collapse would be dependent on loss of beach material at the base of the wall. Typically, the design of this type of seawall would be based upon the sheet piles at the toe remaining embedded and not exposed, thus resisting rotational failure. Up to a decade ago, these beaches did receive some recycled material to help maintain them and reduce this risk, but none in recent years. At present there is some occasional exposure of the top of the piles in Zone 1, more in Zone 2 but not excessive (generally less than 30-50cm). Anecdotally there are not perceived to be any issues of concern in that regard at the moment, consequently this risk is presently considered to be low albeit would continue to be monitored.

Assessment of the timber 'groynes' fronting the seawall through Zones 1 to 4 determined that these are largely ineffective at holding any more sand in front of that wall (Jacobs, 2021). The nature and elevation of these structures suggest that these were not designed to act in the same way as traditional groynes and interrupt wave-driven alongshore transport of material on the upper beach, but to limit migration of the nearshore channel and influence tidal current flows.

A.1.2 Zone 5

The main risk in Zone 5 is that the beach ridge/dunes are cut back to a point where overtopping or overwash could further reduce the level and result in a full breach occurring.

Some cliffing of the upper beach and dune face does occur regularly at the northern end and down towards the centre of this zone, possibly (from observation on site) exacerbated by some eddying around the ramp at the end of the seawall. Annual beach recycling still includes placement of some material here, albeit modest amounts in most years.

With respect to the perceived 'narrowness' of the dune at this location, this is however in fact presently at a level in excess of +8.00mOD, with a width in excess of 18m at the +6.35mOD level even where the cliffing takes place (based upon winter surveys from 2020, 2021 and 2022). So considerably wider and higher than the minimum criteria.

Analysis undertaken for WECMS also considered the Standard of Protection (SoP) provided by the beach ridge along the entire frontage, using two different methods to establish whether storm events of different magnitudes would be likely or not to result in a breach. That indicated that SoP across this frontage was comfortably better than 2% (exceedance by a 1:50 year return period event).

Appendix K7 of WECMS (RHDHV, 2014) notes that, with a do-nothing approach (i.e. ceasing recycling), '*….the area is likely to become unsustainable for caravan parks and agricultural use in approximately* ***5 years***' although this is a statement referring to the whole of Unit C, so unclear whether this applies to Zone 5 and Heacham or is more relevant to those further south at Shepherd's Port where the SoP is also significantly lower.

However, the main WECMS strategy document (RHDHV, 2015) states '*Doing nothing in Unit C would result in rapid failure of the shingle ridge to the north of the unit, possibly in* ***three years'*** *time* <u>*depending on the occurrence of storms*</u>*. The shingle ridge in the south could fail in approximately five years where it is more sheltered*', which is contradictory to the appendix.

There is no calculation or basis shown in any of the documents associated with the Strategy to support either of those statements, so the provenance for these is completely unknown. However, given the SoP of the ridge is 1:50 or lower along most parts of the frontage here and to the south, it must also be assumed that those time estimates would also only apply to the occurrence of storms with a magnitude up to but not exceeding those return periods.

A.1.3 Zones 6 and 7

One of the contributing factors to the perceived roll back of dunes here is that these properties appear to have been built within what was the dunes, not behind them. Over time it would appear that a large area of what would have been dune has been levelled to facilitate buildings and access. Consequently, the mobility of sand in this area is a feature of it working within its natural environment. Whether there has actually been roll back of the crest too is something considered in Section 4 in this report.

The actions of property owners to actively reduce the height of the dunes poses a serious risk of breaching through lowering the level across which water could reach and overwash, but also weakening the dunes resistance to withstanding wave attack during storms. Indeed, extensive trampling of the dunes by pedestrian traffic is also reducing vegetation cover and sand trapping efficiency, which is not only also weakening the dunes as above but would also be likely to increase the potential for wind-blown sand to go further inland and onto those properties.

The SoP for this area was calculated in WECMS as being in excess of 5% (1 in 20 year) but not as high as 2% (1 in 50 year). That would not however have accounted for the local lowering by owners described above, so could be further reduced if that damage is not rectified.

A.1.4 Zone 8(a)

Profile analysis indicates that the ridge and dunes at the back of the beach comfortably exceed the minimum criteria set in the BMM, and given this stretch does not receive any recycled material suggests a degree of healthy stability and little risk of breach at the moment.

The SoP for this area was calculated in WECMS as being in excess of 5% (1 in 20 year) but not as high as 2% (1 in 50 year).

A.1.5 Zone 9 (including Zones 8b and 10a)

The Heacham Dam structure has been calculated to have a SoP of 2% (a 1:50 year event) against overtopping (RHDHV, 2012). Unlike the seawalls in Zones 1-4, this structure does not have a sheet piled toe although it is reported (anecdotally) that the concrete block slope extends some distance below the present beach level. Nonetheless, exposure of the toe could result in those blocks becoming destabilised and exposing the core material to wash out and progressive failure.

This structure now protrudes some distance seaward of the natural dune line either side, and very little sand or shingle is able to stabilise and form a beach in front of this. This protrusion contributes to erosion of the natural dunes either side, which has become the main focus of recycling operations in recent years to prevent outflanking and breaching. Significant cliffing occurs here, in part due to the height of the material placed during those operations which is subsequently cut back by wave action.

It should though be noted that even in these adjacent areas (8b and 10a) the dunes appear to have a height and width well in excess of the minimum criteria set out in the BMM.

If this structure is located at a former low spot in the dunes where the now re-routed river may have previously discharged, then the potential for breaching here might be greater than adjacent frontages if the wall were to be destabilised or outflanked, although the extent to which flood waters might then propagate is not certain without further analysis.

A.1.6 Zone 10(b)

Zone 10 is another natural frontage, although the ‘dunes’ here are uncharacteristically low and flat. There is little evidence of cliffing and this zone has not recently required management through recycling, although it will likely benefit from some of the updrift operations (placement of material Zones 8b, 9 and 10a).

The SoP for this area was calculated in WECMS as being in excess of 5% (1 in 20 year) but not as high as 2% (1 in 50 year).

A.1.7 Zone 11

To the north of the beach access point at Shepherd’s Port, Zone 11 extends approximately 400m fronting the beach car park. This high and narrow shingle beach ridge is largely unvegetated (except on its landward side) and appears to protrude seaward and thus sit seaward of what might be expected to be the natural shore alignment. Extensive cliffing does occur here, and this zone is a regular recipient of beach recharge on an annual basis.

The SoP for this area was calculated in WECMS as being in the range of 10-20% (1 in 5 to 1 in10 year) only.

A.1.8 Zone 12

Zone 12 is fronts Shepherd’s Port, where there are a mixture of caravans, holiday homes and residential properties as well as a sailing club. This zone is mostly characterised by a lower but wide beach, backshore and low dunes. Other than on one occasion in the past decade, Zone 12 has not required management through recycling of additional beach material, although it would likely benefit from material placed updrift in Zone11.

The SoP for this area was calculated in WECMS as being in excess of 5% (1 in 20 year)

Whereas Zone 11 does appear to curve seaward, Zone 12 is more concave, so it is quite possibly a case of some long term natural realignment occurring between these two frontages, noting that the accumulation of material in Zone 12 does not seem to be at the expense of material also returning to the scalp (Zone 13) as described below.

A.1.9 Zone 13

Zone 13 is Snettisham Scalp, where beach material typically accumulates as part of a sand and shingle spit formation and is the area from which beach material for the annual recycling is taken.

The main 'risk' here is that of having inadequate volume available to remove on an annual basis, and there have been concerns in recent years whether sufficient material is reaching this area to be taken and thus enable the annual recycling to take place. Although another potential risk is the operations continuing is not enough material building up here, or moving on to the zones further south, to help reduce the potential for erosion or inundation to these areas.

A.2 Secondary embankment

As described in WECMS, relevant failure modes for the grassed secondary embankment are water overflow and landward geotechnical breach. Wave related failure mechanisms (overtopping or erosion of the bank) were not assessed on the basis that, even if a breach did occur in the shingle ridge, the remains of this and the ground behind would continue to provide shelter and/or attenuate waves to prevent significant wave action on the secondary line defence.

Information available to WECMS indicated that the average landward and seaward slope angles are approximately 1:3. The width of the embankment at ground level (around +4mOD or above) is approximately 15 metres. For all sections, the crest height of the defence comfortably exceeds the water levels with a 0.01% AEP (1:10,000 per year).

Geotechnical analysis was qualified as only indicative due to the lack of information available on soil parameters and thus all assessments would require verification based upon better information particularly for any future management approaches which would rely more heavily on this defence. Based on these general assumptions, and furthermore assuming that the embankment consists of acceptable materials, the preliminary conclusion was that earth embankment would likely meet the requirements for a 2% AEP (1:50 per year) Standard of Protection.

Appendix B. The Beach Management Manual and its application

B.1 The Beach Management Manual

The 'Beach Management Manual' (BMM) was first prepared in October 2002, with further reviews of this in subsequent years. Earlier versions are no longer available, but the most recent update was in 2014, which should form the basis for present and most recent recycling operations.

The BMM states that the basis for the beach management approach is "the greater the volume of material on the upper beach, the greater is its capacity to withstand a storm and hence secure the defences", i.e. resisting being breached by extreme waves and water levels causing it to be breached.

The BMM presents overall criteria and direction for scheduled and unscheduled maintenance, although it is specified that the actual extents and requirements for those maintenance activities and working arrangements will be identified each year by the team operating on site (EA, Contractor, Natural England and RSPB). Beach material is moved as agreed between these parties prior to commencement. The output from annual monitoring and survey work is intended to provide the data for the planning of the annual recycling works.

Further pertinent details as they exist within the BMM are outlined below, noting that no further technical details beyond these are contained therein.

B.1.1 Scheduled Maintenance as stated in the BMM

B.1.1.1 Timing

It is important to optimise the beach profile at the start of the winter or "storm" season, however, the BMM notes that practice showed that, since the initial beach nourishment, levels had remained relatively high (excepting localised scour) into the start of winter with insufficient material deposited on the Spit for recycle use. This situation could quickly change from mid to late winter when action is more likely to be necessary and material becomes available. This had led to the carrying out of recycling works in early to mid February - the latest practicable time which enables work to be completed within environmental time constraints (restrictions on working in the breeding bird season), leaving the beach in good condition for the next season. The planned works must be completed before 15th March each year (excepting emergency and safety works) to comply with the working arrangements agreed with Natural England and RSPB.

B.1.1.2 Extraction

Beach material should be mainly recovered from the shingle Spit at Snettisham Scalp (Zone 13) although in certain years material may be available from Zone 3. Shingle removal from the Spit is not to exceed deposition.

B.1.1.3 Placement

The necessary volume is governed by beach slope, crest level, crest width and rear slope, with the crest level providing protection against wave overtopping and wash out from the rear. To achieve the required standard of protection (which is not stated in the BMM or anywhere else that can be located) the following criteria are to be applied when beach recycling is undertaken:

- Seaward slope of 1 in 13
- Crest level of +6.35mOD
- Minimum crest width (at +6.35mOD) of 5m

With respect to the crest width, these criteria apply to a recycled material which has a sediment characteristic generally similar to the existing beach material (i.e. 50% sand of mean size 0.26mm and 50% shingle with a mean size of 8.5mm). The BMM notes that some sections will require an additional width to allow for variability in the material grading or in areas of higher uncertainty.

Figure 5 from the BMM (replicated further below in **Error! Reference source not found.**) showed the zones i dentified to be most likely to accrete or erode, based on the monitoring evidence of the prior 16 years, which was to be used as an indication of where recycled material would be expected to be needed.

B.1.2 Unscheduled Maintenance as stated in the BMM

The BMM notes that at any time of the year, but more particularly in the winter, storm tides can cause sudden changes in beach levels necessitating urgent action to remedy.

B.1.2.1 Emergency works

Typically, emergency works would be required should any areas of beach erosion encroach into the crest width thus leaving the sea defence in an endangered state. Repair works should be carried out to reform the beach profile.

B.1.2.2 Public safety works

"Cliffing" of the shingle ridge may occur. This may lead to inconvenience and more importantly, make public access to the beach a safety hazard.

Ideally cliffs greater than 0.5m high but certainly greater than 1m high should be dealt with urgently. The BMM also states that the recommended action is to "collapse the cliffing from the top at a slope of 1 in 1, or as adjudged to be safe (Review Study - Posford Duvivier: April 1993). This should reduce the tendency for recurrence as opposed to filling by pushing material up the beach."

B.2 Review of the BMM criteria

B.2.1 Elevation and width

The beach profile criteria set in the BMM is stated to be the 'design beach profile' and necessary to 'achieve the required standard of protection'. However, that standard is not specified anywhere and nor are the details available of how that particular slope, crest width and elevation were concluded. But, for context, it should be noted that the design level of +6.35mOD is nearly 2m higher than the extreme astronomical tide level (Highest Astronomical Tide – HAT =+4.52mOD), and is in fact higher than the predicted 1:10,000 year extreme water level (+6.10mOD).

Partial records from the 2005 recharge contract establishes that these profile details were actually those which the contractor was given for placement of that material. It would be reasonable to expect that the design used for that recharge operation would have also made allowances for draw down from that profile during a storm to still prevent breach, or more likely potentially several successive storms and allowances for some annual losses (depending upon the design life expectance of the works), although the calculations relating to this are also no longer available.

WECMS does note that the design profile was based on studies with a shoreline profile computer model, in which the landward movement of the shingle ridge during a design storm was assessed for various configurations. The design criterion was apparently that the crest of the design profile should not move landward from the existing crest line at the time, and overtopping calculations determined that this would limit the discharge to less than 2 l/m/s.

Both of those are exceptionally high-performance standards to try to achieve and, given the aforementioned factors that go into a beach recharge design and notes from WECMS, it is surprising that this same profile would also have to be achieved on an annual basis through recycling operations. Furthermore, it is likely that this would most likely have been a profile designed for the contractual measurement of works when material was placed (with tolerances of +/-150mm also permitted), not the natural profile that would then arise from beach material being reworked by waves and tides. Consequently, the validity of having to achieve this profile rather than one that would be closer to a natural equilibrium is questionable.

WECMS used a different approach to calculate SoP, based upon barrier inertia formulae, for existing profiles along the frontage, which is more suited to assessment of this type of feature than standard overtopping analysis. Although used to estimate SoP of the actual beach at that time, this was not done for the theoretical design profile itself, just actual profiles, so this remains unknown. That could be a useful exercise in the future to establish what level of performance that would have been expected to provide, as well as a method for regular re-assessment of the shingle ridge as its shape and size evolves over time, as any calculations of the actual ridge will be time-limited due to the changeable nature of this dynamic structure.

B.2.2 Beach slope

The specified beach slope of 1 in 13 would have most likely been set for the recharge placement measurement, rather than the ultimate beach slope to be achieved to fulfil the performance criteria. A beach will immediately respond to the subsequent wave and tidal conditions and reprofile to a natural equilibrium shape, which will itself alter throughout the year as conditions change. This means that operations designed to produce beach slopes of 1:13 are almost certainly likely to see relatively quick changes in the beach as it seeks to re-establish its natural equilibrium in response to prevailing conditions.

Furthermore, over such a long frontage, it is highly probable that the natural slope would also differ between locations, this being a function of wave exposure and sediment size which are not going to be constant over the entire area. Typically, where waves are larger (so have greater energy), the beach slope for any given beach sediment size would be expected to be flatter. Where the beach sediment size differs under similar wave conditions, the finer material would be expected to lie at a flatter slope.

Although the natural equilibrium slope of a beach is not a constant slope, the overall slope of the ‘active’ beach between Mean High Water Spring (MHWS = +3.5mOD) and the break in slope (+1.0mOD) close to Mean Sea Level (MSL) has been assessed through review of the profile data. Ignoring Zones 1 to 4 as these are much lower and flatter due to the seawall leading to the absence of an upper beach, around Heacham the natural slope generally appears to be closer to 1:14. However, south of Heacham Dam and towards Shepherd’s Port, the natural beach slope appears to be steeper, at between 1:10 and 1:12. Therefore it is inevitable that the beach will not remain at the prescribed slope anyway and will either steepen or cut back.

B.2.3 Beach sediment grading

The BMM refers to the recycled material as expected to have a sediment characteristic generally similar to the existing beach material (noted to be 50% sand of mean size 0.26mm and 50% shingle with a mean size of 8.5mm). This would appear to be similar to that which was brought to site as part of the 2005 recharge works, which themselves were specified to ‘match existing’ beach material.

However, the beach grading is considered to be a primary reason why cliffing occurs on this beach, and indeed was reportedly a feature of the beach pre-nourishment in 2005, being noted by Posford Duvivier in 1996 (ref WECMS). In periods of moderate to high wave activity coupled with high spring tides, the slope of the beach changes and results in the formation of ‘cliffs’ in the shingle at the head of the beach. Whether this was a feature of the natural beach pre-1991, or a consequence of the material brought to this frontage during that earlier larger recharge campaign, is unknown.

This cliffing is related to the sediment grading as well as the action of the waves and water levels. WECMS notes that the material used for beach nourishment was not single sized and had a D_{90}/D_{10} ratio of between

50 and 100 and can therefore act as a bi-modal material, i.e. it exhibits two modes or forms. This material also compacts very well with time due to the wide grading reducing porosity, loosely 'cementing' it together and, when eroded by wave action at the top of the beach, stands up vertically, forming "cliffs".

Consequently, although the principle of seeking to maintain the sediment grading characteristics of the natural beach are usually sound, there is the question of whether this grading does indeed reflect the natural (pre-1991) sediment grading anyway, and obviously by replicating the grading that is known to cause cliffing it should be no surprise that this continues to occur with the current practice either.

B.3 Current Practice

This section reviews what takes place with respect to the annual recycling operations and whether there are differences between that and the intentions of the BMM.

B.3.1 Material Sourcing

Sand and shingle for recycling continues to be sourced from Snettisham Scalp, although in recent years there have been concerns over the availability of beach building material reaching this area and thus limiting the amount of recycling that could be carried out. Overall volume analysis (Section 4), however, indicates this is not in fact the case in terms of net accumulation over the course of the year. So, the perception of less may be because (a) the timing of material reaching the scalp has altered (and thus less being available within the very limited operational window), and (b) that the material that does deposit there is spread more thinly over a wider area than in the past.

With regard to the latter, a sizeable amount of the material recovery now appears to be on the lower foreshore where sand has deposited on the mudflat, and that thin veneer needs to be 'skimmed' off from above that mud. Although there is no information to corroborate, this was quite probably not the intention of the beach management programme which would have more likely expected material built up on the upper beach (and thus of similar grading to that specified updrift) to have been sourced.

A consequence of this might be that sediment being placed at any recycled locations may no longer be of the mix and grading originally anticipated. That would affect the speed with which recycled material is subsequently removed again and could also affect its tendency for cliffing.

B.3.2 Material Placement

Since 2014, recycling has been largely focussed in three areas, the main one being to resist outflanking of Heacham Dam in Zone 9, but also including the very southern end of Zone 8 (referred to in this report as '8b') and very northern end of Zone 10 (referred to in this report as '10a'). Substantial volumes have also been placed in Zone 11, Snettisham Beach car park. The third area has been at the northern end of Zone 5, immediately south of the concrete seawall. See table below.

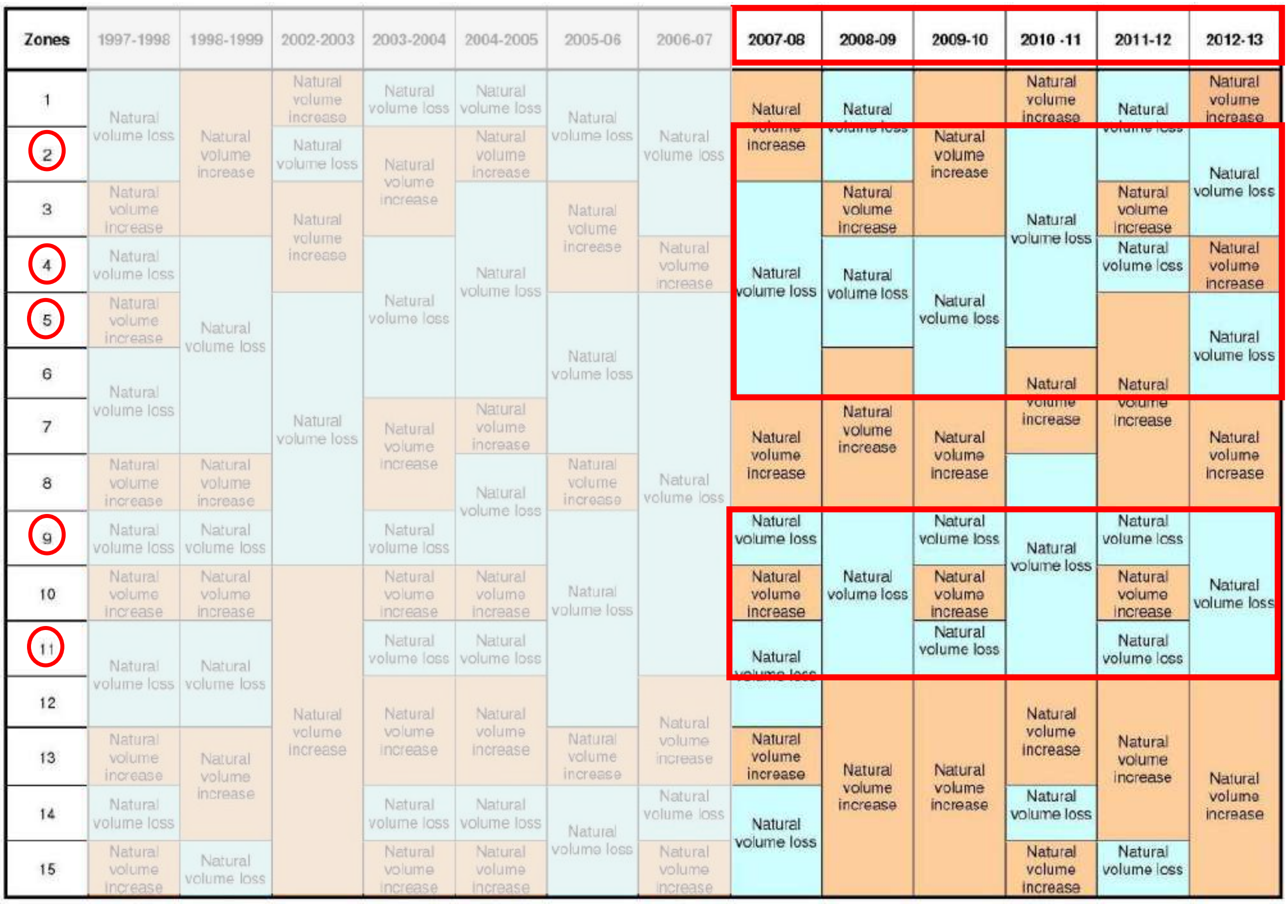
A more significant campaign was necessary at the very start of 2014, following the late December 2013 storm events which caused widespread damage to the defences, including a few breaches towards Snettisham and outflanking of the Heacham Dam.

Table B. 1: Beach recycling volumes per zone

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 14	Zone 15
2012	2,090	0	0	143	1,551	0	0	3,597	0	0	0	0	0	0
2013	2,970	0	0	0	1,518	0	0	2,321	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	2,988	1,900	1,010	1,720	165	630	0
2015	2,233	0	0	0	0	0	0	0	176	44	0	0	0	0
2016	0	0	0	0	488	488	0	2,240	0	420	0	0	0	0
2017	345	0	0	0	480	0	0	3,915	0	855	480	0	0	0
2018	0	0	0	0	294	0	0	5,432	266	266	280	0	0	0
2019	0	0	0	0	1,134	0	0	4,004	105	105	2,240	0	42	0
2020	0	0	0	0	1,302	0	0	3,780	84	84	490	0	28	0
2021	0	0	0	0	588	0	0	3,556	210	210	1,456	0	28	0
2022	0	0	0	0	1,120	0	0	3,262	623	623	0	0	140	0
2023	0	0	0	0	84	0	0	3,486	273	273	2,002	0	252	0

Although there is only a short record of actual placement locations prior to the latest update of the BMM, this is perhaps a somewhat different distribution of material from what was envisaged at the time of that being produced in 2014. The BMM notes that, '*Figure 5 [therein and replicated in the figure below], …shows the zones which are most likely to accrete or erode, based on the monitoring evidence…*' and '*…. can be used as an indication of where recycled material will be needed*'. It is evident from this figure that the zones historically showing losses in most years preceding the BMM have not necessarily been where material has since been placed (and thus presumably not required) since then. Further discussion on the differences in the beaches pre- and post-2014 is provided in Section B.4below.

Figure extracted from 2014 Beach Management Manual (Figure 5)



B.3.3 Meeting the BMM criteria

The primary driver for annual beach recycling are the minimum profile criteria.

Since 2014, the annual beach survey reports have included analysis of whether those criteria were being met along each of the survey profiles. This records the beach berm (crest) width at +6.35mOD, or the maximum level of the beach ridge if below +6.35mOD (later adjusted to +6.38mOD) and level at which the minimum berm width of 5m is found. An example of this is shown in the figure below.

With the caveat that available data currently only extends up to 2022, what is striking about those results is that in none of the years were those minimum criteria not met in Zones 5, 8b, 9, 10a, or 11, i.e. where all of the recycling activity takes place. The only places where the criteria were not met were a few profiles in Zones 10 and 12, where recycling activity does not take place.

To provide some context, in Zone 11 the width of the beach ridge at level +6.38m has been narrow but still 8-10m at its narrowest point, in Zone 5 the actual width of the beach ridge at level +6.38mOD is regularly 18-20m.

It should be noted also that even in those locations where the criteria are not met in Zones 10 and 12 (generally being the same 5 or 6 profiles every year), that they do not actually fall far short of compliance, with the 5m width being achieved at levels never lower than +6.10mOD but mostly between +6.20 and +6.30mOD, and those two zones are also characterised by wider dune belts, so more resilient to breaching.

Hunstanton Heach Beach Management — **Berms widths and sections below 6.38 m AOD**

Shingle Ridge / Hard defences Section Nr.		August 2020 Berm width - metres at 6.38 mAOD)	Max Level (if 6.38m AOD not achieved, or only achieved at one point)	Height difference below 6.38 metres (design)	Increase /Decrease in max height (2019 to 2020)- metres - when below design level	When below 6.38, level where there is 5 metre wide berm	Berm Width Difference Aug 20 from Aug 19 (at 6.38 m AOD(N))	September 2021 Berm width - metres at 6.38 mAOD)	Max Level (if 6.38m AOD not achieved)	Height difference below 6.38 metres (design)	Increase /Decrease in max height (2020 to 2021)- metres - when below design level	When below 6.38, level where there is 5 metre wide berm	Berm Width Difference Sept 21 from Aug 20 (at 6.38 m AOD(N))	September 2022 Berm width - metres at 6.38 mAOD)	Max Level (if 6.38m AOD not achieved)	Height difference below 6.38 metres (design)	Increase /Decrease in max height (2021 to 2022)- metres - when below design level	When below 6.38, level where there is 5 metre wide berm	Berm Width Difference Sept 22 from Sept 21 (at 6.38 m AOD(N))
HH31		19.53					-0.36	19.23					-0.30	19.14					-0.09
HH32		17.67					0.67	17.89					0.22	18.08					0.19
HH33		19.43					1.44	19.07					-0.35	20.06					0.99
HH34		19.10					1.18	19.21					0.10	19.73					0.53
HH35		19.05					1.47	18.36					-0.69	19.56					1.20
HH36		22.86					1.03	22.40					-0.48	23.91					1.51
HH37		13.69					-2.18	12.45					-1.22	12.27					-0.18
HH38		18.39					0.07	15.31					-3.08	14.02					-1.36
HH39		26.42					8.09	27.01					0.59	27.02					0.01
HH40		25.21					2.90	25.76					0.55	26.05					0.29
HH41		19.85					1.34	19.23					-0.61	20.91					1.67
HH42		18.78					-0.93	17.78					-1.00	19.70					1.92
HH43		26.29					-15.03	31.70					3.41	18.56					-13.13
HH44		26.85					0.13	27.17					0.31	25.94					-1.23
HH45		20.47					-0.43	20.50					0.03	21.03					0.53
HH46		22.04					-0.20	22.19					0.15	22.25					0.06
HH47		20.42					-0.14	21.00					0.58	22.53					1.53
HH48		15.16					-0.38	16.62					1.45	17.45					0.83
HH49		14.68					-1.19	16.99					2.31	17.06					0.07
HH50		12.40					0.34	12.91					0.51	13.48					0.57
HH51		15.99					0.34	16.74					0.75	16.84					0.10
HH52		14.94					0.34	14.99					0.05	15.66					0.67
HH53		14.12					0.65	14.28					0.15	13.64					-0.64
HH54		15.71					-0.88	16.76					1.05	16.25					-0.53
HH55	Heacham Dam	12.85					1.07	12.83					-0.02	12.60					-0.23
HH56		12.37					-0.06	12.55					0.19	12.18					-0.36
HH57		10.24					-0.79	11.05					0.81	10.62					-0.43
HH58		23.28					-0.66	26.20					2.92	27.06					0.85
HH59		1.37				6.31	-2.29	0.74				6.33	-0.61	4.39				6.34	3.65
HH60		6.03					-0.87	7.44					1.42	8.13					0.69
HH61		0.00	6.261	-0.12	-0.01	6.15	0.00	0.04				6.25	0.04	4.52				6.37	4.48
HH62		0.00	6.329	-0.05	-0.03	6.22	0.00	0.00	6.376	0.00	0.05	6.34	0.00	4.34				6.37	4.34
HH63		[illegible]					[illegible]	[illegible]					[illegible]	[illegible]					[illegible]

However, these assessments always appear to be based upon the summer (August or September) surveys, which is not when the beach is actually at its lowest, therefore we have repeated that assessment for the most recent 3 years of winter (pre-recycling) surveys for which data is available, with results shown in the figure below. This though shows a similar outcome to the summer profiles in as much that there are only a few locations where the criteria are not met, but (a) those are only slightly below those criteria and (b) these are not necessarily where the recycling then actually takes place.

	Profile	Pre-recycling dates (Jan-Feb) 2020 Berm width (m) at 6.38 m	2020 Max level (m) of ridge	2020 When max level (m) 6.38 m not achieved, at what height is berm width 5m	2020 Max level (m) of ridge where beach ridge or berm is below 6.38 m	2021 Berm width (m) at 6.38 m	2021 Max level (m) of ridge	2021 When max level (m) 6.38 m not achieved, at what height is berm width 5m	2021 Max level (m) of ridge where beach ridge or berm is below 6.38 m	2022 Berm width (m) at 6.38 m	2022 Max level (m) of ridge	2022 When max level (m) 6.38 m not achieved, at what height is berm width 5m	2022 Max level (m) of ridge where beach ridge or berm is below 6.38 m
Zone 5	2d01232	20.0	8.10			19.5	8.05			19.5	8.10		
	2d01228	17.8	8.35			19.0	8.34			19.3	8.36		
	2d01224	17.8	8.20			18.6	8.40			18.7	8.40		
Zone 6 and 7	2d01220	17.5	6.82			12.0	6.80			12.5	6.79		
	2d01216	26.0	6.97			26.5	7.11			25.5	7.04		
	2d01212	18.0	7.89			18.5	7.94			19.5	7.92		
Zone 8	2d01208	44.0	7.80			42.0	7.80				7.60		
	2d01204	19.5	7.94			21.0	7.96			20.5	7.90		
	2d01202	21.0	7.75			22.5	7.85			22.5	7.85		
	2d01200	19.5	7.66			21.0	7.75			20.5	7.65		
	2d01196	16.0	7.88			16.0	7.92			17.0	7.78		
	2d01192	17.0	7.40			15.3	7.47			15.0	7.46		
	2d01188	12.8	7.58			14.5	7.64			12.0	7.61		
Zone 9	2d01186	11.5	7.49			15.0	7.54			12.0	7.50		
	2d01182												
Zone 10	2d01178	24.0	7.10			24.5	7.15			26.5	7.15		
	2d01174	6.8	6.53			8.3	6.56			7.3	6.56		
	2d01172			6.20	6.25			6.20	6.25			6.20	6.31
	2d01170			6.20	6.30			6.25	6.37			6.32	6.37
	2d01168	22.5	6.85			22.5	6.88			22.5	6.85		
Zone 11	2d01164	8.0	6.72			10.0	6.76			9.5	6.75		
	2d01160			6.30	6.60			6.25	6.80			6.25	6.90
Zone 12	2d01159			6.33	6.53			6.37	6.72			6.32	6.41
	2d01157			6.18	6.48			6.20	6.45			6.24	6.45
	2d01155	16.0	6.70			18.0	6.60			18.0	6.62		
	2d01153	8.0	6.58			9.0	6.60			9.0	6.58		
	2d01151	10.0	6.60			10.0	6.65			10.0	6.65		

B.3.4 Dealing with cliffing

Although noted in the BMM as emergency works that could be carried out at any time of year for reasons of public safety, it is believed that works to address cliffing is generally only undertaken at the same time of year as the recycling campaigns when the plant required for that operation is on site.

Although the BMM states that this should be dealt with by "*collapse the cliffing from the top at a slope of 1 in 1, or as adjudged to be safe …. to reduce the tendency for recurrence as opposed to filling by pushing material up the beach*", it is not apparent that this is in fact what takes place. Rather, it seems that material is placed in front of the cliffing, either from recycling or moved up from the lower beach. The effect of this, as also noted in WECMS, "*steepens the profile which is then more vulnerable to cut back and "cliffing" as the successively higher tides gnaw back the beach face and redeposit the sand lower down the beach in the process of reverting it to the natural slope.*"

Obviously, if the 'collapsing' as recommended by the BMM were to lead to a potential for the slope to then be such that it could break through the ridge, that would be not be advisable, but as the previous section indicates, there is currently little evidence to suggest that this has been a major risk in recent years.

As also mentioned in section 3.1, the grading of the material actually placed as part of this operation may also contribute to the tendency for cliffing to continue to occur.

B.3.5 Summary

In summary, the present recycling operations no longer appear to be driven by the outcomes of the surveys, and indeed it might be argued that in most years the recycling requirement as presented in the BMM probably did not exist. In fact there were no winter surveys in 2023 or 2024 for the operations team to refer to, so action had to be planned without those.

But it would appear that the annual operation has now become about two things – addressing concerns about cliffing and outflanking, based upon observations on site. That is not to say those operations are not helping to reduce risks of breaching, but whether they are necessary every single year is questionable; based upon the BMM they are not. This raises the question whether only carrying out the operations when required may in give Snettisham Scalp additional time to recover and accumulate more material for use in those years when it does become necessary.

B.4 Comparison of pre- and post-2014 beach conditions

B.4.1 Background

One reason actual practice has changed from that outlined in the BMM, might be because the risks and requirements have altered from that anticipated at the time of writing that document in 2014. To examine this, comparison has been made of the beach volumes and levels pre- and post-2014 to see if the situation since has been different to those that informed the BMM.

As the requirement here is to just understand overall similarities or differences, the volumes have been averaged across all years for each of the two time periods. This assessment therefore considered and compared the beach volumes in each zone for the 5 years between 2009-2013 with the 4 years 2015-2018. Average beach levels/depths across the zones have also been considered in places, as zone sizes vary considerably and this provides better context for changes in those instances.

The year 2014 itself has not been included as this was, coincidentally, also an usual year in terms of storm surge leading to some breaching and additional material placement to deal with emergency works at the start of the year. By omitting this, the results are not overly skewed by that year's additional operations.

B.4.1.1 Zones 1 to 4

Beach volumes were higher pre-2014, with a drop in average annual volume by approx. 6,600m^3 post-2014. But this is a large area, so this does in fact only equate to a difference in average beach level across the entire area of approx. 3cm.

However, that might also need to be seen in the context of beach levels across these zones which are already very low – typically averaging around 1.5m 'beach depth' compared to the remainder of the zones to the south where that 'depth' was typically 4m or more.

B.4.1.2 Zone 5

Beach levels dropped considerably post-2014 compared to the previous period, with the annual average volume approx. 7,500m^3 lower. This is a more significant reduction than in Zones 1-4, this being a smaller area and so equating to a drop in average beach level of approx. 17cm.

Further notes with respect to Zones 1-5

It is very possible that the BMM may have been based upon the assumptions that the beach volumes in Zone 5 would have in fact been better than they subsequently turned out to be. However, it was at that time recognised in the BMM that this and Zones 1-4 were naturally losing volume, although up to that point this was to a large extent being countered by the recycling regime that had been carried out historically. Looking at the recycling records it is noted that a sizeable amount of the recycled material was regularly being placed in these areas (approx. 4,000m^3 in both 2012 and 2013 for example). However, in the period 2015-2018, these frontages collectively only received just over 2,200m^3 in 2015 and only another 1,600m^3 across the entirety of the following 3 years. Although the actual recycling location data for years 2009-2011 is not available, the average volumes placed amounted to approx. 22,000m^3, which if assumed followed a similar pattern, might indicate a substantial difference in supply to these areas occurred in the recycling regime post-2014.

It is probably unlikely that this change in recycling regime would have been the expectation at the time of the BMM. It is evident from Figure 5 of the BMM that historically three of Zones 1-4 were regularly showing losses every single year, and in Zone 5 beach losses showed to have occurred in all but one of the preceding 12 years.

B.4.1.3 Zones 6 and 7

Although the recycling campaigns does seem to have an influence on beach levels along Zones 6 and 7, post-2014 very little change is observed, with a slight reduction in the average annual volume by approx. 1,800m^3 (equating to a lower average beach level of approx. 5cm). However, that volume change also needs to be put into context that there was one especially high year here (2012), without which the difference would actually be less than 500m^3. Therefore, any assumptions made in 2014 regarding volumes here would have remained valid through the next few years.

B.4.1.4 Zones 8 to 10

Although Zones 8 and 10 extend over some distance, anecdotally it appears that the majority of recycling occurs in the vicinity of Heacham Dam (located mostly in Zone 9) and probably covers a length of no more than a few hundred metres beyond that structure. That being the case, then it might also be concluded that the beach does not grow along that same length area and indeed likely to be where reductions of any significance generally also only occur.

There was a substantial increase in annual average beach volume post-2014, by approx. 15,000m^3, the majority of which accumulated in Zone 8. Given the recycling almost all takes place at the southern extremity and needs redoing each year, this might imply either some northerly drift of placed material or some natural accumulation of material fed by natural drift from the north. It appears that Zone 8 has continued to steadily build year on year too.

Further notes with respect to Zones 8-10

There has been a much stronger focus since 2014 on recycling being placed here rather than further north (Zones 1-5).

Putting 2014 aside, the volumes placed in Zones 8 to 10 appear to have been consistently higher than they were prior to 2014, despite the steadily increasing volumes here over this same period.

This change in recycling regime was quite possibly not the expectation in the BMM with Figure 5 of the BMM indicating that although Zone 9 had always historically shown losses, Zone 8 had shown volume increases in most prior years (as continued post-2014) and Zone 10 had shown a fairly consistent pattern of fluctuating increase/decrease.

In summary, what was reported in the 2014 BMM has appeared to remain the same for Zone 8 with a steady volume increase (but perhaps not with the increasing recycling); Zone 9 has effectively 'flat-lined' with little overall change in volume; and Zone 10 has seen some modest increases although the influence of the increased recycling here and directly north of here is likely to have had some part to play in that regard.

B.4.1.5 Zones 11 and 12

Zone 11 saw a reduction in average volume of approx. 5,200m^3 after 2014 compared to the pre-2014 situation, which equates to a reduction in average beach levels of around 26cm. This however appears to not be a sudden drop but a steady decline year on year, which was also the pattern observed pre-2014 so follows what might have been expected at the time of the BMM being produced.

Zone 12 saw an increase in the average volume of approx. 4,300m^3 after 2014, which equates to an increase in overall beach levels of around 16cm. There had also been a steady increase in volume here prior to 2014, so probably again as might have been expected at the time of the BMM being produced.

B.4.1.6 Zone 13

Overall, there is virtually no difference in the average beach volumes at the scalp either pre- or post-2014. However, there was a change in patterns there, with less material found in the pre-recycling period (on average 1,700m^3 lower) post-2014, but more material arriving during the summer (on average 1,600m^3 more post-2014).

At the time of the BMM it was noted that the timing of operations reflected the greater volumes being deposited during the early winter months but that timing appears to have shifted a little post-2014.

Appendix C. Shoreline Behaviour and Processes

This appendix details the methodology and results of the shoreline behaviour and coastal processes undertaken as part of the Unit C Initial Assessment.

As part of this assessment, a detailed analysis of beach profiles and beach volumes (using beach topographic data) has been undertaken after 2014, i.e. after the most recent update to the Beach Management Manual (BMM), with an assessment of the averaged volumes between two time periods:

- 2015 to 2018: considering the period between the implementation of the updated Beach Management Manual (BMM) and anecdotal evidence of quicker losses following recycling campaigns
- 2019-Present: considering the period between anecdotal evidence of quicker losses following recycling campaigns and present day

The year 2014 itself has not been included as this was coincidentally also a usual year in terms of storm surge leading to some breaching and additional material placement to deal with emergency works at the start of the year. By leaving out the three 2014 surveys altogether, it should mean that the beach may have 'settled down' again by 2015 and results thereafter not overly skewed by the previous year's additional operations.

Beach levels and beach volumes changes have then been correlated with changes observed in wave climate and water levels (over the same two time periods) and also summarised below.

The tables below show in detail items included in the scope and the analysis undertaken for each of them, and where they have been reported.

Table C. 1: Coastal processes analysis scope and outcomes

Scope	Analysis and outcomes
Building from the analysis Jacobs (2021), which used beach profiles from the Anglian Coastal Monitoring (ACM) Programme up to September 2020, more recent data is now available for 2021, 2022 and 2023 (if available). These will be analysed, in conjunction with more recent Beach Survey Annual Monitoring reports for 2020/2021 and 2021/2022 also produced by Jacobs	This has been undertaken using beach profile and beach volume analysis using the last 3-5 years of data. This was compared against previous beach profiles surveys also analysed as part of Jacobs (2021) and the more recent Beach Survey Annual Monitoring reports for 2020/2021 and 2021/2022 also produced by Jacobs. The results of this analysis are described per Zone in Section 4, with more detailed graphs in this appendix.
More recent LiDAR images are now available for 2021 and 2022. Those will be used to update the difference plot analysis undertaken in Jacobs (2021), which will indicate spatially areas of erosion/accretion.	This has been undertaken and results are described in Section C.2.10 of this appendix.
Aerial photography and LiDAR images over a wider, offshore area (area to be discussed with the client) will also be sourced and analysed, which could provide an insight on channel/bank movement close to the Unit C frontage. These will also be correlated to the 4D Radar report and data (if available) (Marlan, 2022)	This analysis was undertaken, but resulted in limited outcomes due to data gaps in Aerial photography and LiDAR offshore within the Wash. In addition, radar data (by Marlan) is quite limited by spatially and temporarily (only one winter collected).

Scope	Analysis and outcomes
Aerial photography and LiDAR images will also be used to investigate the general condition and potential changes to the sand ridges located to the southern section of Unit C	This has been undertaken and results are described in Section C.2.10 of this appendix and also in Appendix A.
Potential changes in wave climate will be analysed using data from CEFAS WaveNet Buoy located at North Wells, which covers the period between 2006 and 2023	This has been undertaken and results are described in Section C.3 of this appendix.
Correlation of wave data with storm records and beach profile changes.	This has been undertaken and results are described in Section C.3 of this appendix.
A high-level analysis of sediment transport potential changes will be undertaken. This is a simple approach which uses wave climate and the average sediment grain sizes from the beaches along Unit C to indicate changes to sediment transport potential over the last few years	It was not possible to do develop this analysis due to lack of sediment grain size. However, this was inferred based on wave direction information from the wave buoy and extreme WL analysis from tide gauge.
Changes in longshore sediment transport will be inferred from the analysis above	This has been undertaken and the results of this analysis are described in Section 4.

The outcomes of the analysis above were then correlated with management practices, as described in the table below.

Table C. 2: Correlation of coastal processes outcomes with management practices: scope and outcomes

Scope	Analysis and outcomes
Annual volumes of recycled material and their placement location will be requested to the Environment Agency; those will be correlated to the findings of the coastal processes review	This has been developed and is described in this appendix.
The beach levels prior to beach recycling and the condition of the wave climate before and after recycling campaigns will help inform the review of current management practices, including beach recycling, beach reprofiling, and seawall maintenance, to build an understanding whether those are still effective along the frontage	This has been developed and is described in Sections 3.2, 4, 5, 6 and in this appendix.

C.1 Methodology

The analysis undertaken as part of the coastal processes review used a variety of datasets as described in Table C. 3.

Table C. 3: Datasets used, sources and analysis type undertaken

Data type	Source of information	Surveys/ frequency	Analysis
Topographic beach profiles	ACM/EA	Between 1992 and 2022, mostly three surveys per year (pre-recycling usually undertaken between Dec-Feb), Spring (Mar-Apr) and Autumn (Aug-Oct).	Beach profile data was used to display and analyse profiles over varying temporal scales and to conduct volume analysis. The volume analysis was conducted using 'Coastal Process Unit Analysis' tool in 'SANDS Asset Management' software.
LiDAR	ACM/EA	Between 2018 to 2022, different spatial extents using DTM data.	Difference plots were created using 'ArcGIS Pro' to determine beach level (i.e. elevation in metres) variance over different spatiotemporal scales.
Water levels	EA	Kings' Lynn tide gauge – between 2013 to 2023	Using Mike21 toolbox for tidal analysis, recorded total water levels were divided into predicted and residual values. This was then corrected with known storms in the area.
Wave buoy	Cefas/Wavenet	North Well Wave Buoy-Annual data between 2007 and 2022	Wave roses displaying '% occurrence of Significant Wave Height (Hs) Peak Wave Period (Tp) and Wave Period (Tz) were produced using 'SANDS Asset Management' software.

The subsections below detail further the methodology for each analysis undertaken.

C.1.1 Beach profile and beach volume analysis

Figure C. 1 shows the position of the beach profiles throughout the whole study area; Figure C. 2 shows the same beach profiles split into the zones analysed. A total of 71 profiles were included in the beach profile and volume analysis, which are shown in Table C. 4.

Beach profiles were plotted using different combinations of surveys to ensure comparison among certain timeframes were possible, as follows:

- Within the same frame, beach profiles between 2008 and 2013 used a black line, between 2014 and 2018 used a red line and between 2019 and 2022 used a green line. This enabled easy visualisation of profile envelopes within the timeframes defined above.
- For some profiles, pre-recycling, Spring and Autumn surveys within two given years were plotted within the same frame, to enable comparison between those three surveys in any two years chosen, and easy identification of changes amongst these surveys.

For each zone, and between each beach profile listed in Table C. 4 below, beach volumes were calculated yearly using different timeframes, i.e. between two consecutive pre-recycling surveys, two consecutive Spring surveys, and between two consecutive Autumn surveys. This allowed for a comparison of volume between profiles pre-recycling, Spring, and Autumn interannually and to allow for annual comparisons between 2014-2022 volumes.

The calculation of volumes was undertaken using the Coastal Processes Analysis Tool within SANDS Asset Management software, and it calculates volumes above a defined profile called "master profile". Master profiles are unique for each profile location. Initially a level above which volumes are calculated was defined as 1.0mOD. The position of the minimum chainage was defined by the position of the defence toe (if defended) or the most stable 'back of beach feature' such as the dune crest was determined to provide the minimum chainage. Therefore, the calculated beach volumes using the master profiles provided the beach volume between adjacent profile, from the minimum chainage, above 1.0mOD.

The beach volumes were then analysed within each zone boundary along the frontage. Please note due to the nature of this volumetric analysis which calculates volumes between profiles, the zonal split is based on the profile positions within or as close to the zone boundary, rather than following the exact zonal boundaries. For example, 2d01272 is within Zone 1, the volume between 2d01272 and 2d01270 (North of Zone 2) is included in Zone 1 analysis.

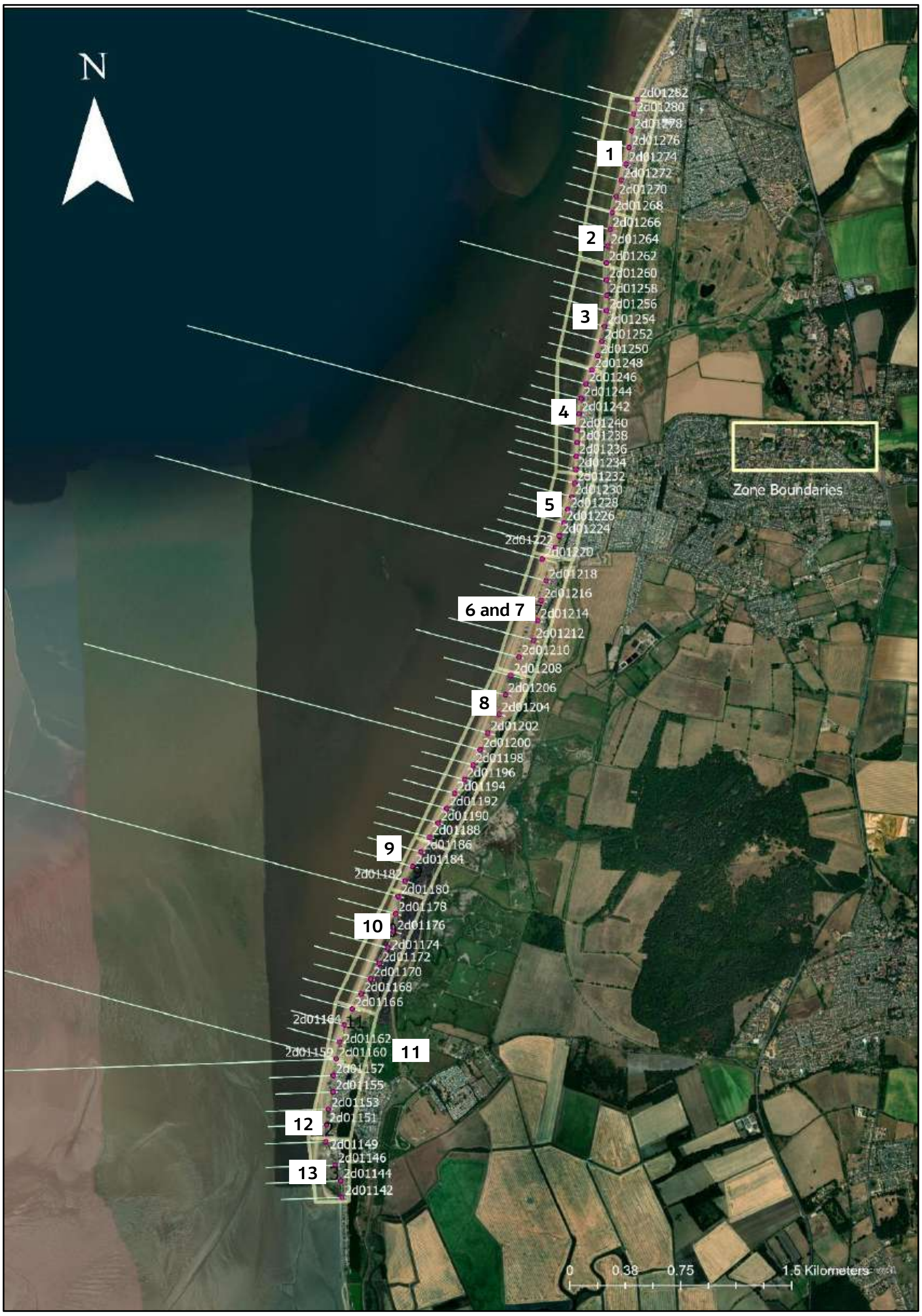


Figure C. 1: Beach profiles and zone boundaries used for analysis along Unit C frontage

Figure C. 2: Beach profiles split into zone boundaries

Table C. 4: 71 beach profiles used in the volume analysis, and the minimum chainage used to define the toe of each profile from which beach volume above 1.0mODN was calculated between 2014-2022, for pre-recycling, Spring and Autumn surveys.

Zone	Profile	Min Chainage (m)	Zone	Profile	Min Chainage (m)
1	2d01282 [HH173]	11.82	8	2d01208 [HH103]	3.33
	2d01280 [W061]	10		2d01206 [HH101]	14
	2d01278 [HH170]	12.14		2d01204 [HH099]	28
	2d01276 [HH168]	12.26		2d01202 [HH097]	14
	2d01274 [HH166]	10.93		2d01200 [W057]	11
	2d01272 [HH164]	9.32		2d01198 [HH094]	16
2	2d01270 [HH162]	8.29		2d01196 [HH092]	11.45
	2d01268 [HH160]	9.38		2d01194 [HH090]	0
	2d01266 [HH158]	8.75		2d01192 [HH088]	-2
	2d01264 [HH156]	9.31		2d01190 [HH086]	-3
	2d01262 [HH154]	9.43		2d01188 [HH084]	-1.4
3	2d01260 [W060]	10	9	2d01186 [HH082]	-2.35
	2d01258 [HH151]	5.9		2d01184 [HH080]	19.9
	2d01256 [HH149]	5.32		2d01182 [HH078]	18.4
	2d01254 [HH147]	4.96	10	2d01180 [W056]	17.8
	2d01252 [HH145]	5.36		2d01178 [HH075]	6
4	2d01250 [HH143]	4.19		2d01176 [HH073]	50
	2d01248 [HH141]	5.96		2d01174 [HH071]	44
	2d01246 [HH139]	7.58		2d01172 [HH069]	41
	2d01244 [HH137]	8.8		2d01170 [HH067]	32
	2d01242 [HH135]	11.37		2d01168 [HH065]	16
	2d01240 [W059]	14	11	2d01166 [HH063]	0
	2d01238 [HH132]	9.45		2d01164 [HH061]	0
	2d01236 [HH130]	8.86		2d01162 [HH059]	0
	2d01234 [HH128]	7.62		2d01160 [W055]	0
5	2d01232 [HH126]	0	12	2d01159 [W054]	0.7
	2d01230 [HH124]	-1		2d01157 [HH056]	-1
	2d01228 [HH122]	-3		2d01155 [HH054]	0
	2d01226 [HH120]	-2		2d01153 [HH052]	3.5
	2d01224 [HH118]	-2		2d01151 [HH050]	7
	2d01222 [HH116]	-4	13	2d01149 [HH048]	40
6 and 7	2d01220 [W058]	-52		2d01146 [HH045]	115
	2d01218 [HH113]	14		2d01144 [HH043]	120
	2d01216 [HH111]	49		2d01142 [HH041]	9
	2d01214 [HH109]	65			
	2d01212 [HH107]	80			
	2d01210 [HH105]	30			

C.1.2 LiDAR and Aerial Imagery analysis

LiDAR Digital Terrain Model (DTM) data was downloaded from 'Defra Survey Download Data' (https://environment.data.gov.uk/survey) to denote if any changes in beach and sand ridges occurred over different spatiotemporal periods. Table C. 5 shows the tiles available for both onshore and offshore areas.

Table C. 5: DTM LiDAR tile availability around Hunstanton from 2011 to 2022 (Data Source: Defra)

	Onshore (along Hunstanon Frontage)							Offshore							
2011	TF63NE			TF63SE		TF64SE		TF54SW							TF44SE
2012															
2013															
2014	TF63NE	TF63NW			TF64NE	TF64SE									
2015	TF63NE	TF63NW		TF63SE	TF64NE	TF64SE	TF64SW	TF54SW			TF53SE	TF53NE	TF53NW	TF53SW	TF44SE
2016	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE	TF64SW	TF54SW		TF54NW					TF44SE
2017	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE	TF64SW	TF54SW	TF54SE		TF53SE	TF53NE	TF53NW	TF53SW	TF44SE
2018	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE									
2019	TF63NE	TF63NW	TF63SW	TF63SE				TF54SW			TF53SE	TF53NE	TF53NW	TF53SW	TF44SE
2020	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE	TF64SW	TF54SW		TF54NW					
2021	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE	TF64SW								TF44SE
2022	TF63NE	TF63NW	TF63SW	TF63SE	TF64NE	TF64SE	TF64SW	TF54SW	TF54SE		TF53SE	TF53NE	TF53NW	TF53SW	TF44SE

Difference plots were created using ArcGIS Pro to show how elevation variance has occurred over different timeframes. Using the onshore tiles available, difference plots were produced for the period between 2018 and 2022, in order to analyse potential elevation changes over the last 5 years. The results are shown in Section C.2.10**Error! Reference source not found.**.

Given the incompleteness of the offshore LiDAR tiles available (Table C. 5), analysis of offshore sand ridges was very limited. In an attempt to determine sand ridge changes overtime, Google Earth aerial imagery since 1985 was mapped and the outlines of the sand ridges were defined. This analysis was, however, inclusive mainly due to the lack of metadata (i.e. the stage of tides which those images have been collected was not available), and no further bathymetry data was available to validate the position of mapped sand ridges for the same time frames.

C.1.3 Wave climate analysis

Wave data from the Cefas WaveNet North Well wave buoy was accessed and downloaded via 'Coastal Channel Observatory' (https://coastalmonitoring.org/) for 2007-2023. Information about the Wave Buoy is highlighted in Figure C. 3. Please note 2016, 2017 and 2018 datasets were incomplete during the time period under consideration for this analysis and have therefore been excluded.

For the wave data analysis, focus was placed upon understanding the wave climate between the pre-recycling and Spring surveys, to help determine how the wave climate within this specific period could have influenced the beach levels. Therefore, wave roses of the percentage occurrence of Significant Wave Height (Hs, in metres), Peak Wave Period (Tp, in seconds) and Wave Period (Tz, in seconds) were plotted for each year between 2007 and 2023, defined by the pre-survey and Spring survey data specific to each year. Comparisons were made between each wave rose to determine if the wave climate has varied between the pre-recycling and Spring surveys (see Figure C. 37, Figure C. 38, Figure C. 39). This analysis was undertaken to help determine if there has been a change in wave climate in recent years between the pre-recycling and Spring survey period, which could provide reasoning for the quicker removal of sediment post-recycling, anecdotally observed in recent years.

Location			
OS	565996 E 354077 N		
WGS84	*Latitude:* 53° 03.49' N *Longitude:* 00° 28.53' E		
Instrument type			
Datawell Directional Waverider Mk III			
Water depth	~31m CD	Example buoy in situ. Photo courtesy of Fugro Marine GB Limited	Location of buoy (Google mapping, image ©2019 Landsat / Copernicus)

Figure C. 3: North Well Waverider Buoy information and location

C.1.4 Water level/surge analysis

Total water levels (m) were extracted from the King's Lynn tide gauge (Figure C. 4). Using Mike21 toolbox for tidal analysis, the total water level information was split between astronomical (or predicted) tides and residual (or surges). Since total water level data showed some gaps, the data was queried and only continuous periods longer than 30 days at a time were used in the analysis.

Based on the average of residual values, surges greater than 0.80m were assumed representative of storms. Periods of which at least three consecutive surge records were above 0.80m were then correlated with known storm events in the area. This provided data where storm events have resulted in high water levels/extreme surges. The purpose of this was to correlate how storm events affected wave climate data, and the impact of this on beach profile change.

Figure C. 4: Location of the King's Lynn Tide Gauge

C.2 Results of beach analysis

This section describes the results of the analysis undertaken at each zone or groups of zones.

C.2.1 Zones 1 to 4

Within Zones 1 to 4, beach volumes (Figure C. 6) showed an increase of around 6,000m^3 between 2015 and 2018, with a subsequent drop in volumes of around 7,500m^3 between 2019 and 2022. Post-2014, beach recycling campaigns occurred only twice in Zone 1, with the placement of around 2,000m^3 in 2015 and 350m^3 in 2017 (Table 3-1), which could partially explain the accumulation of material up to 2018 with a subsequent loss up to 2022.

It is also important to note that, whilst Zone 1 seems to be stable over time (Figure C. 6), with more recent (2019-2022) beach levels close to the defence around 0.5m higher than 2014 levels, Zones 2 and 3 (Figure C. 8 and Figure C. 10, respectively) showed a decrease in beach volume (with beach levels dropping by over 1.5m in places close to the defence – 2d01260 Figure C. 11a and b), for the benefit of Zone 4 (Figure C. 12), which seems to be increasing in beach volume since, at least 2014 (with beach levels around 1m higher in 2022 compared to 2014 closer to the defence – 2d01236 Figure C. 13c).

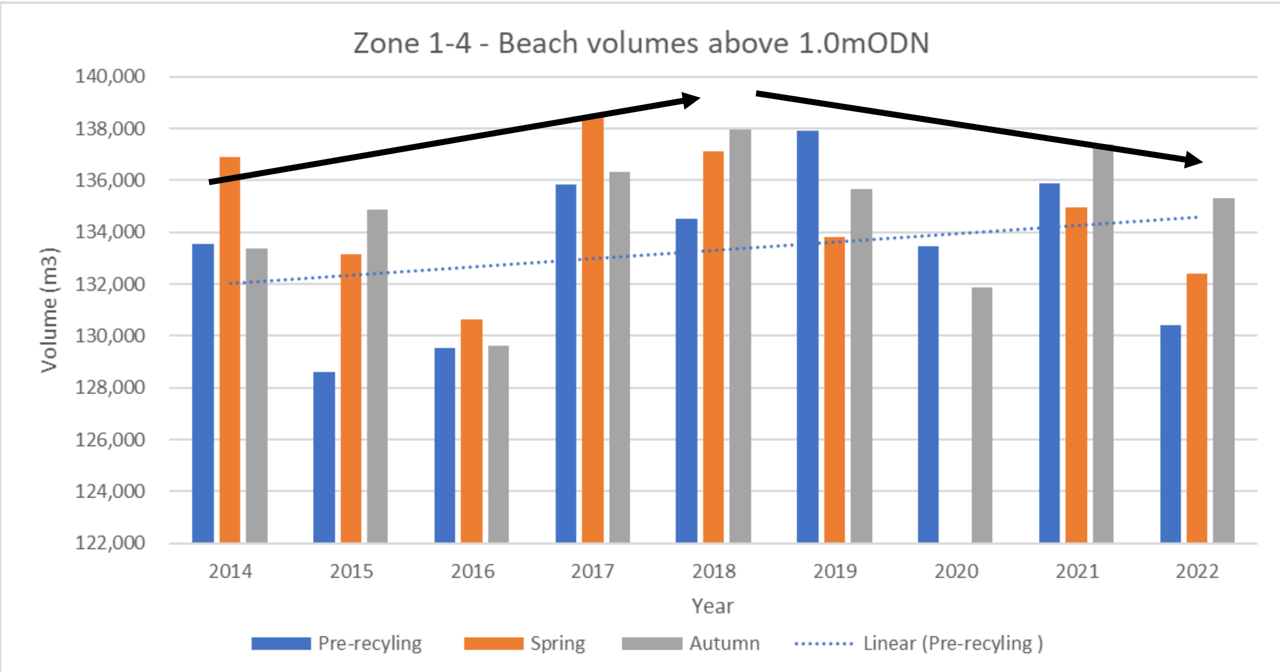


Figure C. 5: Total beach volumes (above 1mODN) for Zones 6 and 7, considering pre-recycling, Spring and Autumn surveys. The black arrows indicate general trends within these zones.

Figure C. 6 shows beach volumes above 1.0mOD (in m^3) for Zone 1 and Figure C. 7 shows a comparison of beach profile changes amongst three time periods: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at two profiles within Zone 1 (2d01264 and 2d01262).

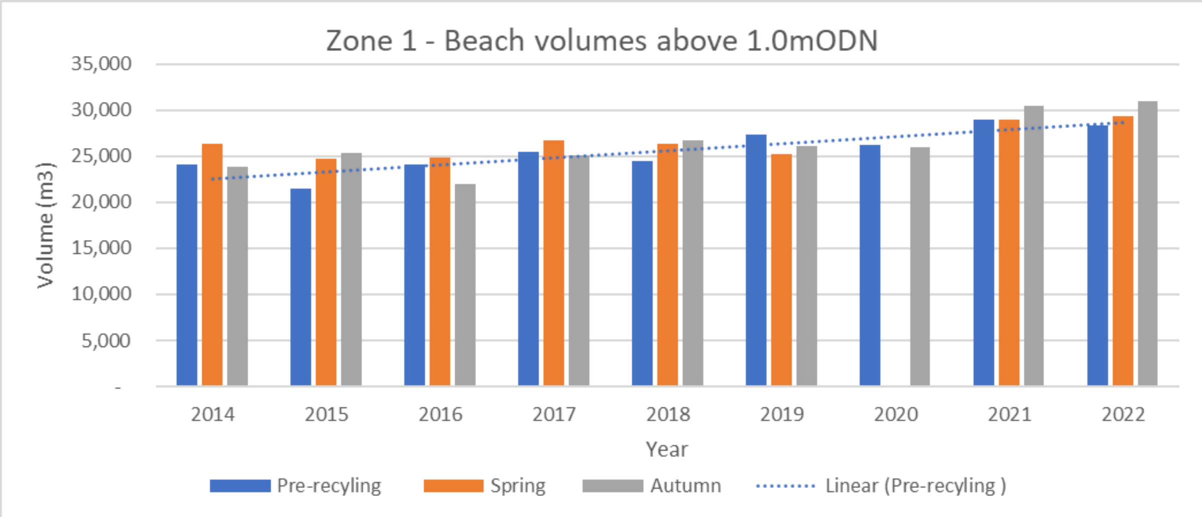
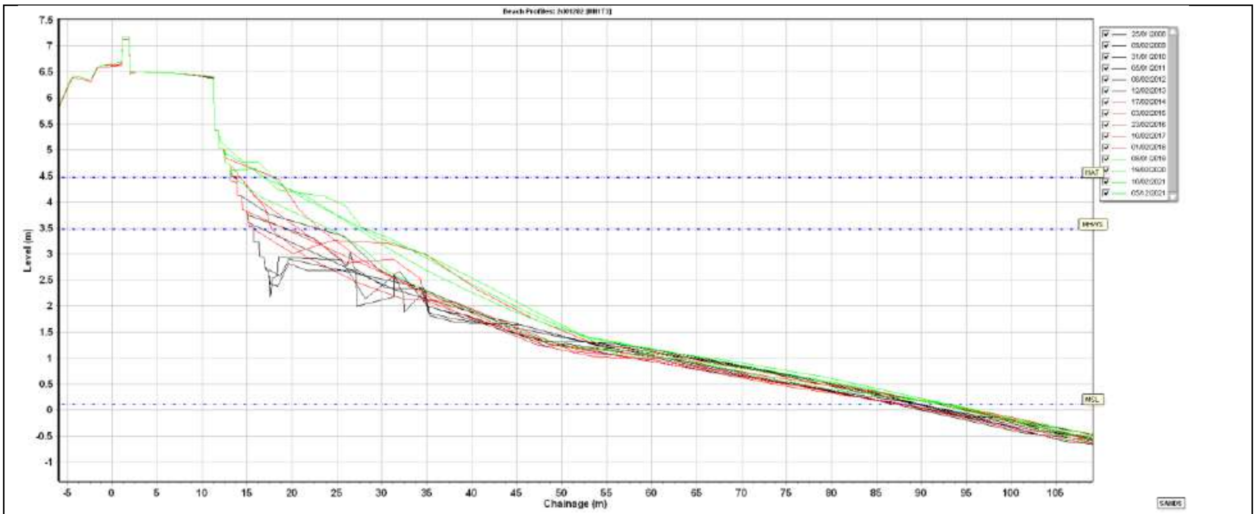
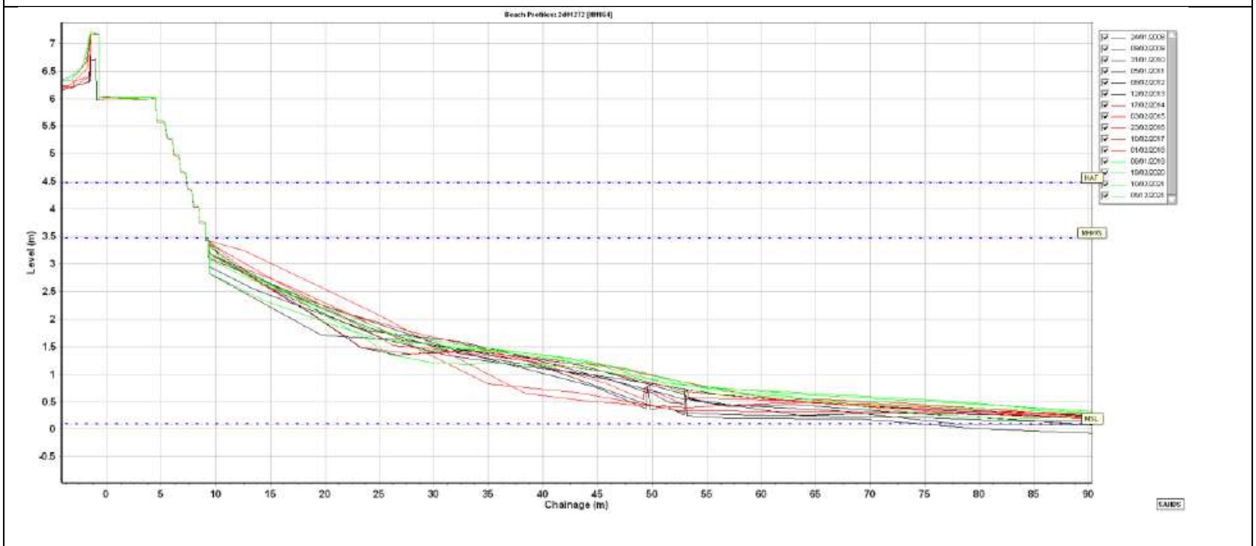


Figure C. 6: Beach volume (m3) above 1.0mODN, calculated for pre-recycling, Spring and Autumn surveys, from 2014 to 2022 in Zone 1



a) Profile 2d01282



a) Profile 2d01272

Figure C. 7: Examples of profile analysis in Zone 1 showing profile change between 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at a) profile 2d01282and b) 2d01272

Figure C. 8 shows beach volumes above 1.0mOD (in m^3) for Zone 2 and Figure C. 9 shows a comparison of beach profile changes amongst three time periods: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at two profiles within Zone 2 (2d01264 and 2d01262).

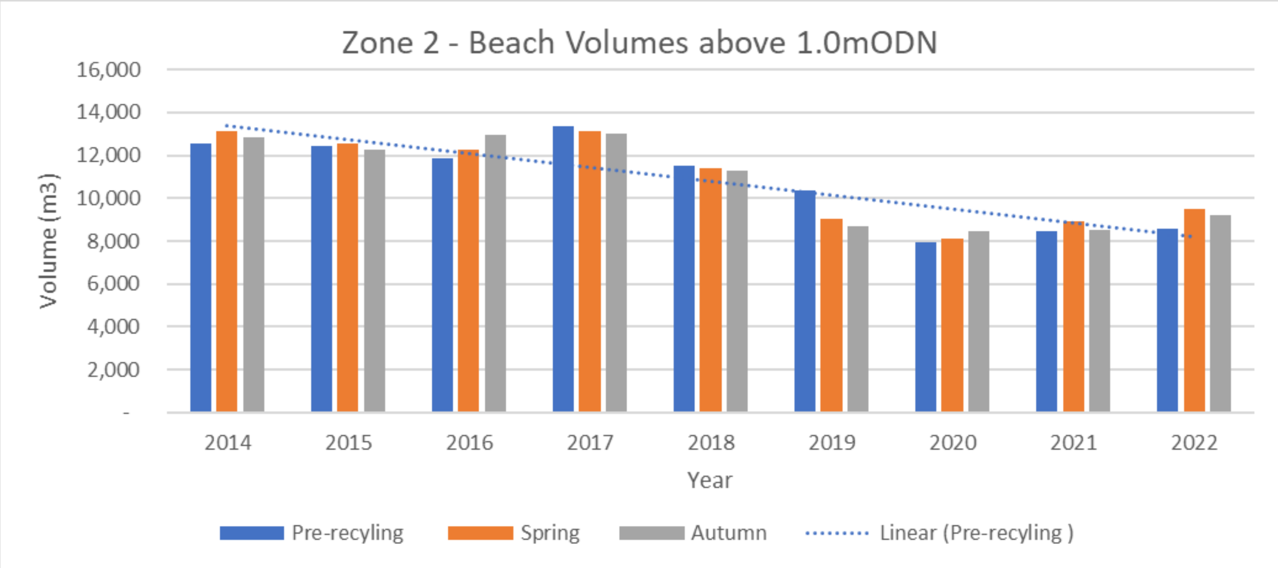
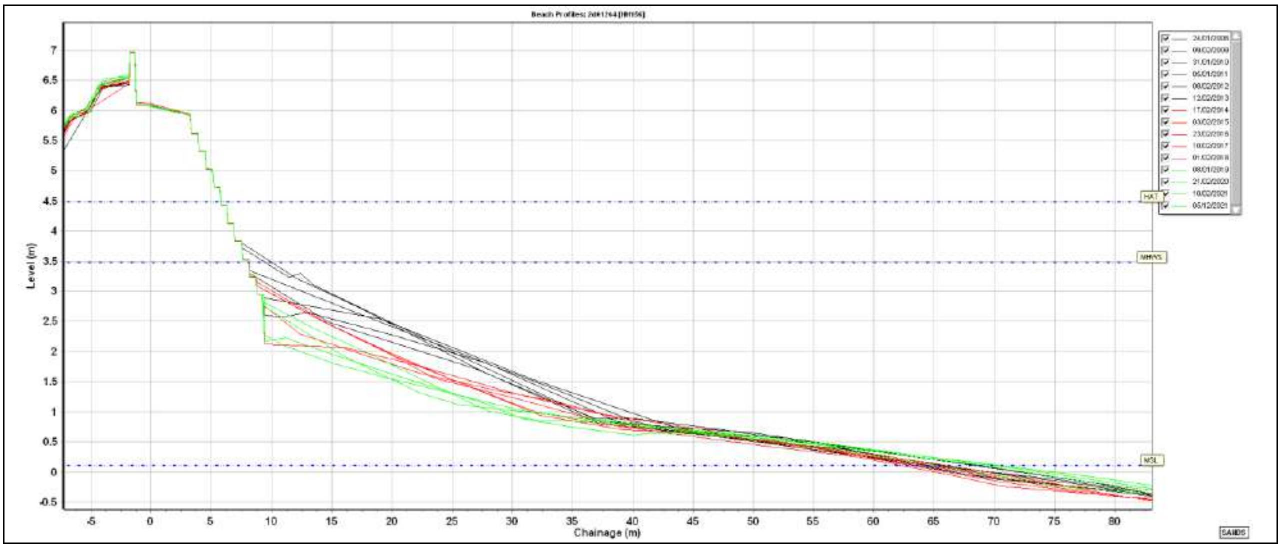
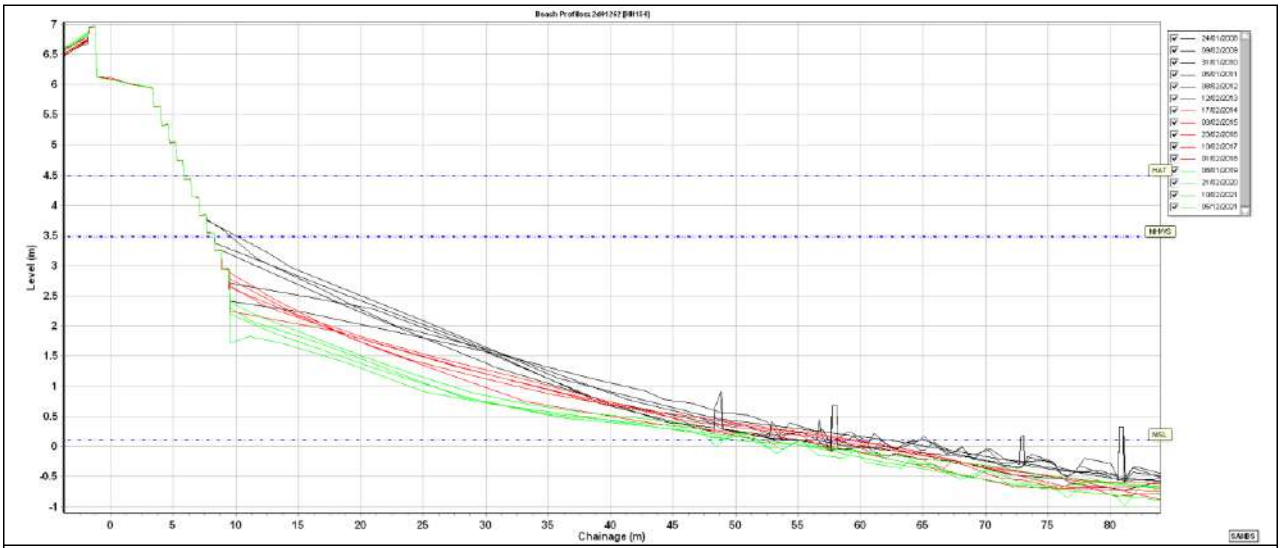


Figure C. 8: Beach volume (m3) above 1.0mODN, calculated for pre-recycling, Spring and Autumn surveys, from 2014 to 2022 in Zone 2



a) Profile 2d01264



b) Profile 2d01262

Figure C. 9: Examples of profile analysis in Zone 2 showing profile change between 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at a) profile 2d01264 and b) 2d01262

Figure C. 10 shows beach volumes above 1.0mOD (in m^3) for Zone 3 and Figure C. 11a and c show a comparison of beach profile changes amongst three time periods: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at two profiles within Zone 3 (2d01260 and 2d01252). Figure C. 11b shows a comparison amongst specific surveys (1998, 2006, 2014 and 2022) along profile 2d01260.

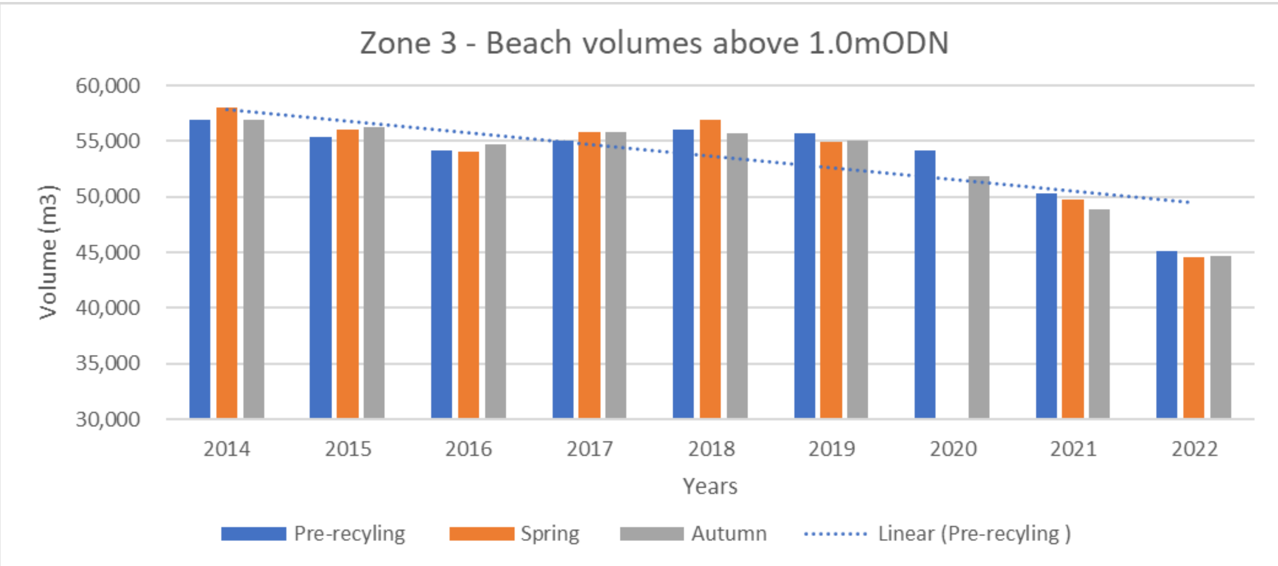
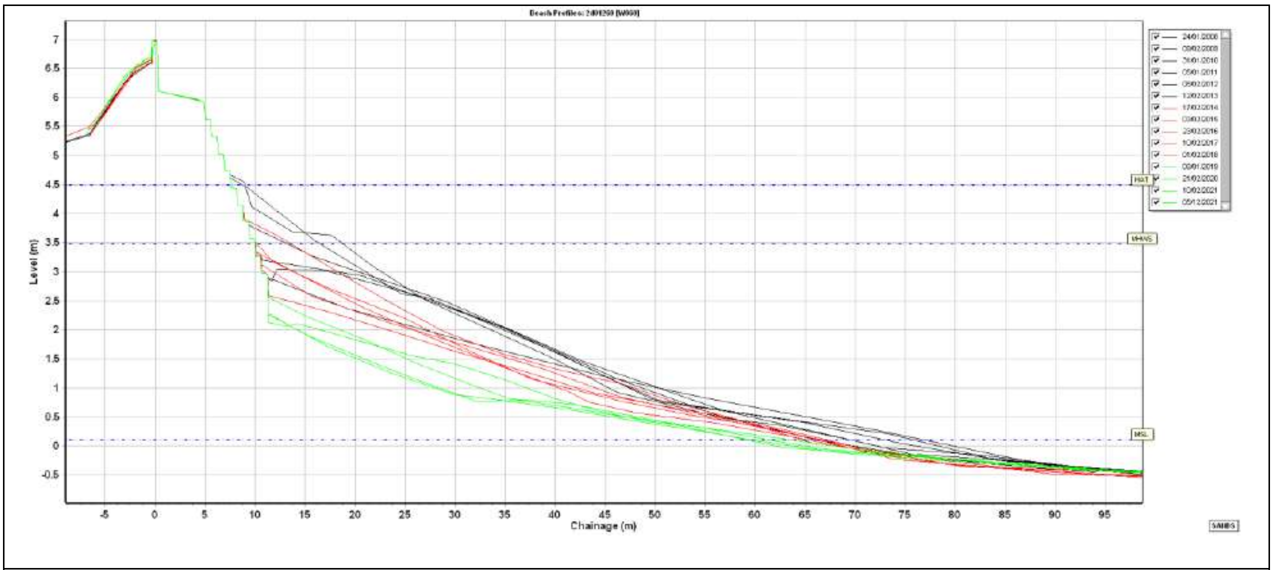
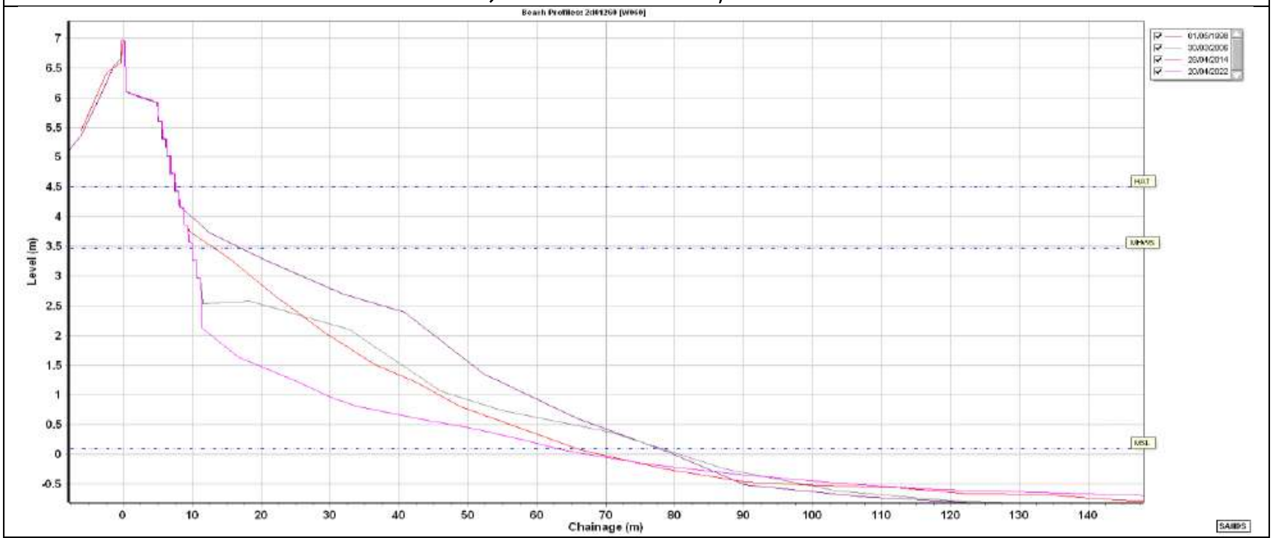


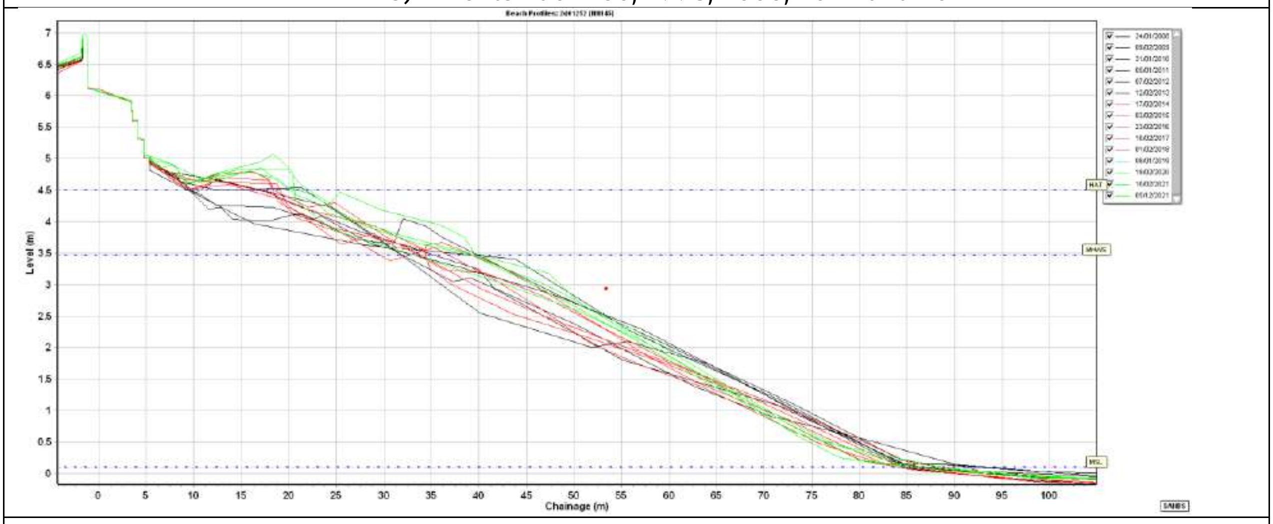
Figure C. 10: Beach volume (m3) above 1.0mODN, calculated for pre-recycling, Spring and Autumn surveys, from 2014 to 2022 in Zone 3



a) Profile 2d01260, 2008 to 2022



b) Profile 2d01260, 1998, 2006, 2014 and 2022



c) Profile 2d01252, 2008 to 2022

Figure C. 11: Examples of profile analysis in Zone 3 showing profile change between 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at a) profile 2d01260 and c) 2d01252. Plot b) shows four specific surveys (1998, 2006, 2014 and 2022) along profile 2d01260

Figure C. 12 shows beach volumes above 1.0mOD (in m^3) for Zone 3 and Figure C. 13a and b show a comparison of beach profile changes amongst three time periods: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at two profiles within Zone 3 (2d01248 and 2d01242). Figure C. 13c shows a comparison amongst specific surveys (1998, 2006, 2014 and 2022) along profile 2d01236.

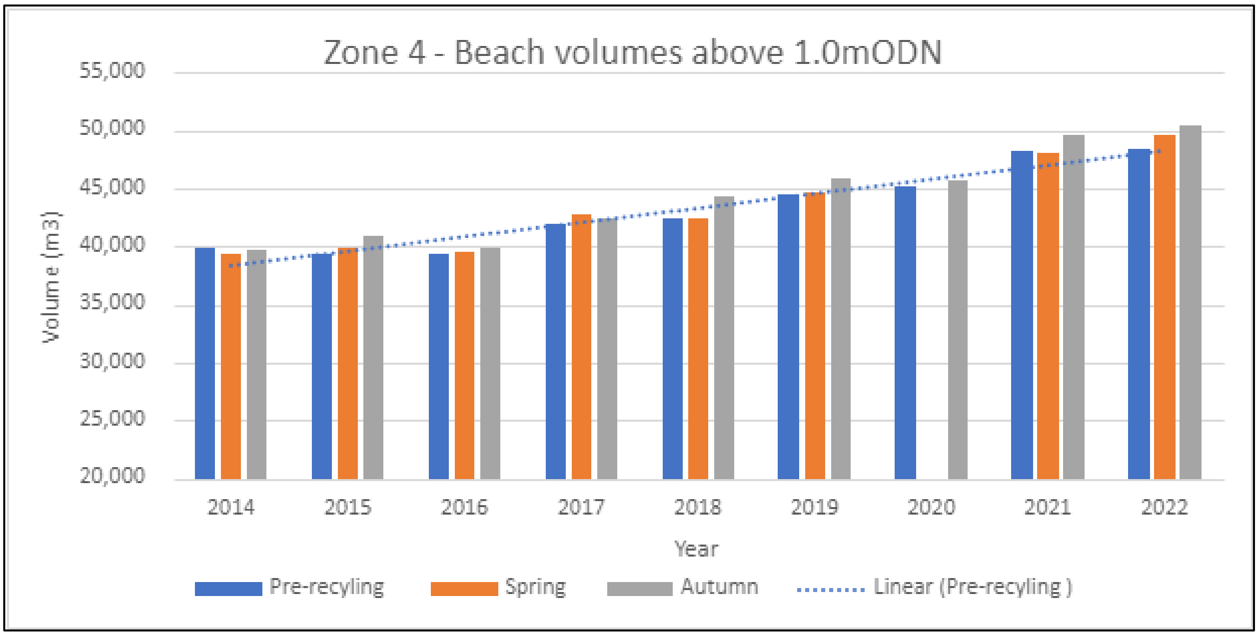
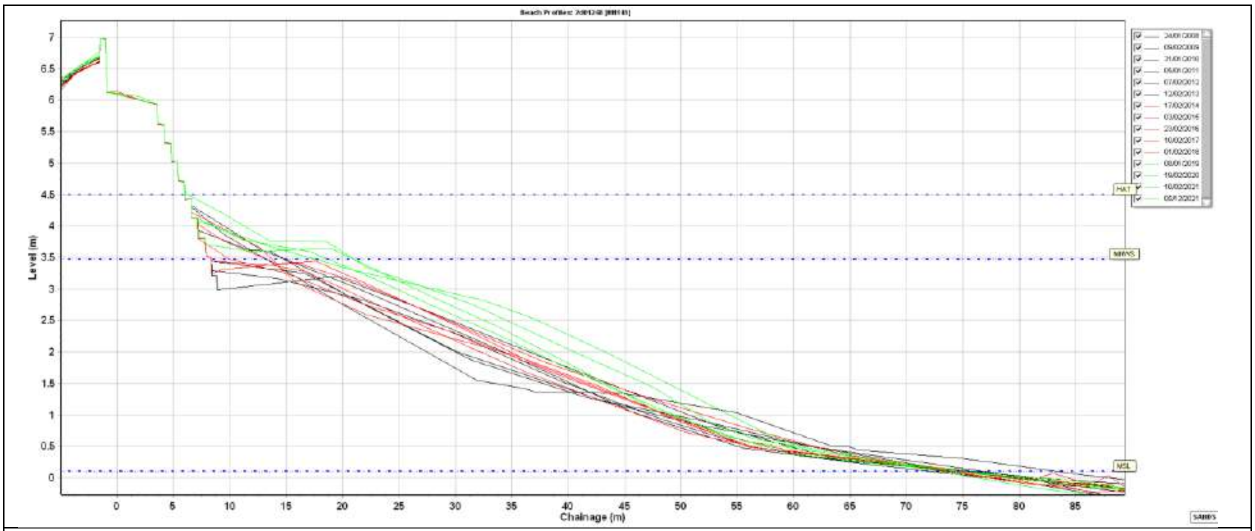
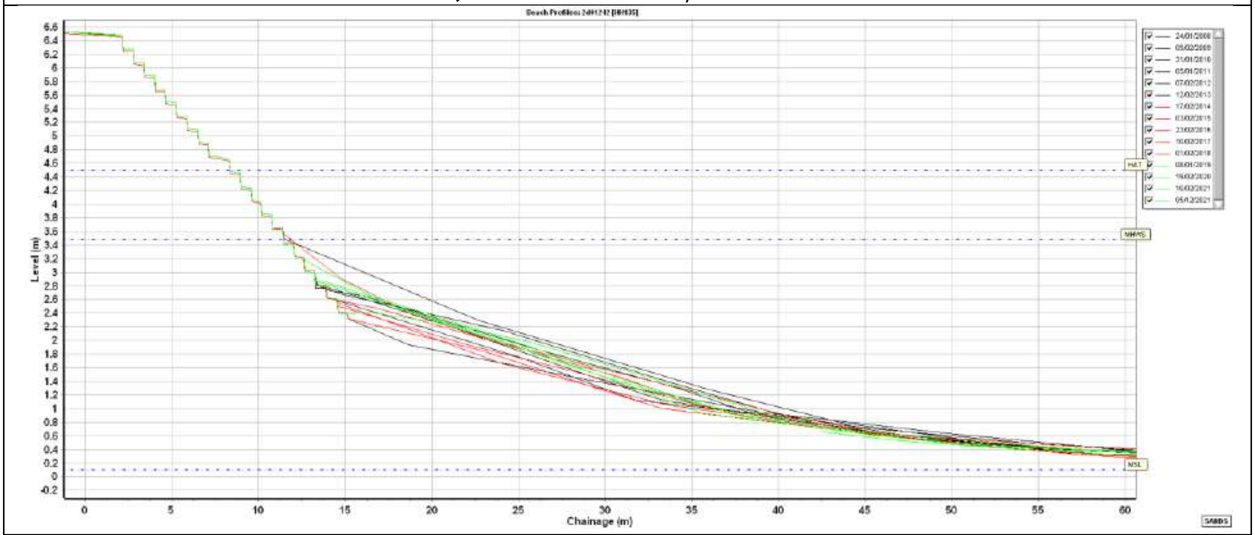


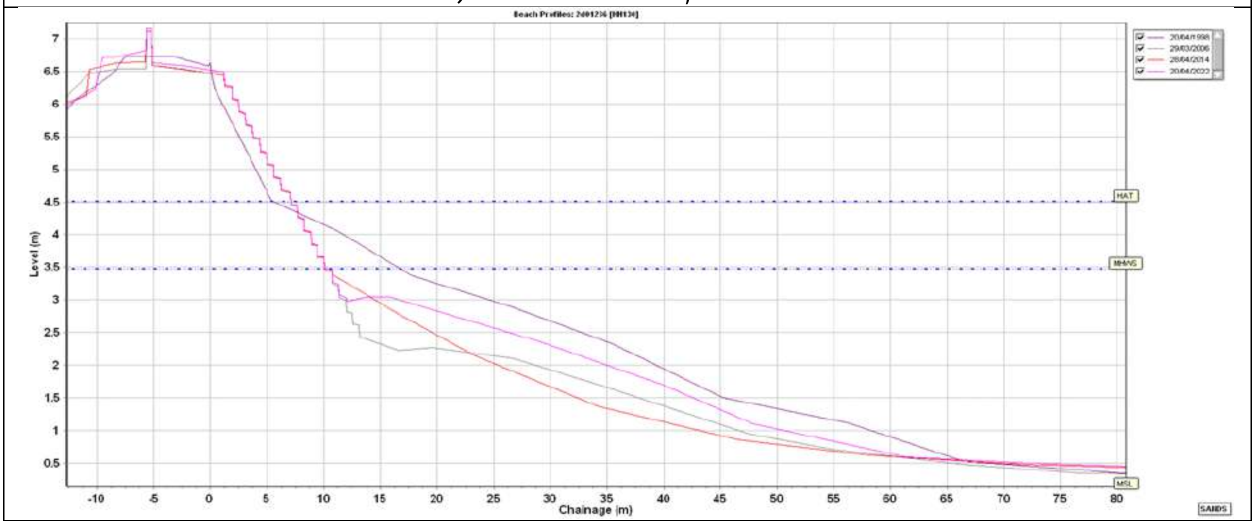
Figure C. 12: Beach volume (m3) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zone 4



a) Profile 2d01248, 2008 to 2022



b) Profile 2d01242, 2008 to 2022



c) Profile 2d01236, 1998, 2006, 2014 and 2022

Figure C. 13: Examples of profile analysis in Zone 4 showing profile change between 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at a) profile 2d01248 and b) 2d01242. Plot c) shows four specific surveys (1998, 2006, 2014, 2022) along profile 2d01236

C.2.2 Zone 5

Zone 5 is the zone with the greatest losses of beach volume observed since 2014 across all zones along the frontage, although the greatest losses seem to have occurred up to 2018 (Figure C. 14), since when volumes appear to have stabilised more. Whilst a loss of sediment has also been observed between 2019 and 2022, this was less significant than the previous period, having occurred mainly around and immediately above HAT (5m recession of HAT between 2019 and 2022 - Figure C. 15).

Evidence from beach profile analysis (Figure C. 16) demonstrates that cliffing seems to have always occurred (evidenced by a comparison between the 1998 and 2022 surveys); the perception of cliffing occurring more often along this frontage (as suggested by anecdotal evidence) may be enhanced due to a higher the dune crest over time (up to 2m higher since 1998). The whole beach profile is becoming steeper over time, with a higher dune crest and a more seaward position of the active beach.

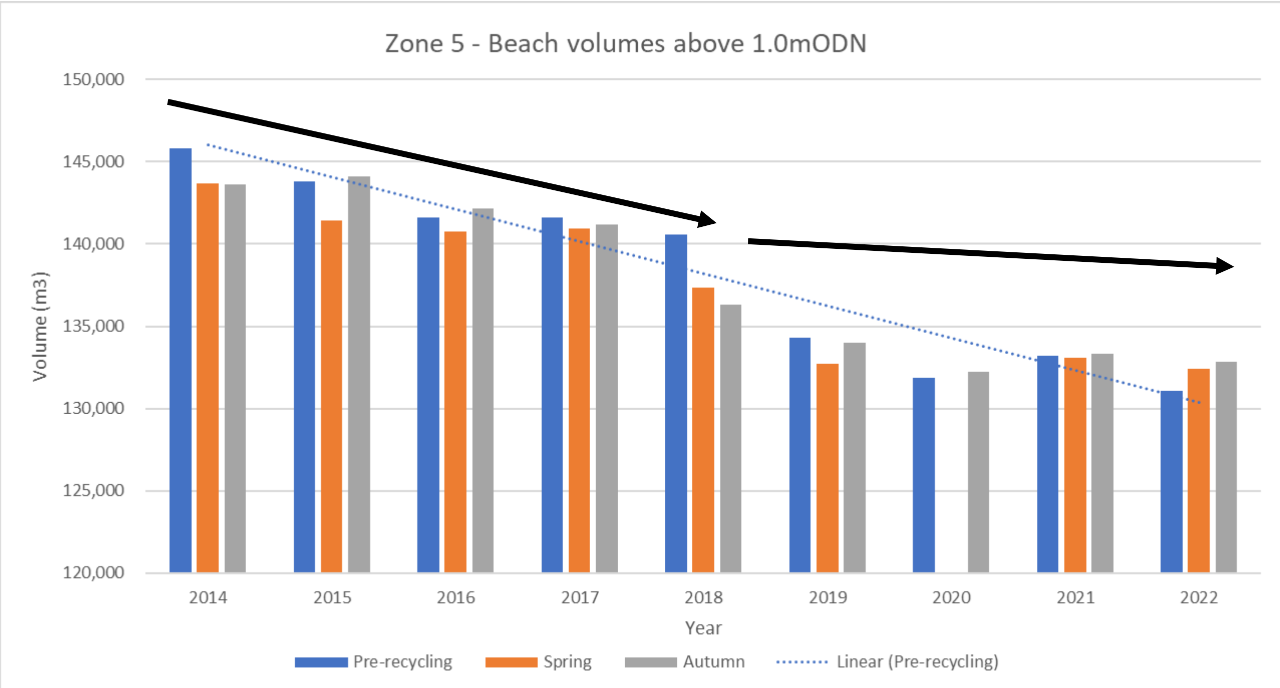
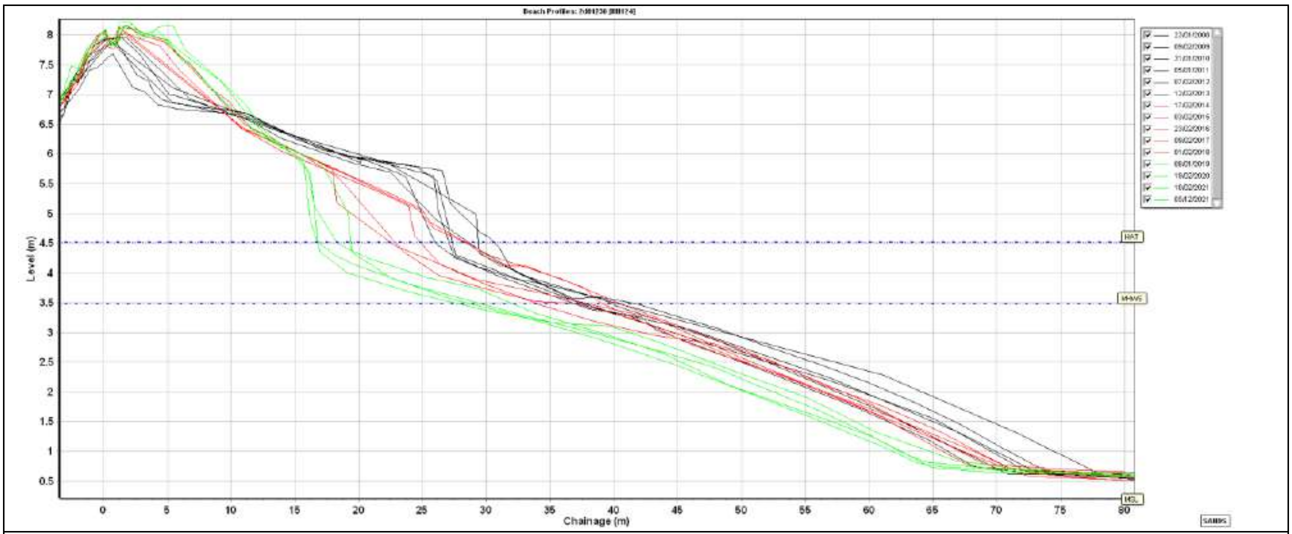
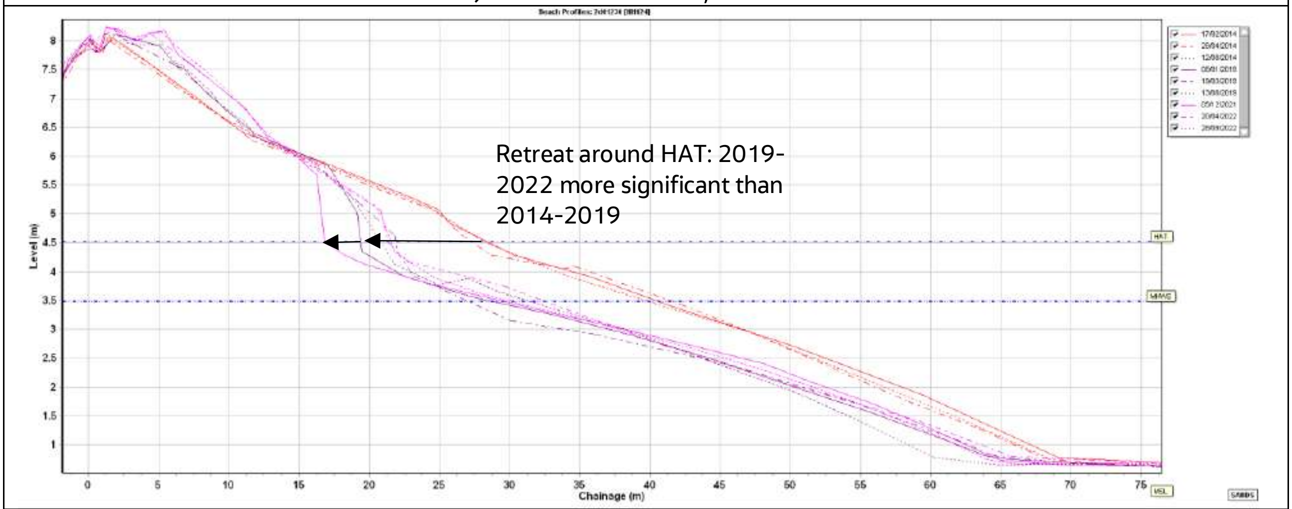


Figure C. 14: Beach volumes (m3) within Zone 5 above 1.0mODN comparing pre-recycling, Spring and Autumn survey campaigns since 2014. The black arrows indicate a greater loss of material up to 2018, with a decrease in erosion rates up to 2022.



a) Profile 2d01230, 2008 to 2022



b) Profile 2d01230, 2014, 2019 and 2022

Figure C. 15: Profile 2d01230 in Zone 5 showing profile change (a) between three timeframes: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) and (b) between four specific surveys (1998, 2006, 2014, 2022).

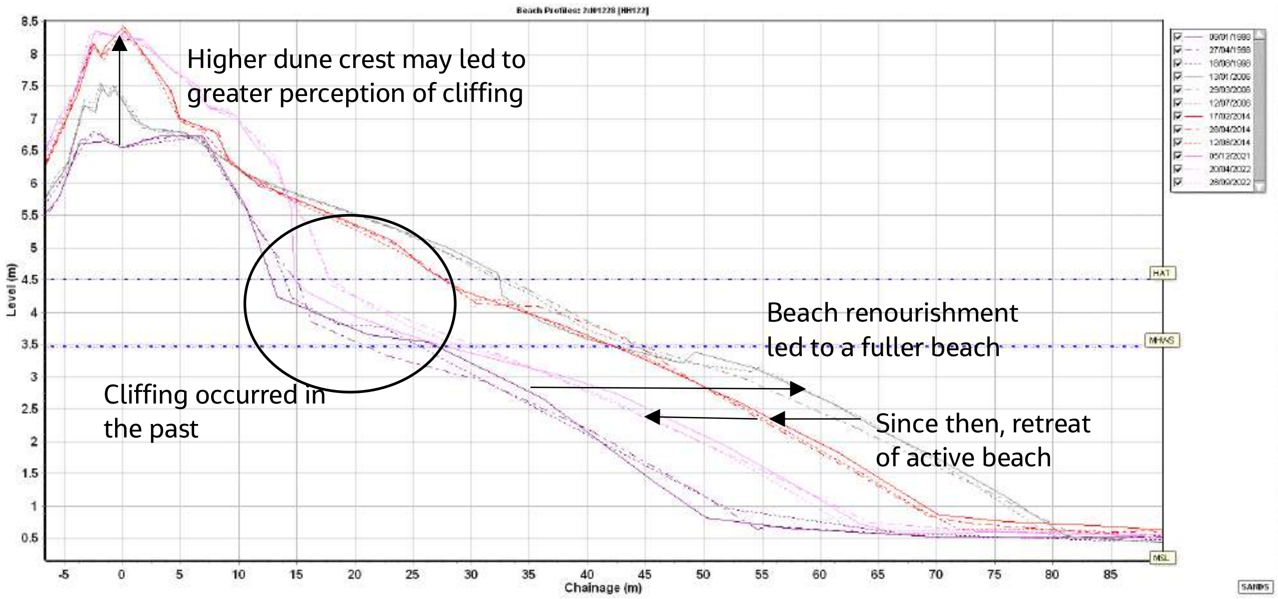


Figure C. 16: Profile 2d01228 within Zone 5. Comparison between pre-recycling, Spring and Autumn surveys for 1998, 2006, 2014 and 2022.

C.2.3 Zones 6 and 7

Within this area, beach volumes have been fluctuating over time (Figure C. 17), which can be partially correlated to the recycling regime in Zone 5. No material was placed in Zone 5 in 2014 and 2015, which could be related to the decrease of overall beach volumes in Zones 6 and 7 up to 2016. A subsequent increase in beach volumes up to 2021 correspond to recycling resuming in Zone 5 and more material being placed both in 2019 and 2020.

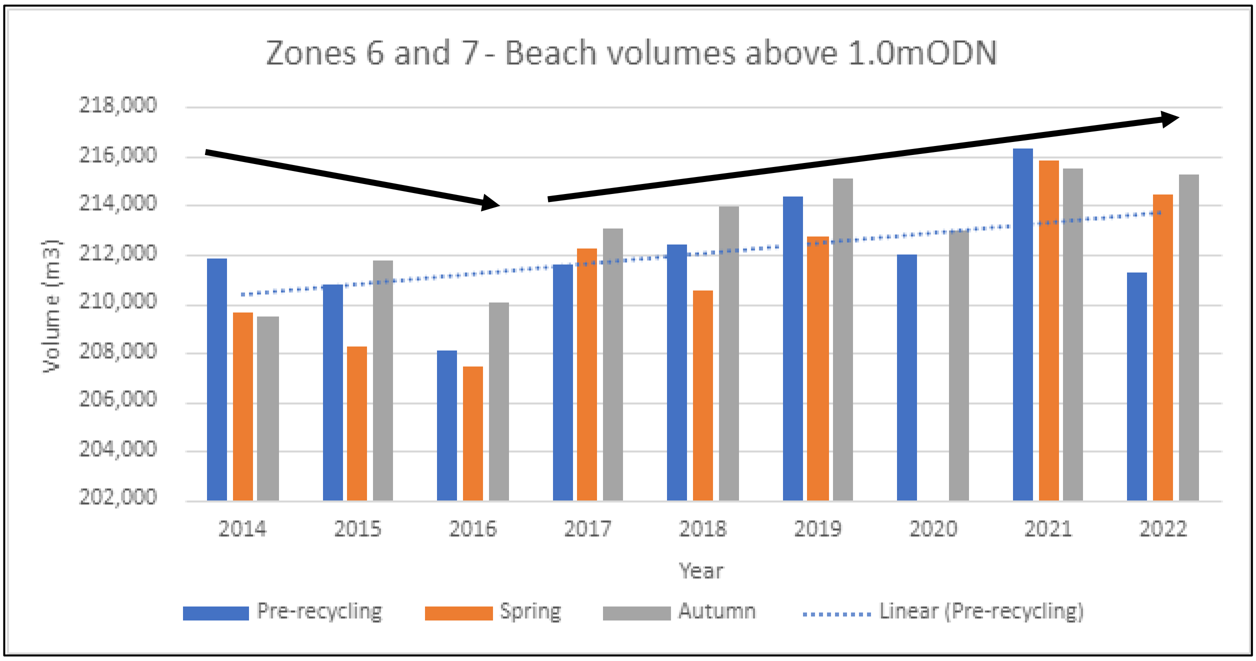
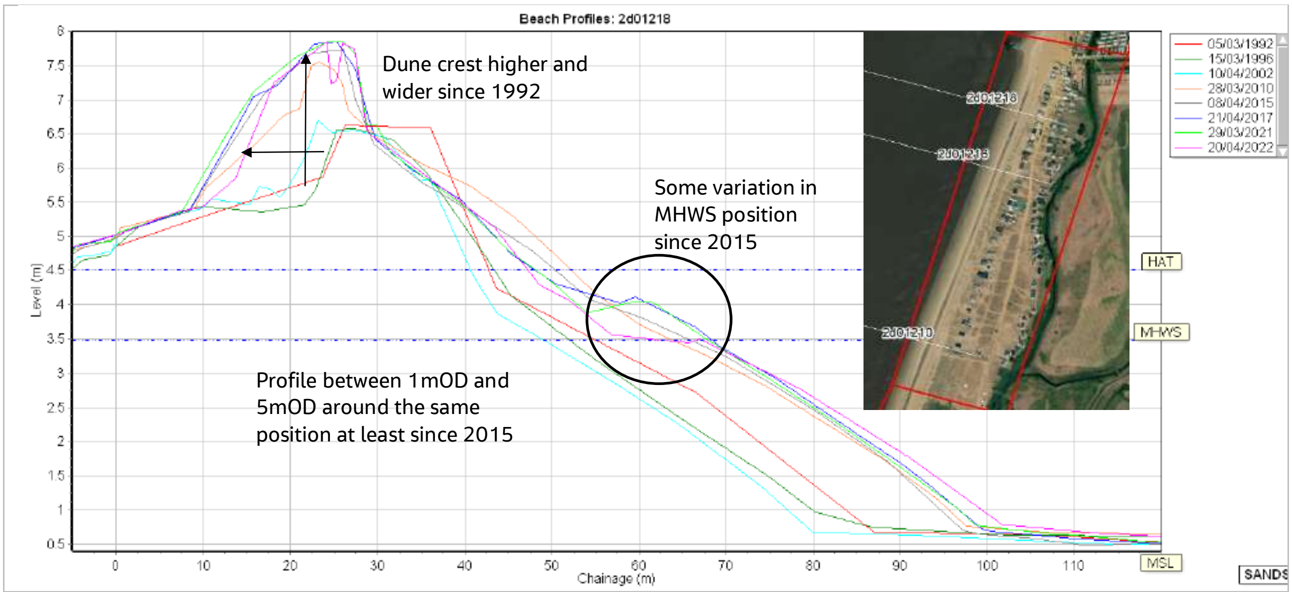


Figure C. 17: Total beach volume (m3) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zones 6 and 7. The black arrows indicate general trends within these zones.

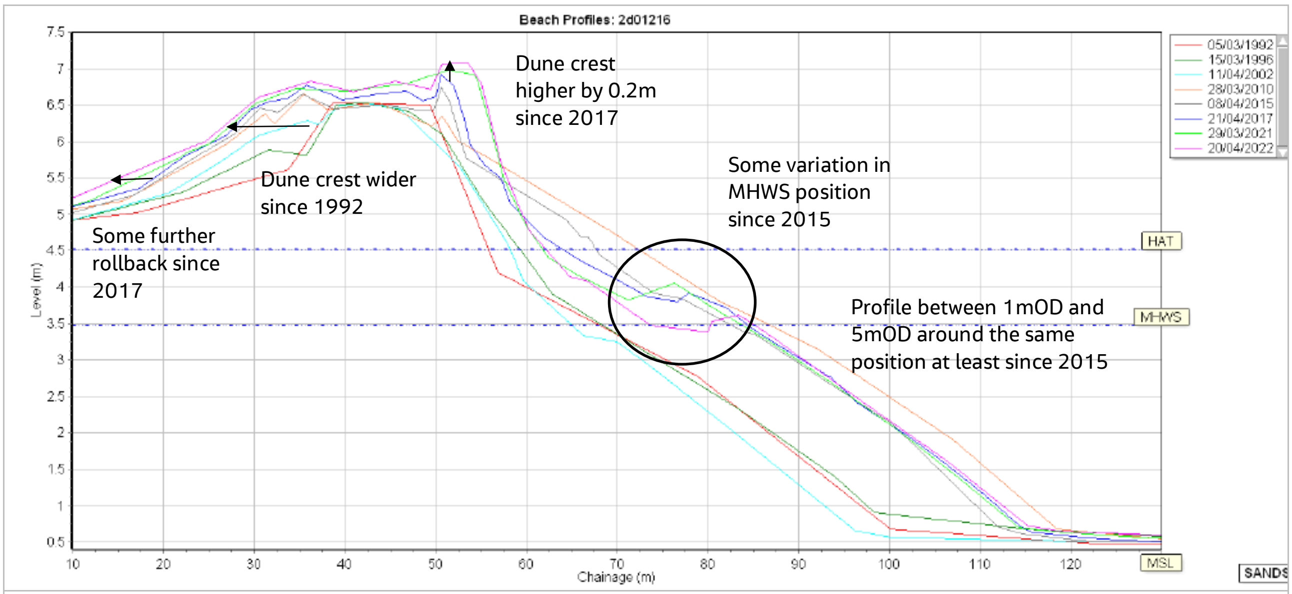
Evidence from beach profiles (Figure C. 18)) showed that beach renourishment in 2005 had a positive effect in making the beaches along the northern section of this area fuller. Between 2014 and 2022, the active beach along Zones 6 and 7 at the northern section between 1mOD and 5mOD (Figure C. 18a and b) has been relatively stable at the same position, with some variation in the position of MHWS throughout the period.. At the southern section of this area, the active beach between 1mOD and MHWS showed a year-on-year seaward movement (Figure C. 18c), with a similar pattern of variation in MHWS position and a more stable upper beach around HAT.

In addition to general changes along the beach described above, the dunes located at the back of this beach has shown signs of accretion and roll back. Anecdotal evidence from local residents stated that this issue has started after the last beach renourishment campaign in 2005. However, evidence from beach profiles (2d01218, 2d01216 and 2d01210 – Figure C. 18a, b and c, respectively) showed that the position of the dune crest seems to be stable since 2001, increasing in height by around 1.5m between 2001 and 2022. Accumulation of sediment both at the back and at the front of the main dune ridge has been ongoing since at least 1992 when records began, with an increase in dune ridge width of around 10m. Whilst evidence from beach profile analysis does show a spike in accumulation and rollback after the last beach renourishment in 2005, this process of dune rollback is likely to have natural causes and likely to have started much earlier, at least since 1992.

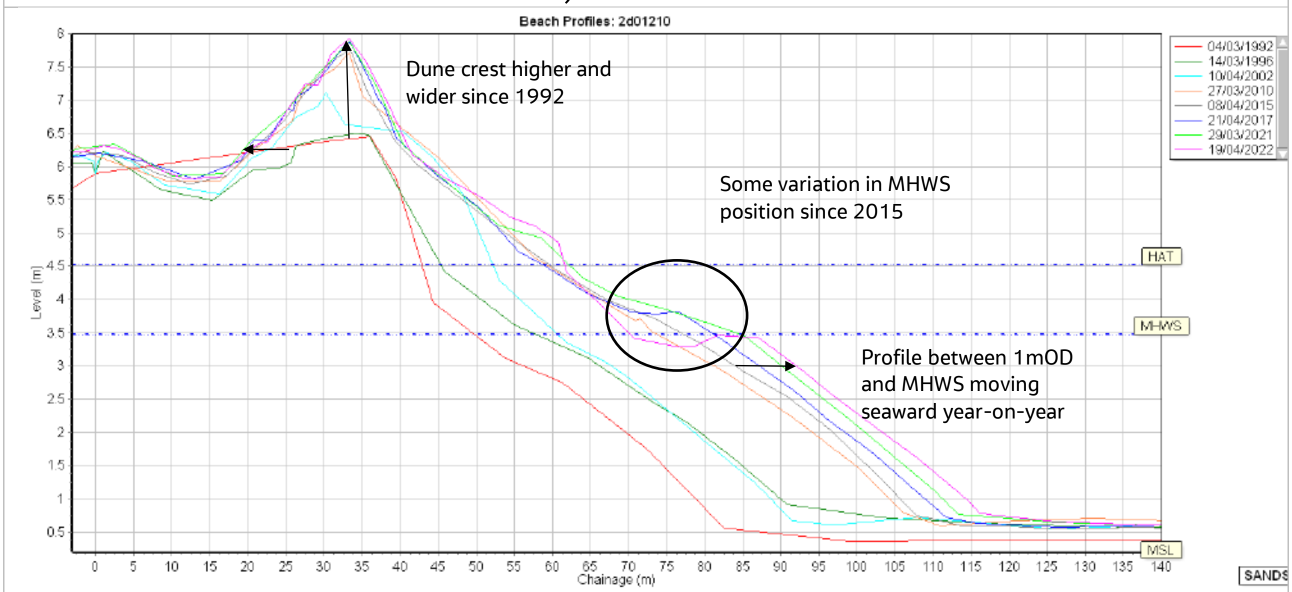
More specifically since 2019, dune crest height and rollback has shown very little change compared to the period between 2015-2018 along most of Zones 6 and 7. The exception to this is at the central area of this zone around profile 2d01216 (Figure C. 18b): here since 2019 dune crest has increased around 0.2m and some further accumulation of material at the back of the dunes, which could partially explain the current issue with wind-blown sand into the seaside properties.



a) Profile 2d01218



b) Profile 2d01216



c) Profile 2d01210

Figure C. 18: Beach profiles a) 2d01218, b) 2d01216, and c) 2d01210 along Zones 6 and 7

C.2.4 Zone 8a

Within Zones 8a, beach recycling activities do not take place. Analysis in Zone 8a (Figure C. 19) showed that, since 2014, beach volumes have increased by around 15,000m^3. Given the recycling almost all takes place at the southern extremity (8b), this accumulation of material in Zone 8a could suggest either some northerly drift of placed material or some natural accumulation of material fed by natural drift from the north.

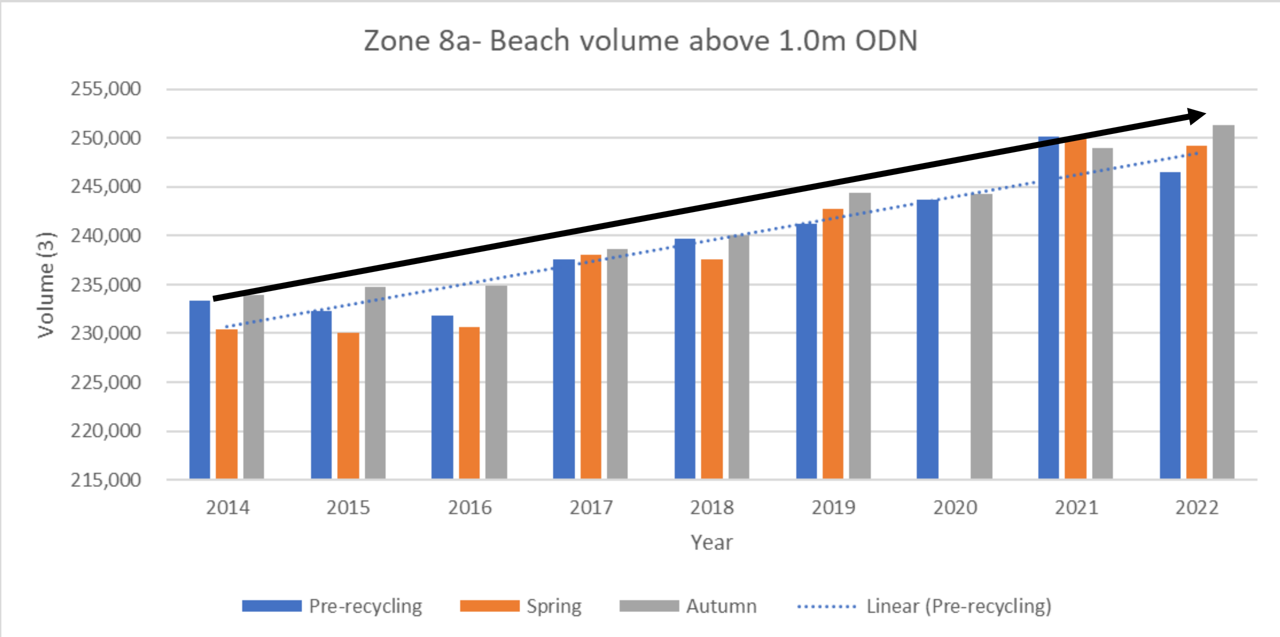
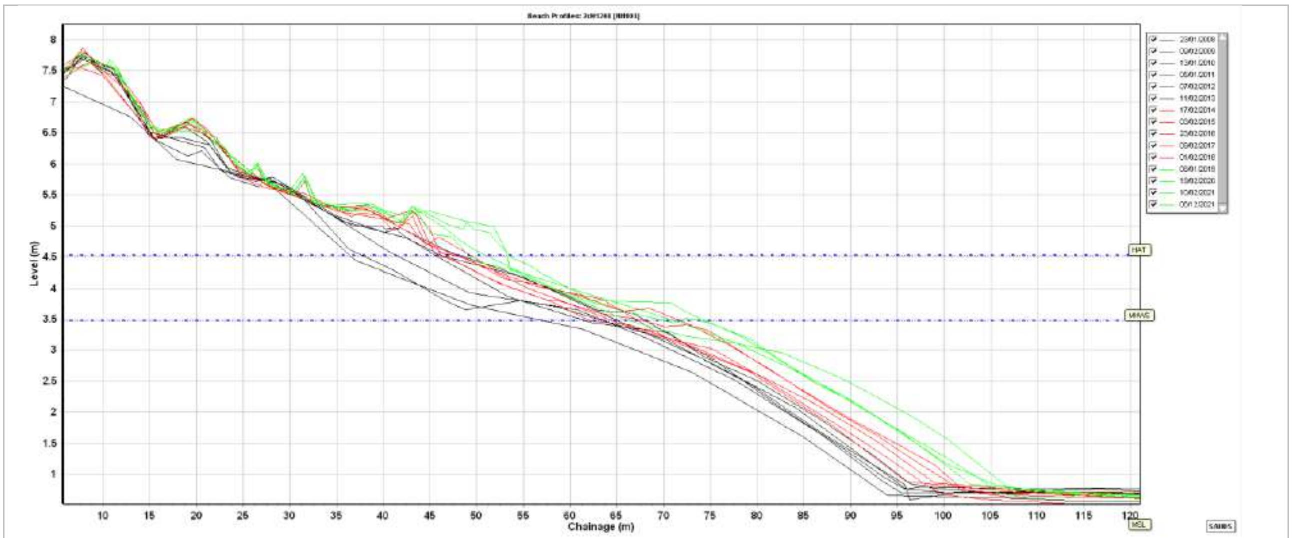
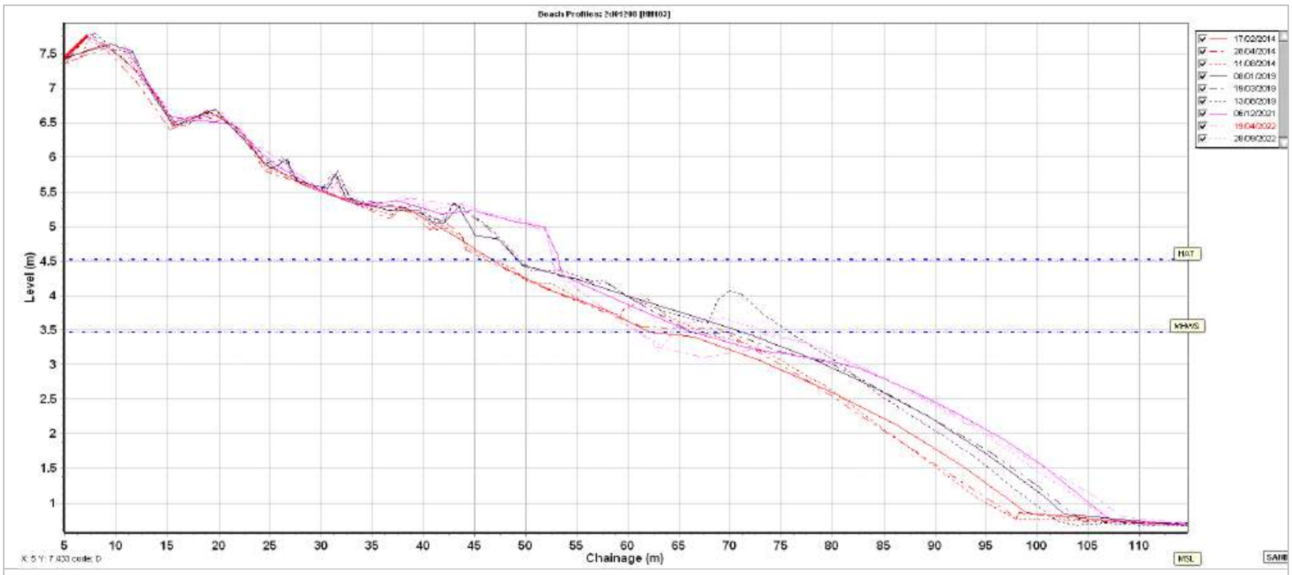


Figure C. 19: Total beach volumes (m3) for Zone 8a, considering pre-recycling, Spring and Autumn surveys

Figure C. 20 shows profile 2d01208 at Zone 8a; Figure C. 20a shows a comparison of beach profile changes amongst three time periods: 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) whilst Figure C. 20b shows a comparison between pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.



a) Profile 2d01208, 2008 to 2022



b) Profile 2d01208, 2014, 2019 and 2022

Figure C. 20: Profile analysis in Zone 8a, profile 2d01208, showing profile change between a) 2008-2013, 2014-2018 and 2019-2022, and b) between the pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.

C.2.5 Zone 9 (including Zones 8b and 10a)

Although Zones 8 to 10 extend over 2.5km, the majority of recycling occurs in the vicinity of Heacham Dam (located mostly in Zone 9). Evidence from beach profile analysis does confirm this understanding, with recycled material placed between within approx. 250m of the southern section of Zone 8 (see Figure C. 22 for example of beach profile within this area)and approx. 280m of the northern section of Zone 10 (see Figure C. 24 for example of beach profile within this area).

The effect of beach recycling is clearly observed with Spring volumes higher than pre-recycling volumes (Figure C. 21). A drop from Spring to Autumn indicates that the material continues to move from here throughout the year. In addition, a gradual increase in beach volumes along this frontage, at least since 2016, suggests that beach recycling is likely to have a positive effect in maintaining, and indeed increasing, beach volumes over time. Since 2019, therefore, the beach along the recycled area seems to be accumulating material, albeit mostly below Mean High Water Spring (MHWS).

Similarly to Zone 5, cliffing was observed both pre and post 2019; however, this might be accentuated here because the beach recycling material is placed much higher on the edges of the Dam than the surrounding natural dunes, which then leads to higher cliffing in this zone, of around up to 3m in places.

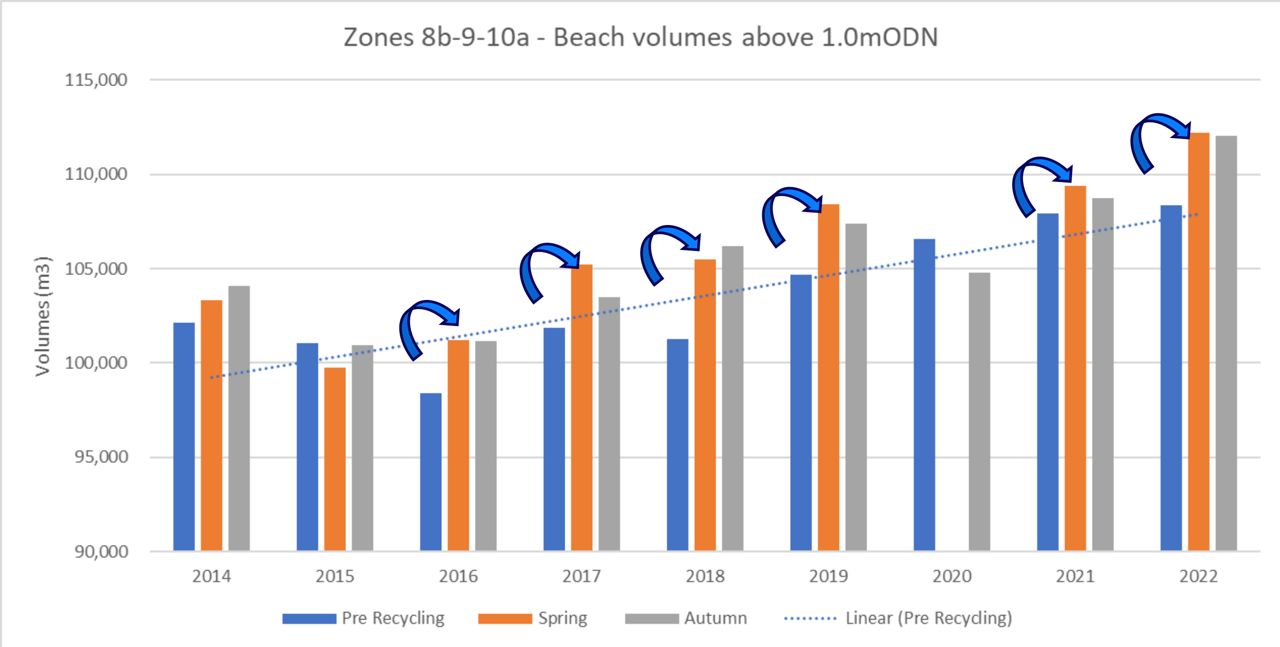
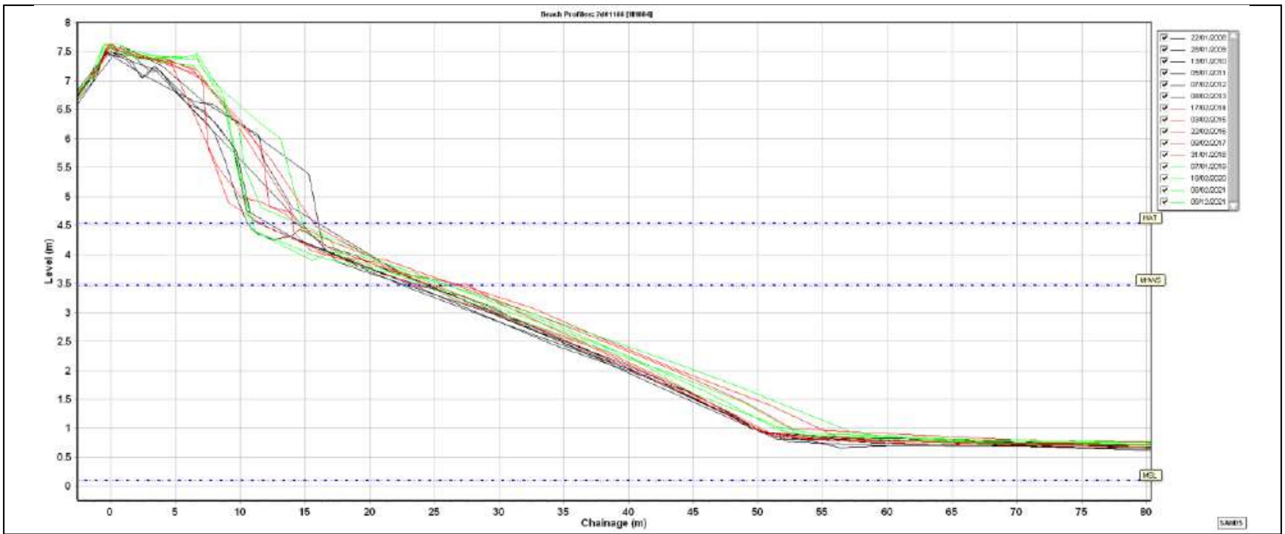
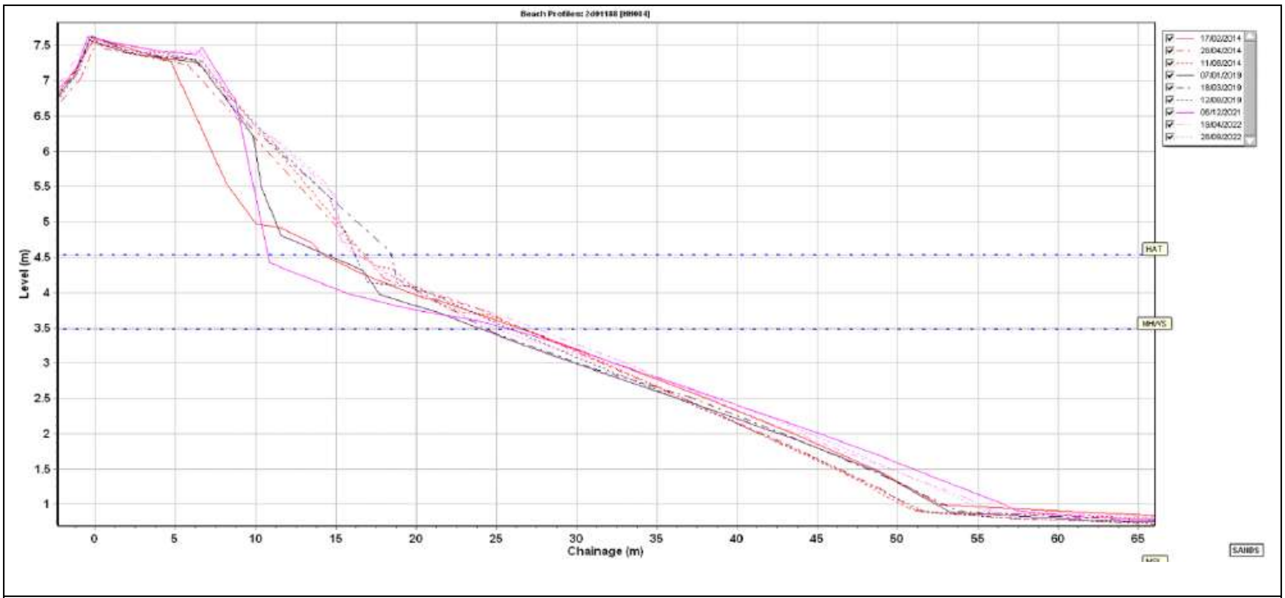


Figure C. 21: Total beach volumes (above 1mODN) for Zones 8b, 9 and 10a combined, considering pre-recycling, Spring and Autumn surveys. The arrows indicate the increase in beach volume following beach recycling

Figure C. 22 shows examples of beach profile analysis undertaken at Zone 8b (profile 2d01188); Figure C. 23 shows an example of profile in Zone 9 (profile 2d01186) and Figure C. 24 shows examples of profile analysis undertaken at Zone 10a (2d01178).



a) Profile 2d01188, 2008 to 2022



b) Profile 2d01188, 2014, 2019 and 2022

Figure C. 22: Profile analysis in Zone 8b, profile 2d01188, showing profile change between a) 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line), and b) between the pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.

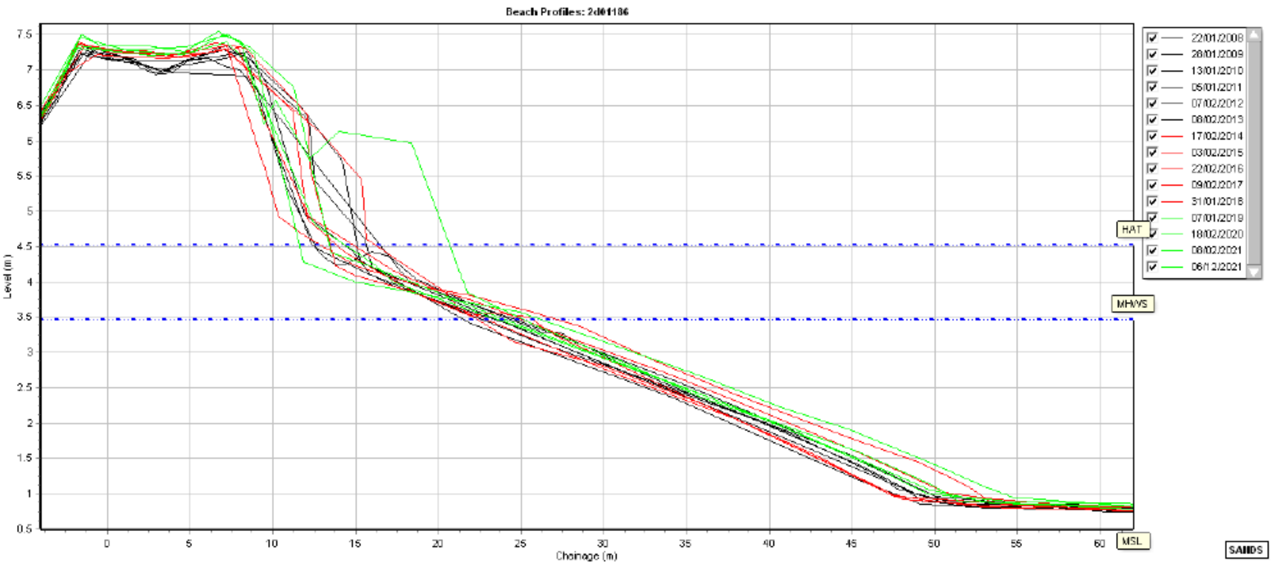
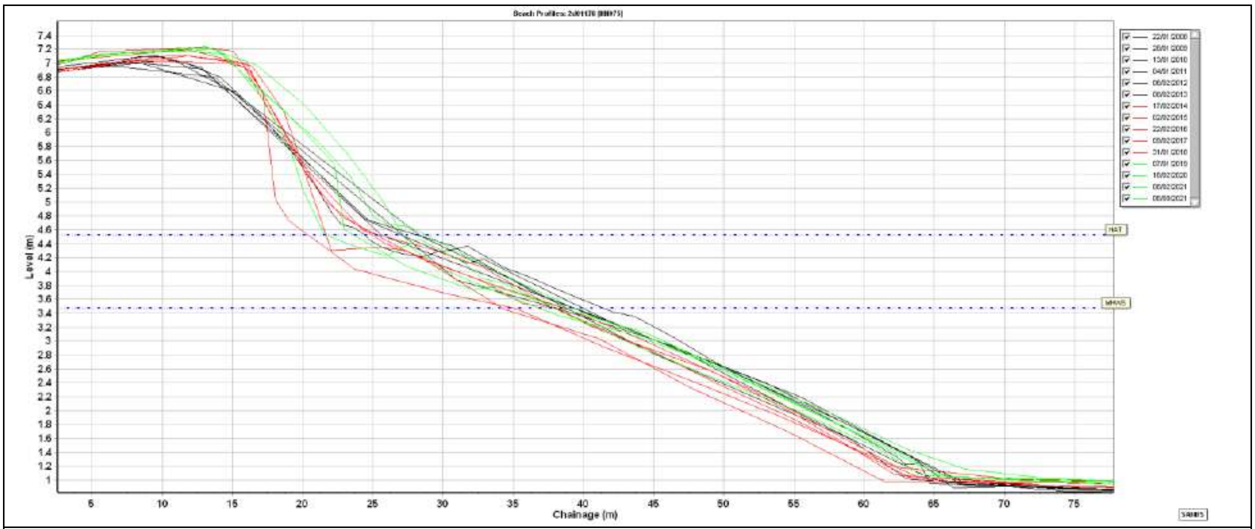
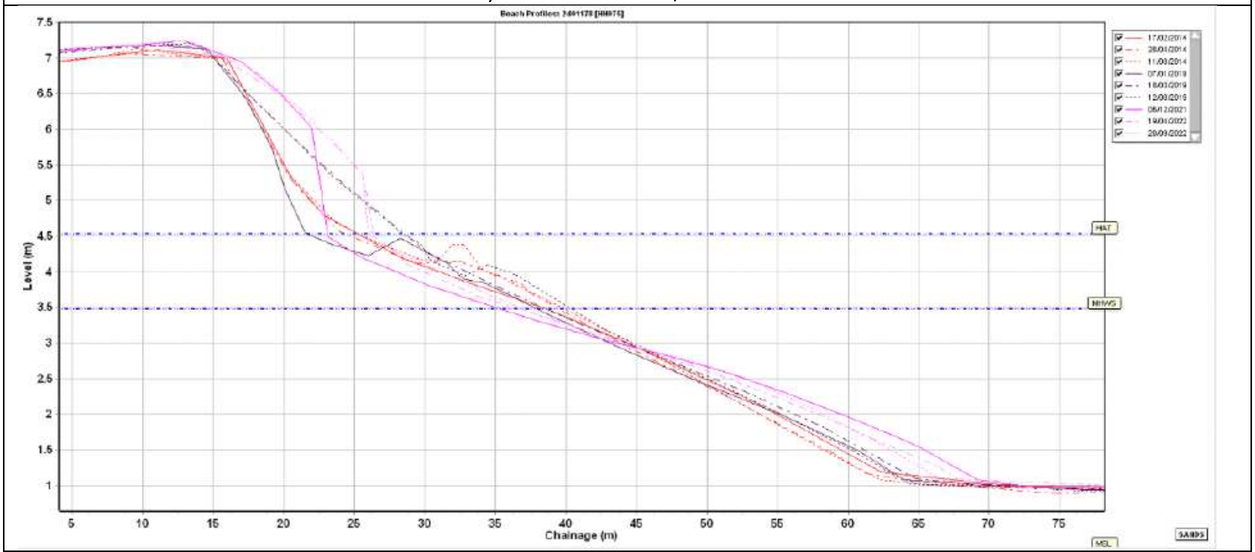


Figure C. 23: Profile 2d01186 within Zone 9. Black lines represent the general position of beach profiles between 2008 and 2013; red lines between 2014 and 2018, and green lines between 2019 and 2021 (Dec 2021 represents the pre-recycling survey of 2022).



a) Profile 2d01178, 2008 to 2022



b) Profile 2d01178, 2014, 2019 and 2022

Figure C. 24: Profile analysis in Zone 10a, profile 2d01178, showing profile change between a) 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line), and b) between the pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.

C.2.6 Zone 10b

Similarly to Zone 8a, beach recycling activities do not take place in Zone 10b. In contrast to Zone 8a, there is very little change in beach volume over time in Zone 10b, south of the recycling area (Figure C. 25).

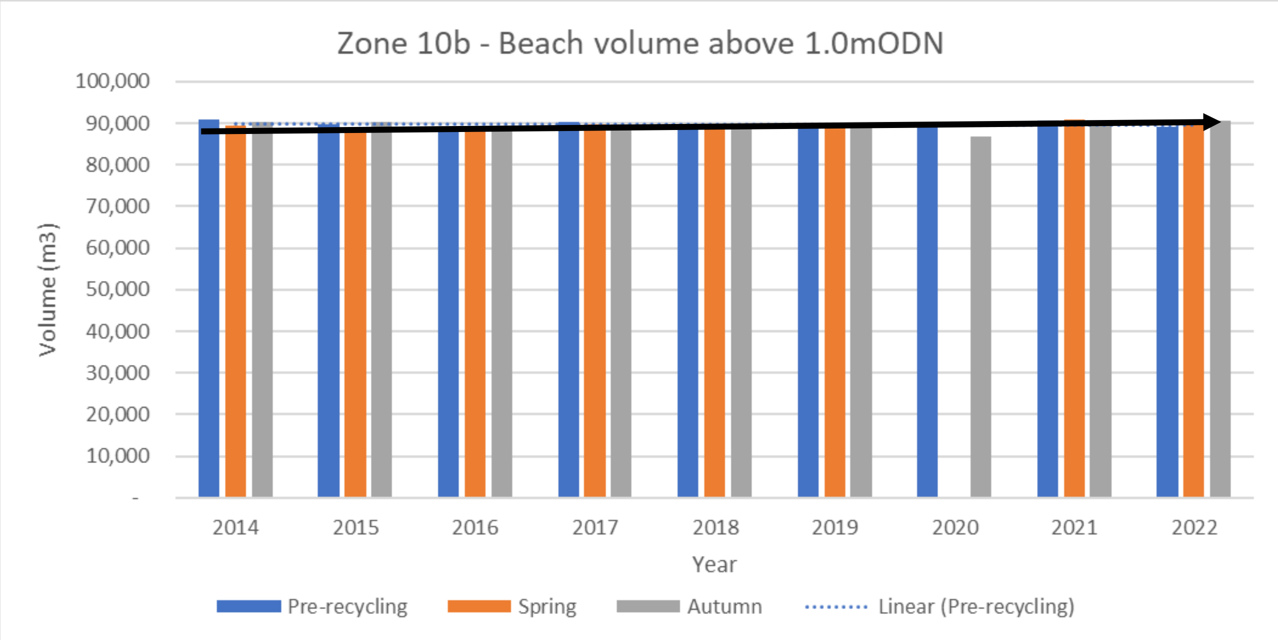
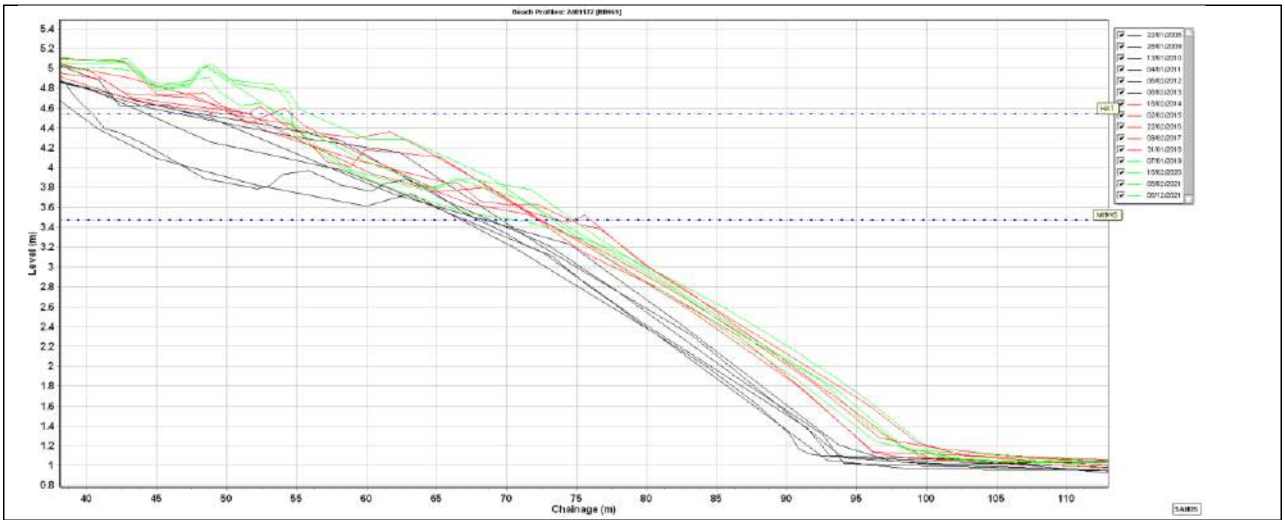
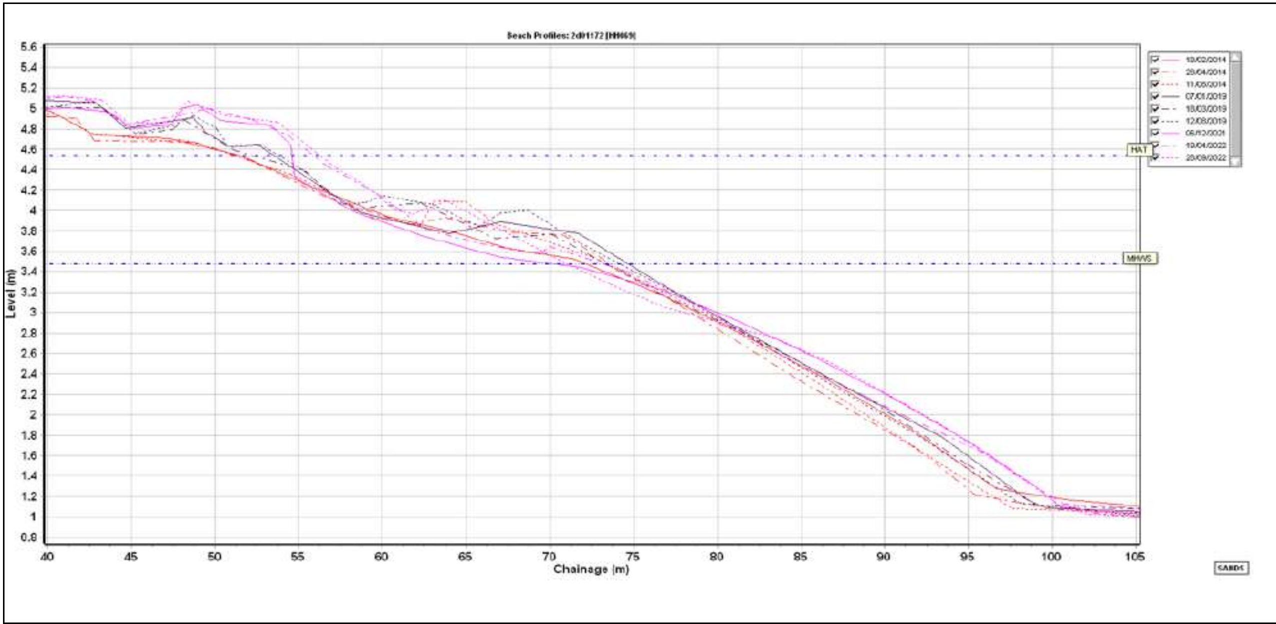


Figure C. 25: Total Beach volume (m3) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zone 10



a) Profile 2d01172, 2008 to 2022



b) Profile 2d01172, 2014, 2019 and 2022

Figure C. 26: Profile analysis in Zone 10b, profile 2d01172, showing profile change between a) 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line), and b) between the pre-recycling, Spring and Autumn surveys in 2014, 2019 and 2022.

C.2.7 Zone 11

A steady year-on-year reduction in beach volumes seemed to have occurred at least since 2014, but similarly to Zone 5, the trends of decrease were steeper up to 2018. Since 2019, beach volumes seem to be generally stable (Figure C. 27). Evidence from beach profiles (Figure C. 28) showed that, in general, the active beach between 1m and 5mOD has retreated at least 5m between 2014 and 2019, but with minimal change since. The upper beach around and above HAT, however, is the area that has showed most changes since 2019.

Whilst the crest of the dune ridge has been the same height since 2014, the dune face around 6mOD showed a seaward movement of around 3m since 2019, leading to a steeper and higher cliff (of around 1.5m in Dec 2021). It is important to note, however, that cliffing did occur between 2015-2018: surveys between 2015-2018 (red lines in Figure C. 28b) showed cliffing occurring pre-2019.

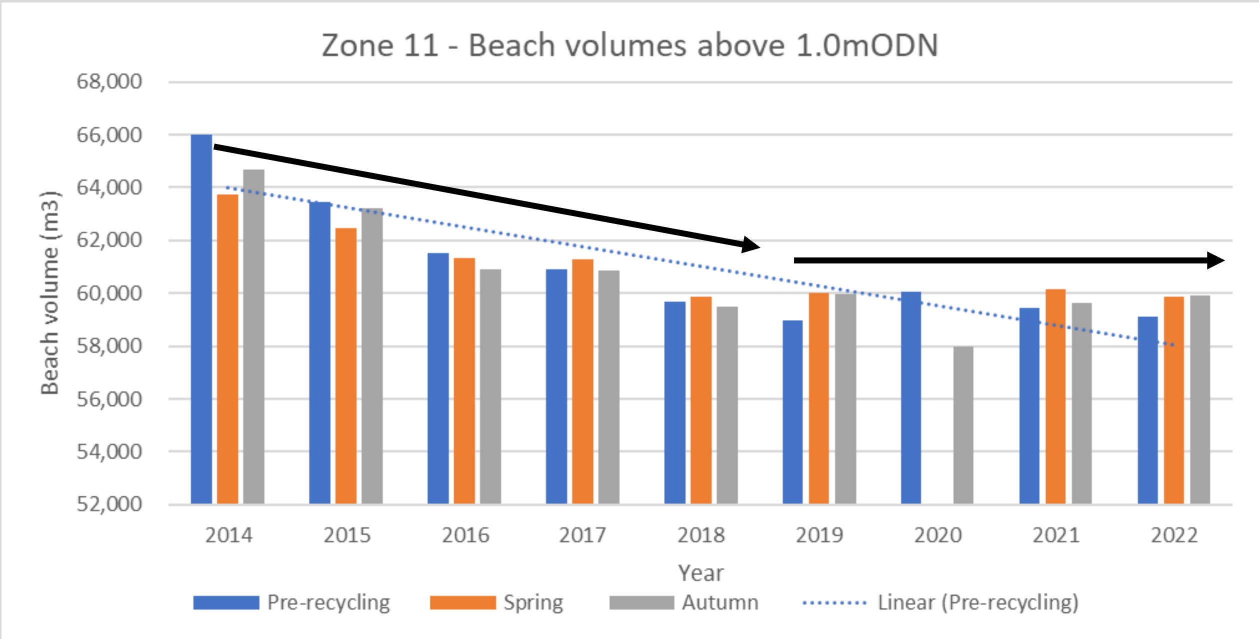
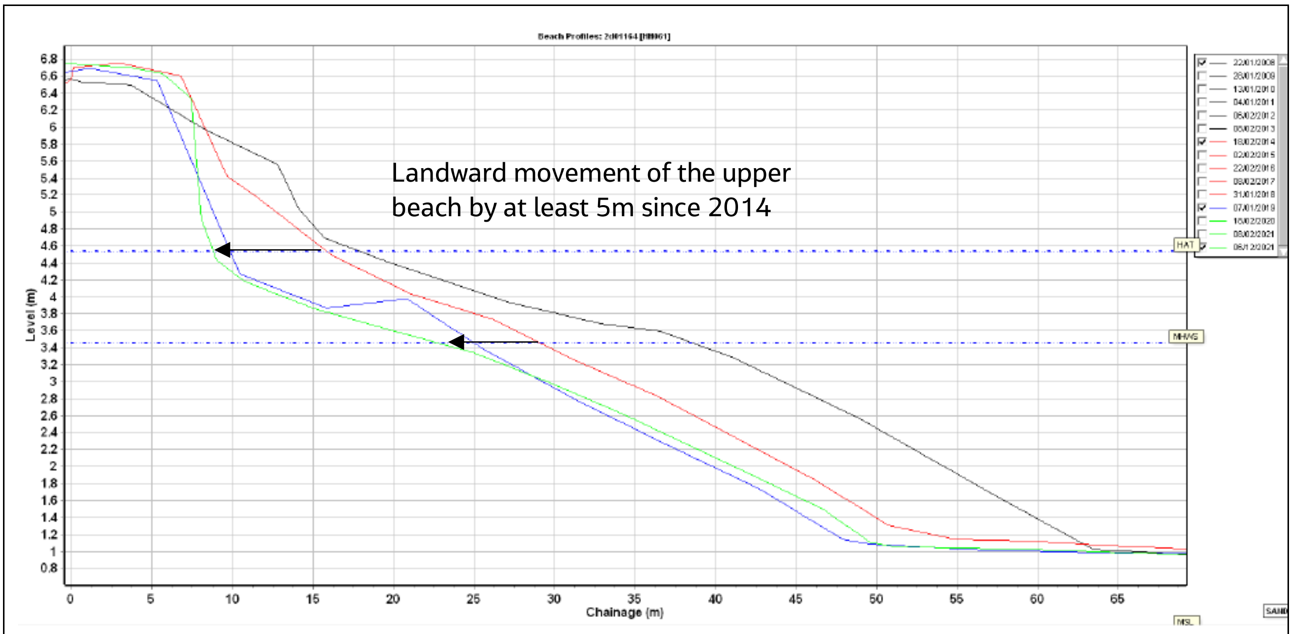
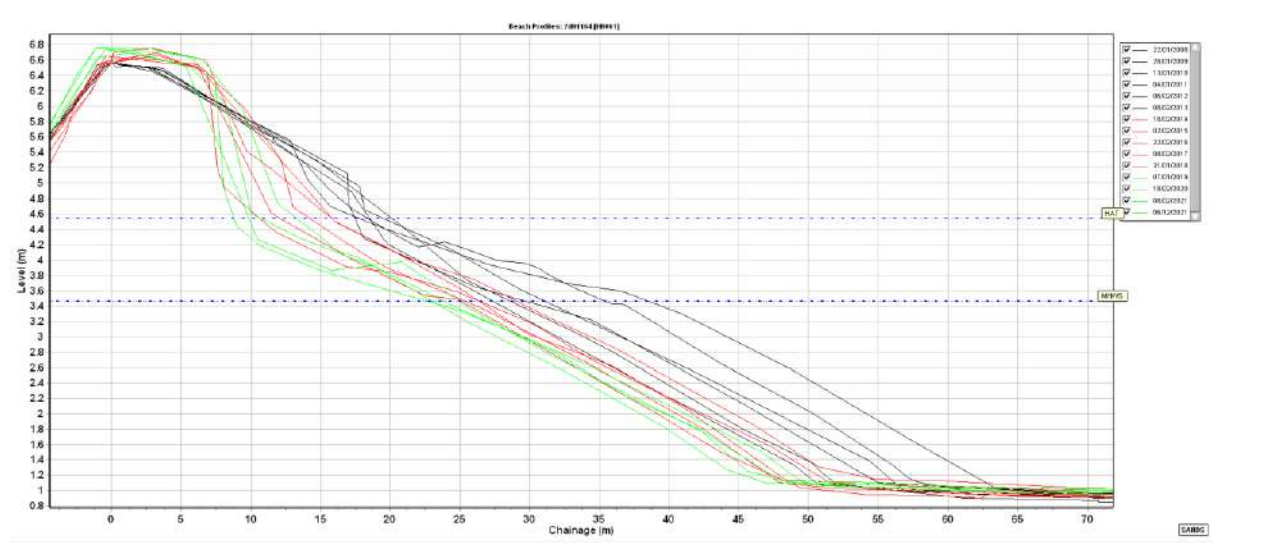


Figure C. 27: Total beach volume (m3) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zone 11. The black arrows indicate a greater loss of material up to 2018, with a stabilisation up to 2022.



a) Profile 2d01164, showing pre-recycling surveys in 2008, 2014, 2019 and 2022 (Dec 2021 was the pre-recycling survey for 2022)



b) 2d01164: 2008 to 2022

Figure C. 28: Profile 2d01164 within Zone 11 a) showing pre-recycling surveys in 2008, 2014, 2019 and 2022; and b) showing profile change between 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line)

C.2.8 Zone 12

Similarly to Zone 8a, Zone 12 showed an general trend of sediment accumulation since 2014 (Figure C. 29). Evidence from beach profiles (Figure C. 30) showed that most of this occurred within the active beach between 1mOD and HAT, with a seaward movement of around 15m.

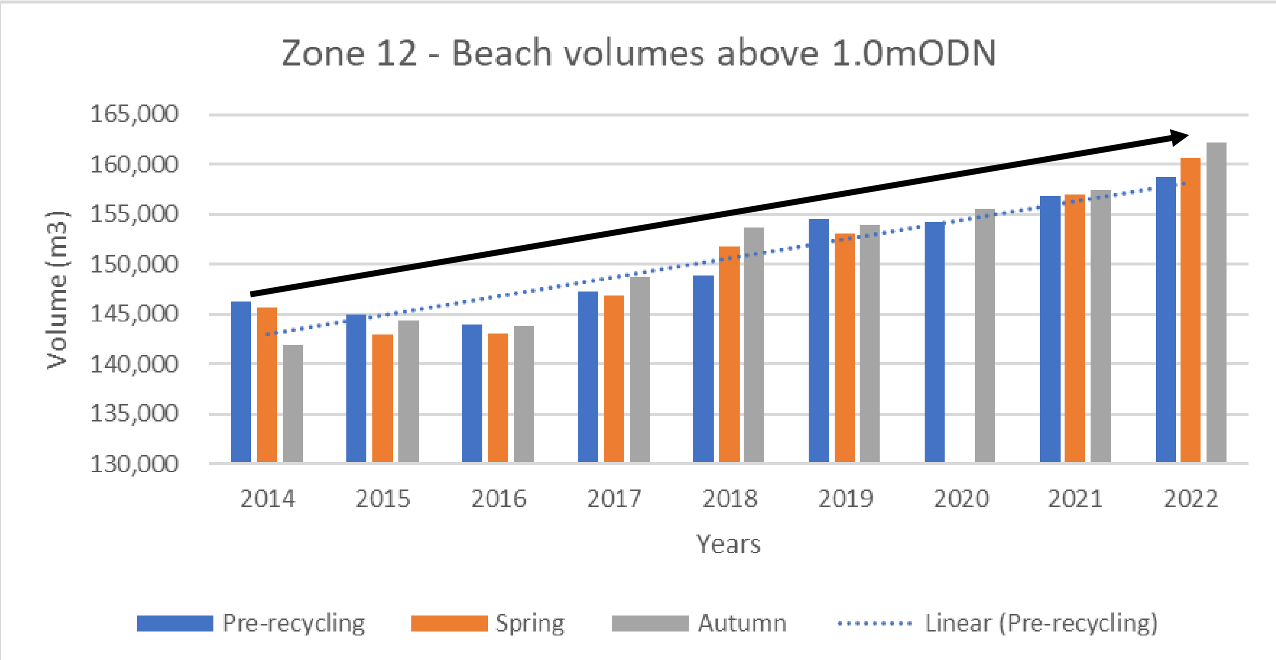


Figure C. 29: Beach volume (m3) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zone 12

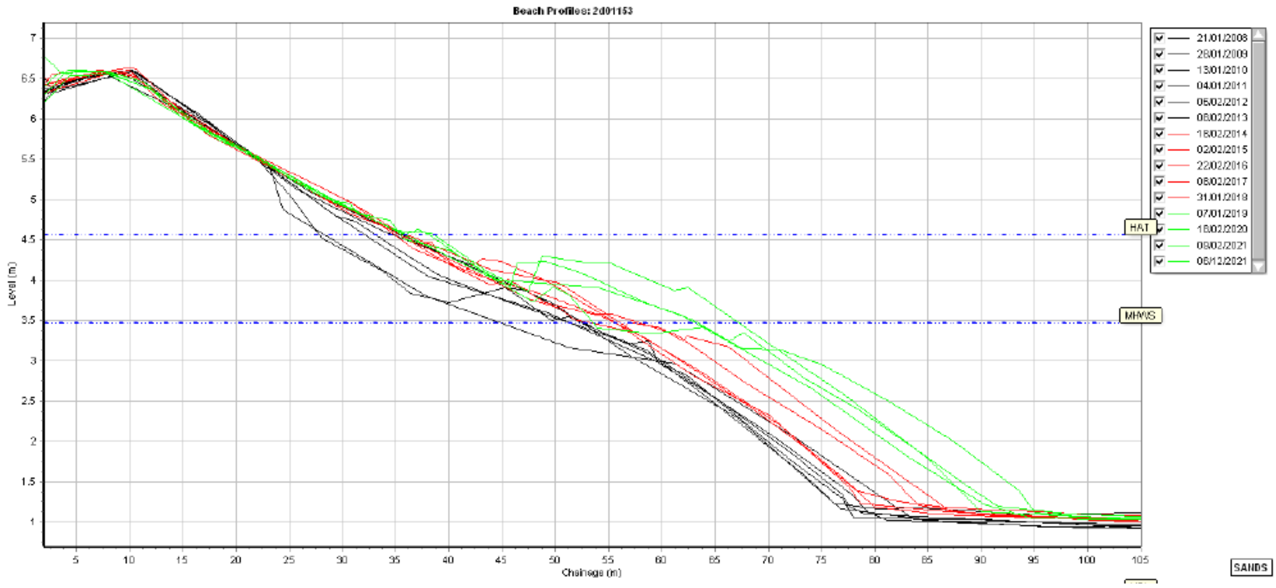


Figure C. 30: Profile 2d01153 within Zone 12. Black lines represent the general position of beach profiles between 2008 and 2013; red lines between 2014 and 2018, and green lines between 2019 and 2021 (Dec 2021 represents the pre-recycling survey of 2022)

C.2.9 Zone 13

Zone 13 is the scalp area for sourcing the recycling material. Since 2014, there has been a steady year-on-year accretion of material along this zone, specially up to 2019, as observed in Figure C. 31. Overall volumes in 2022, however, are slightly higher than volumes in 2014. This is also evidenced by Figure C. 32, which shows beach volumes (m^3) per metre of beach.

Of notice is the fact that, following extraction of beach material (observed by the drop in volumes between pre-recycling and Spring surveys), there is a recovery of beach volumes by Autumn (marked by the dark blue arrows -Figure C. 31) following by a further accumulation of material by the next pre-recycling survey (light blue arrows -Figure C. 31). This is also evidenced by the beach profiles (Figure C. 33), which showed a general seaward movement of the active beach between 1.5m and 3.5mOD of around 5m. This demonstrates that enough sediment has been reaching the scalp to at least recover the material extracted for recycling.

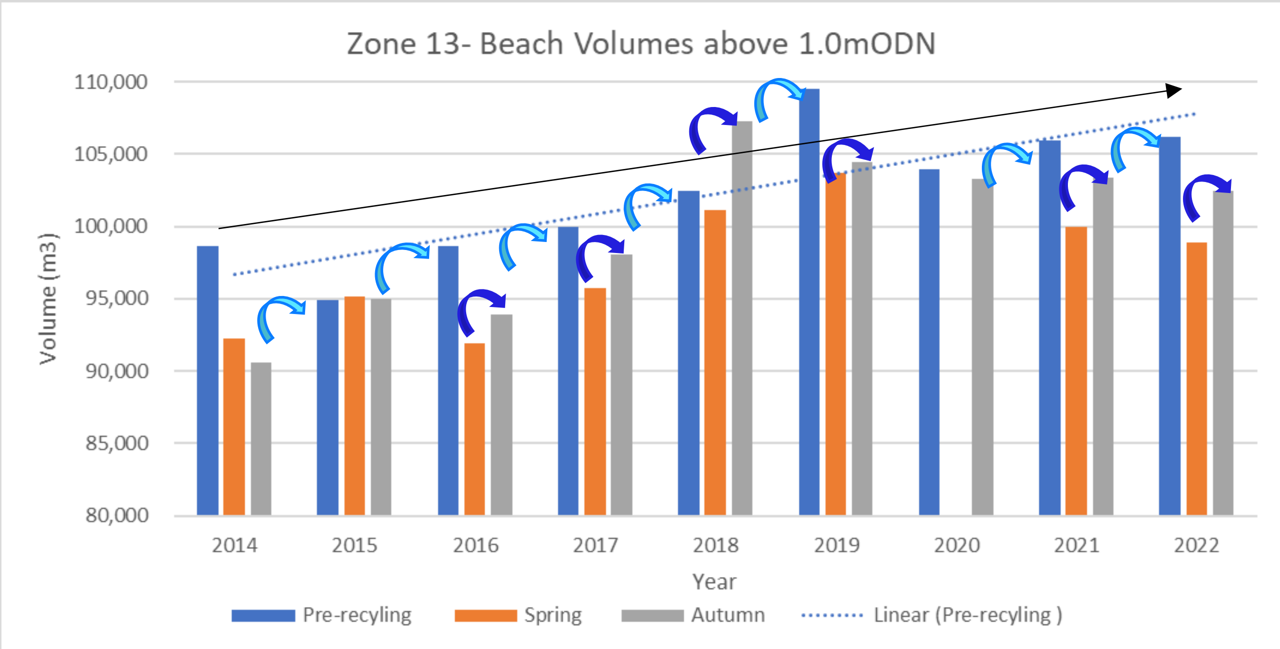


Figure C. 31: Total beach volumes (m3) above 1mODN for Zone 13, considering pre-recycling, Spring and Autumn surveys. The black arrow indicates a general trend of accretion within this zone. Following extraction of beach material there is a recovery of beach volumes by Autumn (dark blue arrows) following by a further accumulation of material by the next pre-recycling survey (light blue arrows).

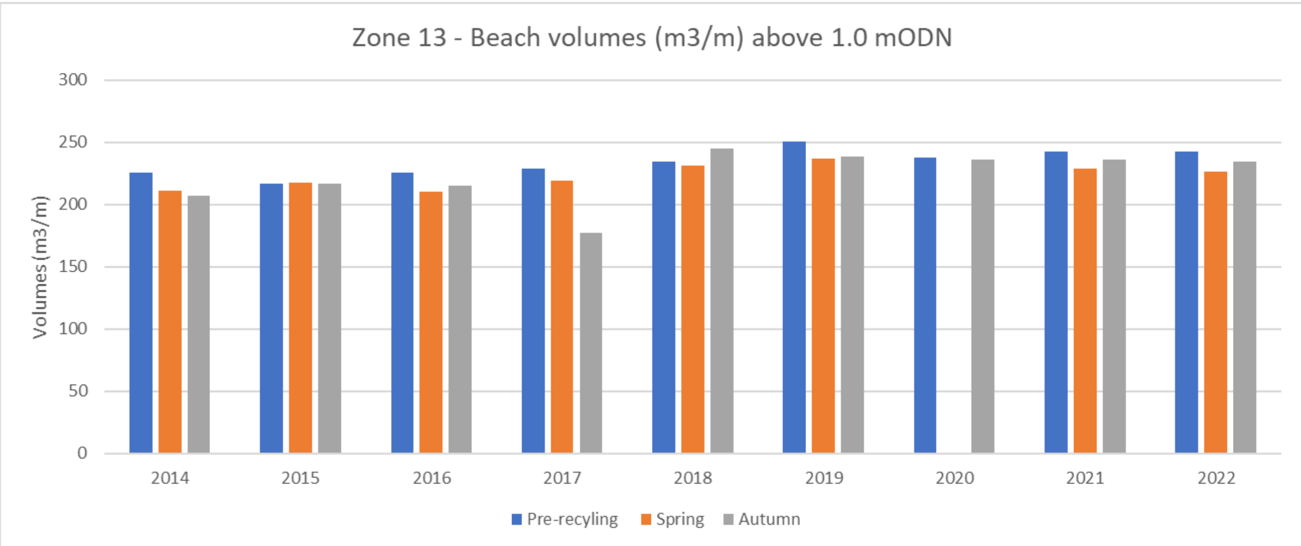
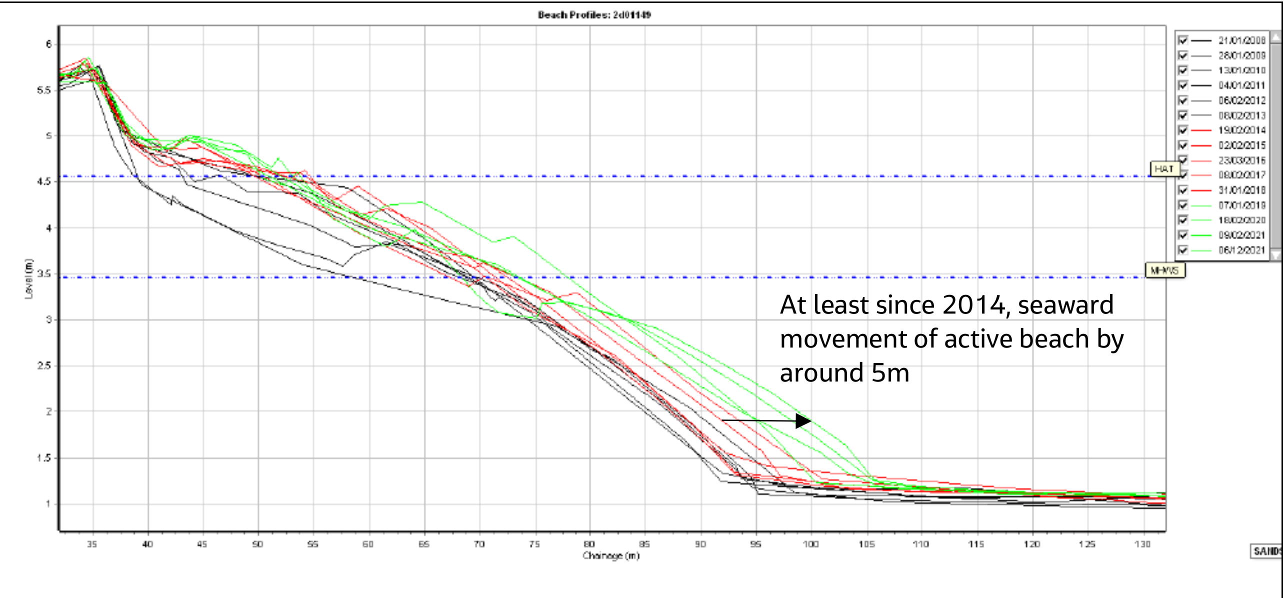
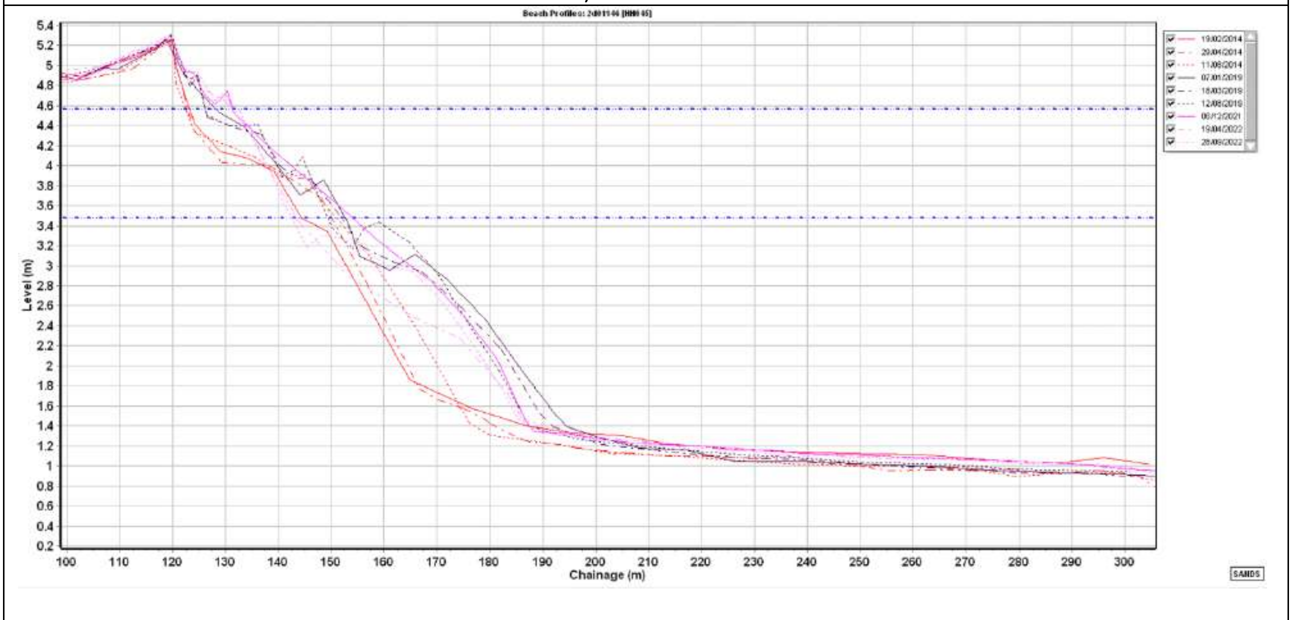


Figure C. 32: Beach volume (m3/m) above 1.0mODN, calculated from pre-recycling, Spring, and Autumn surveys, from 2014 to 2022 in Zone 13



a) Profile 2d01149



a) Profile 2d01146

Figure C. 33: Examples of profile analysis in Zone 13, showing a) profile changes for three time periods 2008-2013 (black line), 2014-2018 (red line) and 2019-2022 (green line) at profile 2d01149; and b) profile change between the pre-recycling, spring and autumn surveys in 2014, 2019 and 2022 at profile 2d01146.

C.2.10 LiDAR analysis

Figure C. 34 shows the elevation difference (in metres) between 2018 and 2022 LiDAR data. As demonstrated by the beach profile analysis, most of the erosion along the frontage between this period occurred in Zones 3, 5 and 11, with some localised reduction at the back of the beach, likely due to cliffing in Zones 6 and 7, 8 and southern section of Zone 10. The reduction in elevation observed in Zone 13 is likely due to sediment extraction.

LiDAR differences between 2020 and 2022 (Figure C. 35) and between 2021 and 2022 show the same overall pattern, but to a lesser scale (Figure C. 36).

Due to lack of long-term data offshore, a comparison of the differences in elevation along the sand ridges could only be done annually between 2020 and 2022 (Figure C. 35 and Figure C. 36). In general terms, the top of the sand ridges seemed to lose height over these two years of analysis (up to 0.7m in places), whilst the wider offshore seemed to have accreted in height by around 0.4m (up to 1.3m at very localised locations). It is important to note, however, that there was no sufficient offshore LiDAR to review bank/channel movement in great detail.

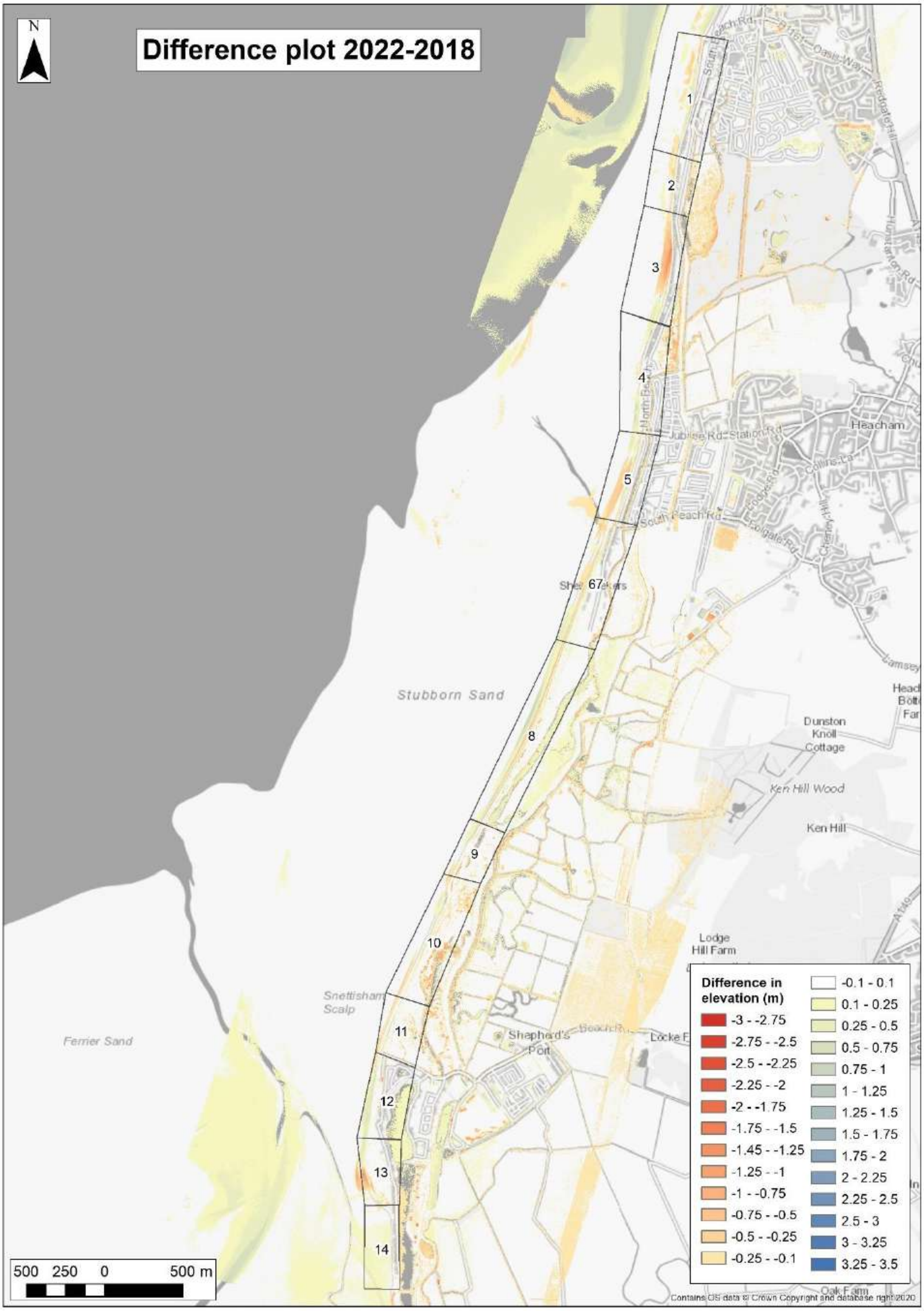


Figure C. 34: Difference plot showing elevation difference (in metres) between 2022-2018 LiDAR data

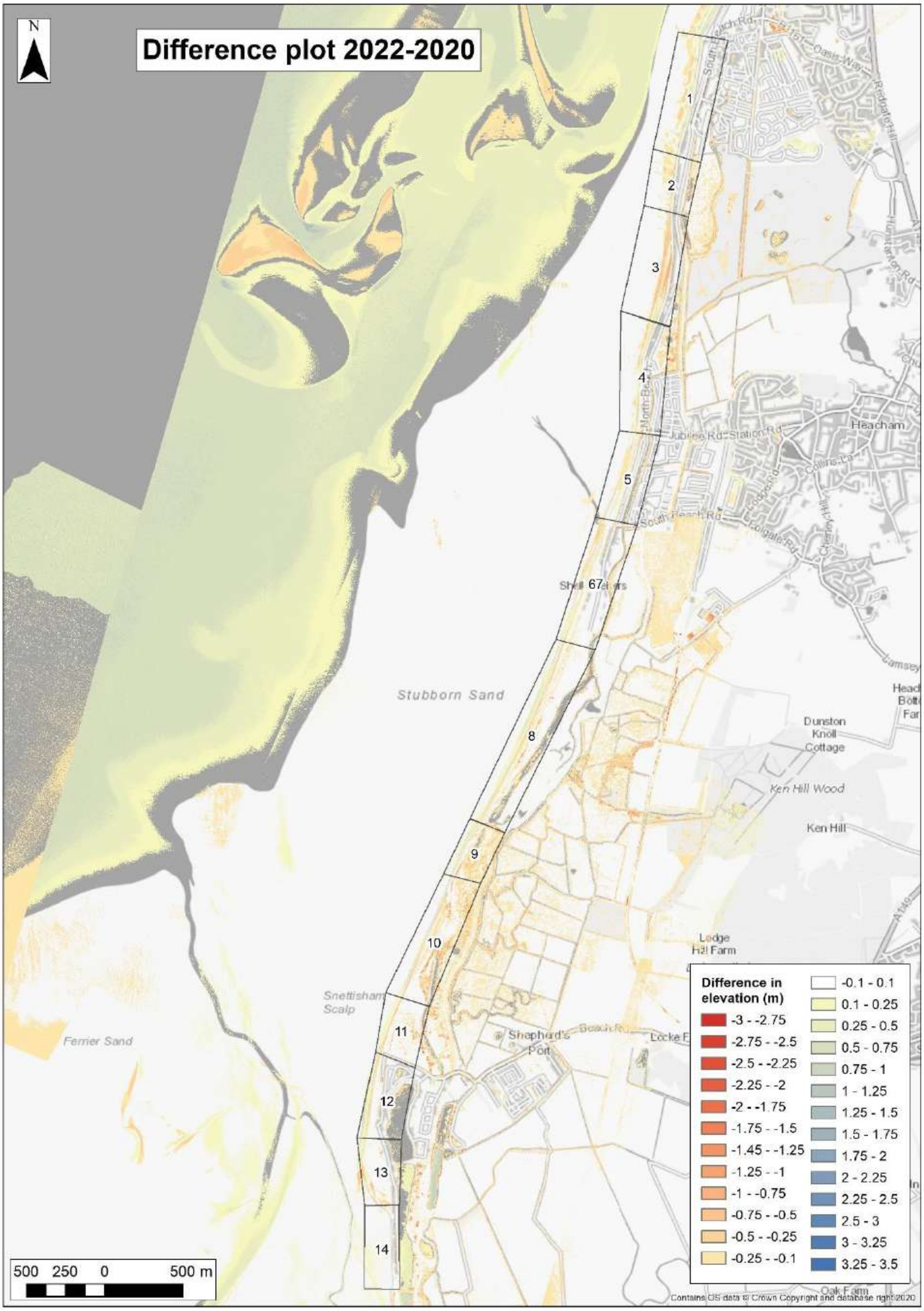


Figure C. 35: Difference plot showing elevation difference (in metres) between 2022-2020 LiDAR data

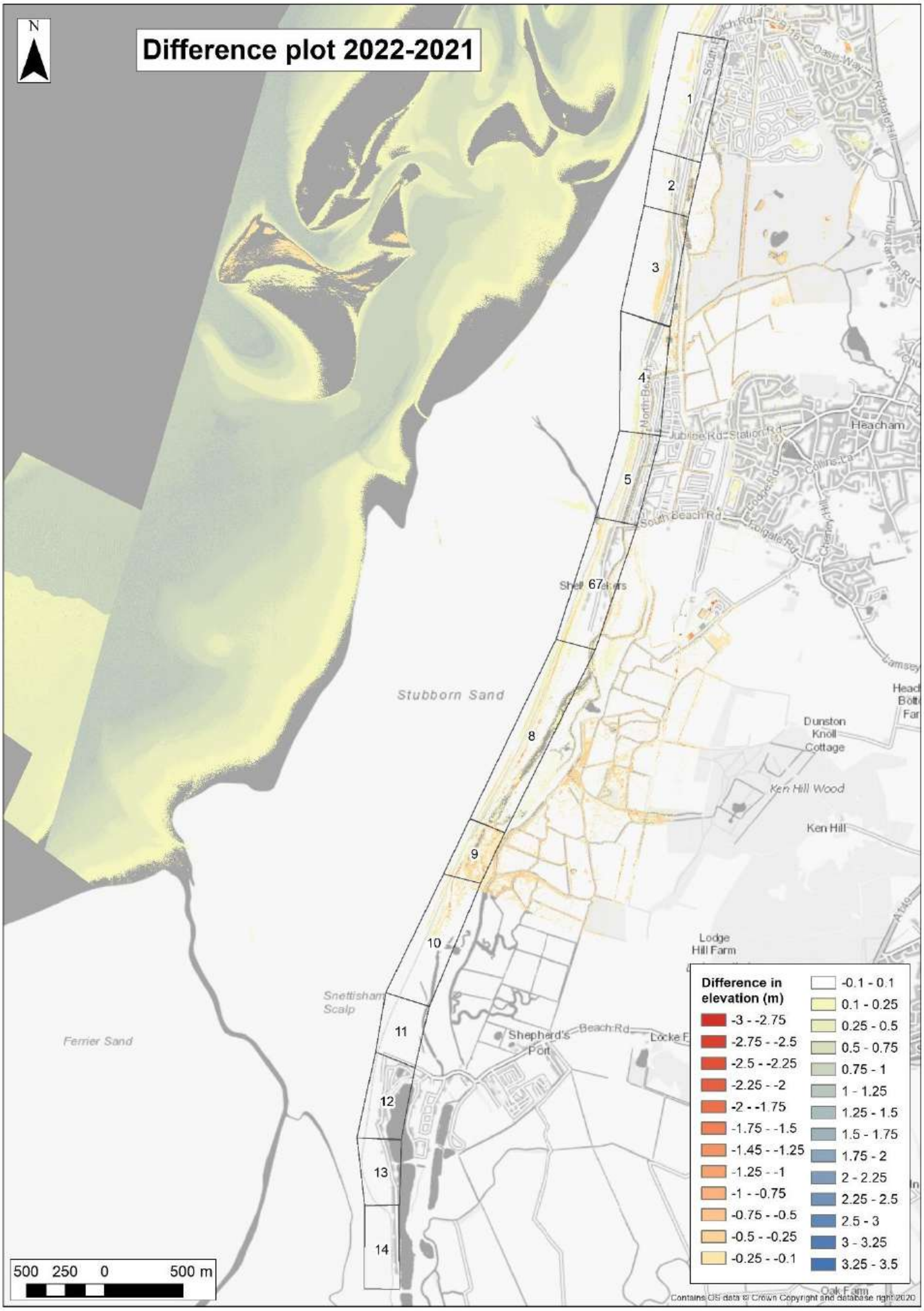


Figure C. 36: Difference plot showing elevation difference (in metres) between 2022-2021 LiDAR data

C.3 Results of hydrodynamics and correlation with beach profiles

Two pieces of hydrodynamic assessment have been undertaken:

- Analysis of Cefas Wavenet North Well wave buoy during and immediately after the recycling period to identify potential changes to significant wave height and/or changes in wave direction
- Analysis of the King's Lynn tide gauge records, which provides total Water Levels measured. This has been split between predicted tides and surges, and correlate to known storms in the area

The results of these analyses have then been correlated with the outcomes of the beach profile and volumes described above.

C.3.1 Wave climate analysis

Wave records were analysed for the period between pre-recycling and spring surveys each year, with exception to 2016, 2017 and 2018 due to wave data gaps. In addition, interannual periods were also reviewed between October-March and April-September to identify any variances within and throughout the years.

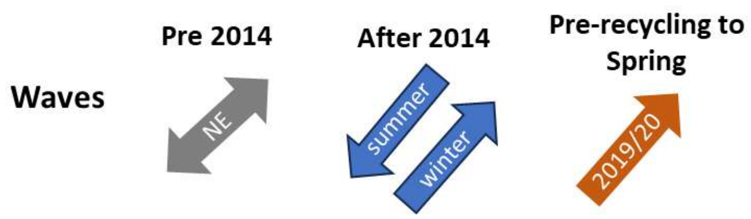
Data from the North Well Buoy shows that % occurrence of Hs (Figure C. 37), Tp (Figure C. 38) and Tz (Figure C. 39) comes from the Northeast and Southwest direction. From 2021 to 2023 (between pre-recycling and Spring surveys), the % occurrence of Hs, Tp, and Tz is dominant from the Northeast. This is an evident shift compared to 2019 and 2020 where the %occurrence of Hs, Tp and Tz is dominant from the Southwest.

The outcome of this analysis is described in more detail below, divided by time periods:

Pre-2014:

Between pre-recycling and Spring surveys, the period pre-2014 showed that NE waves are slightly more dominant than SW waves, with higher Significant Wave Height (Hs) of around 2-2.5m) from NE. The highest Peak Period (Tp) of around17s occurred from NE, but Tp from SW also reached up to 14s over this period (NE-SW Tps were similar in frequency).

In addition, the winter periods pre-2014 had a similar NE-SW wave frequency, with a slightly more NE dominance. The summer period dominance was varied year on year between NE and SW.



2015-2018:

Between pre-recycling and Spring surveys, this period showed an equal dominance of NE and SW waves, with more frequent Hs of 0.5-1m. Maximum Tp did not exceed 10s. It is important to note, however, that no waves were analysed between 2016-2018 due to data gaps.

2019-2023:

Between pre-recycling and Spring surveys, a shift in wave dominance was observed from NE to SW in 2019-2020. There was a high percentage occurrence of Hs between 1.5 and 2m and Tp ~8s from the SW over this period, with some extreme waves (but low frequency) of around 3m from NE.

Between 2021-2023, NE waves became once again slightly more dominant than SW waves, with highest Hs 2-2.5m and high Tp ~18s. There was a high percentage occurrence of Tp <6s from both NE and SW and <8s from NE.

In addition, after 2014, a stronger dominance of SW waves in winter was observed, as opposed to similar NE-SW frequency pre-2014.Likewise in the summer, NE waves showed a higher dominance post-2014.

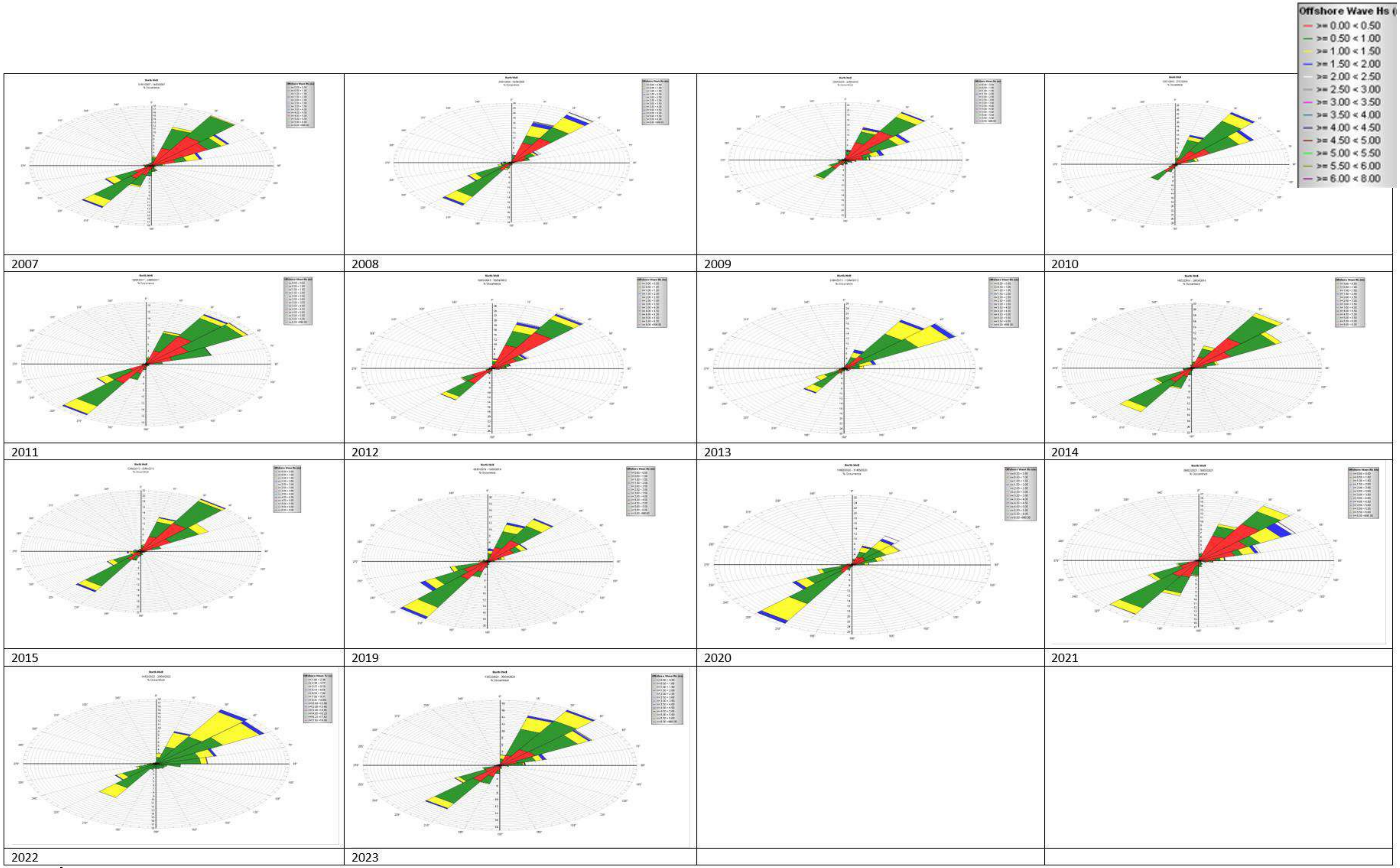


Figure C. 37: Significant Wave Height (Hs) (m) from 2007 to 2023 (excluding 2016, 2017 and 2018 due to lack of data) between the pre-recycling and Spring survey dates specific to each year.

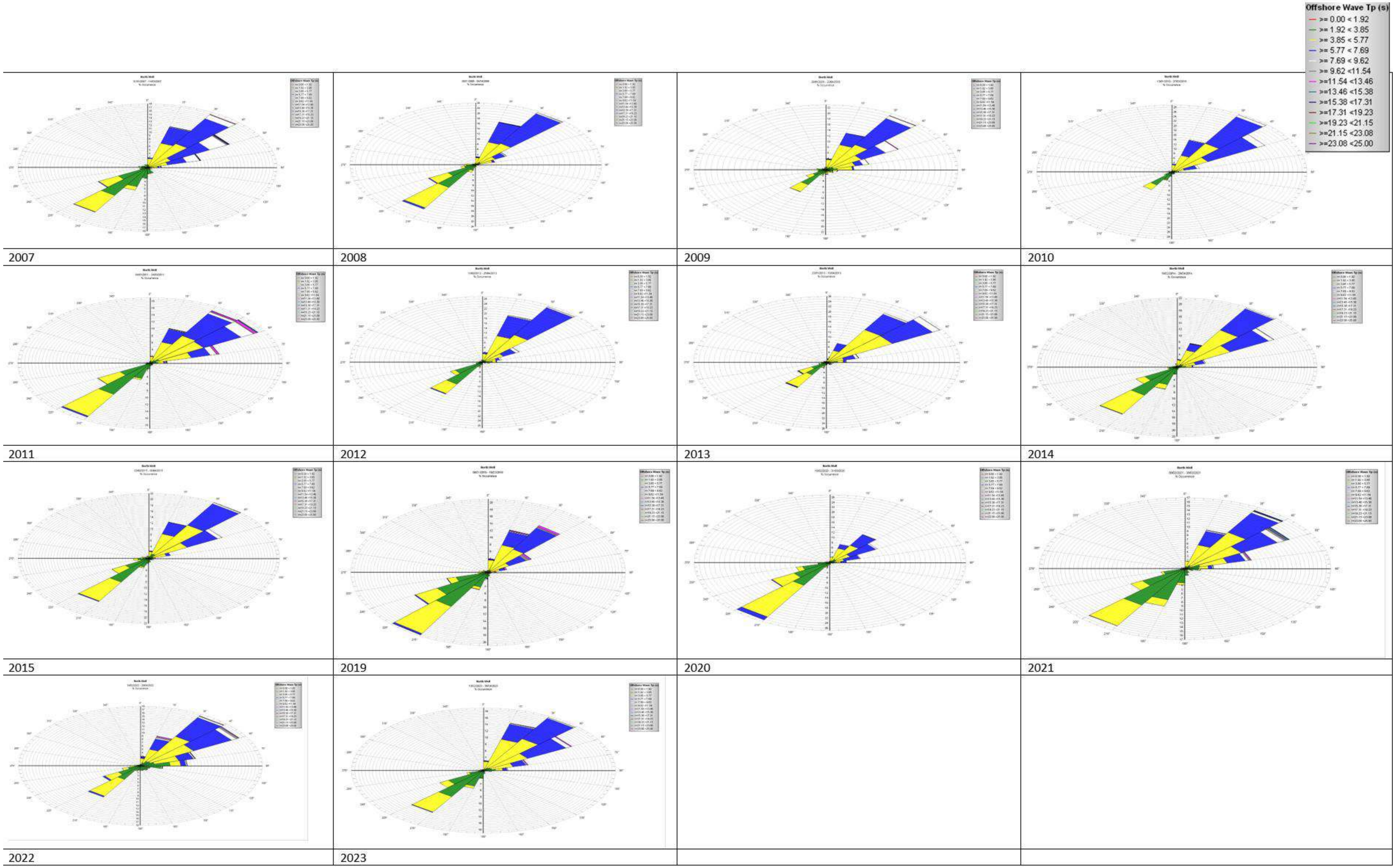


Figure C. 38: Peak Wave Period (Tp) (s) from 2007 to 2023 (excluding 2016, 2017 and 2018 due to lack of data) between the pre-recycling and Spring survey dates specific to each year.

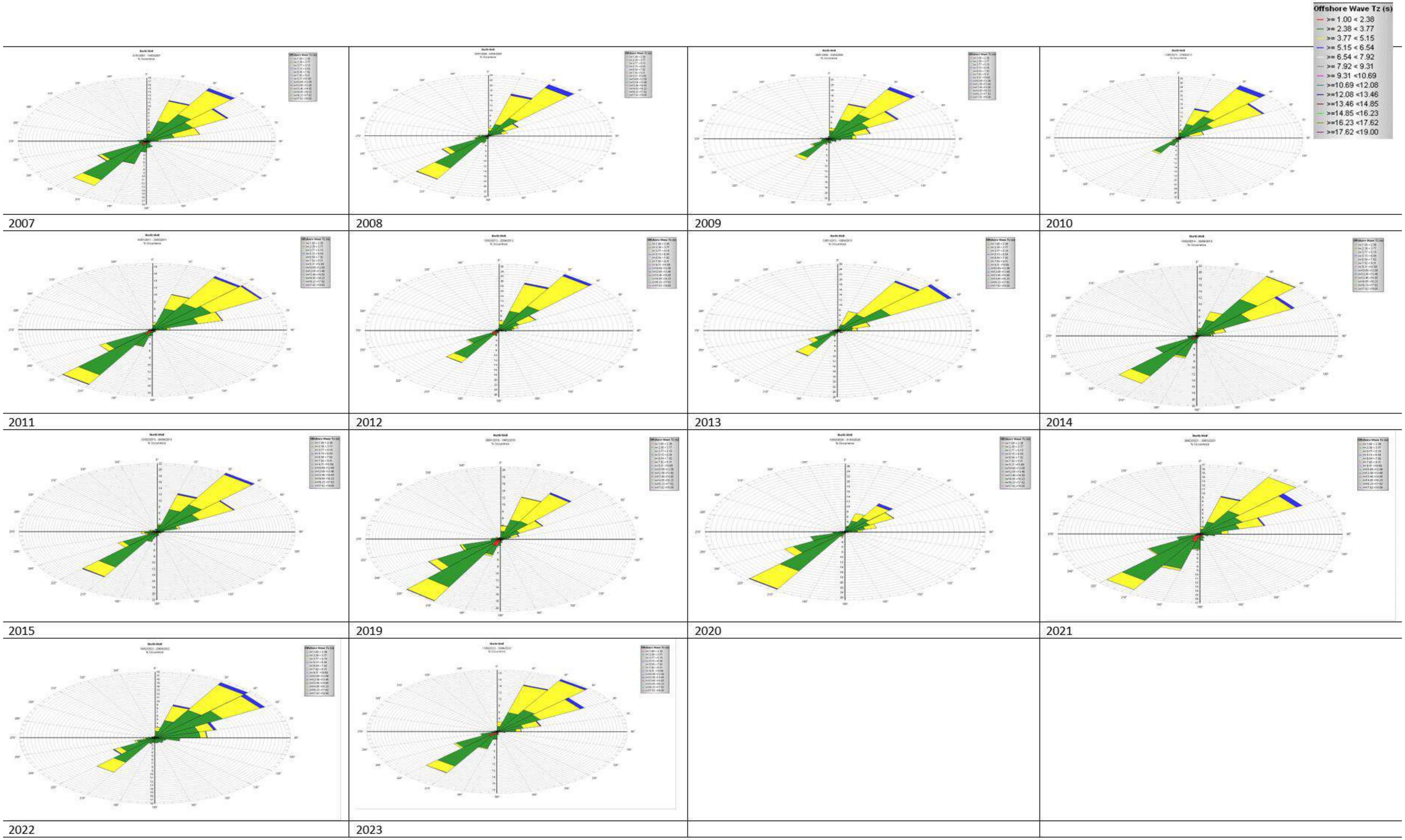


Figure C. 39: Mean Wave Period (Tz) (s) from 2007 to 2023 (excluding 2016, 2017 and 2018 due to lack of data) between the pre-recycling and Spring survey dates specific to each year

C.3.2 Water levels

Table C. 6 shows which extreme water level events since 2015 and a correlation between those and the dates of pre-recycling and Spring surveys. This indicates when storm high surges/ extreme water level events occurred within the beach recycling period of each year since 2015. Before 2019, extreme water levels generally occurred between October- February. Although in 2017 Storm Doris occurred in February (between pre-recycling and Spring surveys), this storm had lower extreme water levels than storms occurring after 2019.

Between 2019 and 2023 extreme water levels occurred between October to February, but also within March and April. These storms were also significant in terms of extreme water levels, reaching up to 4.2m in extreme water levels. This shift has resulted in more extreme water level events occurring post-recycling, potentially impacting the placement and retainment of recycled material (Table C. 6).

Table C. 6: Extreme water level events which have occurred between pre-recycling and Spring survey dates from 2015-2023 (excluding 2018 due to no data). The more yellow the highlighted cell, the more extreme and relevant was the event between pre-recycling and Spring surveys.

Year	Pre-recycling survey date	Spring survey date	Extreme water levels events between pre-recycling and spring survey	Events
2015	03 Feb 2015	08 Apr 2015	None	Between Oct and Nov 2014
2016	23 Feb 2016	24 Mar 2016	None	Between Dec 2015 and Feb 2016
2017	09 Feb 2017	21 Apr 2017	22 Feb 2017 (Storm Doris)	Most events occurred in Jan 2017 with an extreme water level of up to 4.7m (surges alone reached 2.2m). Storm Doris occurred end of Feb 17, but extreme water levels did not exceed 2.7m (surges alone up to 1m).
2019	08 Jan 2019	19 Mar 2019	08 Jan and 27 Jan 2021	Jan 2019 events reached extreme water levels up to 4.3m (surges of up to 2m)
2020	19 Feb 2020	N/A**	Unknown**	Jan and Apr 2020 Jan 2020 events did not exceed extreme water levels above 2.9m (surges of up to 1m); Apr 2020 events also had surges up to 1m but these occurred at low tides (extreme WL<1.8m).
2021	10 Feb 2021	29 Mar 2021	None, but 05 Apr 2021 storm occurred just after Spring survey	Apr 2021 events reached surges of up to 1.7m, with extreme water levels of 2.2m.
2022	05 Dec 2021*	20 Apr 2022	19 Jan, 27 Jan and 21 Feb 2022	Jan 2022 events reached up to 1.9m surges, with extreme water levels of 4.2m. Feb events reached max WL of 3.7m.
2023	13 Feb 2023	(Data unavailable)	14 Mar 2023	Mar 2023 events reached up to 1.1m surges, with extreme water levels of 3m.

*The winter (Dec 2021) survey is used as the pre-recycling survey for 2022, due to no data being available for this

**There was no spring survey completed in 2020

Table C. 7 shows the occurrence of high surges/water level events (above 0.8m) throughout the year. Pre-2019, high surges/ water level events used to occur between October and February, but more often in January and February (which was the case for 2016, 2017 and 2019), pre-recycling campaigns. There has been only one surge in 2017 which occurred between pre-recycling and spring surveys, albeit small and spanning a couple of hours only. However, post-2019, high surges/water level events occurred a bit later in the year, between March and April, i.e. after the recycling campaigns (which was the case for 2020, 2021 and 2023), in addition to winter (Jan-Feb) events. These events occurring later in the year could also be responsible for more variation in beach profiles over the year/seasons.

Table C. 7: High surges/water level events (above 0.80m) occurrence throughout the year from 2015 to 2023 (2018 excluded due to no data availability). The red box shows more high surge events in Spring from 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2015										x	x	x
2016	x	x										x
2017	x	x								x	x	x
2019	x											x
2020	x			x				x	x		x	x
2021	x	x		x							x	
2022	x	x									x	
2023			x									

C.4 Overall changes to coastal processes

Through the analysis undertaken above it is possible to draw conclusions and answer the questions posed at the beginning of this chapter: why the recycled material is being lost quickly after placement, and whether coastal processes over the last 3 to 5 years have changed.

In general terms, very little change was observed in beach volumes along the frontage, with significant loss of beach material in the last 3-5 years. Zones 5 and 11 were the only zones to show a consistent loss of beach volume since 2014, but this was more significant between 2014 and 2018. In addition, since 2014, beach recycling activities have been occurring within the same zones since 2014 (Zones 5, 8 to 11), with small changes in amounts placed at each location.

The beach material does not seem to be lost offshore, but only relocated both to the upper and/or lower beaches, which demonstrates that cross-shore sediment transport has been playing an important role over the last 3-5 years. This is evidenced by cliffing at the upper beach and accumulation of material in the lower sections of the beach. Whilst cliffing has been observed in a number of zones (i.e. 5, 9 and 11), both anecdotally and through the beach profile analysis, it has frequently occurred in the past. More recently, however, the higher ridges at the back of the beach make the cliffing seem more pronounced than previously.

A shift in wave dominance from NE to SW from 2019-2020, and the occurrence of extreme water level events more often in March/April from 2019/2020 could explain the quick loss of material following beach recycling campaigns. Whilst a NE wave dominance has been resumed in the period between pre-recycling campaigns and spring, it is currently unknown whether more severe storms (from extreme water levels) are from now on more often to occur in March/April, as opposed to the winter months pre-2019.

Beach volumes at the scalp do seem to recover and have even been increasing over time, leading to the conclusion that sediment supply is not currently an issue along this frontage, and that longshore drift is still effective in transporting the material mostly southwards. What has been observed, however, it that beach material has been reaching the scalp earlier in the year than previously.

it is not possible to determine at this stage whether the interannual shift of more SW dominated waves in the winter and more NE dominated waves in the summer observed post 2014 is a permanent change in the wave climate. However, this may be the reason why more sediment is currently reaching the Scalp earlier in the year than pre 2019 albeit volumes did not change.

Therefore, a greater incidence of large storms in the time period directly after recycling activities is likely to be the reason why cross-shore sediment transport processes seem to be more evident in relocating sediment across the beach quickly after beach recycling, following by beach material being reaching the scalp earlier in the year over the last 3-5 years.

Table C. 8 provides a summary of the coastal processes changes observed through this analysis.

<table>
<tr><th rowspan="2">Zones</th><th colspan="3">Recycling?</th><th rowspan="2">Reported zones</th><th colspan="2">Overall changes at beach/dune</th></tr>
<tr><th>Y/N</th><th>When?</th><th>Av. Volumes</th><th>2015-2018</th><th>2019-2022</th></tr>
<tr><td>01</td><td>Y</td><td>2012, 2013, 2015, 2017</td><td>~2,500m3; 2017 = 345m3</td><td rowspan="4">01-04</td><td rowspan="4">6,000m3 accumulation; could be related to recycling placed in Zone 1.</td><td rowspan="4">7,500m3 loss; could be related to lack of recycling. Zone 4 accreting material since 2014, whilst Zones 2 and 3 losing</td></tr>
<tr><td>02</td><td>N</td><td>-</td><td>-</td></tr>
<tr><td>03</td><td>N</td><td>-</td><td>-</td></tr>
<tr><td>04</td><td>Y</td><td>2012</td><td>143m3</td></tr>
<tr><td>05</td><td>Y</td><td>Since 2012, apart from 2014 and 2015</td><td>~1,200m3</td><td>05</td><td>Considerable loss, with active beach (1m-5mOD) retreating by 10m.</td><td>Loss, but less significant, having occurred mainly above HAT. Dune crest higher - steeper profile</td></tr>
<tr><td>06</td><td>Y</td><td>2016</td><td>488m3</td><td rowspan="2">06-07</td><td colspan="2" rowspan="2">Volumes in Zones 6 and 7 overall stable since pre-2014. More significant cliffing occurs at the northern section (between MHWS-HAT), but overall active profile stable/moving seaward. Dunes show signs of rollback since 1992 (increase in width at the back of the dune by 10m) and increased in height since 2001 by 1.5m.</td></tr>
<tr><td>07</td><td>N</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Northern section of Zone 8 does not receive recycling material. Only reprofilling (evidenced from north of profile 1192)</td><td>8a</td><td>~7,000m3 accumulation; this section does not receive recycling material</td><td>~6,000m3 accumulation; total beach volume peaked in 2021. Increased in material could be due to stronger wave generated drift from SW waves.</td></tr>
<tr><td>8</td><td>Y</td><td>Since 2012, apart from 2015</td><td>~4,000m3</td><td rowspan="3">8b-9-10a</td><td colspan="2" rowspan="3">This zone is heavily influenced by the beach recycling activities. Although loss of material after recycling, there was a significant increase in annual average beach volume by 15,000m3.</td></tr>
<tr><td>09</td><td>Y</td><td>Since 2014, apart from 2016 and 2017</td><td>~400m3</td></tr>
<tr><td>10</td><td>Y</td><td>Since 2014</td><td>~600m3</td></tr>
<tr><td colspan="4">Southern section of Zone 10 does not receive recycling material (evidenced from south of profile 1176)</td><td>10b</td><td colspan="2">Very little change in beach volume since 2014 in this zone.</td></tr>
<tr><td>11</td><td>Y</td><td>Since 2014, apart from 2015, 2016 and 2022</td><td>~1,500m3</td><td rowspan="2">11-12</td><td colspan="2">Steady, year-on-year decrease of beach volumes, totally around 5,200m3 loss since 2014. This could be related to the overall direction and curvature of the shoreline at this location, slightly seaward.</td></tr>
<tr><td>12</td><td>Y</td><td>2014</td><td>165m3</td><td colspan="2">Steady, year-on-year increase of beach volumes, totally around 4,300m3 gain since 2014. This could be related to the overall direction and curvature of the shoreline at this location,more concave.</td></tr>
<tr><td>13</td><td colspan="3">Extraction</td><td>13</td><td colspan="2">No different in material reaching the Scalp pre or post 2014, but post-2014, more material is available in the summer months. This could be related to the stronger dominance of NE waves in the summer months post 2014.</td></tr>
</table>

<table>
<tr><th colspan="2">Hydrodynamics</th><th>Pre-2014</th><th>2015-2018</th><th>2019-2022</th></tr>
<tr><td rowspan="3">Overall hydrodynamic changes</td><td>Description of wave climate in the period between pre-recycling and spring surveys</td><td>This period shows that NE waves are slightly more dominant than SW waves, with higher Hs (~2-2.5m) from NE.
Highest Tp (~17s) from NE, but SW also reached Tp of 14s over this period (NE-SW similar in frequency).</td><td>This period shows an equal dominance of NE and SW waves (no record for 2016-2018), with more frequent 0.5-1m Hs. Maximum Tp is less than 10s</td><td>A shift in wave dominance is observed from NE to SW in 2019-2020. Higher % occurrence of Hs between 1.5 and 2m, Tp ~8s over this period, with some extreme waves (but low frequency) ~3m from NE. Between 2021-2023, NE waves become once again slightly more dominant than SW, with highest Hs 2-2.5m and high Tp ~18s.Higher % occurrence of Tp <6s from both NE and SW and <8s from NE.</td></tr>
<tr><td>Description of wave climate interannually</td><td>Pre-2014, the winter period had a similar NE-SW wave frequency, with a slight more NE dominance. The summer period dominance was varied year on year between NE and SW</td><td colspan="2">After 2014, more dominance of SW waves in winter. In addition, after 2014, in the summer NE waves showed a higher dominance.</td></tr>
<tr><td>Description of extreme water levels/ surges</td><td colspan="2">High surges/ water levels occurred only between October and February (more often in Jan/Feb - 2016, 2017 and 2019). Only one surge in 2017 occurred between pre-recycling and spring surveys, albeit small and spanning a couple of hours only.</td><td>High surges/water levels occurred between pre-recycling and spring surveys or later in April (March/April in 2020, 2021 and 2023). More extreme events later in the year, which could be responsible for more variation in beach profiles over the year/seasons.</td></tr>
</table>

Table C. 8: Summary of coastal processes changes

Appendix D. Update on costs and benefits

D.1 Aims of this update

This appendix details the updates on costs and benefits undertaken as part of the Unit C Initial Assessment and are based upon operations set out in the 2016 OBC (CH2M, 2016). The aims of this update are as follows:

- High level review of benefits previously included in the Wash East Coastal Management Strategy (WECMS) and Outline Business Case (OBC), providing a new baseline for affordability and total Grant in Aid (GiA) which would have been secured back in 2016;
- Provide a better understanding on what is potentially affordable based on 2023/2024 updated costs and benefits up to the end of the OBC appraisal period for this scheme, which is 2031, and how much GiA could be secured in light of the updated benefits.

It is important to note that this is not a full update of the economic assessment reconsidering a full range of options, as those would need to be further developed in order to get accurate values, and a complete review of benefits along this frontage is required in light of new technical information now available. This exercise was undertaken simply to improve the understanding of potential limitations on affordability and GiA available for this frontage.

A total of two separate cases were assessed:

- **Case A: Updated 2016 calculations,** which was undertaken in two steps:
    - Step 1: The numbers of assets/areas at risk have been adjusted to restate the damages/benefits that should be considered. This is referred thereafter as Case A1.
    - Step 2: as per Step 1 with adjusted options costs, in which the actual costs of works that have now transpired are used in place of the previously assumed costs. This is referred thereafter as Case A2.
- **Case B: 2024 update values**, which identifies the potential affordability of undertaking works for the reminder of the OBC appraisal period (to 2031), using updated 2023 values for both costs and benefits.

Each of these Cases are explained in detail in the sections below.

D.2 Previous economic appraisals

Economic appraisals have been previously undertaken for the Wash East Unit C:

- Economic assessment part of the WECMS. Although approved in 2015, the economics was undertaken with 2012 values (Royal HaskoningDHV, 2015).
- This was then updated as part of the OBC for the Wash East coastal frontage from Hunstanton to Wolferton Creek in 2016 (CH2M, 2016).

Table D1 shows a summary of the appraisals' assumptions and how those compare to this assessment.

Table D1: Assumptions from the WECMS and OBC

	WECMS	OBC	This assessment
Appraisal period	100 years from 2015	15 years from 2016-2031	Case A (Steps 1 and 2) – Appraisal period 15 years from 2016; Case B – Appraisal period 7 years from 2024
Basis for uplift	CPI from 2012 to 2015	GDP Deflator index from 2012 to 2016	Case A (Steps 1 and 2): uses OBC values; Case B uses GDP Deflator index from 2012 to 2023
Options tested	Do nothing Do minimum Sustain Defence Standard (SDS) Equal Improvements 1 and 2 Equal Standards 1 and 2	Do nothing Do Minimum/ Sustain: Assume annual recycling with one recharge campaign in year 6	Case A1: Updated 2016 components of damages/benefits Case A2: as per A1 and using updated costs if those were available in 2016 Case B: Updated damages/benefits and costs to 2023 values; tested different expenditure profiles
Residential properties count	Unclear – range between 230-317. Partnership Funding (PF) states 254	Assumed WECMS' values. PF states 254	139 seawards of the secondary embankment
Non-residential properties count	Unclear – range between 253-256.	Assumed WECMS values	Assumed WECMS values
Deprivation	Assumed 65 houses within the 21-40% most deprived, and 189 houses within the 60% least deprived	As per WECMS	Updated based on Deprivation index 2019. All 139 residential properties are within the 60% least deprived
Holiday parks	Considered Compartments 1 to 3 and 5, and accounts for relocation costs.	As per WECMS, but only account for 15-year appraisal period.	Excluded Compartment 5 as this is behind the secondary embankment

	WECMS	OBC	This assessment
Recreation	Recreation losses progressively increase from 10% of their total value to full loss at year 20.	As per WECMS, but updated using GDP Index and only account for 15-year appraisal period.	Assumptions as per WECMS. Case A (Steps 1 and 2) uses OBC values+15-year appraisal; Case B updated values using GDP Index to 2023
Tourism	Assumed tourism losses increase rapidly to 50% up to year 5, and decline more slowly to maximum annual losses of 95% by year 22. Tourism losses was reduced to 50% to avoid double counting with recreation losses	As per WECMS, but updated using GDP Index and only account for 15-year appraisal period.	Assumptions as per WECMS. Case A (Steps 1 and 2) uses OBC values+15-year appraisal; Case B updated values using GDP Index to 2023
Agriculture	Assumed write off of land at severe risk of regular flooding and recurring damages due to infrequent inundation.	As per WECMS, but updated using GDP Index and only account for 15-year appraisal period.	Excluded completely. as this is behind the secondary embankment
Infrastructure	Assumed disruption to the A419 due to flooding, and financial impacts due to road diversions.	As per WECMS, but updated using GDP Index and only account for 15-year appraisal period.	Excluded as A419 is behind the secondary embankment
Health/Mental Health	Used formulae from "The Appraisal of Human related Intangible Impacts of Flooding" (Defra, 2004).	As per WECMS. Values were not updated as assumed to be within the residential properties' losses.	Case A (Steps 1 and 2): as per OBC. Case B: Recalculated using FCERM guidance 2021, and assuming values for more than 100cm flood depth

Both WECMS and the OBC included in the economic assessment damages values for the area landwards of the secondary embankment. These have now been excluded of this assessment, as follows:

- The residential properties now being considered are much lower than WECMS/OBC.
- The total extent of holiday parks is now reduced (Compartment 5 was excluded).
- Agricultural losses are not included.
- Infrastructure losses are not included.

D.3 Assumptions and limitations

The following assumptions and limitation should be considered when reading the results of this assessment:

1. It is unclear which non-residential properties have been included in WECMS (and those were simply updated using the DGP index in the OBC). Based on new property count provided by the EA, it was assumed that non-residential property values previously included are still generally valid and these have been included in this assessment.
2. All 139 residential properties were assumed to decrease one risk band (from Very Significant Risk to Significant Risk) in the PF Calculator independently of the level of affordability tested, due to the currently uncertainty on risk levels along the frontage.
3. A full review of the allowances included for holiday parks, tourism and recreation in the WECMS (and updated in the OBC using the DGP index) has not been undertaken at this stage. The original WECMS values have, therefore, been updated using the same approach as the OBC by applying the GDP Index to Q3 2023.
4. Whilst the PF calculator has been updated in 2020 for projects starting post 01 April 2021, this assessment used the original calculator in both Cases analysed as the current management is still within the 15-year appraisal period the OBC considered back in 2016.
5. Another reason for use of the original PF calculator is the fact that the new PF calculator version requires an Annual Average Damages (AAD) assessment to be added to it, otherwise GiA is reduced. AAD assessment, however, has not been undertaken as part of WECMS and the OBC previously, and to undertake one, a significant review of Standard of Protection of the different defence lines is required. This should be considered in further future studies along this frontage.
6. The new FCERM 2021 guidance notes that environmental enhancement and carbon damages and benefits should be considered for each option appraised as part of an economic assessment. These, however, have not been undertaken as part of this review as the aim here was to provide a general understanding of affordability and potential Grant in Aid achieved, but based simply of past values updated to inflation. These should be considered in further future studies along this frontage.

D.4 Costs updates

The Environment Agency provided updated costs for both year-on-year expenditure on recycling activities (Environment Agency, 2024) and new, high-level estimates on costs for beach recharge (Environment Agency, 2023). Table D2 shows the costs for recycling activities since 2017/2018; efficiencies were made by the Environment Agency by bringing the monitoring and reporting in house.

Table D2: Costs of recycling activities since 2017/2018 (Environment Agency, 2024)

Financial Year	Business Case assumption	Actual spend per year
2017/2018	£149,575	£85,177
2018/2019	£153,315	£78,985
2019/2020	£157,148	£97,812
2020/2021	£161,076	£77,628
2021/2022	£243,724	£128,801
2022/2023	-[1]	£138,458
2023/2024	£206,502	£94,617
Average (£/year)	-	£100,211

[1]The OBC did not account for recycling costs in 2022/2023 as this was when recharge was assumed to take place.

In terms of beach recharge costs, up-to-date estimates were sought in 2022/2023 from two leading contractors well experienced in providing this type of works, and reported in Environment Agency (2023). A summary of the costs can be seen in Table D3.

Table D3: Up-to-date estimated costs of beach recharge activities (EA, 2023; CH2M, 2016)

Item	Contractor A	Contractor B	OBC (2016)
Contractors	£3,752,000	£5,755,300	£1,300,000
Consultants	£250,000[1]	£250,000[1]	£490,000[1]
EA Staff	£60,000	£60,000	£60,000
Total (no risk)	£4,062,000	£6,065,300	£1,896,250
Total (with risk)	>£5,300,000[2]	>£7,900,000[2]	£2,405,000

[1] These values exclude licences, re-design, and other environmental assessments.

[2] These values are indicative only and differ from the ones used in Cases A Step 2 and Case B due to other values included in the calculations undertaken in the supporting tables.

D.5 Case A – Updated 2016 calculations

Case A aimed to update the latest PF Calculator submitted in 2016 as part of the OBC (CH2M, 2016) in order to:

- Step 1 (Case A1): review the components of damages/benefits considered at the time of the OBC, i.e. had we been in 2016 but applying damage calculations based on the review of damage data described below. Annex D1 provides the supporting tables and PF calculator for Case A1.

- Step 2 (Case A2): update the assumed costs included in the OBC with actual costs of works (as per 2023) as well as the updates undertaken in Step 1. The aim of Case A2 was to provide an understanding of the amount of GiA that could have been achieved at the time of the OBC if higher estimated costs for recharge had been used. Annex D2 provides the supporting tables and PF calculator for Case A2.

The appraisal period used for Case A was 15 years, as per the OBC. Case A used the old version of the PF calculator and simply updated the old version of the supporting spreadsheets (Annex D1 and D2). Annex D4 shows in more detail all the assumptions and updates in terms of damage calculations and costs undertaken for this assessment.

D.5.1 Step 1: Adjusting the number of assets/areas at risk

1) Residential property

The number of residential properties used in both the WECMS and the OBC was unclear, potentially varying between 230 to 317 properties (WECMS, 2015). A new property count using NRD data was undertaken by the Environment Agency and considered residential properties only seawards of the secondary embankment, which showed that the count used in both previous economic appraisals were overestimated. The total number of residential properties is 139 (130 detached, 8 semi-detached, and 1 self-contained flat).

2016 Present Value (PV) for residential properties was, therefore, adjusted (using a simple linear interpolation) to represent the number of residential properties seaward of the secondary embankment at the time of the OBC (i.e. the PV was not uplifted with the GDP index for 2024 values in Case A).

Table D4 shows the PV values for residential properties used in Case A, and a comparison with the values used in the WECMS and OBC. See supporting tables in Annex D1 and D4 for more details.

Table D4: Comparison between PV values for residential properties between WECMS, OBC and Case A of this assessment.

PV residential properties	WECMS	OBC	Case A
Do nothing	£13,412,220	£13,900,006[1]	£7,247,697[3]
Do minimum	Unknown	£19,310,359[2]	£10,068,746[3]

[1] This value was updated on the OBC using DGP Index.

[2] It is unclear how this value was obtained.

[3] The values for this review were based on the proportion between the new residential property count (139) and the values from the WECMS (230 or 317).

In addition to this, both the WECMS and the OBC Partnership Funding (PF) calculator used the number of 254 properties within OM2, of which 65 were assumed to be within the 21-40% most deprived areas, and the rest within the 60% least deprived. A review of the Index of Multiple Deprivation (IMD - https://dclgapps.communities.gov.uk/imd/iod_index.html) showed that, in fact, all residential properties seawards of the secondary embankment are within the 60% least deprived in the country.

Another factor that affects the Partnership Funding calculator is prevalence of second homes in the area and the strict planning rules that prevent permanent occupation at many properties. According to FCERM Funding rules, the value of such properties cannot be used, whilst their count can. This will be taken into account in a future review of the economic assessment.

Given that no new information is available in terms of the level of risk of which these properties are at present, it was assumed for this update that, before the scheme, all 139 properties are at Very Significant Risk, and after the scheme, all properties are at Significant Risk.

As per the OBC, it was assumed that most of the damages to residential properties were likely to be damages following breach. The linear breach probability spreadsheet was, therefore, used with the same assumptions as the OBC as follows:

- Do nothing: probability of breach increasing from 2% to 100% in year 5.
- Option 2 (recycling with small recharge), probability of breach increasing from 2% in year 0 to 10% in year 10 and 100% by year 30.

The probability adjusted PV Damage was summed over a 15 year period.

2) Agricultural land

Given that both the WECMS and OBC used Grade 3 agricultural land values located landward of the secondary embankment, PV was overestimated. The only section with Grade 4 agricultural land seaward of the secondary embankment is between Zones 6 and 11 (Figure D1); however, it has been assumed for the purpose of this update that this area is, at most, grazing land, and should not have been included in the calculations. All agricultural land values have, therefore, been excluded of this update.

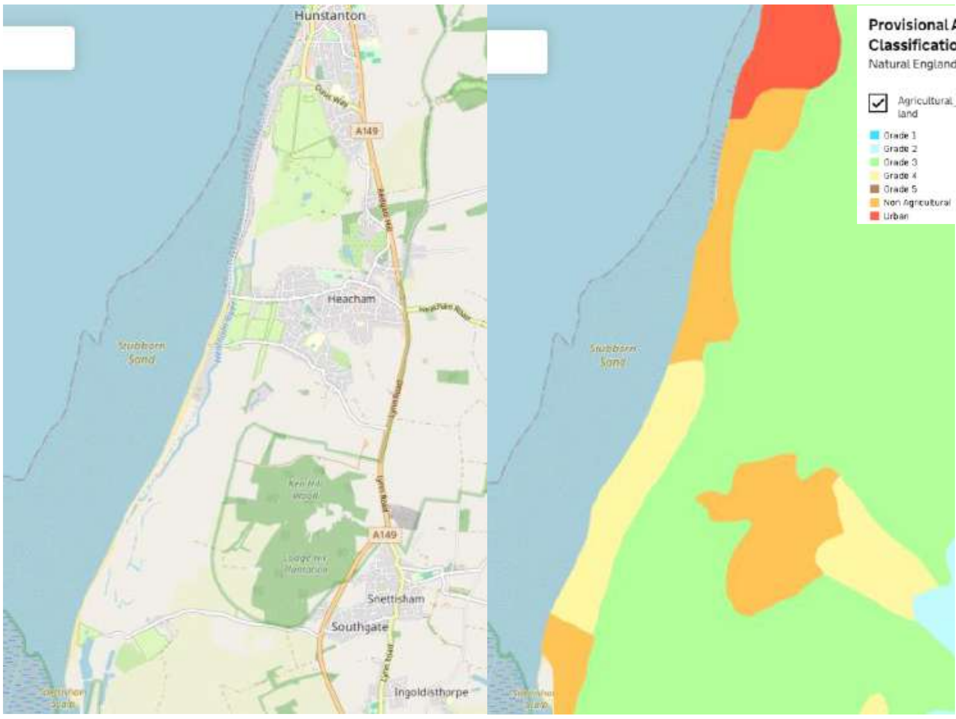


Figure D1: Provisional Agricultural Land Classification for the study frontage (between Hunstanton and Snettisham). Source: Defra (2024)

3) Infrastructure

Given that both the WECMS and OBC considered potential disruption to the A419 which is located 3km inland (and landward of the secondary embankment, infrastructure PV was overestimated. This, therefore, has been excluded of this update.

4) Holiday Parks

Both the WECMS and the OBC assumed costs of relocation of Holiday Parks in Compartments 1 to 3 and 5 as damages to the economics. However, compartment 5 is defended by the secondary embankment and, therefore, was excluded of this update.

The costs of relocation of Compartments 1 to 3 only (as per 2016 PV) have been entered into a linear breach probability spreadsheet, and the same breach assumptions as per the OBC were applied, as follows:

- Do nothing: probability of breach increasing from 2% to 100% in year 3 (for compartment 1 to 3).
- Option 2 (recycling with small recharge), probability of breach 2% in year 0 to 10% in year 10 and 100% by year 20 for compartment 1 to 3.

The probability adjusted PV Damage was summed over a 15-year period.

5) **Other damages**

- Non-residential properties

As with the residential properties, the number of non-residential properties used in both the WECMS and the OBC was unclear, potentially varying between 253 to 256 (WECMS, 2015). A new property count using NRD data was undertaken by the Environment Agency and considered non-residential properties only seawards of the secondary embankment. However, the NRD description of property type was unclear to ensure an accurate number. Considering that this up-to-date count returned 18 caravans, 129 holiday let/ accommodation and 82 privately owned holiday caravan/ chalets, resulting in a total of 229 non-residential properties, and due to the uncertainty around the NRD description, the OBC PV for non-residential properties was simply applied to the PF calculator in the same way the OBC has done.

In addition, the same breach assumptions as per the OBC were used:

  - Do nothing: probability of breach increasing from 2% to 100% in year 3.
  - Option 2(recycling with small recharge), probability of breach increasing from 2% in year 0 to 10% in year 10 and 100% by year 30.

The probability adjusted PV Damage was summed over a 15 year period.

- Recreation

The recreation values were copied directly from the WECMS/OBC breach spreadsheets, and the same assumptions as per the OBC were applied:

  - Do nothing: the recreation damages increase from 10% (of the annual loss) to full annual loss by year 20.
  - Option 2 (recycling with small recharge): damages increasing from 10% (of annual loss) to full loss by year 50 (as strategy Do Minimum), but reset to 10% following Recharge (as WECMS SDS).

The probability adjusted PV Damage was summed over a 15-year period.

- Tourism

Tourism benefits in the WECMS are related to the income generated from tourism. The same assumptions as per the OBC were applied:

  - Do nothing, losses increasing from 10% in year 1 to 50% in year 5 and 50% thereafter.
  - Option 2 (recycling with small recharge), as per strategy Do Minimum losses, but reset to zero following Recharge (as WECMS SDS). This assumes tourism is able to recover following Recharge.

Note the annual tourism losses used throughout was reduced by 50% in the WECMS and in the OBC, and also assumed in this assessment, to attempt to avoid double counting with recreation losses.

- Vehicle, accommodation and emergency services

As per the WECMS and the OBC, these were assumed to be included in property damages.

- Environment, Utilities, Health, Risk to Life/ Vulnerability

These were not updated as part of this assessment (for Case A).

D.5.2 Step 2: Using present-day costs of recharge within the OBC in 2016

The aim of Step 2 (Case A2) was to provide an understanding of the amount of GiA that could have been achieved at the time of the OBC if higher estimated costs for recharge had been used. Therefore, in addition to Step 1 updates on damages and benefits, Step 2 updated the cost of recycling and recharge activities used in the 2016 version of the PF calculator.

The values of recycling activities are provided in Table D2; these were applied to the OBC supporting tables for calculation of PV costs (tab “Costs inc RechargeYr 6”, Column O, Annex D2), excluding 2.5% inflation (Table D5) which is then added back in in Column Y of the spreadsheet (this is shown in Table D5 below as the “Total cost including 95%ile risk and 2.5% inflation per annum”). Likewise, recharge costs added to Column P in the spreadsheet were assumed to be Contractor A’s estimates without risk (Table D3). The total PV value for the 15-year appraisal period was now calculated to be around £7.5 million (as opposed to £4.5 million used in the OBC PF calculator). As per the OBC, the PF calculator assumes this to be the PV design and construction costs. To this, the PF then adds PV appraisal costs and PV post-construction costs, with a total PV Whole-Life Costs of £7,581,574.

Table D5: Costs included in Case A2 of this assessment. See more details in Annex D2.

Financial Year	Recycling (no risk, no values remove 2.5% inflation)	Beach recharge (no risk, no inflation)	Total cost including 95%ile risk and 2.5% pa inflation
2016/17	£60,000		£126,273
2017/18	£83,100		£157,904
2018/19	£75,179		£151,844
2019/20	£90,828		£175,907
2020/21	£70,327		£153,090
2021/22	£113,841		£380,760
2022/23	£119,388	£4,100,000	£6,178,125
2023/24	£79,598		£223,859
2024/25	£100,000		£256,419
2025/26	£100,000		£262,829
2026/27	£100,000		£269,400
2027/28	£100,000		£276,135

Financial Year	Recycling (no risk, no values remove 2.5% inflation)	Beach recharge (no risk, no inflation)	Total cost including 95%ile risk and 2.5% pa inflation
2028/29	£100,000		£234,517
2029/30	£100,000		£240,380
2030/31	£100,000		£246,390
Total cash	£1,392,262	£4,100,000	£9,333,832
Total PV value	£1,089,813	£3,335,353	**£7,463,910**

D.5.3 Results

Table D6 below shows the updated results for PV damages for each component considering the adjustments described above for both options considered under the OBC: Do nothing and Do Minimum/ Sustain (with recharge in Yr6), and compares the updated values with previous OBC values as approved in 2016.

Table D6: Comparison between previous OBC PV damages and updated PV damages for Case A for both options considered in the OBC (Do Nothing and Do Minimum/Sustain)

Components of damage calculations	OBC values – PV damages		Case A – Updated PV damages	
	Do Nothing	Do Minimum/ Sustain (with recharge Yr6)	Do Nothing	Do Minimum/ Sustain (with recharge Yr6)
Residential properties	£15,205,815	£11,797,789	£7,928,568	£6,151,565
Non-Residential properties	£8,694,884	£7,008,346	£8,694,884	£7,008,346
Holiday Parks	£17,550,563	£12,226,225	£16,097,508	£11,507,792
Recreation	£7,713,150	£1,755,690	£7,713,150	£1,755,690
Tourism	£8,063,227	£320,340	£8,063,227	£320,340
Agriculture	£14,651,746	£13,151,587	-	-
Infrastructure	£2,267,584	£0	-	-
Total PV damages	£74,146,970	£46,259,977	£48,497,337	£26,743,734

Figure D2 and D3 show the results of the PF calculator for Case A1 and A2, respectively. Table D7 compares the outcomes of the Do Minimum/Sustain option considered in the OBC with the PF calculator outcomes for Cases A1 and A2. This shows that the Benefit to Cost Ratio of the scheme if the updated components of damages/benefits (Case A1) had been considered would have dropped from 6.08 to 4.74, due to the reduced amount of Grant in Aid that could potentially have been obtained from £1.8mi to £1.4mi. This means that funding contributions from external sources of £2.7mi as considered at the time of the OBC would not have been enough to undertake the works, and an additional £470,000 would have been needed.

If, in addition to the updated components of damages/ benefits, the costs had been adjusted as per current estimates (Case A2), the Benefit to Cost Ratio of the scheme would have dropped even further, to 2.87. An additional £3.5mi would have needed to be sourced from external contributions to cover the works.

Table D7: Comparison of outcome PF calculator values between the Do Minimum/Sustain OBC option and Cases A1 and A2

PF items	OBC	Case A1	Case A2
Scheme Benefit Cost Ratio	6.08	4.74	2.87
PV Damages	£46,259,997	£26,743,734	£26,743,734
PV Benefits	£27,886,993	£21,753,603	£21,753,603
Total PV Whole-Life Costs	£4,588,532	£4,588,532	£7,581,574
Grant in Aid value	£1,865,133	£1,397,025	£1,397,025
Total external contributions or saving required to achieve an Adjusted Score of 100%	£2,723,398	£3,191,507	£6,187,549
Raw Partnership Funding Score	41%	30%	18%
Adjusted PF score	100%	75%	29%
Total PV Contributions	£2,723,667	£2,723,667[1]	£2,723,667[1]
Additional external contributions required to undertake the works in Cases A1 and A2	-	**+£467,840**	**+£3,460,882**

[1] Assumes that the same contributions to the OBC were applied to Cases A1 and A2.

FCRM Partnership Funding Calculator for Flood and Coastal Erosion Risk Management Grant in Aid (FCRM GiA)
Version 8 January 2014

Project Name	Unit C Initial Assessment Case A1 (OBC 15yr Do Min / Sustain (one recharge with recycling))
Unique Project Number	With recharge in year 6

Key: Input cells; Calculated cells

All figures are in £'s
Figures in Blue to be entered onto Medium Term Plan

SUMMARY: prospect of FCRM GiA funding

Scheme Benefit to Cost Ratio:	4.74	to 1
Effective return to taxpayer:	4.74	to 1
Effective return on contributions:	7.99	to 1

Raw Partnership Funding Score	30%	(1)
External Contribution or saving required to achieve an Adjusted Score of 100%	3,191,507	(2)
Adjusted Partnership Funding Score (PF)	75%	(3)
PV FCERM GiA towards the up-front costs of this scheme (PV Cost for Approval)	-	(4)

Cell (2) shows the minimum amount of contributions and/or reductions in scheme cost that are required to raise the Adjusted PF Score to at least 100%. Further increases on this will improve this scheme's chances of an FCRM GiA allocation in the desired year. Planned savings and contributions should be entered into cells(9,10,12) and cells(14-17). See NOTE below.

1. Scheme details

Risk Management Authority type of asset maintainer	EA	(5)
Duration of Benefits (years)	15	(7)
PV Whole-Life Benefits:	21,753,603	(8)
PV Costs		
PV Appraisal Costs	75,000	(9)
PV design & Construction Costs	4,470,868	(10)
Sub Total - PV Cost for Approval (appraisal,design,construction)	4,545,868	(11)
PV Post-Construction Costs	42,664	(12)
PV Whole-Life Costs:	4,588,532	(13)
PV Contributions secured to date		
PV Local Levy secured to date	461,255	(14)
PV Public Contributions secured to date	14,000	(15)
PV Private Contributions secured to date	2,248,412	(16)
PV Funding form other Environment Agency functions/sources secured to date		(17)
PV Total Contributions secured to date	2,723,667	(18)

WARNING: Contributions less than minimum required in cell (2)

Yes (6) Is evidence available that a Strategic Approach has been taken, and that double counting of benefits has been avoided ?

All costs and benefits must be on a Present Value (PV) Whole-Life basis over the Duration of Benefits period. Where Contributions are identified these should also be on a Present Value basis.

The total value of any necessary contributions will depend on whether maintenance (ongoing costs) is funded through revenue FCRM GiA, or by other means.
NOTE: This scheme is to be maintained by the EA (ref cell 5). Any contributions needed (ref cell 2) are to help fund both up-front costs (cell 11) and future ongoing costs (cell 12) and should be entered into cells(14-17).

2. Qualifying benefits under Outcome Measure 2: households better protected against flood risk

Number of households in:	Before: Moderate risk	Before: Significant risk	Before: Very significant risk	After: Moderate risk	After: Significant risk	After: Very significant risk	Change due to scheme: Moderate risk	Change: Significant risk	Change: Very significant risk
20% most deprived areas							0	0	0
21-40% most deprived areas							0	0	0
60% least deprived areas			139		139		0	139	-139
Annual damages avoided (£), compared with a household at low risk							150	600	1,350

Change in household damages, in:	Per year	Over lifetime of scheme	Qual. benefits (discounted)	
20% most deprived areas	£ -	£ -	OM2 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM2 (21-40%)	£ -
60% least deprived areas	-£ 104,250	-£ 1,563,750	OM2 (60%)	£ 1,304,940

3. Qualifying benefits under Outcome Measure 3: households better protected against coastal erosion

Number of households in:	Before: Long-term loss	Before: Medium-term loss
20% most deprived areas		
21-40% most deprived areas		
60% least deprived areas		

Damages per household avoided:	Long-term loss	Medium-term loss	
Annual damages avoided	£ 6,000	£ 6,000	
Loss expected in	50	20	years
Present value of Year 1 loss (i.e. first year damages, discounted based on when loss is expected)	£ 1,184	£ 3,015	

Change in household damages, in:	Year 1 loss avoided:	Over lifetime of scheme:	Qual. benefits (discounted):	
20% most deprived areas	£ -	£ -	OM3 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM3 (21-40%)	£ -
60% least deprived areas	£ -	£ -	OM3 (60%)	£ -

4. Qualifying benefits under Outcome Measure 4: statutory environmental obligations met

Payments under:			Assumed benefits per unit:	Qual. benefits (discounted):	
OM4a		Hectares of net water-dependent habitat created	£ 15,000	OM4a	£ -
OM4b		Hectares of net intertidal habitat created	£ 50,000	OM4b	£ -
OM4c		Kilometres of protected river improved	£ 80,000	OM4c	£ -
				OM4	£ -

5. Qualifying benefits arising from the overall scheme, for entry into the Medium-Term Plan

OM, deprivation:		Qual. benefits:	Payment rate:	FCRM GiA contribution:
OM1		£ 20,448,663	5.56 p in the £1	£ 1,136,037
OM2	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ 1,304,940	20.0	£ 260,988
OM3	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ -	20.0	£ -
OM4		£ -	100.0	£ -
Total		£ 21,753,603		£ 1,397,025

Maximum for Outcomes delivered. The actual value any scheme is eligible for may be less.

Figure D2: PF Calculator (version 2014) for Case A1, Do Minimum/ Sustain (recycling with recharge on year 6)

FCRM Partnership Funding Calculator for Flood and Coastal Erosion Risk Management Grant in Aid (FCRM GiA)
Version 8 January 2014

Project Name	Unit C Initial Assessment Case A2 (OBC 15yr Do Min / Sustain (one recharge with recycling)) with updates costs
Unique Project Number	With recharge in year 6

Key	
	Input cells
	Calculated cells

All figures are in £'s
Figures in Blue to be entered onto Medium Term Plan

SUMMARY: prospect of FCRM GiA funding

Scheme Benefit to Cost Ratio:	2.87 to 1
Effective return to taxpayer:	2.87 to 1
Effective return on contributions:	7.99 to 1

Raw Partnership Funding Score	18%	(1)
External Contribution or saving required to achieve an Adjusted Score of 100%	6,184,549	(2)
Adjusted Partnership Funding Score (PF)	29%	(3)
PV FCERM GiA towards the up-front costs of this scheme (PV Cost for Approval)	-	(4)

Cell (2) shows the minimum amount of contributions and/or reductions in scheme cost that are required to raise the Adjusted PF Score to at least 100%. Further increases on this will improve this scheme's chances of an FCRM GiA allocation in the desired year. Planned savings and contributions should be entered into cells(9,10,12) and cells(14-17). See NOTE below.

1. Scheme details

Risk Management Authority type of asset maintainer	EA	(5)
Duration of Benefits (years)	15	(7)
PV Whole-Life Benefits:	21,753,603	(8)
PV Costs		
PV Appraisal Costs	75,000	(9)
PV design & Construction Costs	7,463,910	(10)
Sub Total - PV Cost for Approval (appraisal,design,construction)	7,538,910	(11)
PV Post-Construction Costs	42,664	(12)
PV Whole-Life Costs:	7,581,574	(13)
PV Contributions secured to date		
PV Local Levy secured to date	461,255	(14)
PV Public Contributions secured to date	14,000	(15)
PV Private Contributions secured to date	2,248,412	(16)
PV Funding form other Environment Agency functions/sources secured to date		(17)
PV Total Contributions secured to date	2,723,667	(18)

WARNING: Contributions less than minimum required in cell (2)

Yes (6) Is evidence available that a Strategic Approach has been taken, and that double counting of benefits has been avoided ?

All costs and benefits must be on a Present Value (PV) Whole-Life basis over the Duration of Benefits period. Where Contributions are identified these should also be on a Present Value basis.

The total value of any necessary contributions will depend on whether maintenance (ongoing costs) is funded through revenue FCRM GiA, or by other means.
NOTE: This scheme is to be maintained by the EA (ref cell 5). Any contributions needed (ref cell 2) are to help fund both up-front costs (cell 11) and future ongoing costs (cell 12) and should be entered into cells(14-17).

2. Qualifying benefits under Outcome Measure 2: households better protected against flood risk

Number of households in:	Before: Moderate risk	Before: Significant risk	Before: Very significant risk	After: Moderate risk	After: Significant risk	After: Very significant risk	Change due to scheme: Moderate risk	Change due to scheme: Significant risk	Change due to scheme: Very significant risk
20% most deprived areas							0	0	0
21-40% most deprived areas	-						0	0	0
60% least deprived areas			139		139		0	139	-139
Annual damages avoided (£), compared with a household at low risk							150	600	1,350

Change in household damages, in:	Per year	Over lifetime of scheme		Qual. benefits (discounted)
20% most deprived areas	£ -	£ -	OM2 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM2 (21-40%)	£ -
60% least deprived areas	-£ 104,250	-£ 1,563,750	OM2 (60%)	£ 1,304,940

3. Qualifying benefits under Outcome Measure 3: households better protected against coastal erosion

Number of households in:	Before: Long-term loss	Before: Medium-term loss
20% most deprived areas		
21-40% most deprived areas		
60% least deprived areas		

Damages per household avoided:	Long-term loss	Medium-term loss	
Annual damages avoided	£ 6,000	£ 6,000	
Loss expected in	50	20	years
Present value of Year 1 loss (i.e. first year damages, discounted based on when loss is expected)	£ 1,184	£ 3,015	

Change in household damages, in:	Year 1 loss avoided:	Over lifetime of scheme:		Qual. benefits (discounted):
20% most deprived areas	£ -	£ -	OM3 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM3 (21-40%)	£ -
60% least deprived areas	£ -	£ -	OM3 (60%)	£ -

4. Qualifying benefits under Outcome Measure 4: statutory environmental obligations met

Payments under:			Assumed benefits per unit:		Qual. benefits (discounted):
OM4a		Hectares of net water-dependent habitat created	£ 15,000	OM4a	£ -
OM4b		Hectares of net intertidal habitat created	£ 50,000	OM4b	£ -
OM4c		Kilometres of protected river improved	£ 80,000	OM4c	£ -
				OM4	£ -

5. Qualifying benefits arising from the overall scheme, for entry into the Medium-Term Plan

OM, deprivation:		Qual. benefits:	Payment rate:	FCRM GiA contribution:
OM1		£ 20,448,663	5.56 p in the £1	£ 1,136,037
OM2	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ 1,304,940	20.0	£ 260,988
OM3	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ -	20.0	£ -
OM4		£ -	100.0	£ -
Total		£ 21,753,603		£ 1,397,025

Maximum for Outcomes delivered. The actual value any scheme is eligible for may be less.

Figure D3: PF Calculator (version 2014) for Case A2, Do Minimum/ Sustain (recycling with recharge on year 6)

D.6 Case B – 2024 updated values

The aim of Case B was to look ahead to the next 7 years of the current approved scheme appraisal period (up to 2031), taking 2023 as the base year for updated damages and benefits (due to GDP Index 2023 Q3 availability) and current costs for both recharge and recycling activities as per estimates obtained in 2023, but still using the old version of the PF calculator (given this is still within the same scheme which started in 2016). Therefore, the appraisal period used for Case B was 7 years. Further assumptions are listed in Section D.3.

Apart from residential property values, which were uplifted using the average increase in house prices obtained from the Land Registry, all other damage values were uplifted using the GDP Deflator Index, as per the OBC methodology. This is a broader measure of inflation than the Consumer Prices Index and the recommended approach by LPRG economists (CH2M, 2016). At the time of this assessment, the latest available data was for 2023 Q3, which gave an increase of 34.6% from the 2012 Q4 (WECMS economics base date). The OBC used data for Q1 2015, which provided an increase of 3.6% from 2012 Q4.

The intention of this exercise was to understand the maximum GiA that could be potentially obtained given the updated benefits to present day (2023) values to the area, and assess affordability of different options, which would ultimately lead to the same outcome by 2031. Therefore, this case firstly reviewed whether the preferred option of beach recharge as set out in the 2016 OBC would still be affordable using present day costs and damages/benefits. In addition, alternatives to the planned approach were investigated in terms of how much could be spent if (i) works are still undertaken every year as currently done and (ii) how much could be afforded if a one-off scheme was to be undertaken now.

Therefore, for Case B, three sub-cases were assessed:

- Case B1: Review whether the preferred option of beach recharge as set out in the 2016 OBC is still affordable using the up-to-date estimates of beach recharge costs and adjusted damage/benefits to present day values. This assumed a one-off expenditure in year 0 (2024) and nothing else done until 2031.
- Option B2: What is the maximum affordable expenditure per year between 2024 and 2031.
- Option B3: What is the maximum affordable expenditure for a one-off scheme in year 0 (2024) and do nothing else until 2031

Annex D3 provides the supporting tables and PF calculator for Case B. Annex D4 shows in more detail all the assumptions and updates in terms of damage calculations and costs undertaken for this assessment.

D.6.1 Update of damaged/benefits to 2023 values

1) Residential property

As per Case A, the number of residential properties used in Case B was 139 (130 detached, 8 semi-detached, and 1 self-contained flat). Property values were updated based on the following:

- The 2016 Present Value (PV) for residential properties was adjusted (using a simple linear interpolation) to represent the number of residential properties seaward of the secondary embankment at the time of the OBC.
- This PV value was then uplifted to 2023 values using the average increase in houses prices between 2012 and 2023 (of 50%) for the three property types found in the study area (detached, semi-detached and flat). The average increase in house prices was obtained from the Land Registry website (https://landregistry.data.gov.uk/app/standard-reports).
- As per the OBC, to calculate the Do Nothing PV damage due to breach/failure, these values were divided by the Discount Factor at the year 5, which is when the probability of breach/failure is 100%.

In terms of breach assumptions, these were also changed from the OBC, and assumed for residential properties:

- Do Nothing: probability of breach increasing from 2% to 100% in year 5.
- Other sub-cases B: 2% probability of breach constant between year 0 and year 7, and increasing to 100% by year 20.

The probability adjusted PV Damage was summed over a 7-year period (between 2024 and 2031). In addition, the deprivation values were applied as per Case A.

Table D8 shows the PV values for residential properties used in this Case B, and a comparison with the values used in the WECMS and OBC. See supporting tables in Annex D3 for more details.

Table D8: Comparison between PV values for residential properties between WECMS, OBC and Case B of this assessment.

PV residential properties	WECMS	OBC	Case B (values updated to 2023 prices) and over the 7-year appraisal period
Do nothing	£13,412,220	£13,900,006[1]	£12,463,992[3]
Other cases	Unknown	£19,310,359[2]	£1,860,088[3]

[1] This value was updated on the OBC using DGP Index.

[2] It is unclear how this value was obtained at OBC stage.

[3] The values for this review were based on the proportion between the new residential property count (139) and the values from the WECMS (230 or 317), uplifted by average increase in house prices from the Land Registry.

2) Mental Health

The new FCERM guidance from 2021 states that mental health costs vary depending on the depth of flooding and also due to the average number of adults at different property types. For the purpose of this assessment, it has been assumed that, if flood occurs along the frontage, it will result in a flood depth of more than 100cm, which gives a value of £4,136 per adult per flood event due to mental health losses. Given an average of 1.82 adults per household, the total damage due to mental health losses was calculated to be £1,046,325.

This value was then entered into the residential property linear breach probability spreadsheet, using the same assumptions applied for residential properties. See Annex D3 for more details.

3) Non-residential properties

Given the uncertainties of non-residential property count and NRD description as detailed in Section D.5.1, the WECMS values for non-residential properties were simply uplifted using the GDP Index. This base value was divided by the discount factor at the year 5, which is when the probability of breach/failure is 100% to obtain the Do Nothing PV damage due to breach/failure for non-residential properties.

Similarly to the residential properties, breach assumptions were as follows:

  - Do Nothing: probability of breach increasing from 2% to 100% in year 5.
  - Other sub-cases B: 2% probability of breach constant between year 0 and year 7, and increasing to 100% by year 20.

The probability adjusted PV Damage was summed over a 7-year period.

4) Holiday Parks

Similarly to Case A, Compartment 5 has been excluded from Case B assessment. The costs of relocation for Compartments 1 to 3 were uplifted using the GDP Index and entered into a linear breach probability spreadsheet, using the following assumptions:

- Do nothing: probability of breach increasing from 2% to 100% in year 3 (as per WECMS and OBC)
- Other sub-cases B: 2% probability of breach constant between year 0 and year 7, and increasing to 100% by year 20.

The probability adjusted PV Damage was summed over a 7-year period.

5) Recreation

The recreation damage values from the WECMS were uplifted using the GDP Index. The same assumptions for Do nothing were applied (recreation damages increase from 10% of the annual loss to full annual loss by year 20). For the other sub-cases B, damages were assumed to increase from 10% (of annual loss) to full loss by year 50 (as per WECMS Do Minimum), but do not reset to 10% following Recharge (as the WECMS SDS and OBC assumed).

The probability adjusted PV Damage was summed over a 7-year period.

6) Tourism

The tourism damage values from the WECMS were uplifted using the GDP Index. The same assumptions for Do nothing were applied (losses increasing from 10% in year 1 to 50% in year 5 and 50% thereafter. For the other sub-cases B, it has been assumed uplifted WECMS Do Minimum losses throughout the 7-year appraisal period (i.e. losses do not reset to zero after Recharge as per OBC). The annual tourism losses used throughout was also reduced by 50% in the WECMS and in the OBC, and also assumed in this assessment, to attempt to avoid double counting with recreation losses.

7) Other damages

- Agricultural and infrastructure

Similarly to Case A, these have been excluded from Case B assessment.

- Vehicle, accommodation and emergency services

As per the WECMS and the OBC, these were assumed to be included in property damages. No value uplift was undertaken.

- Environment, Utilities, Risk to Life/ Vulnerability

These were not updated as part of this assessment (for Case B). The new FCERM guidance 2021 notes that environmental enhancement and carbon benefits can be used as part of the PF calculator. In addition, altering the natural processes of a beach and habitats, and any options such as beach recharge would incur carbon costs which must also be taken into account . However, these have not been included in this assessment due to the nature of this general review and the need to further studies to gather more accurate, up-to-date information to inform these inclusions.

D.6.2 Results

Table D9 below shows the results for PV damages for each component considering in Case B for both Do nothing and all the other sub-cases updated for present-day (2023) values.

Table D9: Updated PV damages for Case B Do nothing and sub-cases B1, B2 and B3

Updated PV damages	Case B - Do nothing	Case B – B1, B2 and B3
Residential properties	£11,480,219	£1,660,240
Non-Residential properties	£11,862,327	£1,715,499
Holiday Parks	£20,908,022	£2,964,864
Recreation	£4,449,078	£1,710,215
Tourism	£4,302,623	£747,118
Life/Health Damages	£1,009,561	£148,542
Total PV damages	£54,011,831	£8,946,478

The costs added to Case B assumed the following:

- Sub-case B1: A one-off beach recharge campaign occurring in year 0 (2024) and nothing else spent up to 2031 (end of the OBC appraisal period). For this case, a cost of £7.5 million for beach recharge was assumed, which is closer to the high estimates provided by the contractors in 2023 (Table D3). An additional £350,000 in year 0 was assumed for other costs potentially arising. No inflation was accounted for in this sub-case as all the money was assumed to be spent in year 0.
- Sub-case B2: different values were tested until the maximum annual expenditure until 2031 which provided a 100% Raw Partnership Funding Score was found. This value was around £275,000 per year plus an allowance for other costs potentially arising of around £55,000 per year, over the next 7 years. An average inflation of 3% a year up to 2031 was assumed.
- Sub-case B3: as per sub-case B2, different values were tested until the maximum expenditure in year 0 which provided a 100% Raw Partnership Funding Score was found. This value was around £2.25 million to be spent in year 0 plus an additional £350,000 in year 0 was assumed for other costs potentially arising. No inflation was accounted for in this sub-case as all the money was assumed to be spent in year 0.

See tab “PV Costs” in Annex D3, Case B_supporting_FCERM_final spreadsheet for more details.

Figures D4 to D6 show the PF calculator results of the different sub-cases considered as part of Case B. In addition, Table D10 compares each of the sub-cases B considered.

Table D10: Comparison of outcome PF calculator values for all options considered under Case B of this assessment

PF items	Sub-Case B1	Sub-Case B2	Sub-Case B3
Scheme Benefit Cost Ratio	5.74	17.31	17.33
PV Damages	£8,946,478	£8,946,478	£8,946,478
PV Benefits	£45,065,352	£45,065,352	£45,065,352
Total PV Whole-Life Costs	£7,850,000	£2,556,461	£2,560,000
Grant in Aid value	£2,610,764	£2,610,764	£2,610,764
Total external contributions or saving required to achieve an Adjusted Score of 100%	£5,239,236	£0	£0
Raw Partnership Funding Score	33%	100%	100%

This assessment showed that:

- Assuming present-day (2023) costs of beach recharge of around £7.5 million, external contributions of over £5.2 million would be required in order to cover costs of the scheme.
- The maximum annual expenditure which does not require any external contributions is around £275,000 (per year), plus an additional of £55,000 per year (sub-case B2). This is similar to sub-case B3, which showed that a maximum one-off expenditure of £2.25 million in year 0 could potentially be covered by GiA.

It is important to note that to ensure the total amount of GiA that could potentially be obtained, a full review of the damages and benefits is required, to ensure more certainty on the values and assumptions used, and also consider other components now available for the FCERM guidance 2021, such as environmental enhancement and carbon costs and benefits.

FCRM Partnership Funding Calculator for Flood and Coastal Erosion Risk Management Grant in Aid (FCRM GiA)
Version 8 January 2014

Project Name	Unit C Initial Assessment Sub-Case B1
Unique Project Number	Beach recharge in year 0

Key: Input cells; Calculated cells

All figures are in £'s
Figures in Blue to be entered onto Medium Term Plan

SUMMARY: prospect of FCRM GiA funding

Scheme Benefit to Cost Ratio:	5.74	to 1
Effective return to taxpayer:	5.74	to 1
Effective return on contributions:	n/a	to 1

Raw Partnership Funding Score	33%	(1)
External Contribution or saving required to achieve an Adjusted Score of 100%	5,239,236	(2)
Adjusted Partnership Funding Score (PF)	33%	(3)
PV FCERM GiA towards the up-front costs of this scheme (PV Cost for Approval)	-	(4)

Cell (2) shows the minimum amount of contributions and/or reductions in scheme cost that are required to raise the Adjusted PF Score to at least 100%. Further increases on this will improve this scheme's chances of an FCRM GiA allocation in the desired year. Planned savings and contributions should be entered into cells(9,10,12) and cells(14-17). See NOTE below.

1. Scheme details

Risk Management Authority type of asset maintainer	EA	(5)
Duration of Benefits (years)	7	(7)
PV Whole-Life Benefits:	45,065,352	(8)
PV Costs		
PV Appraisal Costs		(9)
PV design & Construction Costs	7,850,000	(10)
Sub Total - PV Cost for Approval (appraisal,design,construction)	7,850,000	(11)
PV Post-Construction Costs		(12)
PV Whole-Life Costs:	7,850,000	(13)
PV Contributions secured to date		
PV Local Levy secured to date		(14)
PV Public Contributions secured to date		(15)
PV Private Contributions secured to date		(16)
PV Funding form other Environment Agency functions/sources secured to date		(17)
PV Total Contributions secured to date	0	(18)

WARNING: Contributions less than minimum required in cell (2)

Yes (6) Is evidence available that a Strategic Approach has been taken, and that double counting of benefits has been avoided ?

All costs and benefits must be on a Present Value (PV) Whole-Life basis over the Duration of Benefits period. Where Contributions are identified these should also be on a Present Value basis.

The total value of any necessary contributions will depend on whether maintenance (ongoing costs) is funded through revenue FCRM GiA, or by other means.
NOTE: This scheme is to be maintained by the EA (ref cell 5). Any contributions needed (ref cell 2) are to help fund both up-front costs (cell 11) and future ongoing costs (cell 12) and should be entered into cells(14-17).

2. Qualifying benefits under Outcome Measure 2: households better protected against flood risk

Number of households in:	Before: Moderate risk	Before: Significant risk	Before: Very significant risk	After: Moderate risk	After: Significant risk	After: Very significant risk	Change due to scheme: Moderate risk	Change due to scheme: Significant risk	Change due to scheme: Very significant risk
20% most deprived areas							0	0	0
21-40% most deprived areas	-						0	0	0
60% least deprived areas			139		139		0	139	-139
Annual damages avoided (£), compared with a household at low risk							150	600	1,350

Change in household damages, in:	Per year	Over lifetime of scheme	Qual. benefits (discounted)	
20% most deprived areas	£ -	£ -	OM2 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM2 (21-40%)	£ -
60% least deprived areas	-£ 104,250	-£ 729,750	OM2 (60%)	£ 741,691

3. Qualifying benefits under Outcome Measure 3: households better protected against coastal erosion

Number of households in:	Before: Long-term loss	Before: Medium-term loss
20% most deprived areas		
21-40% most deprived areas		
60% least deprived areas		

Damages per household avoided:	Long-term loss	Medium-term loss	
Annual damages avoided	£ 6,000	£ 6,000	
Loss expected in	50	20	years
Present value of Year 1 loss (i.e. first year damages, discounted based on when loss is expected)	£ 1,184	£ 3,015	

Change in household damages, in:	Year 1 loss avoided:	Over lifetime of scheme:	Qual. benefits (discounted):	
20% most deprived areas	£ -	£ -	OM3 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM3 (21-40%)	£ -
60% least deprived areas	£ -	£ -	OM3 (60%)	£ -

4. Qualifying benefits under Outcome Measure 4: statutory environmental obligations met

Payments under:			Assumed benefits per unit:	Qual. benefits (discounted):	
OM4a		Hectares of net water-dependent habitat created	£ 15,000	OM4a	£ -
OM4b		Hectares of net intertidal habitat created	£ 50,000	OM4b	£ -
OM4c		Kilometres of protected river improved	£ 80,000	OM4c	£ -
				OM4	£ -

5. Qualifying benefits arising from the overall scheme, for entry into the Medium-Term Plan

OM, deprivation:		Qual. benefits:	Payment rate:	FCRM GiA contribution:
OM1		£ 44,323,661	5.56 p in the £1	£ 2,462,426
OM2	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ 741,691	20.0	£ 148,338
OM3	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ -	20.0	£ -
OM4		£ -	100.0	£ -
Total		£ 45,065,352		£ 2,610,764

Maximum for Outcomes delivered. The actual value any scheme is elligible for may be less.

Figure D4: PF Calculator (version 2014) for Case B1, beach recharge with present costs in year 0, do nothing else over the remainder of the OBC appraisal period (up to 2031)

FCRM Partnership Funding Calculator for Flood and Coastal Erosion Risk Management Grant in Aid (FCRM GiA)
Version 8 January 2014

Project Name	Unit C Initial Assessment Sub-Case B2
Unique Project Number	Maximum expenditure per year over the next 7 years

Key	
	Input cells
	Calculated cells

All figures are in £'s
Figures in Blue to be entered onto Medium Term Plan

SUMMARY: prospect of FCRM GiA funding

Scheme Benefit to Cost Ratio:	17.31	to 1
Effective return to taxpayer:	17.31	to 1
Effective return on contributions:	n/a	to 1

Raw Partnership Funding Score	100%	(1)
External Contribution or saving required to achieve an Adjusted Score of 100%	0	(2)
Adjusted Partnership Funding Score (PF)	100%	(3)
PV FCERM GiA towards the up-front costs of this scheme (PV Cost for Approval)	2,603,657	(4)

Cell (2) shows the minimum amount of contributions and/or reductions in scheme cost that are required to raise the Adjusted PF Score to at least 100%. Further increases on this will improve this scheme's chances of an FCRM GiA allocation in the desired year. Planned savings and contributions should be entered into cells(9,10,12) and cells(14-17). See NOTE below.

1. Scheme details

Risk Management Authority type of asset maintainer	EA	(5)
Duration of Benefits (years)	7	(7)
PV Whole-Life Benefits:	45,065,352	(8)
PV Costs		
PV Appraisal Costs		(9)
PV design & Construction Costs	2,603,657	(10)
Sub Total - PV Cost for Approval (appraisal,design,construction)	2,603,657	(11)
PV Post-Construction Costs		(12)
PV Whole-Life Costs:	2,603,657	(13)
PV Contributions secured to date		
PV Local Levy secured to date		(14)
PV Public Contributions secured to date		(15)
PV Private Contributions secured to date		(16)
PV Funding form other Environment Agency functions/sources secured to date		(17)
PV Total Contributions secured to date	0	(18)

Yes (6)
Is evidence available that a Strategic Approach has been taken, and that double counting of benefits has been avoided ?

All costs and benefits must be on a Present Value (PV) Whole-Life basis over the Duration of Benefits period. Where Contributions are identified these should also be on a Present Value basis.

The total value of any necessary contributions will depend on whether maintenance (ongoing costs) is funded through revenue FCRM GiA, or by other means.
NOTE: This scheme is to be maintained by the EA (ref cell 5). Any contributions needed (ref cell 2) are to help fund both up-front costs (cell 11) and future ongoing costs (cell 12) and should be entered into cells(14-17).

2. Qualifying benefits under Outcome Measure 2: households better protected against flood risk

Number of households in:	Before: Moderate risk	Before: Significant risk	Before: Very significant risk	After: Moderate risk	After: Significant risk	After: Very significant risk	Change due to scheme: Moderate risk	Change due to scheme: Significant risk	Change due to scheme: Very significant risk
20% most deprived areas							0	0	0
21-40% most deprived areas	-						0	0	0
60% least deprived areas			139		139		0	139	-139
Annual damages avoided (£), compared with a household at low risk							150	600	1,350

Change in household damages, in:	Per year	Over lifetime of scheme	Qual. benefits (discounted)	
20% most deprived areas	£ -	£ -	OM2 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM2 (21-40%)	£ -
60% least deprived areas	-£ 104,250	-£ 729,750	OM2 (60%)	£ 741,691

3. Qualifying benefits under Outcome Measure 3: households better protected against coastal erosion

Number of households in:	Before: Long-term loss	Before: Medium-term loss
20% most deprived areas		
21-40% most deprived areas		
60% least deprived areas		

Damages per household avoided:	Long-term loss	Medium-term loss	
Annual damages avoided	£ 6,000	£ 6,000	
Loss expected in	50	20	years
Present value of Year 1 loss (i.e. first year damages, discounted based on when loss is expected)	£ 1,184	£ 3,015	

Change in household damages, in:	Year 1 loss avoided:	Over lifetime of scheme:	Qual. benefits (discounted):	
20% most deprived areas	£ -	£ -	OM3 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM3 (21-40%)	£ -
60% least deprived areas	£ -	£ -	OM3 (60%)	£ -

4. Qualifying benefits under Outcome Measure 4: statutory environmental obligations met

Payments under:			Assumed benefits per unit:	Qual. benefits (discounted):	
OM4a		Hectares of net water-dependent habitat created	£ 15,000	OM4a	£ -
OM4b		Hectares of net intertidal habitat created	£ 50,000	OM4b	£ -
OM4c		Kilometres of protected river improved	£ 80,000	OM4c	£ -
				OM4	£ -

5. Qualifying benefits arising from the overall scheme, for entry into the Medium-Term Plan

OM, deprivation:		Qual. benefits:	Payment rate:	FCRM GiA contribution:
OM1		£ 44,323,661	5.56 p in the £1	£ 2,462,426
OM2	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ 741,691	20.0	£ 148,338
OM3	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ -	20.0	£ -
OM4		£ -	100.0	£ -
Total		£ 45,065,352		£ 2,610,764

Maximum for Outcomes delivered. The actual value any scheme is elligible for may be less.

Figure D5: PF Calculator (version 2014) for Case B2,maximum expenditure per year over the next 7 years

FCRM Partnership Funding Calculator for Flood and Coastal Erosion Risk Management Grant in Aid (FCRM GiA)
Version 8 January 2014

Project Name	Unit C Initial Assessment Sub-Case B3
Unique Project Number	Maximum expenditure in year 0, do nothing over the next 7 years

Key: Input cells / Calculated cells

All figures are in £'s
Figures in Blue to be entered onto Medium Term Plan

SUMMARY: prospect of FCRM GiA funding

Scheme Benefit to Cost Ratio:	17.33 to 1
Effective return to taxpayer:	**17.33** to 1
Effective return on contributions:	**n/a** to 1

Raw Partnership Funding Score	100%	(1)
External Contribution or saving required to achieve an Adjusted Score of 100%	0	(2)
Adjusted Partnership Funding Score (PF)	100%	(3)
PV FCERM GiA towards the up-front costs of this scheme (PV Cost for Approval)	2,600,000	(4)

Cell (2) shows the minimum amount of contributions and/or reductions in scheme cost that are required to raise the Adjusted PF Score to at least 100%. Further increases on this will improve this scheme's chances of an FCRM GiA allocation in the desired year. Planned savings and contributions should be entered into cells(9,10,12) and cells(14-17). See NOTE below.

1. Scheme details

Risk Management Authority type of asset maintainer	EA	(5)
Duration of Benefits (years)	7	(7)
PV Whole-Life Benefits:	45,065,352	(8)
PV Costs		
PV Appraisal Costs		(9)
PV design & Construction Costs	2,600,000	(10)
Sub Total - PV Cost for Approval (appraisal,design,construction)	**2,600,000**	(11)
PV Post-Construction Costs		(12)
PV Whole-Life Costs:	2,600,000	(13)
PV Contributions secured to date		
PV Local Levy secured to date		(14)
PV Public Contributions secured to date		(15)
PV Private Contributions secured to date		(16)
PV Funding form other Environment Agency functions/sources secured to date		(17)
PV Total Contributions secured to date	0	(18)

Yes (6) Is evidence available that a Strategic Approach has been taken, and that double counting of benefits has been avoided ?

All costs and benefits must be on a Present Value (PV) Whole-Life basis over the Duration of Benefits period. Where Contributions are identified these should also be on a Present Value basis.

The total value of any necessary contributions will depend on whether maintenance (ongoing costs) is funded through revenue FCRM GiA, or by other means.
NOTE: This scheme is to be maintained by the EA (ref cell 5). Any contributions needed (ref cell 2) are to help fund both up-front costs (cell 11) and future ongoing costs (cell 12) and should be entered into cells(14-17).

2. Qualifying benefits under Outcome Measure 2: households better protected against flood risk

Number of households in:	Before: Moderate risk	Before: Significant risk	Before: Very significant risk	After: Moderate risk	After: Significant risk	After: Very significant risk	Change due to scheme: Moderate risk	Change due to scheme: Significant risk	Change due to scheme: Very significant risk
20% most deprived areas							0	0	0
21-40% most deprived areas	-						0	0	0
60% least deprived areas			139		139		0	139	-139
Annual damages avoided (£), compared with a household at low risk							150	600	1,350

Change in household damages, in:	Per year	Over lifetime of scheme	Qual. benefits (discounted)	
20% most deprived areas	£ -	£ -	OM2 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM2 (21-40%)	£ -
60% least deprived areas	-£ 104,250	-£ 729,750	OM2 (60%)	£ 741,691

3. Qualifying benefits under Outcome Measure 3: households better protected against coastal erosion

Number of households in:	Before: Long-term loss	Before: Medium-term loss
20% most deprived areas		
21-40% most deprived areas		
60% least deprived areas		

Damages per household avoided:	Long-term loss	Medium-term loss	
Annual damages avoided	£ 6,000	£ 6,000	
Loss expected in	50	20	years
Present value of Year 1 loss (i.e. first year damages, discounted based on when loss is expected)	£ 1,184	£ 3,015	

Change in household damages, in:	Year 1 loss avoided:	Over lifetime of scheme:	Qual. benefits (discounted):	
20% most deprived areas	£ -	£ -	OM3 (20%)	£ -
21-40% most deprived areas	£ -	£ -	OM3 (21-40%)	£ -
60% least deprived areas	£ -	£ -	OM3 (60%)	£ -

4. Qualifying benefits under Outcome Measure 4: statutory environmental obligations met

Payments under:			Assumed benefits per unit:	Qual. benefits (discounted):	
OM4a		Hectares of net water-dependent habitat created	£ 15,000	OM4a	£ -
OM4b		Hectares of net intertidal habitat created	£ 50,000	OM4b	£ -
OM4c		Kilometres of protected river improved	£ 80,000	OM4c	£ -
				OM4	£ -

5. Qualifying benefits arising from the overall scheme, for entry into the Medium-Term Plan

OM, deprivation:		Qual. benefits:	Payment rate:	FCRM GiA contribution:
OM1		£ 44,323,661	5.56 p in the £1	£ 2,462,426
OM2	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ 741,691	20.0	£ 148,338
OM3	20% most	£ -	45.0	£ -
	21-40%	£ -	30.0	£ -
	Least 60%	£ -	20.0	£ -
OM4		£ -	100.0	£ -
Total		£ 45,065,352		£ **2,610,764**

Maximum for Outcomes delivered. The actual value any scheme is elligible for may be less.

Figure D6: PF Calculator (version 2014) for Case B3, maximum expenditure in year 0, do nothing over the remainder of the OBC appraisal period (up to 2031)