Gunton and Corton Options Appraisal

Appendix A - Coastal Processes Report

Document No. 02 | 2.0

March 2022

Coastal Partnership East

Gunton and Corton Options Appraisal

Project No: B2413600
Document Title: Appendix A - Coastal Processes Report
Document No.: Document No. 02
Revision: 1.0
Document Status: Final
Date: March 2022
Client Name: Coastal Partnership East
Client No:
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File Name: Appendix_A_Coastal_Processes Review.docx

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Document history and status

Issue	Date	Description	Author	Checked	Reviewed	Approved
0	October 2021	Draft for client review	Beatriz Serato	Kevin Burgess	Kevin Burgess	Helen Jay
1	January 2022	Issued for stakeholder engagement				Kevin Burgess
2	March 2022	Issued with formatting corrections				Beatriz Serato

Contents

1. Introduction

On behalf of East Suffolk Council, Coastal Partnership East (CPE) have commissioned Jacobs to undertake an updated review of potential options for delivering the Gorleston to Lowestoft Coastal Strategy Plan (2016) – 'the Strategy' – along the frontages extending across Gunton, Corton, and North Corton Cliffs, taking account of the latest changes to the coastal environment. Whilst the Strategy was approved in 2016, the analysis of coastal change predates this (2014).

To help inform any changes to the timeframes in which assets could become at risk, a desk-based review of available coastal data has been undertaken to establish the following:

- What does the most recent beach monitoring information show?
- Do the recent observed changes differ from the assumptions made/ findings reported in the Strategy?
- What are the possible reasons for any differences?

This review has then been used to determine the following, which are reported in the Main report:

- Has there been a change in risk from coastal erosion?
- How does this this affect the Strategy recommendations?

This report, appended to the Main Options Appraisal report, presents the findings of the coastal change analysis undertaken along Gunton Warren, Corton village and North Corton cliffs.

A separate detailed assessment was produced specifically for the Gunton Warren frontage to inform risks to the Anglian Water pipeline (Appendix D), which compliments this appendix. Results from Appendix D are also summarised in this report.

This report has been laid out as follows:

- Section 2: presents the data and methodology applied in this review.
- Section 3: describes the results of the coastal process review and compares this to the previous understanding presented in the Strategy.
- Section 4: presents the general conclusions of this review and summarises the key changes from previous understanding of shoreline behaviour and change.

In addition, the following annexes compliment the coastal processes review:

- Annex A: Beach profile analysis
- Annex B: Regression analysis
- Annex C: Offshore bathymetry
- Annex D: Wave assessment
- Annex E: Reference information from earlier studies

Figure 1-1: Study area for the coastal processes review

2. Analysis of coastal change

This section details the data used and applied methodology for the review of coastal processes along the Gunton, Corton and North Corton frontages.

2.1 Data used

Table 2-1 lists the datasets used in this analysis and their sources.

Topographic data are available from the Anglian Coastal Monitoring Programme and Figure 2-1 shows the location of the beach profiles analysed at each sub-section of the coast. Beach profiles located within the extent of the Anglian Water existing pipeline along the Gunton Warren frontage are highlighted in orange in Table 2-1. Along this section, beach surveys are only available for 2011 (two surveys) and 2016, with the exception of beach profile LW005. Therefore, additional beach levels have been extracted from the 2018 and 2019 LiDAR, and from drone surveys (October 2020 and April 2021) along the same transects to provide a more complete dataset.

Along the other frontages, it was possible to use topographic data collected from the Anglian Coastal Monitoring Programme given the high frequency of the surveys.

Table 2-1: Data used for the coastal change analysis along Gunton frontage

Data type	Source	Details	
		File name/ format	Dates available
Topographic beach profiles (17 in total)	Anglian Coastal Monitoring Programme	3b01434 (N117)	Aug 1992 to Dec 2020; no surveys between Aug 1992 and Aug 1996; bi-annual between 1996 and 2013; quarterly since 2013.
		3b01442 (GY29)	Aug 2003 to Dec 2020; bi-annual between 2003 and 2010; quarterly since 2011.
		3b01449 (GO87)	Aug 1996 to Dec 2020; bi-annual between 1996 and 2012; quarterly since 2013.
		3b01453 (GO91)	
		3b01459 (N118)	Aug 1992 to Dec 2020; bi-annual between 1992 and 2012; quarterly since 2013.
		3b01465 (GO102)	
		3b01468 (GY30)	
		3b01478 (GO114)	Aug 2005 to Dec 2020; bi-annual between 2005 and 2012; quarterly since 2013.
		3b01482 (GO118)	Oct 2008 to Dec 2020; bi-annual between 2008 and 2012. No surveys available between Dec 2012 and Oct 2016. Quarterly surveys since 2018.
		3b01486 (N119)	Aug 1992 to Dec 2020; bi-annual between 1992 and 2007; quarterly since 2008.
		3b01494 (GO129)	Aug 1996 to Dec 2020; bi-annual between 1996 and 2007; no surveys between Jan 2001 and Jul 2004; quarterly since 2008.
		3b01504 (N120)	Aug 1992 to Dec 2020; bi-annual between 1992 and 2007; quarterly since 2008.
		3b01513 (LW001)	Jun 2011 to Dec 2020; bi-annual between 2011 and 2020
		3b01515 (LW003)	Jun 2011 to Dec 2016; no surveys between Dec 2011 and Dec 2016

Data type	Source	Details	
		File name/ format	**Dates available**
		3b01517 (LW005)	Jun 2011 to Dec 2020; bi-annual between 2011 and 2020
		3b01518 (LW006)	Jun 2011 to Dec 2016; no surveys between Dec 2011 and Dec 2016
		3b01519 (LW007)	Jun 2011 to Dec 2016; no surveys between Dec 2011 and Dec 2016
		3b01520 (LW008)	Jun 2011 to Dec 2016; no surveys between Dec 2011 and Dec 2016
		3b01521 (N121)	Aug 1992 to Dec 2020; bi-annual between 1992 and 2007; quarterly since 2008.
LiDAR	Environment Agency	Digital Terrain Model (DTM)	1999, 2003, 2015, 2018 and 2019
Bathymetry	UKHO	1999, 2014 and 2017	
Drone surveys	Anglian Water	Raster files	October 2020 and April 2021
Historical aerial photographs	Google Earth	1945, 1999, 2006 and 2019	Only approximate position of mean sea level has been used.
Wave climate	Anglian Coastal Monitoring Programme	Wave height and direction available from the Lowestoft wave buoy between 2016 and 2020	
Anglian Water datasets	Anglian Water	Existing and proposed pipe alignment; position and invert levels of existing pipeline, provided in CAD format	

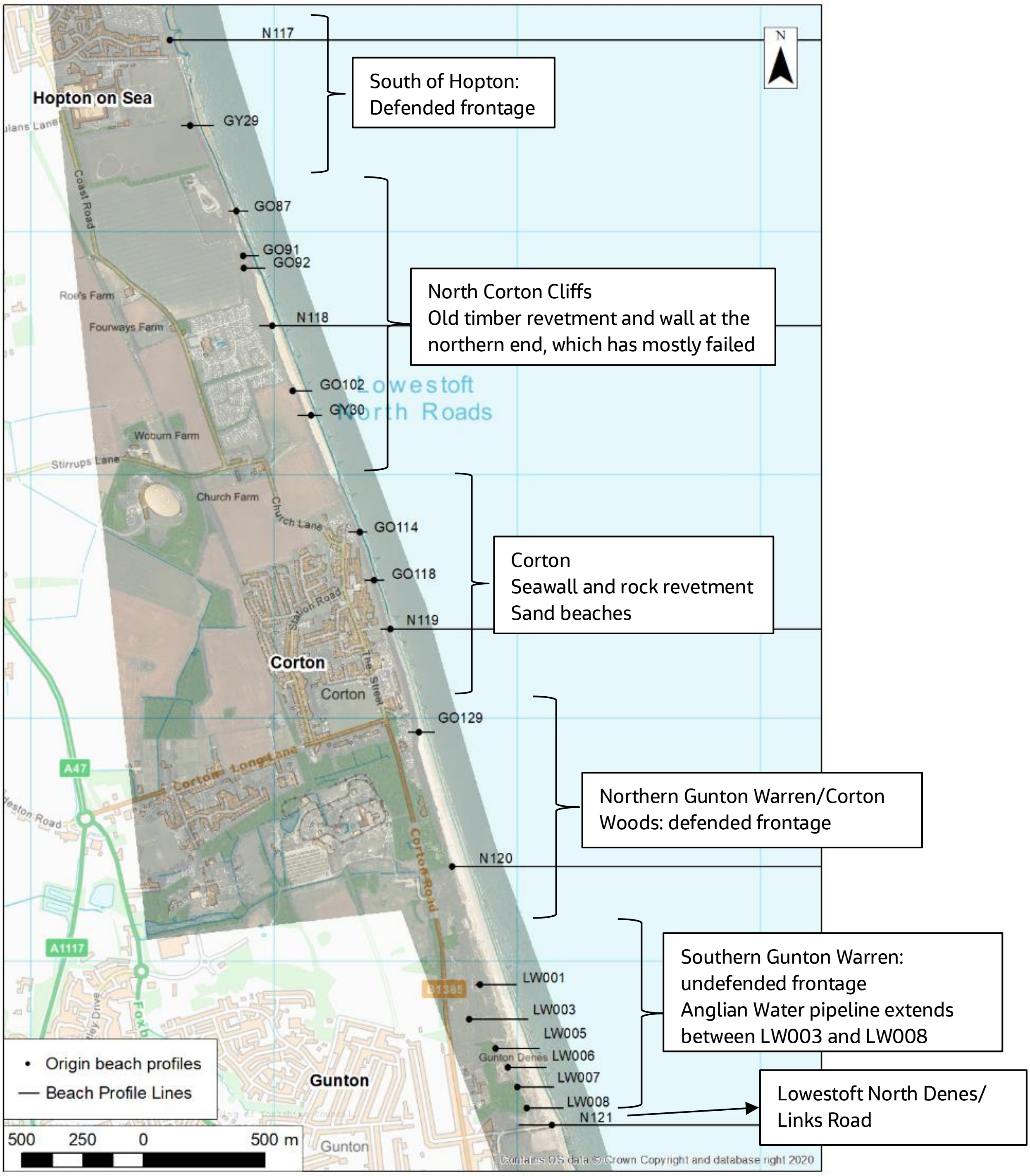


Figure 2-1: Location of the beach profiles used in this analysis. For beach profiles along Southern Gunton Warren frontage (LW003 to LW008) beach levels have also been extracted from LiDAR and drone surveys along the same transects.

2.2 Methodology

Three different analyses were undertaken to provide a comprehensive picture of the changes in the coastal processes:

1) difference plots analysis: this analysis provides an appreciation of changes across the whole frontage;

2) beach/bathymetry profile analysis: this analysis provides a detailed understanding of the cross-shore changes at each profile location; and

3) cliff, dune and tidal level assessment and regression analysis: to provide short and long-term trends of change.

Difference plots using bathymetry, LiDAR and drone surveys (for Southern Gunton Warren frontage only) have been produced, which compare (1) consecutive survey years and (2) the most recent to the oldest surveys. Difference plots have also been produced for each sub-section of the frontage.

The topographic beach profiles since December 2013 have been analysed in detail to determine how beach levels have been changing post-Strategy, and also to determine the impacts (if any) of the 2013/2014 storm events on the beach levels themselves. Prior to December 2013, a detailed analysis of the beach profiles has been undertaken during the Strategy, and this understanding have been incorporated into this review.

The same profile locations used for the topographic analysis have been extended further offshore and bathymetric levels extracted every 2 m, to identify any changes in bathymetry over time. These results have been compared to changes observed from the beach profile analysis.

Erosion rates have been calculated along the beach profiles, using the topographic data (for the whole frontage) and data extracted from the LiDAR and drone surveys (for Southern Gunton frontage only). Erosion rates have been calculated for various levels, depending upon the morphology of the location, including cliff face, dune face and/or beach level (see Table 2-2). The approach to calculating erosion rates has differed slightly at Gunton Warren, compared to the remainder of the frontage.

With the exception of the Gunton Warren frontage, long and short-term erosion rates along the frontage have been calculated using the representative level at each profile as follows:

- To assess the long-term trends, erosion rates have been calculated for two time periods: 1992 to 2020, and 2000 to 2020. This was done to provide a range of long-term rates and to include the oldest and the most recent records available at a given profile, as the date of which records start varies depending on the profile.

- To assess the short-term trends, erosion rates have been calculated for two time periods: 2011 to 2020 and 2016 to 2020, to provide a range of short-term trends and to include some of the profiles which records only started in 2011.

Along the Southern Gunton Warren frontage, erosion rates were calculated using different time periods to specifically assess risk to the Anglian Water pipelines. Using a level of +3 mOD, which is representative of the mid-dune face along the Southern Gunton frontage, erosion rates have been calculated as follows:

- For the assessment of erosion affecting the existing pipe, short-term rates (1-5 years) have been calculated for three time periods: 2016 to 2021, 2019 to 2021, and October 2020 to April 2021.

- To assess the risk of erosion to the future realigned pipe, longer term rates have also been calculated (5-10 years), for three different time periods: 2011 to 2016, 2011 to 2019, and 2011 to 2021. Although data are available pre-2011 for profile LW005, only data post-2011 has been used, as this is considered to best reflect the current trends along this frontage and also to present a worst-case scenario.

Table 2-2: Representative levels of which erosion rates were calculated

Profile name	Representative level
3b01434 (N117)	Mean Sea Level (MSL) = 0.09 mOD
3b01442 (GY29)	MSL = 0.09 mOD Highest Astronomical Tide (HAT) = 1.35 mOD
3b01449 (GO87)	Cliff face = 6 mOD Lower cliff face = 2 mOD MSL = 0.1 mOD
3b01453 (GO91)	Cliff face = 6 mOD MSL = 0.1 mOD
3b01459 (N118)	Cliff face = 6 mOD MSL = 0.1 mOD
3b01465 (GO102)	Cliff face = 6 mOD
3b01468 (GY30)	Cliff face = 6 mOD MSL = 0.1 mOD
3b01478 (GO114)	HAT = 1.34 mOD MSL = 0.09 mOD MLWS = -0.99 mOD
3b01482 (GO118)	HAT = 1.33 mOD MSL = 0.09 mOD MLWS = -0.99 mOD
3b01486 (N119)	MSL = 0.1 mOD
3b01494 (GO129)	MSL = 0.1 mOD
3b01504 (N120)	MSL = 0.11 mOD
3b01513 (LW001)	Dune face = 3 mOD MSL = 0.11 mOD
3b01515 (LW003)	Dune face = 3 mOD
3b01517 (LW005)	Dune face = 3 mOD
3b01518 (LW006)	Dune face = 3 mOD
3b01519 (LW007)	Dune face = 3 mOD
3b01520 (LW008)	Dune face = 3 mOD
3b01521 (N121)	HAT = 1.32 mOD MSL = 0.11 mOD

A linear regression analysis for each time period has been undertaken and used to predict the rate of change and thus the time until assets would be reached. Examples of the regression analysis undertaken are given in Figure 2-2 and Figure 2-3. Full details can be found in Annex B.

Historical aerial photographs since 1945 are available from Google Earth. Those were analysed and the shoreline position was digitalised for 1945, 1999, 2006 and 2019 aerial images to determine possible changes in shoreline alignment. The results were plotted in ArcGIS 10.6 using Esri basemap.

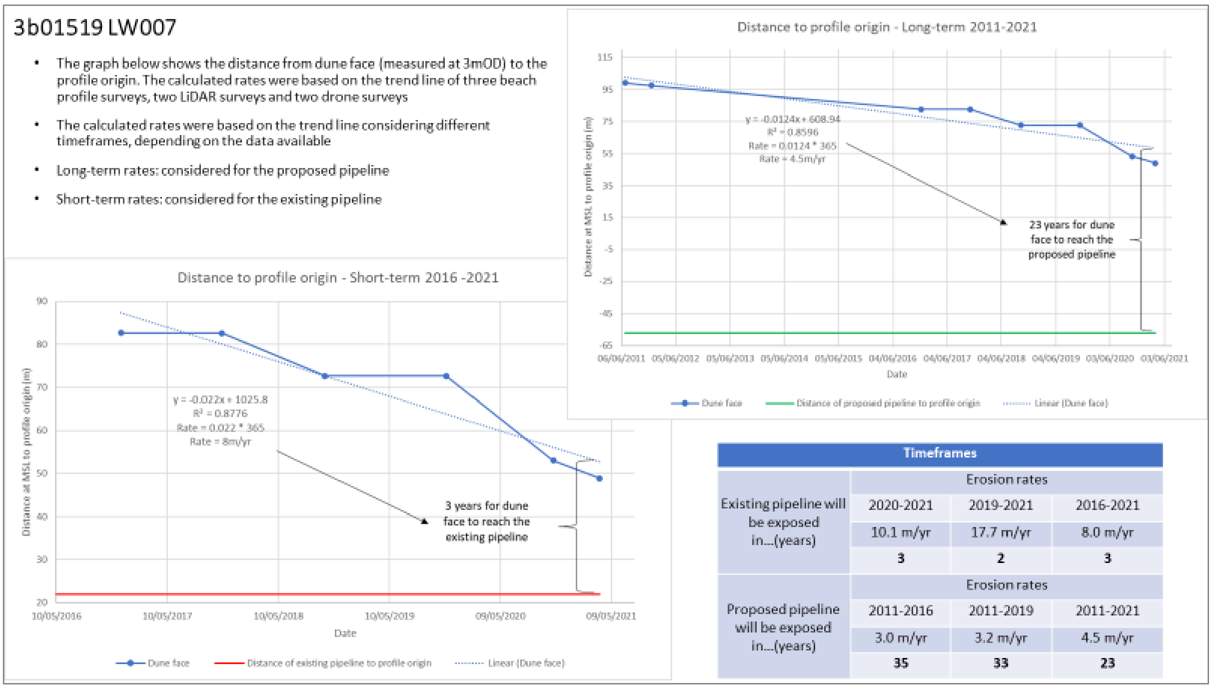


Figure 2-2: Example of the regression analysis undertaken for the Southern Gunton Warren frontage

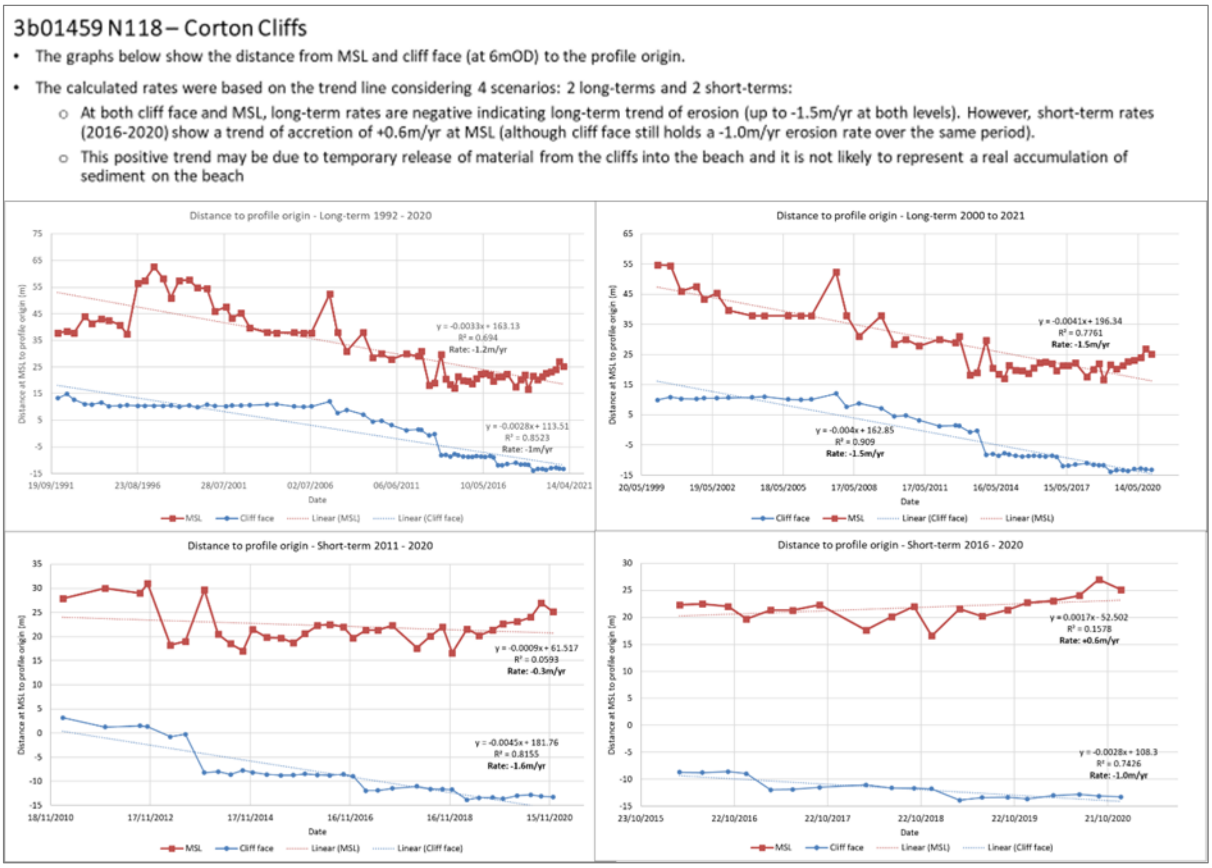


Figure 2-3: Example of the regression analysis undertaken for the Corton and North Corton frontages

3. Assessment of shoreline behaviour

The information presented in this section is supported by the detailed analysis reported in the following appendices:

- Annex A – Beach profile analysis and detailed description of changes
- Annex B – Results of the regression analysis to determine erosion trends
- Annex C – Bathymetry analysis
- Annex D – Wave analysis
- Annex E – Reference information from previous studies

3.1 Recent patterns of shoreline change

This section summarises the analysis undertaken, and changes observed, sub-dividing the whole frontage in five sub-sections (Figure 2-1):

- Lowestoft North Denes/ Links road, fronted by the Lowestoft North seawall;
- Southern section of Gunton Warren, undefended frontage where Anglian Water assets are located;
- Northern section of Gunton Warren, also referred to as Corton Woods, which is currently fronted by wider beaches;
- Corton village, fronted by coastal defences and cliff protection works;
- North Corton, partially undefended cliff frontage;
- South of Hopton-on-Sea, including the Hopton radar station, fronted by coastal defences. Although this section is outside the remit of this study, it has been included to inform the wider coastal processes.

3.1.1 Lowestoft North Denes (Links Road)

Profile N121 is located at Links Road (Figure 3-1). Three strategically important pumping mains and a car park located at Link's Road are protected by the northern end of Lowestoft North seawall. Here, the Strategy identified a less significant trend in beach changes compared to the undefended location of Gunton Warren further north (see Section 3.1.2). A net trend of foreshore lowering was observed up to 2013, with draw-down of material from the narrow upper beach at the toe of the seawall. Since the Strategy, there has been a continuation of the trends observed previously, with some seasonality influencing beach levels and the onshore movement of an inshore bar. The long-term trend at this frontage at Mean Sea Level (MSL) is for erosion, of up to 0.8 m/yr when considering the last 20 years of data.

3.1.2 Southern Gunton Warren: undefended section

The undefended section of the Gunton Warren frontage extends between Links Road to the south and Tramp's Alley to the north, with a total of six profiles analysed (Figure 3-1):

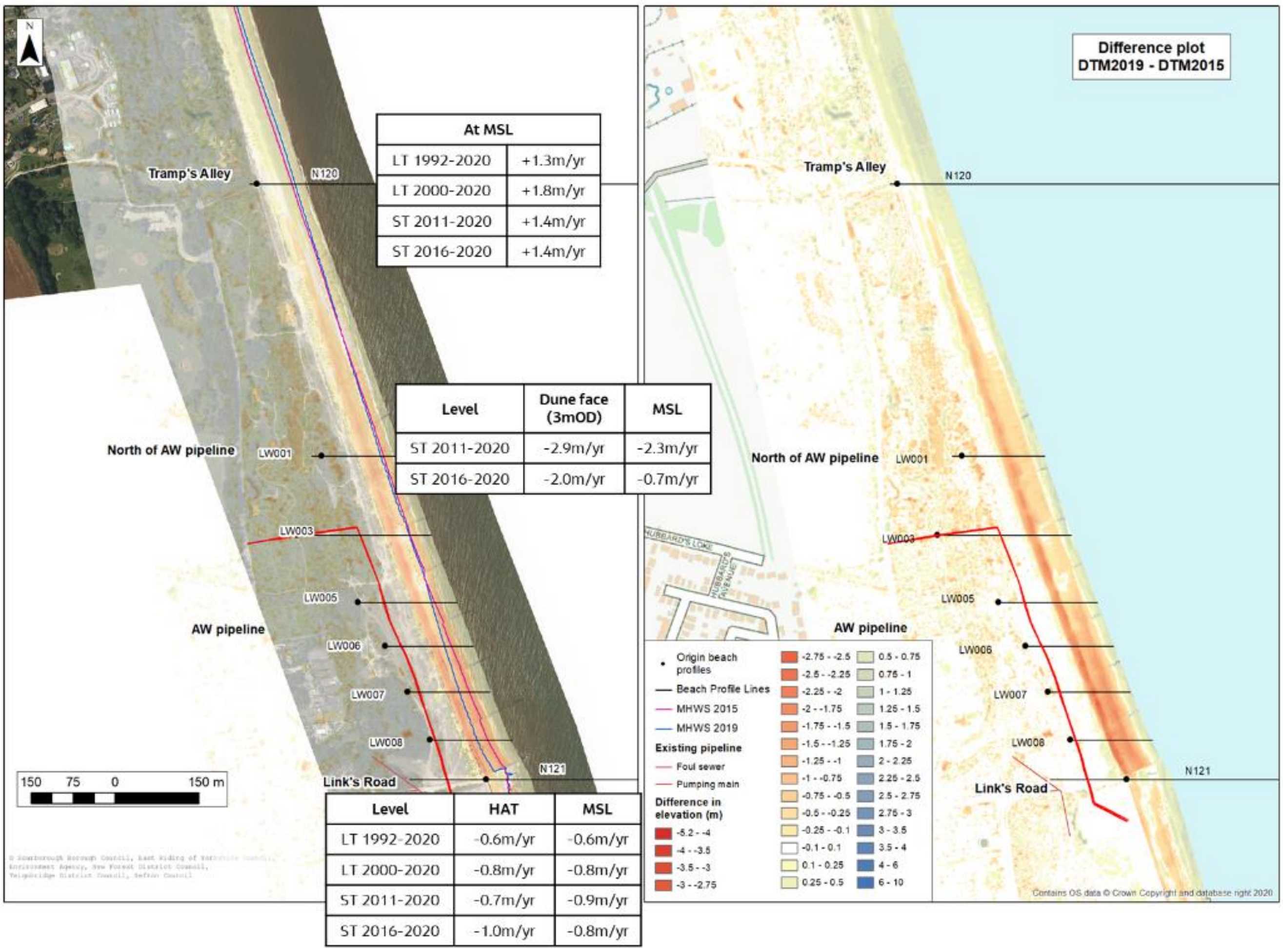
- LW003, LW005, LW006, LW007, LW008: along the pipeline owned by Anglian Water
- 3b01513 (LW001): south of Tramp's Alley

A detailed description of the erosion risk to the existing and proposed Anglian Water pipeline has been provided in a separate Technical Note (Appendix D). In summary, there has been a net erosional trend ongoing since 2011 along this frontage, with a retreat of beach face and scarping of the dune face in response to 2013/2014 storms. A similar pattern is also observed following the 2018 storms. The most recent profile (December 2020) showed a steep slope in both the beach and dune face. Erosion rates along the AW pipeline frontage range between 2.3 m/yr and 21.4 m/yr depending on location (see Figure 3-2).

Figure 3-2 shows the erosion rates for the frontage and estimated timeframes over which the existing Anglian Water pipeline and proposed realigned pipeline could be exposed. The assessments of beach change indicate that, if recent trends continue, then the realigned pipe could become at risk from erosion between approximately 25 and 40 years from now. However, shorter timeframes could put the realigned pipe at risk within less than 20 years at the northern end of the pipeline, where the existing and future pipe alignments converge.

All long and short-term trends here indicate that the existing pipeline is likely to become vulnerable within approximately 15 years and if the erosion rates seen over this past winter were to continue, that exposure could even be within the next year.

The beach fronting the section along Tramp's Alley (at profile LW001 – undefended section) showed small fluctuations in beach levels due to seasonal beach changes, prior to the 2013/2014 storms. Although some recovery is observed, levels are currently lower than pre-2013/2014 storms. The influence of the 2013 storms can be inferred by the greater erosion rate since 2011 at both dune face and MSL when compared to rates calculated since 2016 (Figure 3-1). Nevertheless, the short-term rates (since 2016) are still indicating erosional trends at this profile of 2 m/yr at the dune face and 0.7 m/yr at MSL.



At MSL	
LT 1992-2020	+1.3m/yr
LT 2000-2020	+1.8m/yr
ST 2011-2020	+1.4m/yr
ST 2016-2020	+1.4m/yr

Level	Dune face (3mOD)	MSL
ST 2011-2020	-2.9m/yr	-2.3m/yr
ST 2016-2020	-2.0m/yr	-0.7m/yr

Level	HAT	MSL
LT 1992-2020	-0.6m/yr	-0.6m/yr
LT 2000-2020	-0.8m/yr	-0.8m/yr
ST 2011-2020	-0.7m/yr	-0.9m/yr
ST 2016-2020	-1.0m/yr	-0.8m/yr

Figure 3-1: Gunton Warren and Lowestoft North Denes difference plot, showing difference in beach levels between 2015 and 2019 (using LiDAR). This figure also shows the erosion rates calculated at 3 mOD at seven profiles.

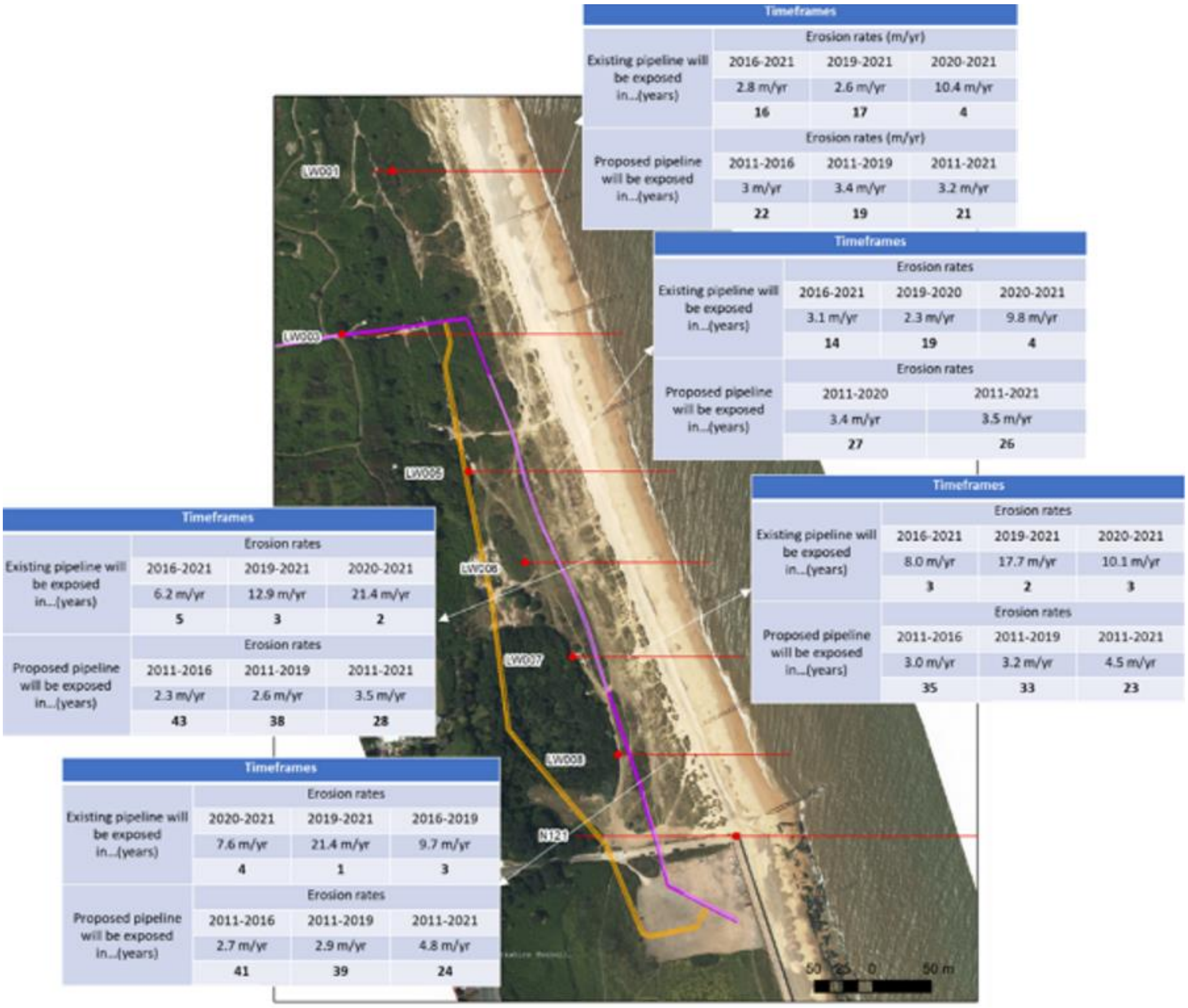


Figure 3-2: Specific erosion rates and timeframe for both existing and proposed pipelines to be exposed shown per beach profile location at Gunton Warren

3.1.3 Northern Gunton Warren (Corton Woods): defended section

The Northern Gunton Warren frontage extends between Tramp's Alley, adjacent to Colman Brook Lodge, and Corton Long Lane, with two profiles analysed (Figure 3-4):

- 3b01504 (N120): north of Gunton Warren, at Tramp's Alley
- 3b01494 (GO129): Corton Woods, at Corton Long Lane

This entire frontage is protected by coastal defences, comprising a concrete revetment between the Azure Sea Holiday Village and south of Tramp's Alley. This revetment is set back around 40 m compared to the defence to the north.

Between Tramp's Alley (profile N120) and Corton Long Lane (profile GO129) the Strategy concluded that beach levels varied up to 2 m due to seasonal changes but showed a general trend of accretion at least since the start of the data record (1999 and 1992, respectively). The analysis for this study indicated a continuation of the accretion trends observed in the Strategy, but at a faster pace at the northern profile (GO129): the calculated short-term rates since 2011 indicate up to 3.4 m/yr accretion at GO129 and 1.4 m/yr at Tramp's Alley (N120) at MSL. Calculated long-term rates also indicate accretion, of up to 1.6 m/yr at GO129 and 1.3 m/yr at Tramp's Alley at

MSL. At profile N120 (Tramp's Alley), both long and short-term rates are consistent and less variable than at Corton Long Lane.

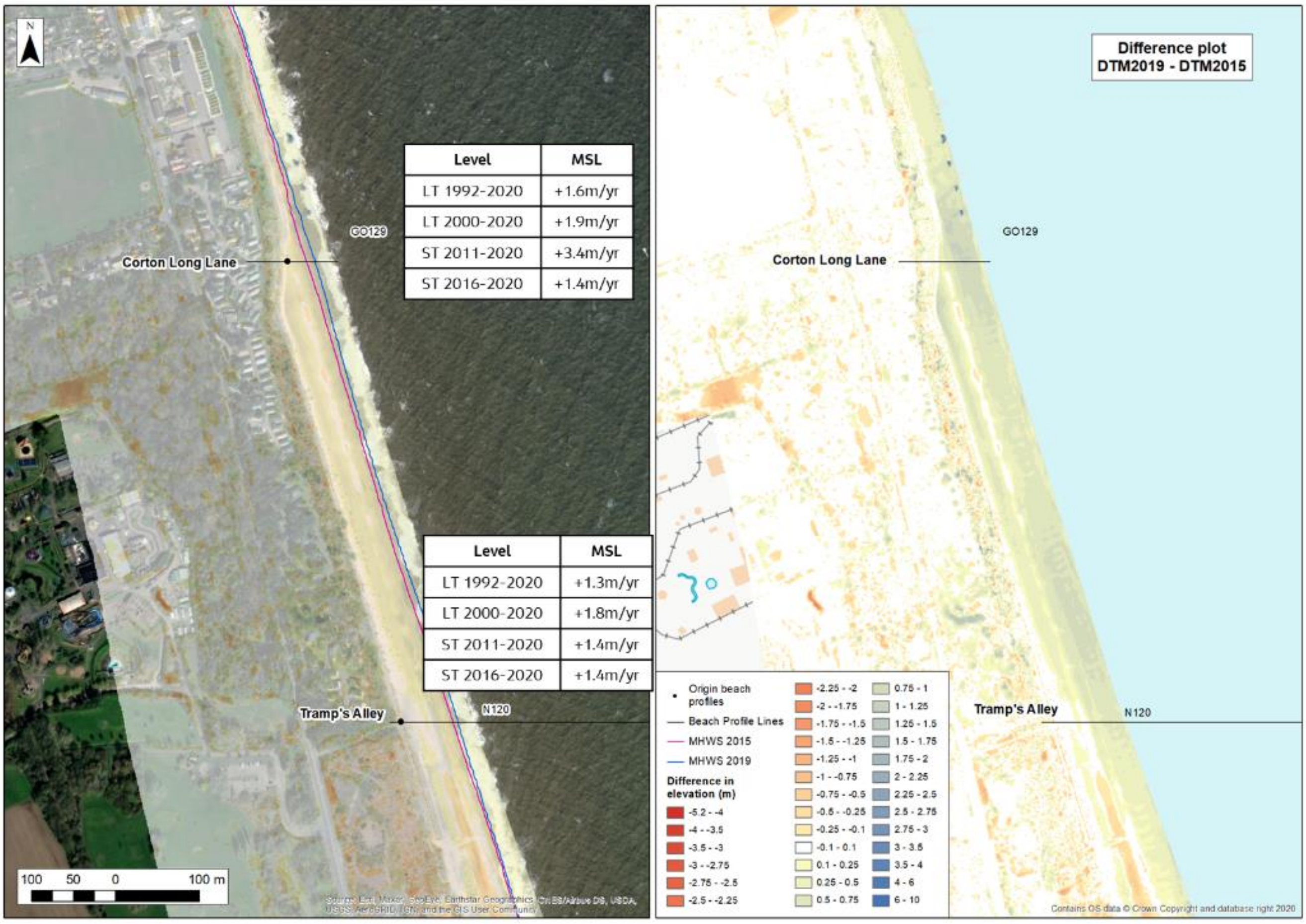


Figure 3-3: Northern Gunton Warren (Corton Woods) difference plot, showing difference in beach levels between 2015 and 2019 (using LiDAR). This figure also shows the erosion rates calculated at MSL at two profiles.

3.1.4 Corton village

The Corton village frontage extends between the rock revetment to the north of Corton Long Lane to Broadland Sands Holiday Park, with a total of three profiles analysed (Figure 3-4):

- 3b01486 (N119): Tibbenham's Score
- 3b01482 (GO118): Tingdene Waterside Park
- 3b01478 (GO114): south of Baker's Score ay Wy-Wurry

This entire frontage is protected by coastal defences, comprising a concrete revetment, with rock armour protection in places, between Baker's Score and the Azure Sea Holiday Village.

At Tibbenham's Score (profile N119), the Strategy described narrow and depleted beaches between 2006 and 2013; this however has since changed, due to a general trend of beach accretion and a resultant shallowing of the beach slope. Beach levels in December 2020 at MSL were generally 1.4 m higher than the level in September 2014. Whilst calculated long-term trends (measured at MSL) indicate a general trend of erosion of around 0.5 m/yr, and indeed rates calculated over the last 10 years also indicate the same (of up to 1 m/yr erosion rate), short-term trends since 2016 indicate recent accretion of up to 0.2 m/yr.

Beaches along the northern section of this frontage (between Baker's Score - GO114 and Tingdene Waterside Park – GO118) are very narrow, with little or no beach retained above mean low water.

South of Baker's Score (GO114), the LiDAR data in Figure 3-4 also some variation in levels on the cliff face (see detail in Figure 3-4 right) between 2015 and 2019, indicating that some instability and slump of the cliff face occurred over this period.

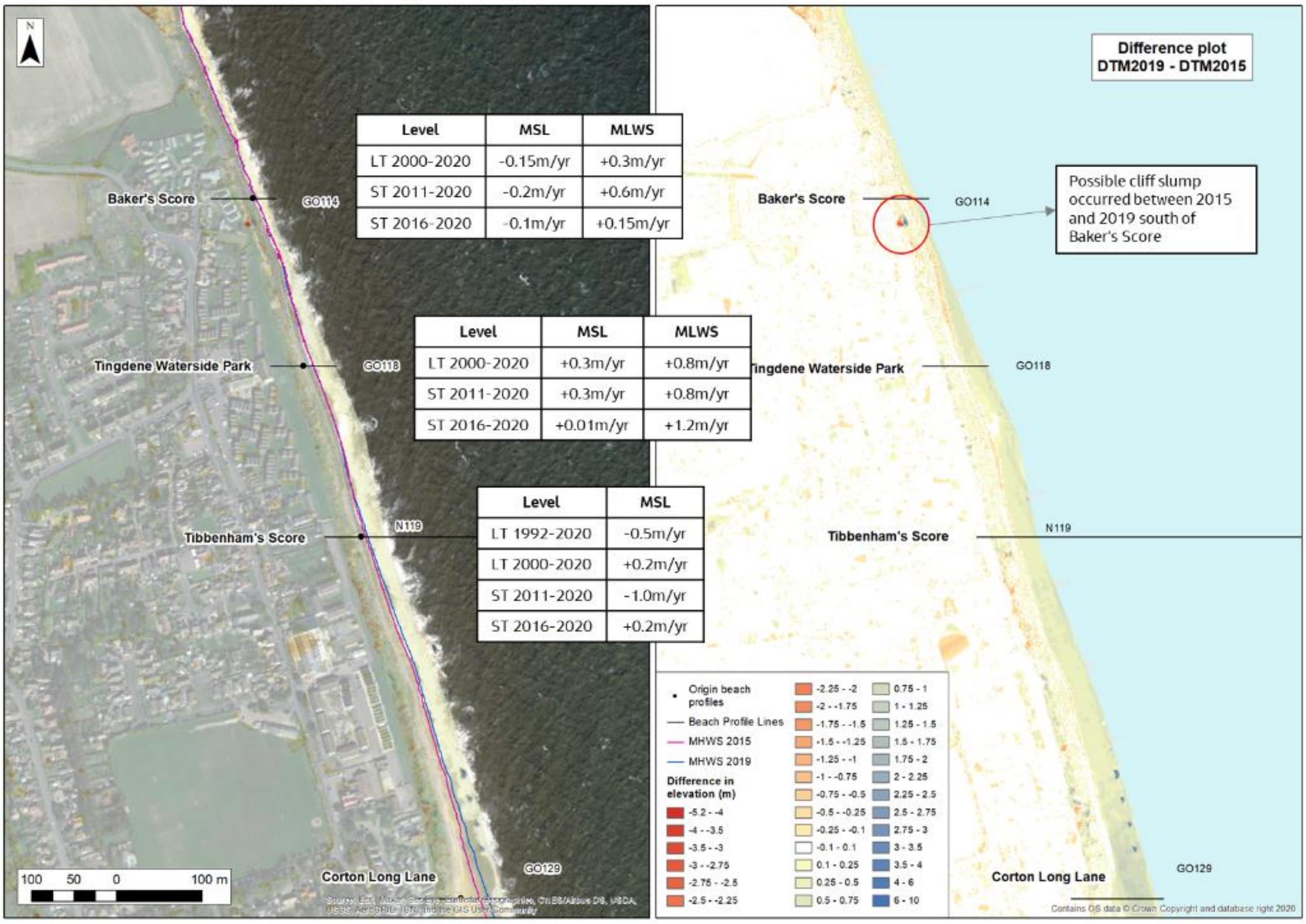


Figure 3-4: Corton village difference plot, showing difference in beach levels between 2015 and 2019 (using LiDAR). This figure also shows the erosion rates calculated at MSL at three profiles.

3.1.5 North Corton cliffs

The North Corton frontage covers the area between Church Farm (to the south) and south of the Hopton radar station (also referred here to RAF Hopton). Although outside of the study area, a further profile located at the Hopton radar station was included here for context. This gives a total of six profiles analysed (Figure 3-5):

- 3b01468 (GY30) – Corton Cliffs, south of Church Farm; partially defended by timber revetment
- 3b01465 (GO102) – Corton Cliffs, at Church Farm; partially defended by timber revetment
- 3b01459 (N118) – Corton Cliffs, at Broadland Sands Holiday Park; partially defended by timber revetment
- 3b01454 (GO92) – south of RAF Hopton/ north of Broadland Sands Holiday Park, currently defended by concrete and timber revetment
- 3b01453 (GO91) – south of RAF Hopton, failed concrete revetment

- 3b01449 (GO87) – RAF Hopton; failed concrete revetment (outside the study area but included for context)

Between profiles GY30 and GO92, along Broadland Sands Holiday Park and Church Farm, protection was provided by a timber revetment, which has failed in places. Even where it has not yet failed structurally, it is no longer fully functioning as a coastal defence and cliff erosion is ongoing behind it. The analysis for this study shows a continuation of the trends observed in the Strategy along this southern section, with a year-on-year gradual cliff retreat since 1992. Long-term erosion rates (measured at 6 mOD) are, therefore, the most representative of trends along this southern section, varying between 1 m/yr (at profile N118), 1.3 m/yr (at profile GY30) and 2.2 m/yr (at profile GO102). Figure 3-5 showed that, between 2015 and 2019, cliff recession reached up to 15 m over the four-year period.

At the location of profile GO92, the concrete revetment is still holding the original position, but it is believed to be at imminent risk of failure, given that both north and south of this location, there is currently rapid erosion (Figure 3-5).

The location of RAF Hopton between profiles GO87 and GO91 used to be fronted by a concrete revetment until 2013, when the storms in 2013/2014 resulted in its failure (Annex A, Figure A 17 and Figure A 18). Following the failure of defences, erosion rates (measured at 2 mOD – lower cliff face) have significantly increased, currently being up to 4.9 m/yr. Long-term rates of erosion are not representative of the ongoing trends due to the protection provided by defences prior to failure. Likewise, erosion rates calculated at profile GO91 are only available up to 2019, which are not representative of the ongoing trend.

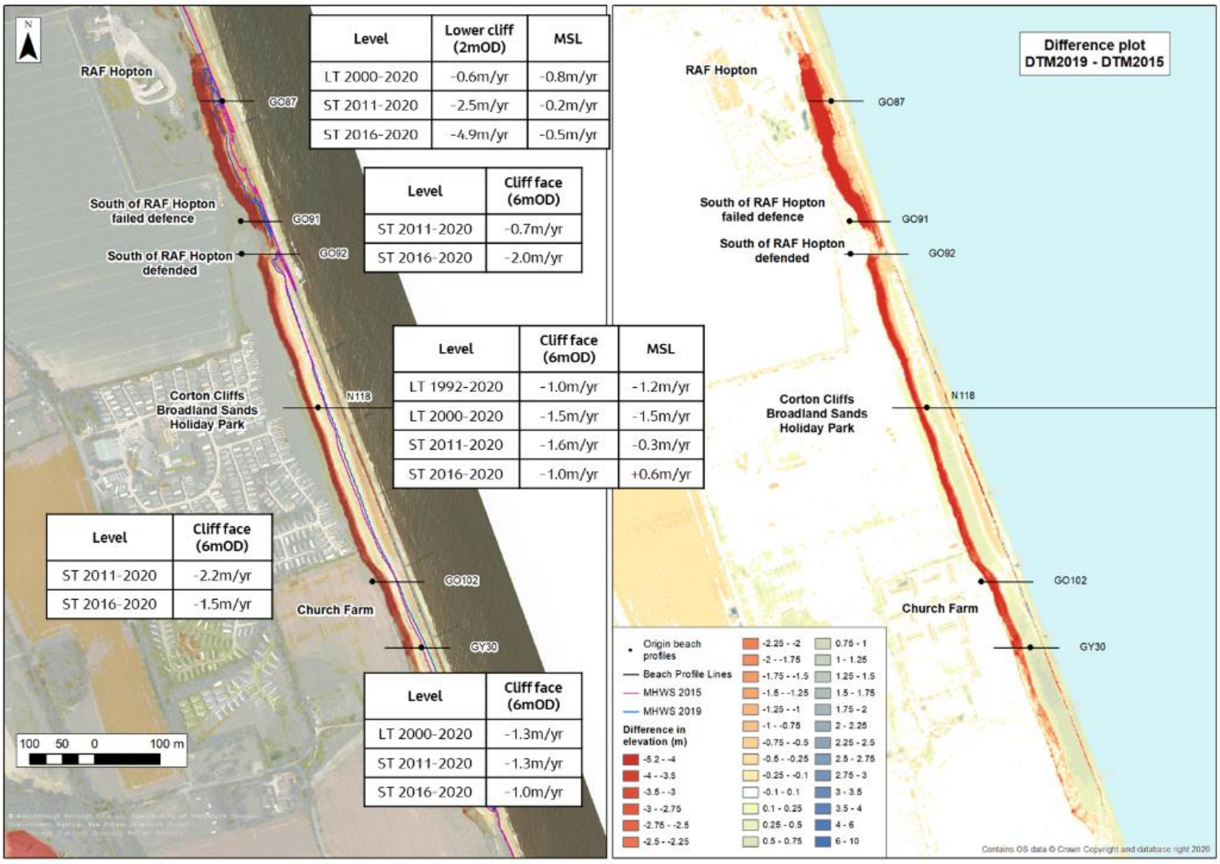


Figure 3-5: North Corton cliffs difference plot, showing difference in beach levels between 2015 and 2019 (using LiDAR). This figure also shows the erosion rates calculated at cliff face and MSL at five profiles. Erosion rates were not calculated for GO92 given that the current defence is still in place.

Interestingly, the retreating cliffs seem to be forming a more sheltered bay, indicating that material eroded from the cliffs is temporarily retained on the beach. This, in combination with the partially failed timber revetments, appears to have some sheltering effect along this frontage (between RAF Hopton to the north and Church Farm to the south), either slowing down or accreting beach levels immediately behind it (demonstrated by rates calculated at MSL).

3.1.6 South of Hopton-on-Sea

Although south of Hopton-on-Sea outside the remit of this study, analysis of the processes along this section has been undertaken to provide a complete picture of the changes ongoing along the whole frontage. This section is fronted by a rock revetment, which was extended south of the Beach Road along Potters Leisure Resort in 2016, and fish tail groynes, which were constructed around 2014. Along this frontage, two beach profiles were analysed (Figure 3-6):

- 3b01434 (N117) – Southern end of Hopton-on-Sea
- 3b01442 (GY29) – Potters Leisure Resort

Figure 3-6 shows the location of these profiles and the difference in beach elevation between 2015 and 2019. This difference plot illustrates the impact of the rock revetment extension, which was completed in 2016 and has effectively shifted the position of Mean High Water Springs (MHWS) offshore by around 5 m.

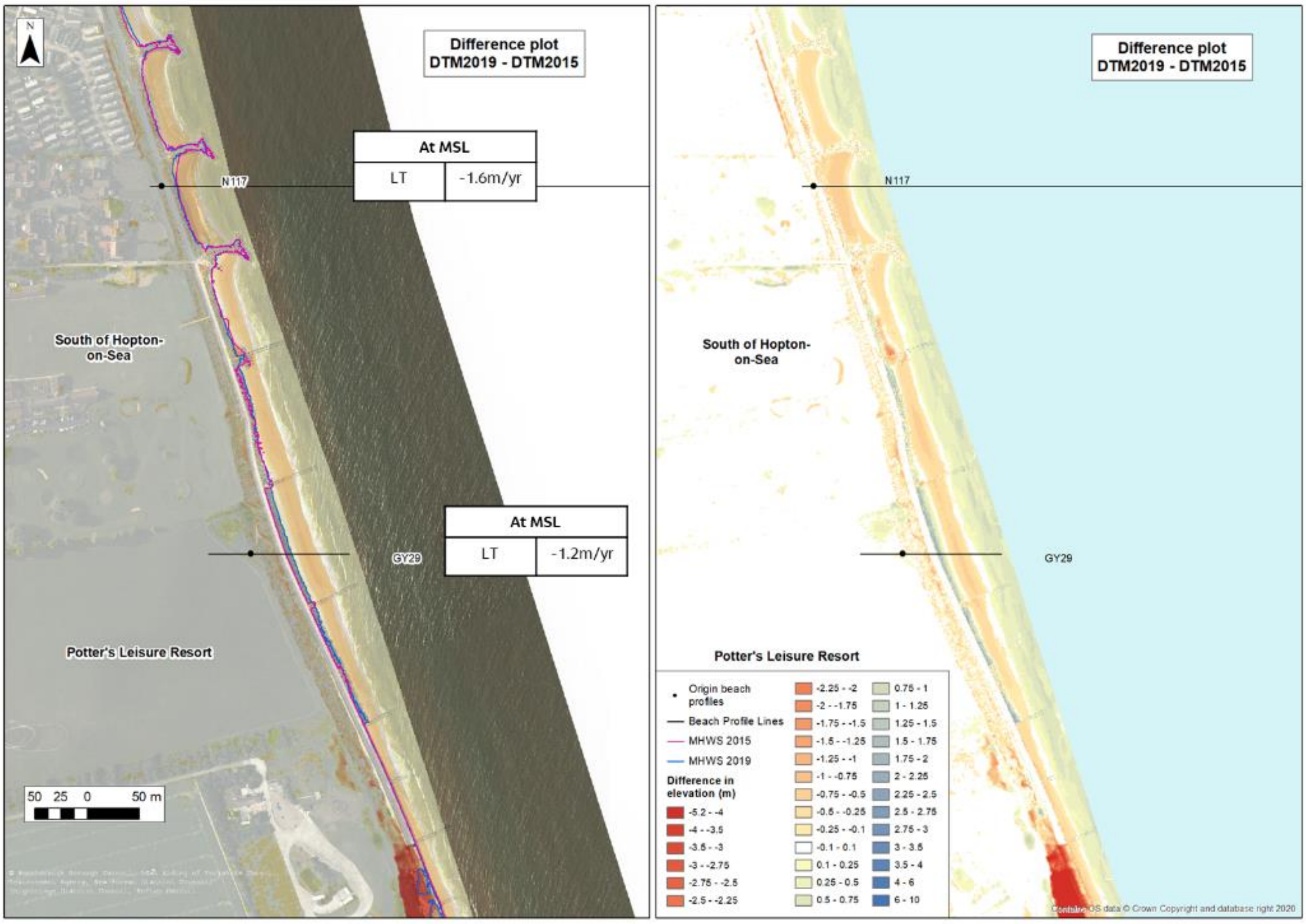


Figure 3-6: South of Hopton-on-Sea difference plot, showing difference in beach levels between 2015 and 2019 (using LiDAR). This figure also shows the erosion rates calculated at MSL at both profiles.

Along this frontage, variations in beach levels are associated with seasonal changes with typically lower beach levels during the winter and a partial recovery during the summer, albeit not as high as previous summers. The analysis shows a continuation of the trends observed in the Strategy, of a general net lowering of the beaches at least since 2007. Beaches in front of Potters Leisure Resort (profile GY29) were at their lowest recorded level in March 2013. Following the construction of the new rock revetment at this location in 2016, the data suggest that there was some beach recovery over the next couple of summers. Nevertheless, the beach along this frontage still showed a net lowering of up to 0.5 m between 2015 and 2019 (Figure 3-6).

At profile N117, calculated long and short-term trends of erosion at MSL both show similar rates of erosion, of around 1.6 m/yr. At profile GY29, long-term trend of erosion is around 1.2 m/yr, which is consistent to the northern section.

3.2 Changes in shoreline alignment

Historical aerial photographs have been examined to assess whether there has been a net change in plan form over time. Corton village has been fixed by defences for at least 70 years and, due to its protrusion, it functions as a headland between Hopton-on-Sea and Link's Road. This analysis has therefore examined changes in shoreline alignment to both the north and south of Corton village.

The approximate orientation of the beach (using MSL) in 1945, 1999, 2006 and 2019 was mapped using Google Earth aerial imagery (see Figure 3-7).

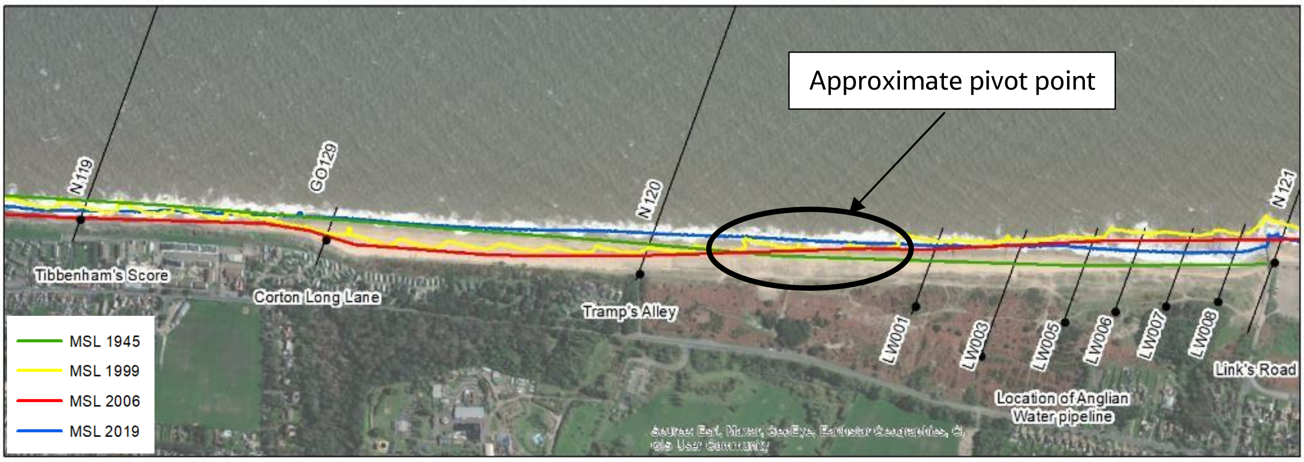


Figure 3-7: Shoreline orientation over time between Corton village (left) and Links Road (right). Basemap from Esri.

Figure 3-7 shows that the beach has both advanced and retreated since 1945, but at the larger scale the whole shoreline between Corton and Links Road has rotated. Between 1945 and 1999, there was net advancement (offshore movement) of the shoreline at the southern end of this frontage, but corresponding retreat (onshore movement) at the northern end (immediately south of Corton village), indicating a net anticlockwise rotation. In 2006, the shore orientation was similar to 1999, but by 2019 it had rotated back clockwise, with retreat to the south (at southern Gunton Warren), and advancement to the north (at northern Gunton Warren/Corton Woods).

It is also notable that the 1945 the position of MSL was much further inland than in 2019, mainly along the Gunton frontage, suggesting that the location of the existing Anglian Water pipeline may lie within what was previously the active beach zone.

Over time, the shoreline alignment has rotated by up to 5 degrees, with the pivot point located around Tramp's Alley (profile N120), at North Gunton. This orientation may reflect the predominant wave direction during those periods, indicating this has also altered over time (see Section 4).

A possible change in shore alignment has also been investigated to the north of Corton, but due to the history of interventions along that frontage no patterns could be determined.

The changes that have occurred show that this shoreline has changed in alignment in the past and therefore it is possible that the current trends may reverse again in the future, i.e. the beach along south of Corton/Corton Woods may recede whilst the beach along the southern end of Gunton Warren may begin to advance. However, due to uncertainty regarding the complexity of factors which may drive this, it is not possible to predict when this could occur.

4. Summary and conclusions

Significant recession (landward movement) has occurred along the undefended Gunton Warren shoreline in recent years, especially towards the very southern end (Links Road). The beach line remains some distance from the relict vegetated cliffs, but movement of the beach has resulted in some cut back into the low vegetated backshore 'dunes' that sit below the cliffs. This has led to exposure of buried oil deposits, concerns over risks to the existing AW pipelines, and also the potential for localised exposure and undermining of the east-west section of the seawall alongside Links Road car park. The recent set back of the beach at this location represents a significant increase in shoreline change anticipated by either the SMP or the Strategy. This is not, however, a new situation and may be attributable to changes at a larger scale.

In contrast to the southern end of Gunton Warren, the northern end has seen a steady accretion of the beach over recent years. However, this was not always the case. The current trend of accretion was reported in the Strategy, with accretion ongoing since around 2000/2001; prior to then the beaches tended to fluctuate but with no net trend of growth or erosion evident over the preceding years for which monitoring data was available (up to 1992). Historical aerial photographs show the beach line at this location has previously been some distant landward of its present position. The more recent data analysed by this study has found that although seasonal fluctuations of beach levels occur, there is currently a continuation of the previously observed accretion.

Beaches along the Corton frontage can fluctuate in level but in general have remained very narrow since monitoring surveys began, with commonly little or no beach above MSL. Since the Strategy, the monitoring data shows that beaches at Corton have both accreted and depleted at times, but with a net accumulation of sand along some of the frontage. This is likely to have resulted in the re-orientation observed to the south. Historically, however, this frontage has shown a long-term (50+ years) trend of recession, and the beach has gone through previous phases of improving and depleting. Even the recent growth is still only producing a narrow and low beach with little sign or suggestion of more considerable accumulations forming.

At North Corton, the presence of failing defence structures has had an effect on the rates of cliff erosion seen along this section of the shoreline with an initial increase of erosion rates. Short-term rates seem to be affected by the state of disrepair of the failing structures, which were themselves not generally designed to halt erosion, just slow it. Observations of rates at MSL showed that the timber revetment in combination with a more sheltered bay forming due to cliff retreat, has continued to have some sheltering effect along this cliff frontage, either slowing down or accreting beach levels immediately behind it.

In general terms, this analysis shows a continuation of the trends observed in the Strategy along the North Corton cliffs and concurs with the Strategy observation that the rate of erosion is not linear through time. Here long-term rates of erosion of the cliff face (rather than the beach) are the most representative of the levels of risk along North Corton, due to the localised influence of the relict defence structures. In contrast to the findings from the Strategy, this study found evidence to suggest that material eroded from the cliff is being retained locally on the beach.

There are a number of factors that potentially affect shoreline change between Gunton Warren and south of Hopton-on-Sea and it is likely that a combination of these have resulted in the changes in erosion and accretion patterns that have been observed.

One possible cause could be a change in the dominant wave direction. Wave data are available from the Anglian Coastal Monitoring Programme for the Lowestoft wave buoy, located approximately 4 km offshore of Lowestoft. Analysis of this (Annex D) indicates that there has been some change in the dominant direction of wave approach over time for both summer and winter wave climates. The changes in wave direction could then have increased the net northerly sediment drift, causing more deposition of sand along Corton and Northern Gunton Warren frontages, with a historical trend of shoreline re-orientation.

Another factor is likely to be changes to the nearshore bathymetry, as the area offshore of the Norfolk and Suffolk coastlines is characterised by a number of nearshore sandbanks, which extend between Winterton Ness to the north and Benacre Ness to the south. The banks move and migrate (within a semi-fixed location) due to the influence of ebb and flood tidal currents and are themselves a major influence on waves and tidal flows along this and adjacent coastlines.

Changes in these shallow banks can have a significant effect on waves at the shoreline, with waves being refracted and attenuated as they travel over those banks. Consequently, a change in the banks can also translate directly to a change in predominant wave direction at the shoreline.

Recent changes in the local bathymetry are discussed in Annex C. From analysis of available data, it has been found that there was a net shallowing of sandbanks and a deepening of subtidal channels around 2 km offshore of Corton-Gunton frontages between 1999 and 2017. The offshore data also indicates the presence of sand waves some 250 m from the coast (see in Annex C). These infer strong shore-parallel tidal currents in a northward direction fairly close to the shoreline.

Annex A. Beach profile analysis

A.1 Lowestoft North Denes (Links Road)

Figure A 1 shows beach profile 3b01521 N121 at Links Road. Records along this profile started in August 1992. The Strategy described the coastal processes (pre 2014) as follows:

- Less distinct beach change trends compared to other locations.
- Fluctuations in beach levels, more recently levels have tended to drop with drawdown of material from the upper beach, at the toe of the seawall.
- Cross sectional area above -1 m OD dropped by 30 m^2 (15-20% of original cross-sectional area).

The new analysis undertaken for this study shows that between March 2014 and December 2020 there has been:

- Fluctuations in beach levels observed with some seasonal changes and onshore movement of an inshore bar.
- Beach levels in December 2015 were the highest since 1992.
- A retreat of MSL observed between December 2015 and March 2019 (around 7 m), partial recovery by December 2020 (around 4 m). Therefore, a net retreat of 3 m from March 2019 to December 2020.
- Latest survey (December 2020) shows the lowest recorded beach levels at the toe of the defence (around 3 mOD).

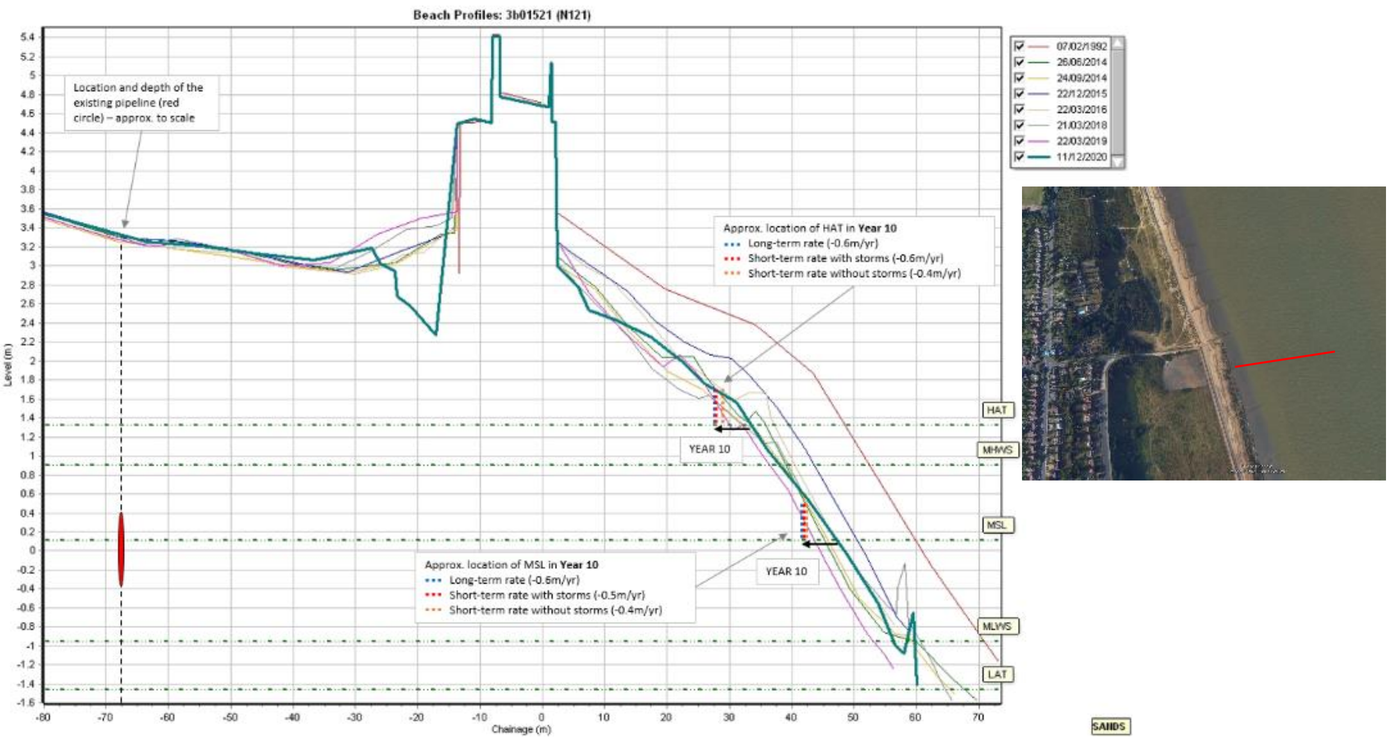


Figure A 1: Beach profile 3b01521 N121 – Links Road.

A.2 Southern Gunton Warren: undefended section

Figure A 2 shows profile 3b01520 LW008, located immediately north of Links Road, at southern Gunton Warren. Progressive retreat of the dune and beach face was observed since 2011, when records along this profile began. This figure also shows the LiDAR records for 2018 and 2019.

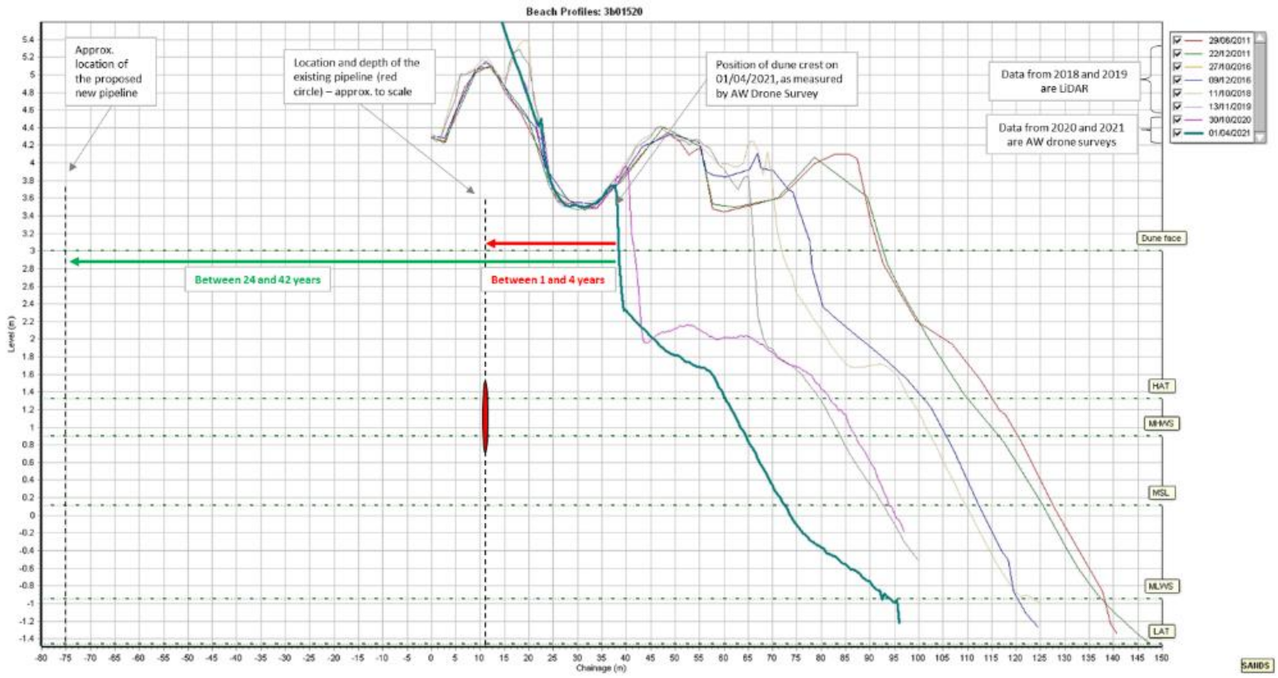


Figure A 2: Beach profile 3b01520 LW008 – southern Gunton Warren.

Figure A 3 shows profile 3b01519 LW007, located at southern Gunton Warren. Progressive retreat of the dune and beach face was observed since 2011, when records along this profile began. This figure also shows the LiDAR records for 2018 and 2019.

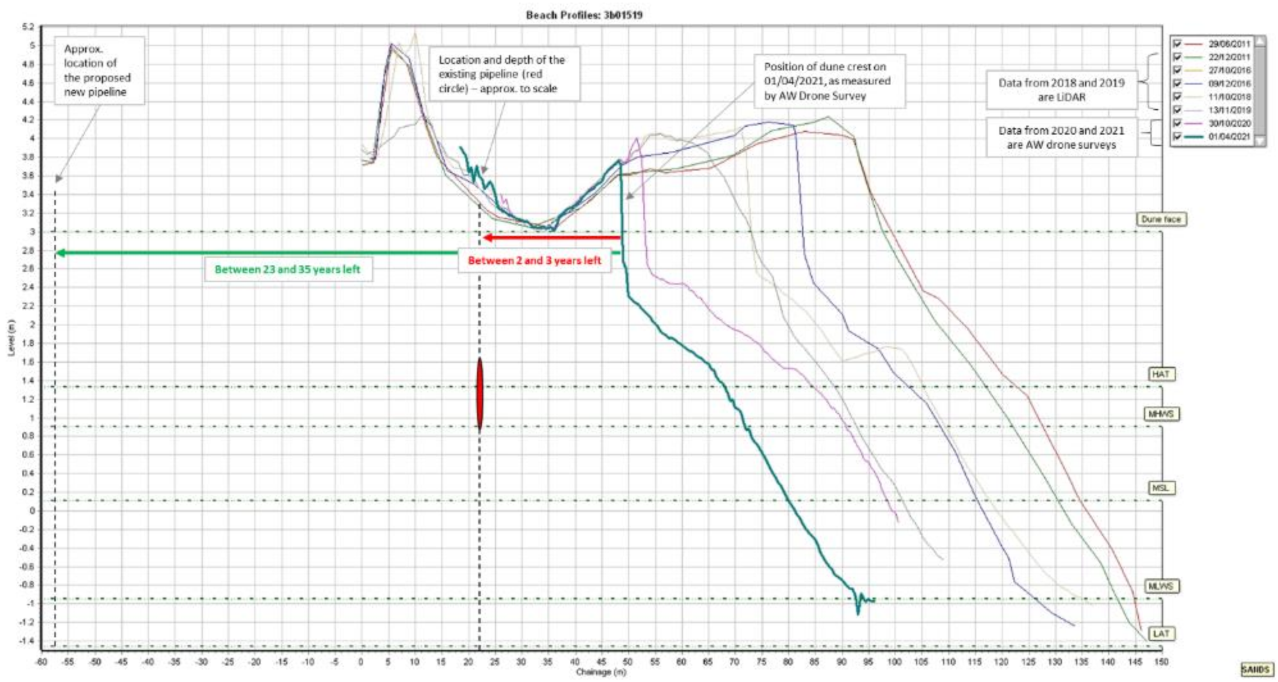


Figure A 3: Beach profile 3b01519 LW007 – southern Gunton Warren.

Figure A 4 shows profile 3b01518 LW006, located at southern Gunton Warren. Progressive retreat of the dune and beach face was observed since 2011, when records along this profile began. This figure also shows the LiDAR records for 2018 and 2019.

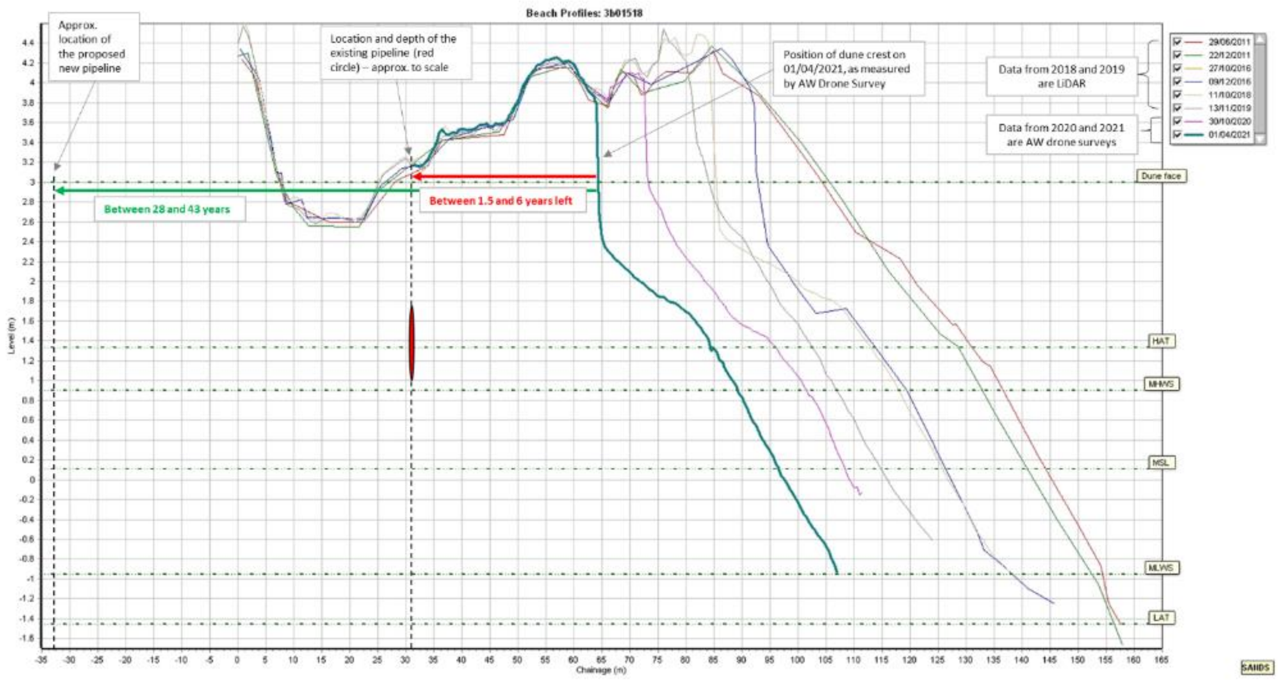


Figure A 4: Beach profile 3b01518 LW006 – southern Gunton Warren.

Figure A 5 shows profile 3b01517 LW005, located at southern Gunton Warren. Records along this profile started in June 2011. Coastal processes prior to the Strategy (pre 2014) were described as follows:

- Since records began in 2011, beach levels at this profile showed a trend of erosion, with retreat of the beach face and generally stable dune.
- A retreat of beach face and scarping of the dune face occurred by mid December 2013, probably related to the 05 December 2013 storms.

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- Further scarping of the dune face and retreat of the beach occurred by June 2014 (probably due to the 2013/2014 storms), by around 7 m.
- Since then, erosion and scarping is evident, with the profile March 2018 showing the lowest recorded levels close to the dune face.
- The latest profile available (Dec 2020) shows a parallel retreat of the beach profile, with a continuation of scarping of both beach face and dune face.

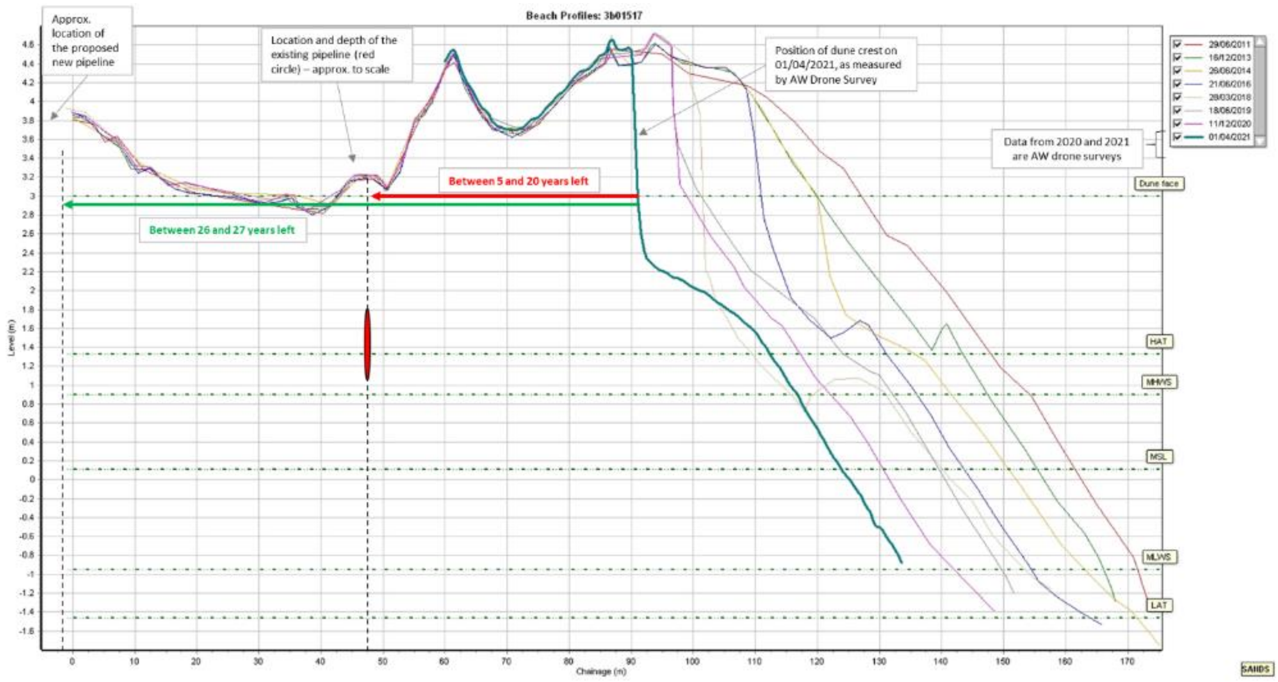


Figure A 5: Beach profile 3b01517 LW005 – southern Gunton Warren.

Figure A 6 shows profile 3b01518 LW006, located at southern Gunton Warren. Progressive retreat of the dune and beach face was observed since 2011, when records along this profile began. This figure also shows the LiDAR records for 2018 and 2019.

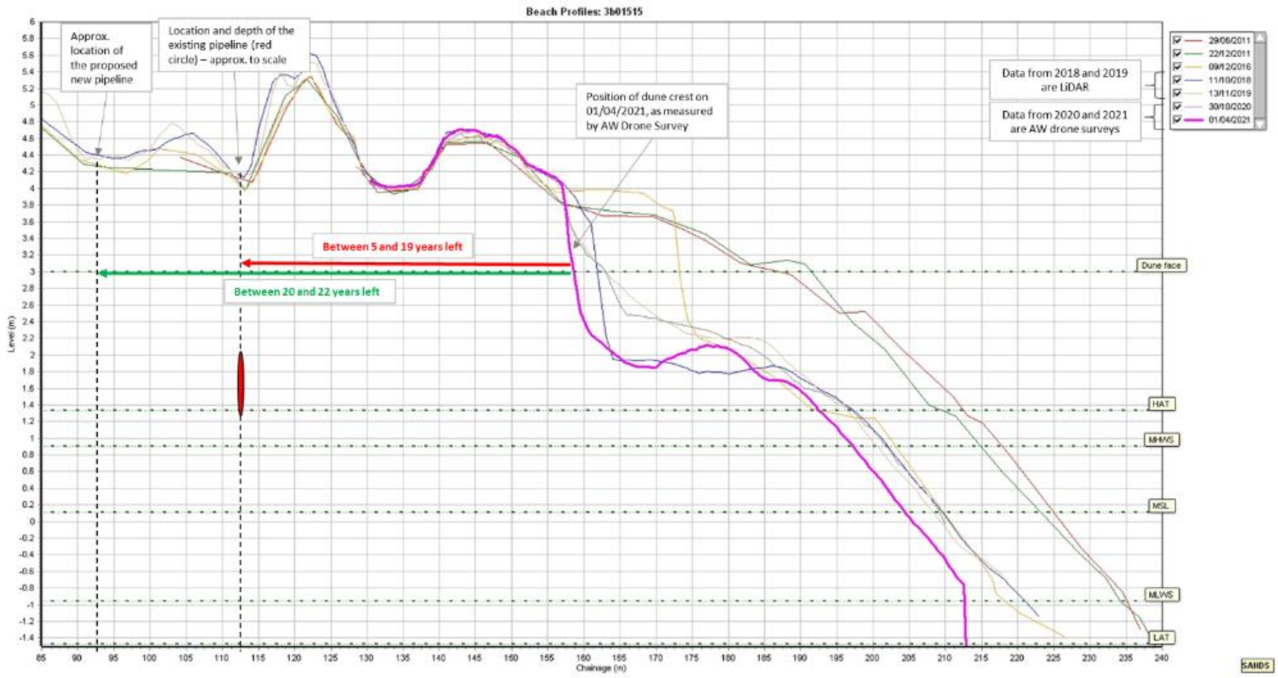


Figure A 6: Beach profile 3b01515 LW003 – southern Gunton Warren.

Figure A 7 shows beach profile 3b01513 LW001, located at southern Gunton Warren. Records along this profile started in June 2011. The Strategy described the coastal processes (pre 2014) as follows:

- Since records began in 2011, beach levels have been relatively stable, with fluctuations due to seasonality.

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- Retreat of the beach face (between HAT and LAT) by around 5 m (measured at MSL) due to the 2013/2014 storms.
- Since the storms, the beach face and dunes have retreated.
- Lowest beach / dune levels were recorded in March 2018 with significant retreat of the dune face (20m at HAT between June 2017 and March 2018).
- By December 2020, both the beach and dune face recovered, but HAT was still landward of the June 2017 position.

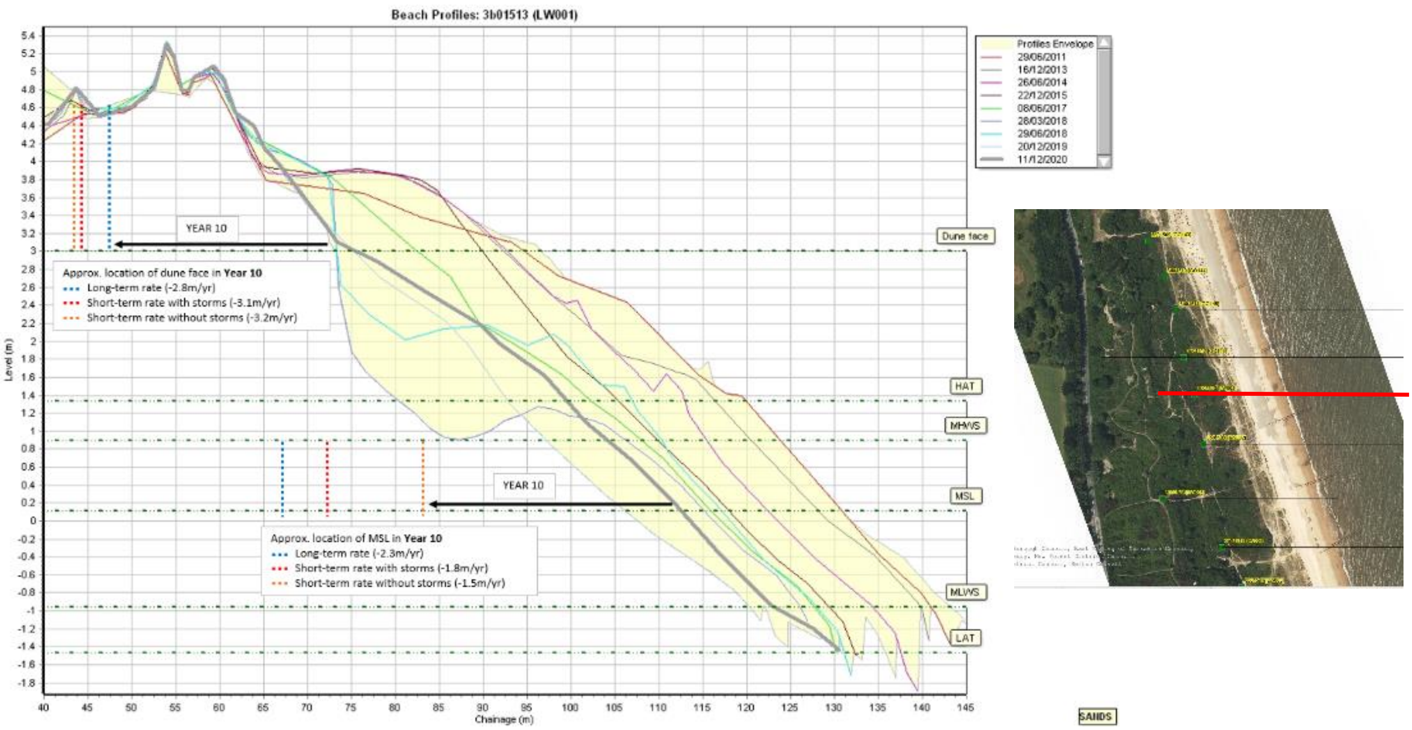


Figure A 7: Beach profile 3b01513 LW001 – southern Gunton Warren.

A.3 Northern Gunton Warren (Corton Woods): defended section

Figure A 8 shows beach profile 3b1504 N120, located at Tramp's Alley. Records along this profile started in 1992. The Strategy described the coastal processes (pre 2014) as follows:

- Since 1992 shallowing of beach slope and no net growth.
- Ongoing trend of beach accretion since 2001 – increase of cross-sectional area of 100 m^2.

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- Trend of beach slope shallowing continuing with an advance of MSL by around 10 m.

- The back of the beach has maintained the same level (3.8mOD) albeit with some seasonal fluctuations.

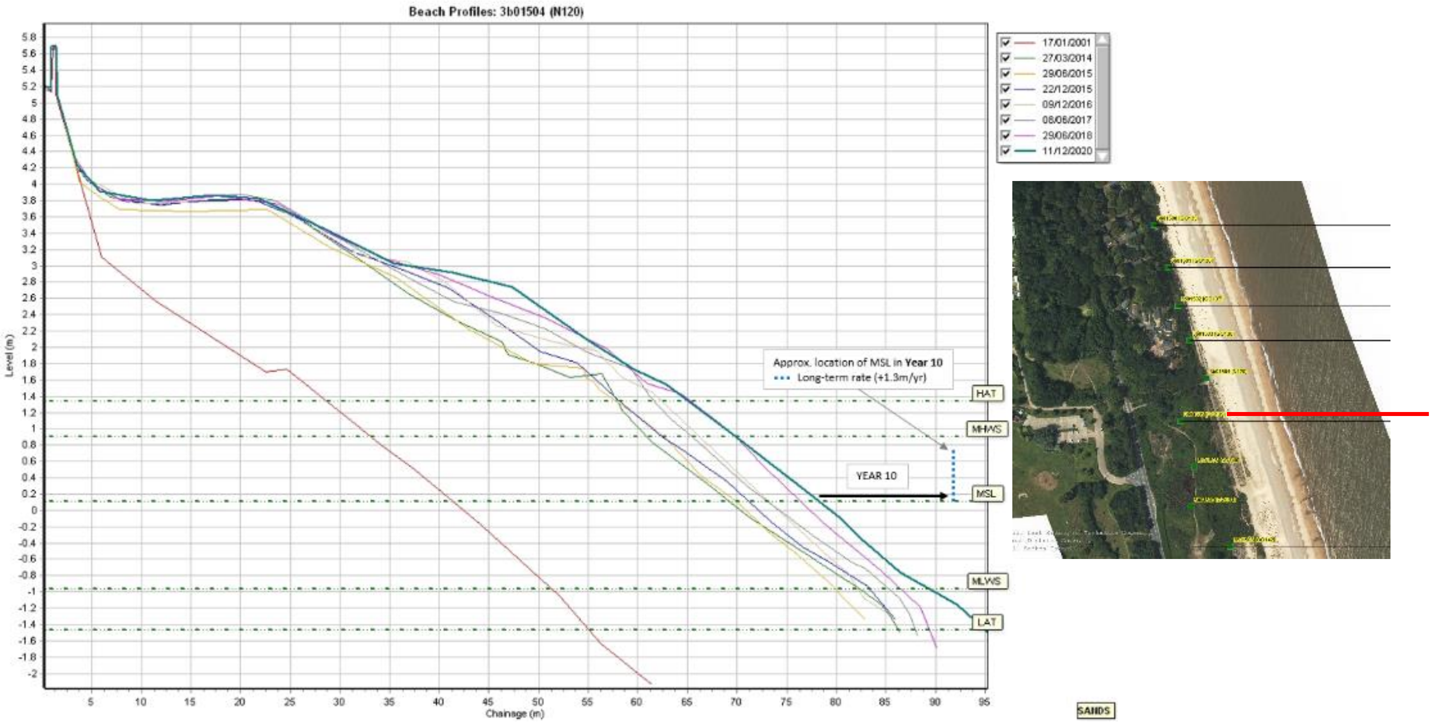


Figure A 8: Beach profile 3b01504 N120 – northern Gunton Warren (Corton Woods), at Tramp's Alley.

Figure A 9 shows beach profile 3b01494 GO129, located at Corton Long Lane, Corton Woods. Records along this profile started in 1992. The Strategy described the coastal processes (pre-2014) as follows:

- Since records began, the lowest beach level close to the toe of the defence was recorded in August 1999.
- There appears to be beach draw-down and recovery on 6 month cycles, showing the highest levels in the winter and lowest levels in the summer – levels vary up to 2 m.

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- Beach levels fluctuate with a general accretional trend (around 1.8 m/yr).
- Less fluctuation in beach levels observed since the Strategy.

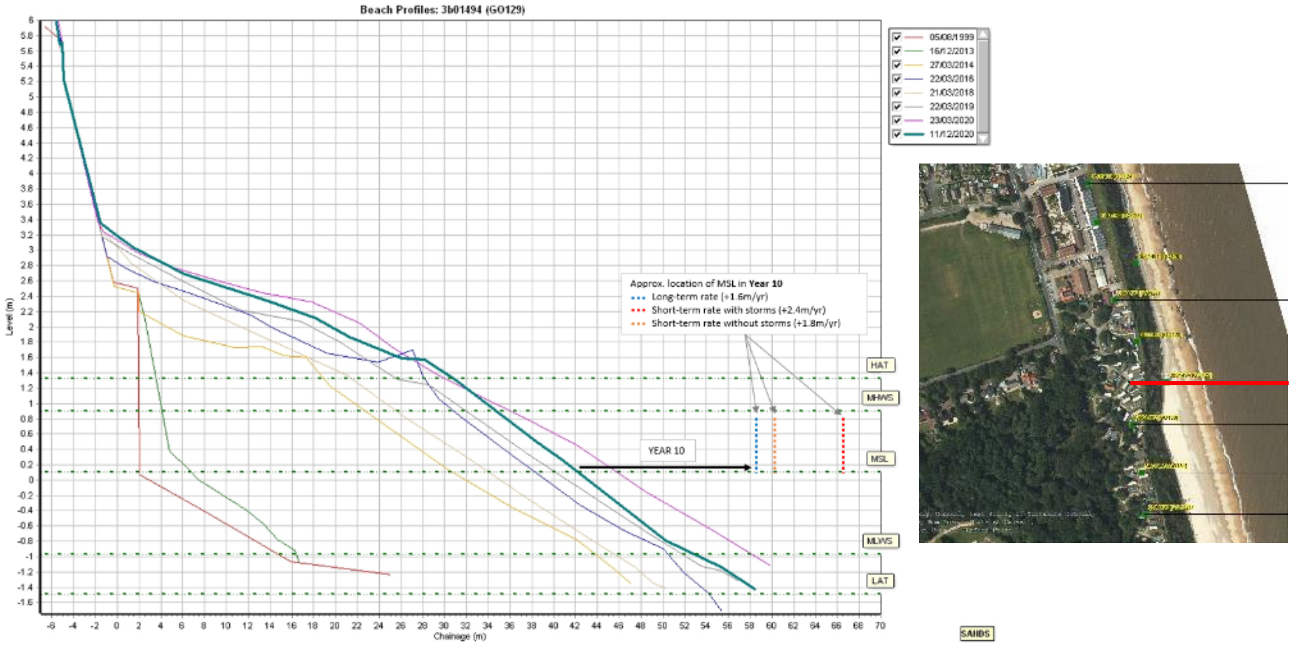


Figure A 9: Beach profile 3b01494 GO129 – Corton Woods, at Corton Long Lane.

A.4 Corton village

Figure A 10 shows beach profile 3b01486 N119, located at Tibbenham's Score in Corton village. Records along this profile started in 1992. The Strategy described the coastal processes (pre 2014) as follows:

- Narrow beach in the area since surveys began. Previously levels were higher in 1992/1993, with a large drop off in 1996.
- Little to no beach retained above MLW since around 2006. Minimal change in foreshore levels since 2006 (rock toe constructed in 2006).

The new analysis undertaken for this study showed that between December 2013 and December 2020:

- The beach face seems to have accreted around 1.3 m between September 2014 and March 2016, although there was a substantial drop of around 1 m in December 2014 in front of the revetment.
- Beach levels dropped again in September 2016 by 0.5 m (around 2 m chainage), but beach levels continue the trend of accretion with current levels 1.4 m higher than September 2014 at MSL.

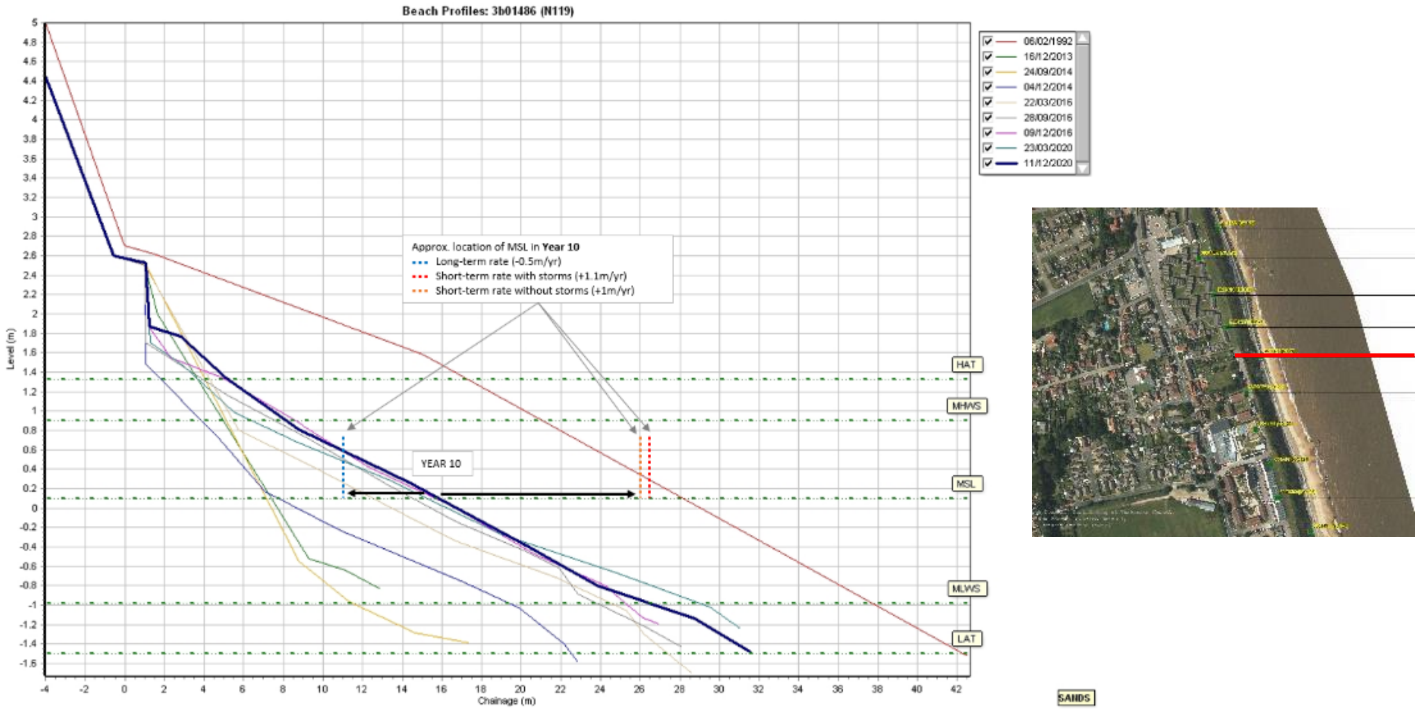


Figure A 10: Beach profile 3b01486 N119 – Corton, at Tibbenham's Score.

Figure A 11 shows beach profile 3b01482 GO118 at Tingdene Waterside Park. Records along this profile started in October 2008. The following was observed throughout the whole record:

- Fluctuations of beach levels reached their lowest point (at 0.8 mOD, around MHWS) in front of the defence (around 7.5 m chainage) in June 2018.
- Recovery in beach levels were observed until June 2019, before a drop again in December 2020.

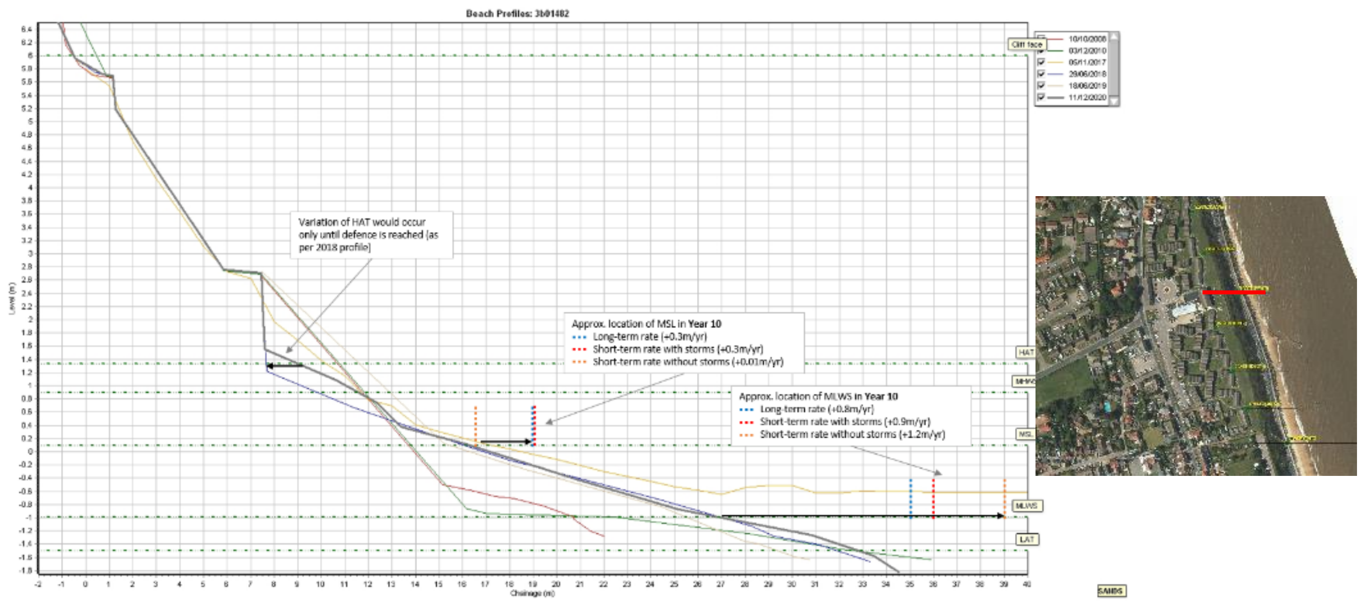


Figure A 11: Beach profile 3b01482 GO118 – Tingdene Waterside park.

Figure A 12 shows beach profile 3b01478 GO114, at Wy-Wurry, just south of Baker's Score. Records along this profile started in August 2005. The following was observed throughout the whole record:

- Fluctuations of beach levels reached the lowest point (at 0.8 mOD, around MHWS) in front of the defence around in March 2020.
- Some recovery in beach levels occurred between March 2020 and December 2020.
- Some erosion at the landward side of the defence (around -10 m chainage) was observed until July 2013 but works have since been completed to improve the cliff protection in the area.

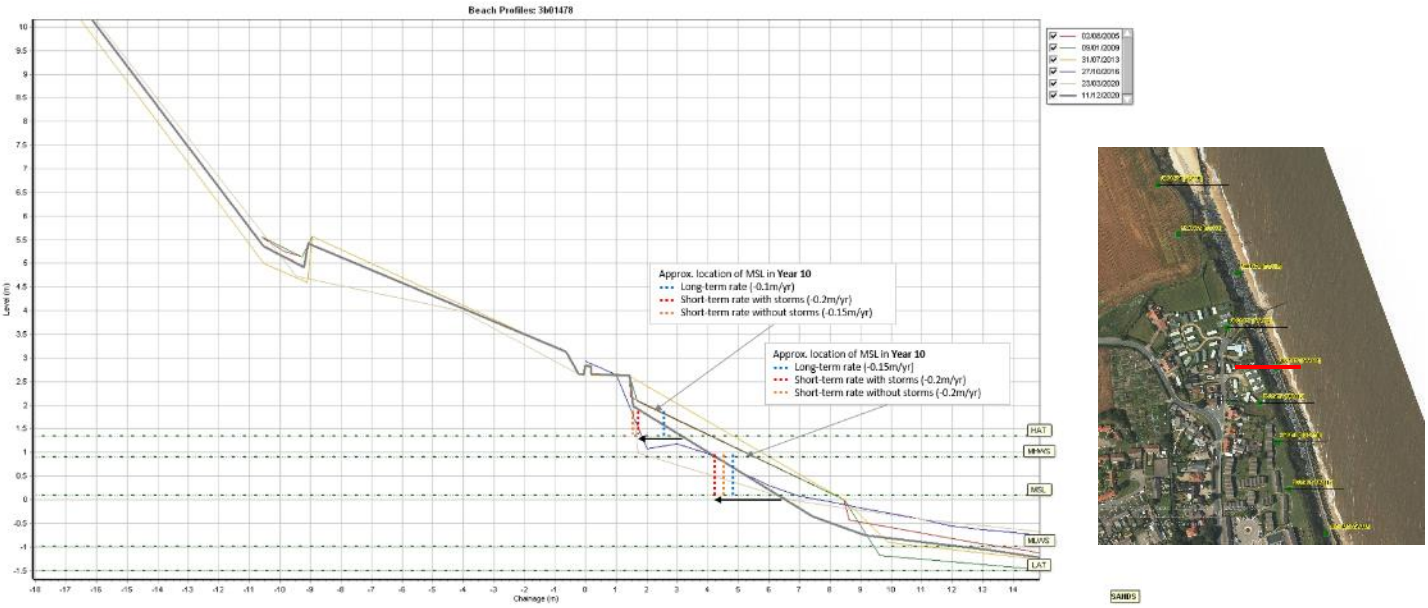


Figure A 12: Beach profile 3b01478 GO114 – South of Baker's Score at Wy-Wurry.

A.5 North Corton cliffs

Figure A 13 shows beach profile 3b01468 GY30 at Church Farm South. Records along this profile started in August 2003. The following was observed throughout the whole record:

- Erosion has been ongoing behind the timber revetment, similar to the locations to the north.
- Retreat of cliff face over the survey period of around 18 m in 17 years (2003 to 2020).
- Beach levels have dropped significantly over time behind the timber revetment, however levels fluctuate, and sediment eroded from the cliffs seems to temporarily accumulate behind the revetment before being carried away by waves and currents.

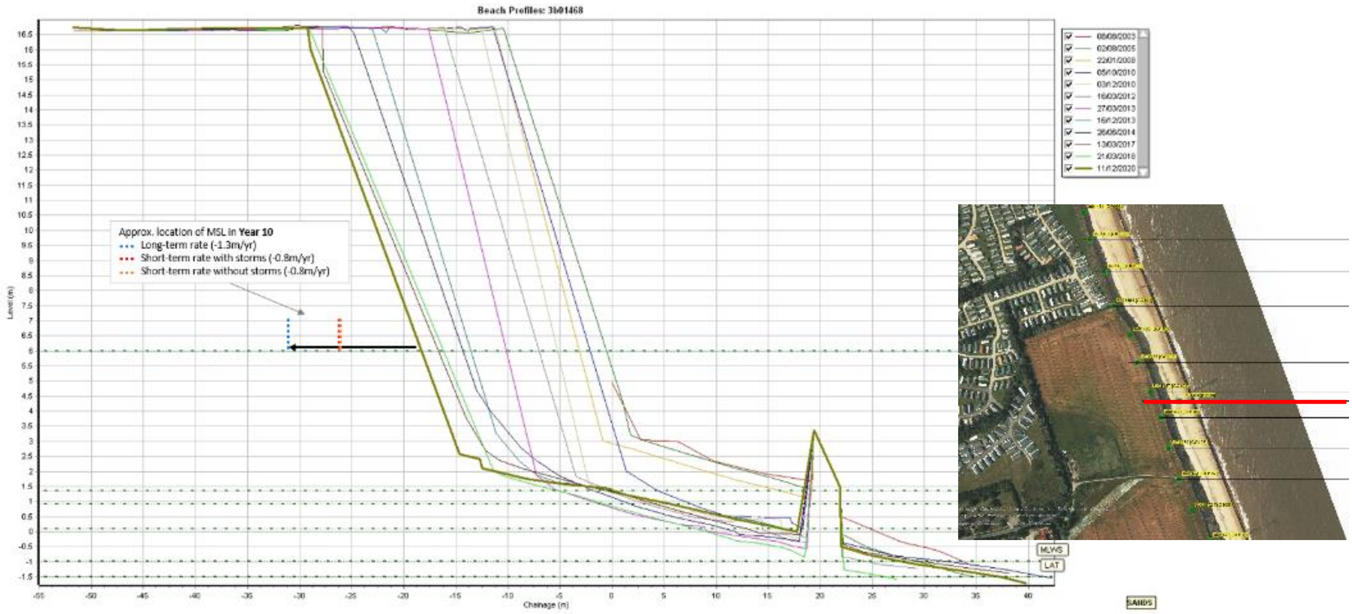


Figure A 13: Beach profile 3b01468 GY30 – North Corton Cliffs, Church Farm South.

Figure A 14 shows beach profile 3b1465 GO102 at Church Farm. Records along this profile started in June 2011. The following was observed throughout the whole record:

- Erosion has been ongoing behind the timber revetment, similar to the profiles to the north.
- There is a gap in the available surveys from 2011 to 2016.
- Retreat of cliff face over the survey period of around 17 m in 8 years (2011 to 2019).
- Between 2017 and 2019, the cliff top was stable but the base and central part has retreated by 3 m over the same period.
- There seem to be accumulation of eroded sediment from the cliffs behind of timber revetment.

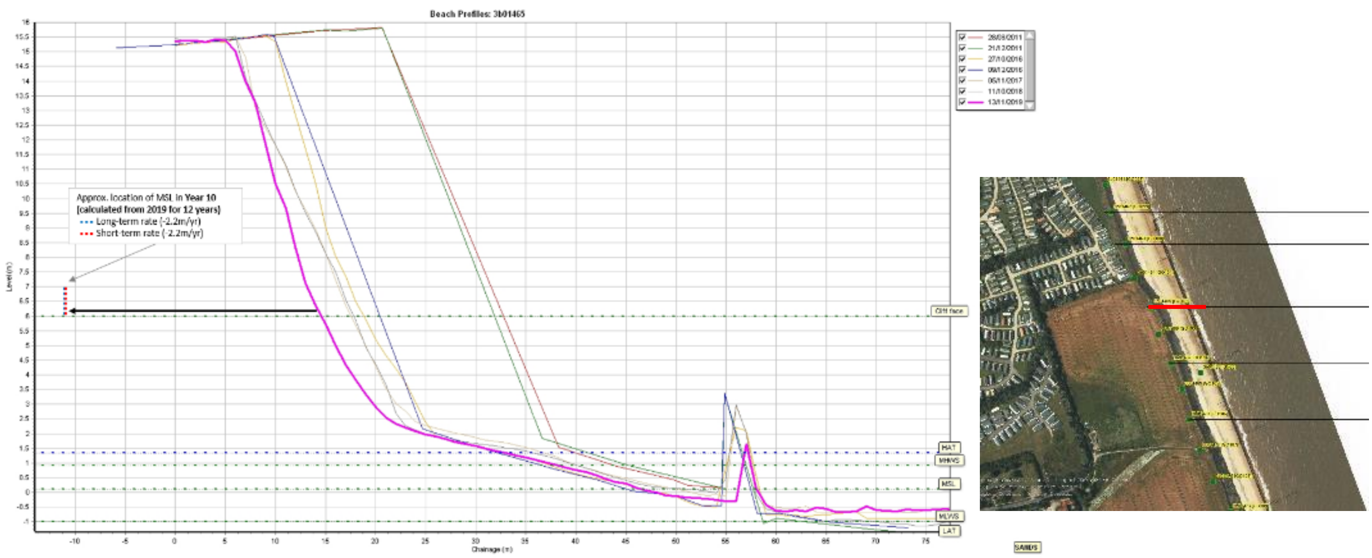


Figure A 14: Beach profile 3b01465 GO102 – North Corton Cliffs, at Church Farm.

Figure A 15 shows beach profile 3b01459 N118 at Broadland Sands Holiday Park. Records along this profile started in 1992. The Strategy described the coastal processes (pre 2014) as follows:

- Significant cliff erosion since 1992 (5 m retreat between 1992 and 1996).
- Beach lowering trend 1999 onwards in front of timber revetment.
- Critical condition reached in 2005 with net drop. As the cliff has eroded, there has been lateral translation of the beach profile between cliff toe and revetment but little change in front of the revetment.
- Gradual cliff retreat between 2009 and 2013 (significant cut back between July and December 2013).

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- Continuation of the trends observed in the Strategy
- Between March 2016 and March 2017, a retreat of 3 m has been observed.
- 2018 storms caused beach lowering between the cliff face and the timber revetment of around 0.5 m.
- The cliff face has retreated by around 5 m between March 2014 and December 2020.
- The beach in front of the timber revetment has lowered by around 1 m since December 2013, mostly due to storms in 2014.

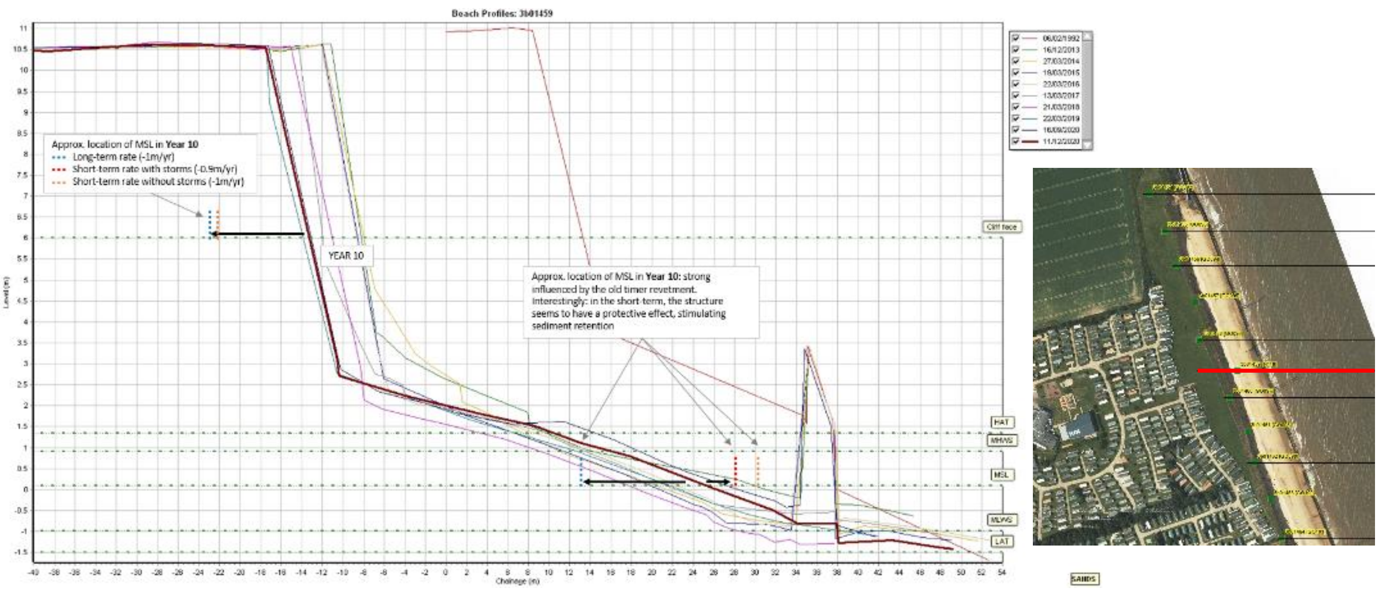


Figure A 15: Beach profile 3b01459 N118 – Corton Cliffs, at Broadland Sands Holiday Park.

Figure A 16 shows beach profile 3b01454 GO92, north of Broadland Sands Holiday Park (defence failure imminent here). This location shows the difference along this frontage between an area with failed defences (3b01453 GO91) and an area where the defences have not yet failed (3b01454 GO92). Some cliff retreat is observed here, but at a slower rate than at the undefended area to the north.

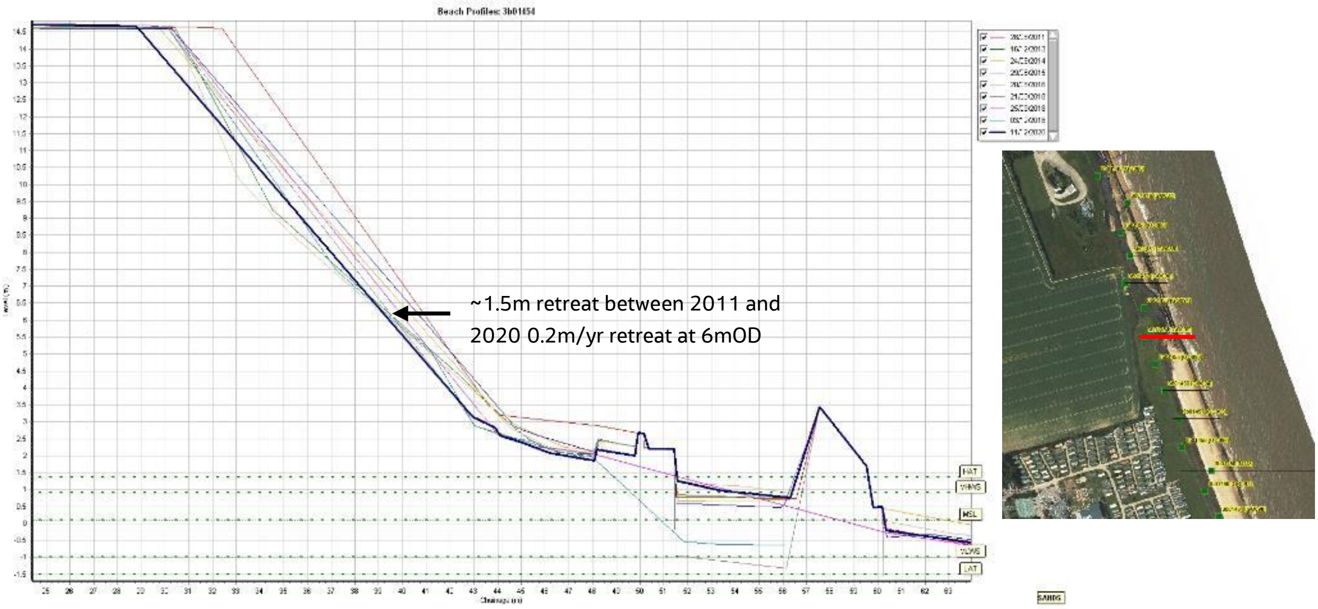


Figure A 16: Beach profile 3b01454 GO92 – North of Broadland Sands Holiday Park (defence failure imminent).

Figure A 17 shows beach profile 3b01453 GO91, south of RAF Hopton (failed defences). Records along this profile started in June 2011 and showed the following:

- Defence failure occurred at some point between 2011 and 2016 along this profile. Since this, the cliffs have been retreating year by year, with a total of 7 m (measured at 6 mOD) between 2016 and 2019.
- Beach levels in front of the failed defences do not seem to have changed considerably over time.

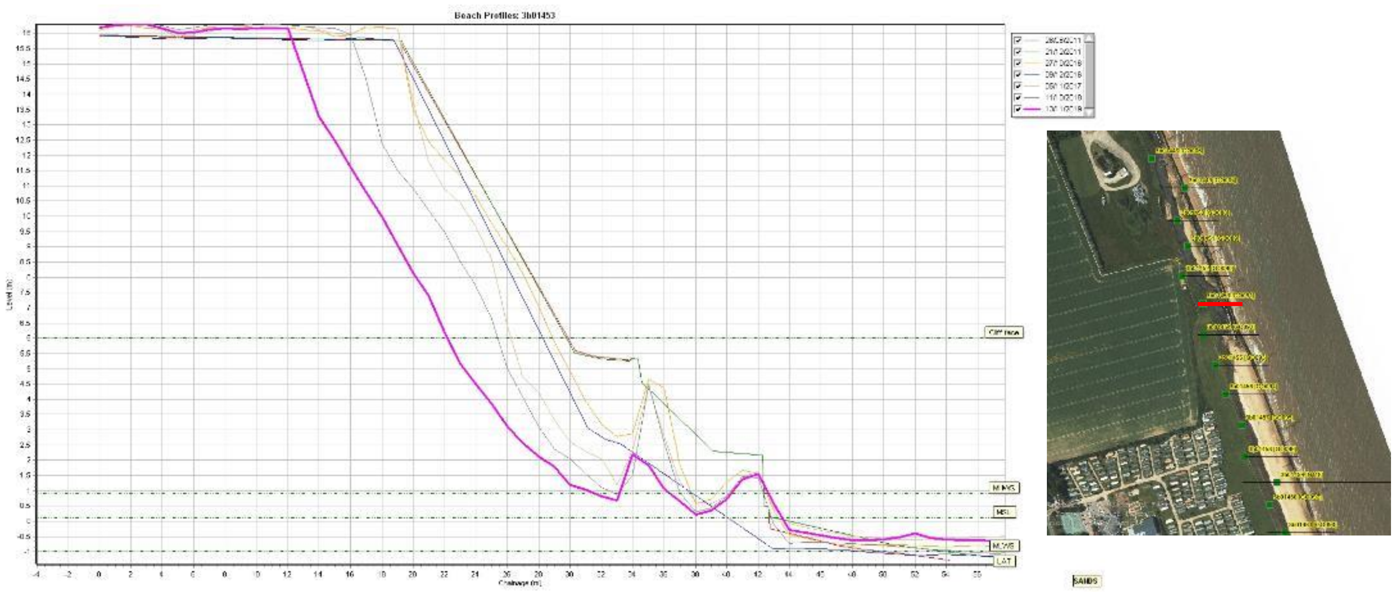


Figure A 17: Beach profile 3b01453 GO91 – North Corton cliffs, south of RAF Hopton (failed defences)

Figure A 18 shows the beach profile 3b01449 GO87, located at RAF Hopton. Records along this profile started in August 1996 and showed the following:

- Beach levels fluctuated up to January 2001, when beach lowering in front of the wall starts to occur.

- By January 2010 beach levels dropped considerably, reaching MSL (0.2 mOD) in front of the defence.
- By June 2011, although beach levels had recovered slightly, cliff instability behind the defence is evident.
- By December 2013 (following the storms of 5th December), defences seemed to have failed and the cliff cut back. It is possible that this was a turning point in terms of cliff erosion, as cliffs have been retreating at a fast pace (4.9 m/yr measured at 2 mOD, between 2016 and 2020 – See Figure B 17.
- More recently (December 2020), beach levels in front of the defence are still around MSL, but the cliff has significantly retreated.

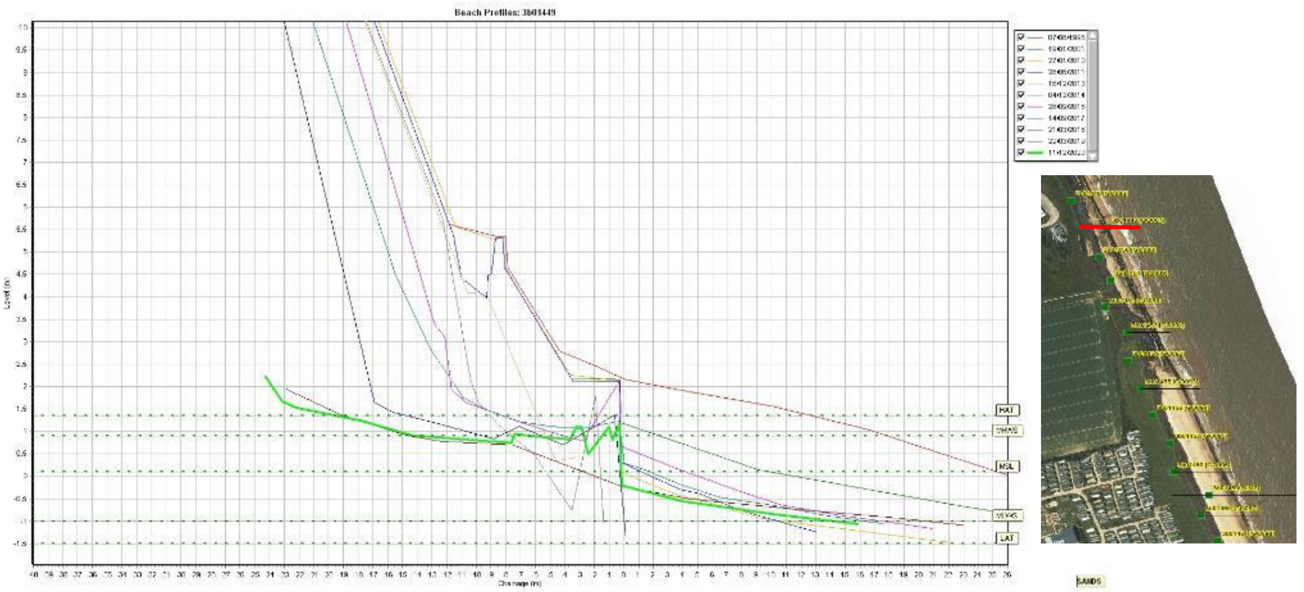


Figure A 18: Beach profile 3b01449 GO87 – North Corton: RAF Hopton

A.6 South of Hopton-on-Sea

Figure A 19 shows the beach profile 3b01442 GY29, located at Potters Leisure Resort. Records along this profile started in August 2003 and are as follows:

- Beach levels fluctuated until January 2007, followed by a net lowering of beach levels.
- By December 2010, the levels had dropped to 0.2 mOD from 1.8 mOD in January 2007.
- Beach levels recovered in 2011 to original (2003) levels, but in March 2013 the lowest observed levels along this frontage (-0.6 mOD) occurred.
- Levels oscillated up to June 2016 when 2003 levels were reached again. Around this time a new rock revetment was constructed. Since then, beach levels have continued to fluctuate on a seasonal basis, with some recovery over the next couple of summer. However, December 2020 levels are within the lowest observed since the rock revetment was constructed.

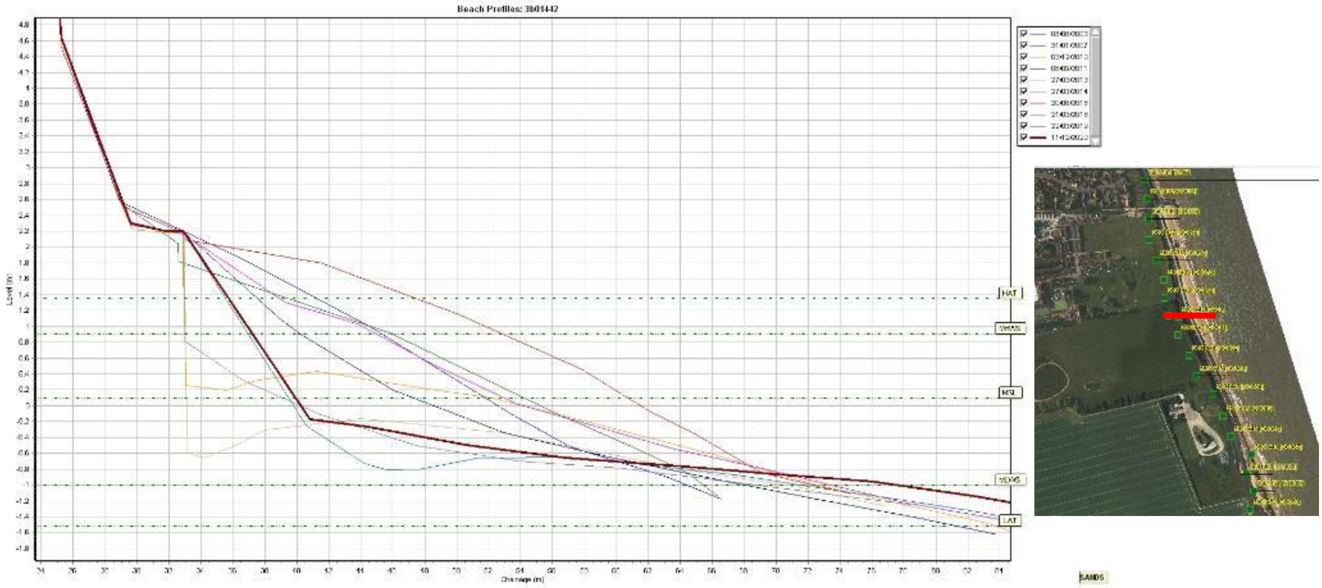


Figure A 19: Beach profile 3b01442 GY29 – North Corton: defended frontage at Potter's Leisure Resort.

Figure A 20 shows the beach profile 3b10434 N117, located at the southern end of Hopton. Records along this profile started in August 1992. The Strategy described the coastal processes (pre mid 2013) as follows:

- Net drop in beach levels and net loss of beach;
- Section prone to sudden drops in beach volume and subsequent recovery (up to 1.5m change) – seasonal and storm events.

The new analysis undertaken for this study showed that, between December 2013 and December 2020, there has been:

- A continuation of trends observed in Strategy along this profile;
- Net erosion, but with seasonal fluctuations;
- Following 2018 storms, the beach face retreated resulting in a drop in beach levels by up to 1 m; levels had partially recovered by September 2018. December 2020 survey shows a similar pattern.

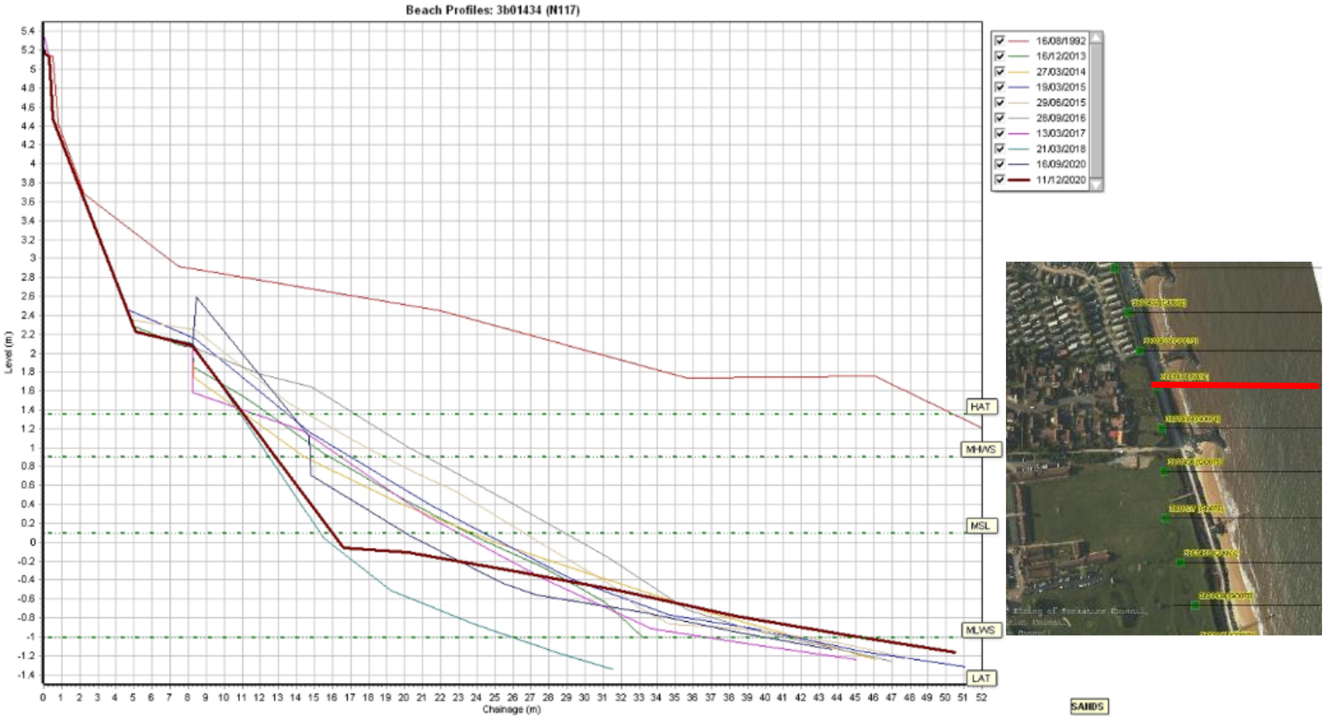


Figure A 20: Beach profile 3b01434 N117 – Southern end of Hopton.

Annex B. Regression analysis

Table B 1 shows a summary of rates of change along the study area, calculated using regression analysis. The sub-sections below show the figures and rates for each timeframe analysed (long-term/ short-term) and for each level assessed per profile. Note that rates of change have not been calculated at South of Hopton-on-Sea (profiles GY29 and N117) as this is outside the study frontage.

Table B 1: Summary of rates of change along the study frontage

Group	Profile	Rate of change (m/yr)			
		Long-term		Short-term	
		1992-2020	2000-2020	2011- 2020	2016-2020
Hopton-on-Sea	3b01434 - (N117)	-1.6 (MSL)	NA	NA	NA
	3b01442 - (GY29)	NA	-1.2 (MSL)[1]	NA	NA
North Corton	3b01449 - GO87	NA	-0.8 (MSL)[2] -0.6 (at 2m lower cliff face)[2]	-0.2 (MSL) -2.5 (at 2m lower cliff face)	-0.5 (MSL) -4.9 (at 2m lower cliff face)
	3b01453 – GO91	NA	NA	-0.7 (at 6m cliff face)	-2.0 (at 6m cliff face)
	3b01459 – N118	-1.2 (MSL) -1.0 (at 6m cliff face)	-1.5 (MSL) -1.5 (at 6m cliff face)	-0.3 (MSL) -1.6 (at 6m cliff face)	+0.6 (MSL) -1.0 (at 6m cliff face)
	3b01465 – GO102	NA	NA	-2.2 (at 6m cliff face)	-1.5 (at 6m cliff face)
	3b01468 – GY30	NA	-1.3 (at 6m cliff face)[3]	-1.3 (at 6m cliff face)	-1.0 (at 6m cliff face)
Corton	3b01478 – GO114	NA	-0.15 (MSL)[5] +0.3 (MLWS)[5]	-0.2 (MSL) +0.6 (MLWS)	-0.1 (MSL) +0.15 (MLWS)
	3b01482 – GO118	NA	+0.3 (MSL)[5] +0.8 (MLWS)[5]	+0.3 (MSL) +0.8 (MLWS)	+0.01 (MSL) +1.2 (MLWS)
	3b01486 – N119	-0.5 (MSL)	+0.2 (MSL)	-1.0 (MSL)	+0.22 (MSL)
Corton Woods	3b01494 – GO129	+1.6 (MSL)[4]	+1.9 (MSL)	+3.4 (MSL)	+1.4 (MSL)
	3b01504 – N120	+1.3 (MSL)	+1.8 (MSL)	+1.4 (MSL)	+1.4 (MSL)
Gunton Warren	3b01513 - LW001	NA	NA	-2.9 (at 3m dune face) -2.3 (MSL)	-2.0 (at 3m dune face) - 0.7 (MSL)
	3b01515 - LW003	NA	NA	-3.2 (at 3m dune face)	-2.8 (at 3m dune face)
	3b01517 - LW005	NA	NA	-3.5 (at 3m dune face)	-3.1 (at 3m dune face)
	3b01518 - LW006	NA	NA	-3.5 (at 3m dune face)	-6.2 (at 3m dune face)
	3b01519 - LW007	NA	NA	-4.5 (at 3m dune face)	-8.0 (at 3m dune face)
	3b01520 - LW008	NA	NA	-4.8 (at 3m dune face)	-9.7 (at 3m dune face)

Group	Profile	Rate of change (m/yr)			
		Long-term		Short-term	
		1992-2020	2000-2020	2011- 2020	2016-2020
	3b01521 - N121	-0.6 (HAT/ MSL)	-0.8 (HAT/ MSL)	-0.7 (HAT) -0.9 (MSL)	-1.0 (HAT) -0.8 (MSL)
1 Long-term rates calculated from 2003 when records began 2 Long-term rates calculated from 1999 when records began 3 Long-term rates calculated from 2005 when records began 4 Long-term rates calculated from 1997 when records began 5 Long-term rates calculated from 2008 when records began					

B.1 Lowestoft North Denes (Links Road)

Figure B 1: Regression analysis at beach profile 3b01521 N121 – Links Road

B.2 Southern Gunton Warren: undefended section

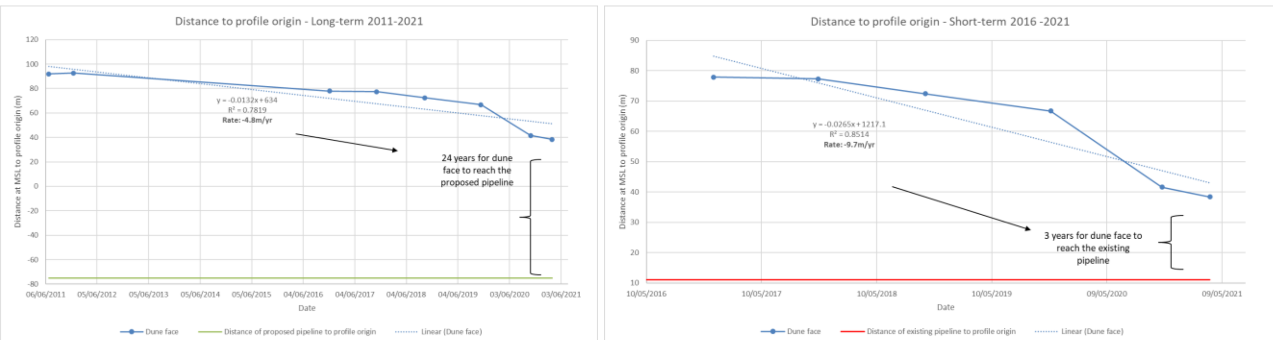


Figure B 2: Regression analysis at beach profile 3b01520 LW008 – southern Gunton Warren

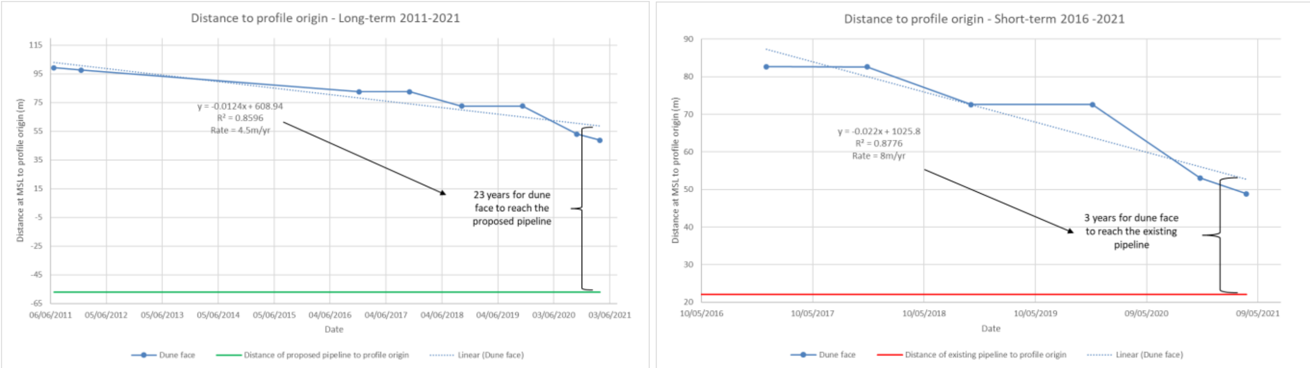


Figure B 3: Regression analysis at beach profile 3b01519 LW007 – southern Gunton Warren

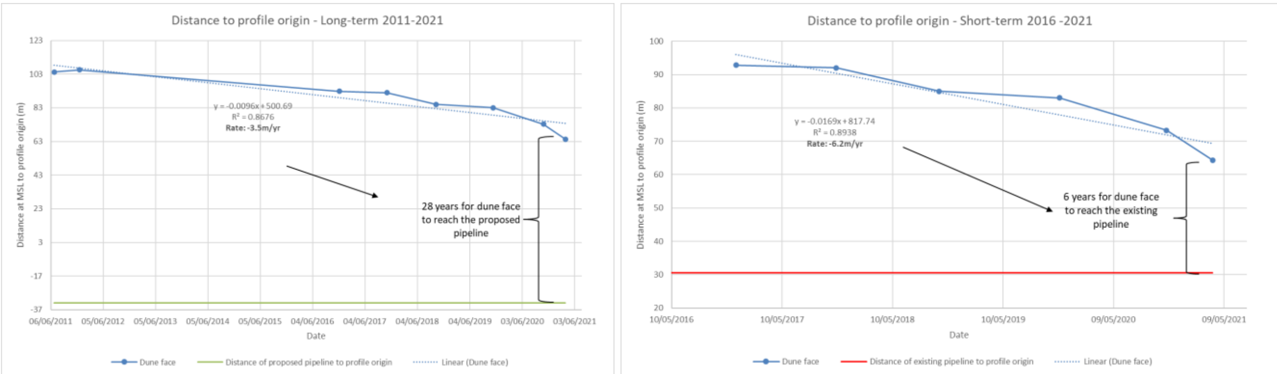


Figure B 4: Regression analysis at beach profile 3b01518 LW006 – southern Gunton Warren

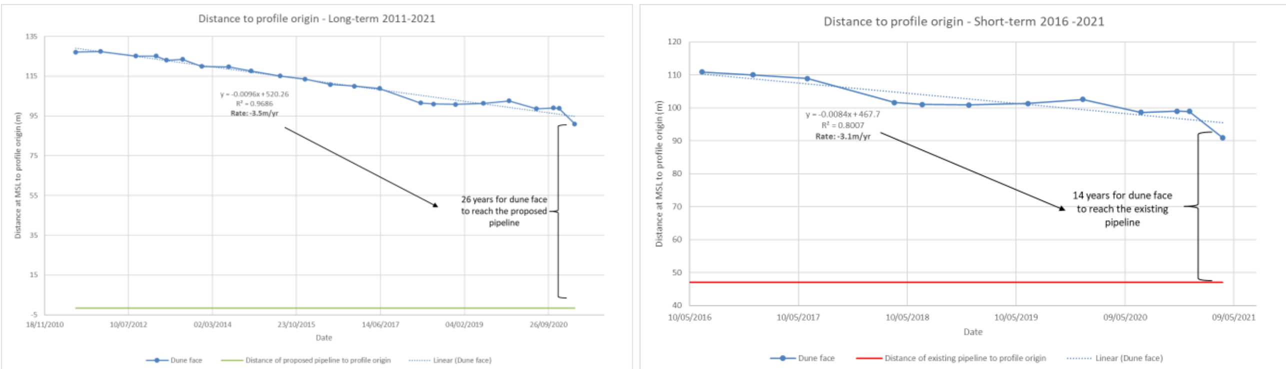


Figure B 5: Regression analysis at beach profile 3b01517 LW005 – southern Gunton Warren

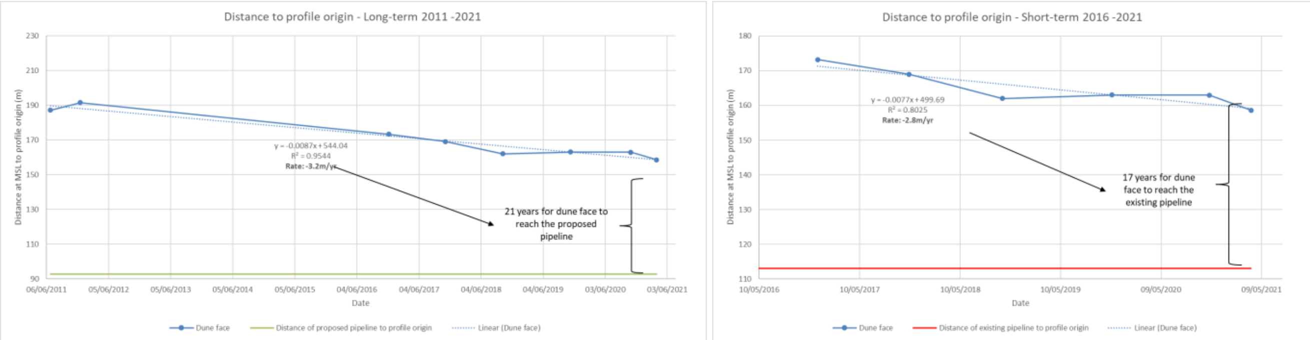


Figure B 6: Regression analysis at beach profile 3b01515 LW003 – southern Gunton Warren

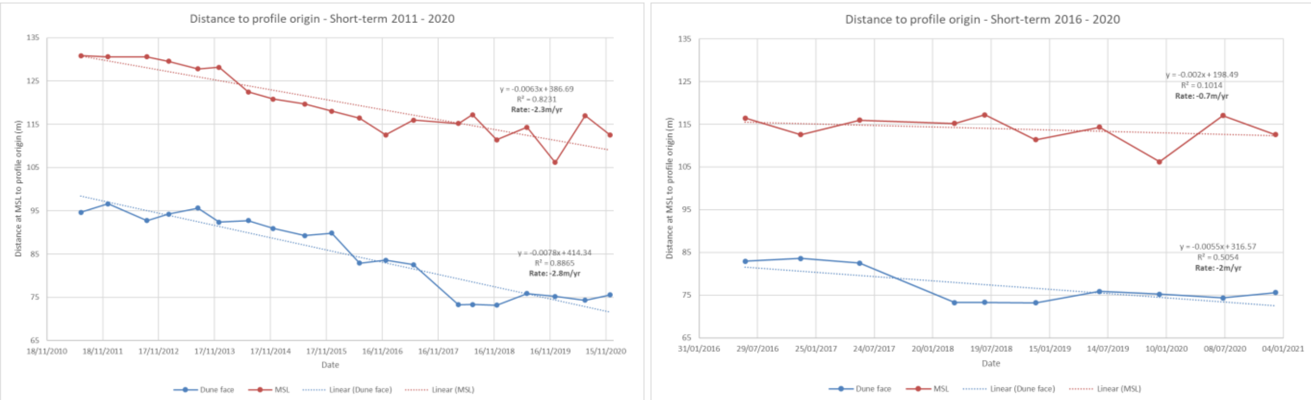


Figure B 7: Regression analysis at beach profile 3b01513 LW001 – southern Gunton Warren

B.3 Northern Gunton Warren (Corton Woods): defended section

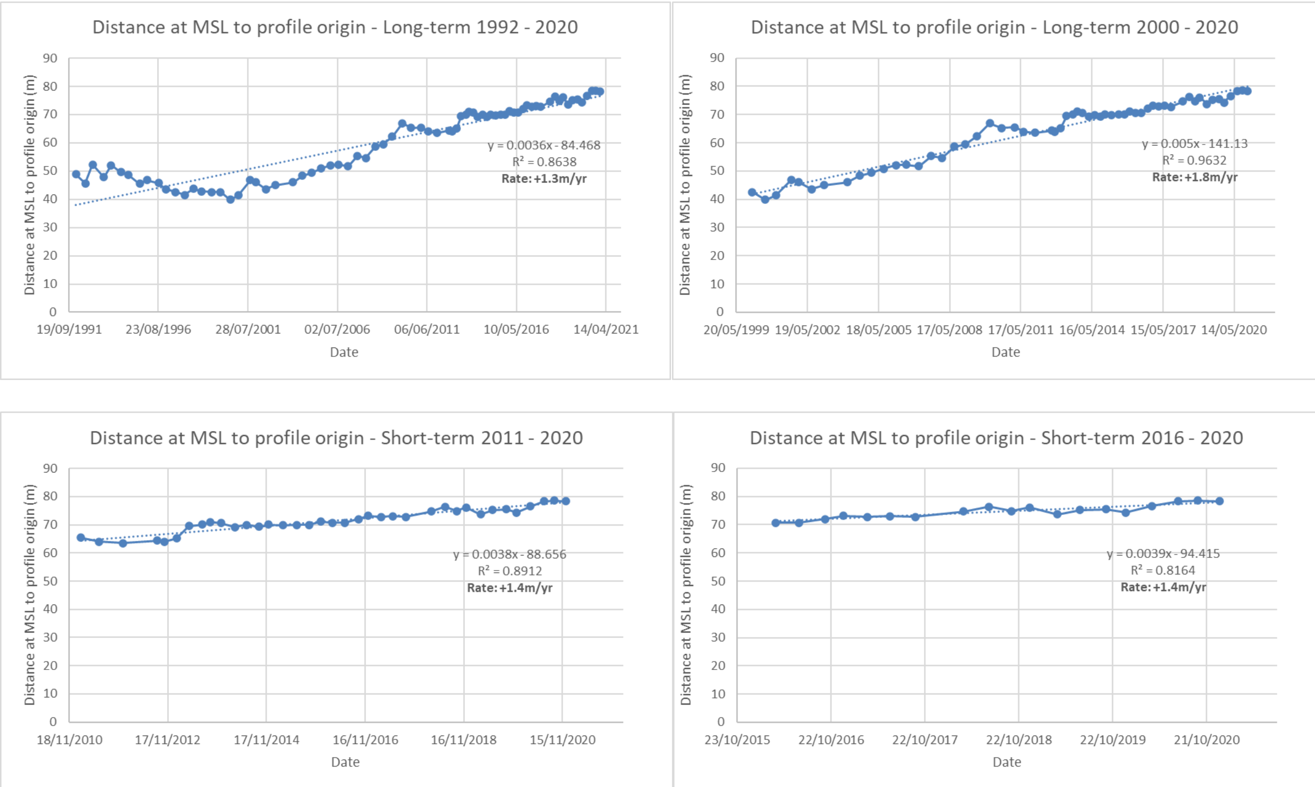


Figure B 8: Regression analysis at beach profile 3b01504 N120, northern Gunton Warren (Corton Woods), at Tramp's Alley

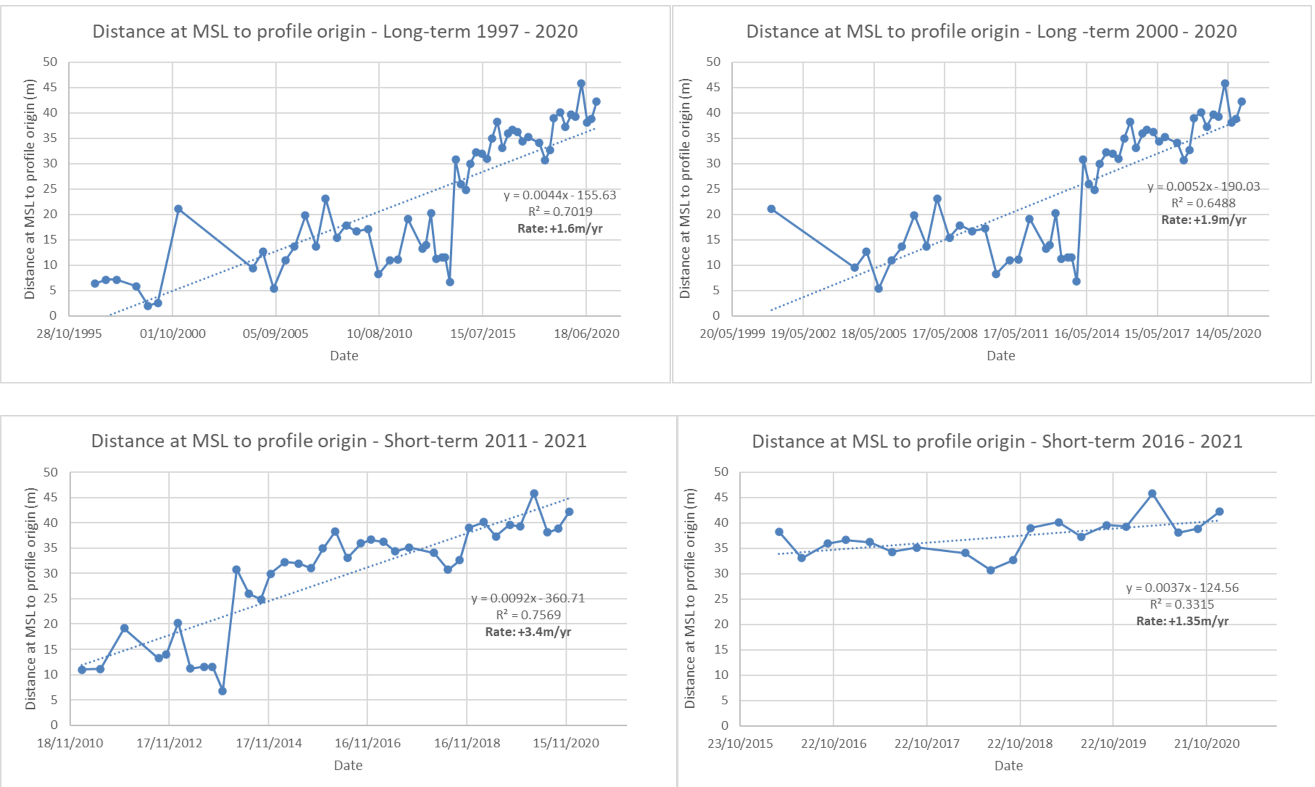


Figure B 9: Regression analysis at beach profile 3b01494 GO129, northern Gunton Warren (Corton Woods), at Corton Long Lane

B.4 Corton village

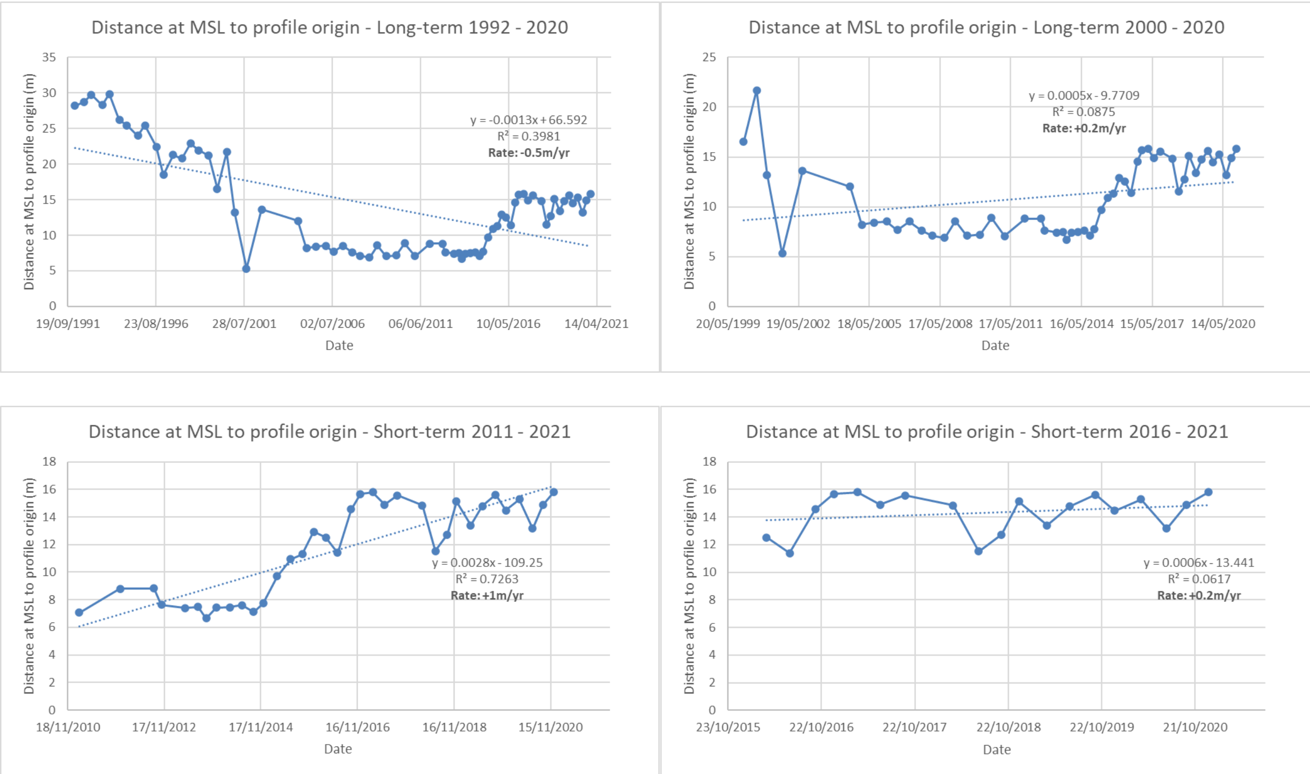


Figure B 10: Regression analysis at beach profile 3b01486 N119 – Corton, at Tibbenham's Score.

Figure B 11: Regression analysis at beach profile 3b01482 GO118 – Tingdene Waterside park.

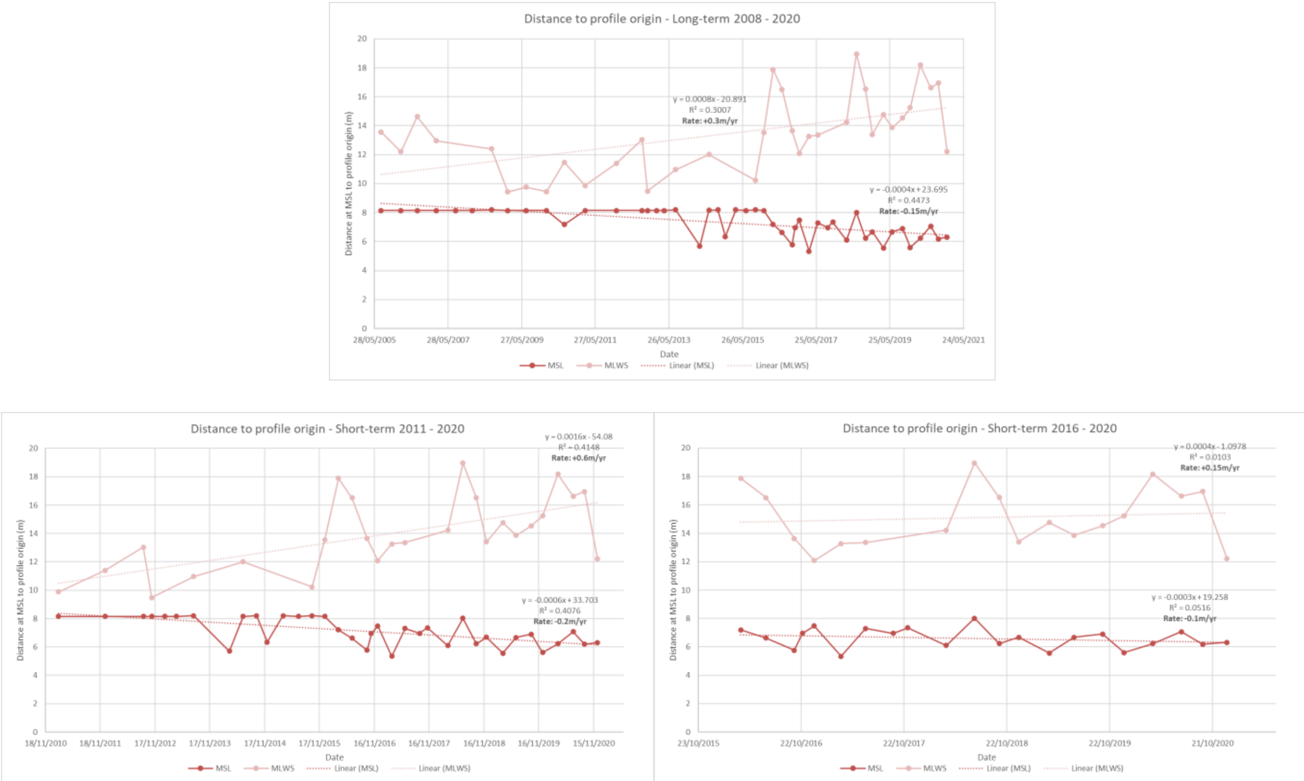


Figure B 12: Regression analysis at beach profile 3b01478 GO114 – South of Baker's Score at Wy-Wurry.

B.5 North Corton cliffs

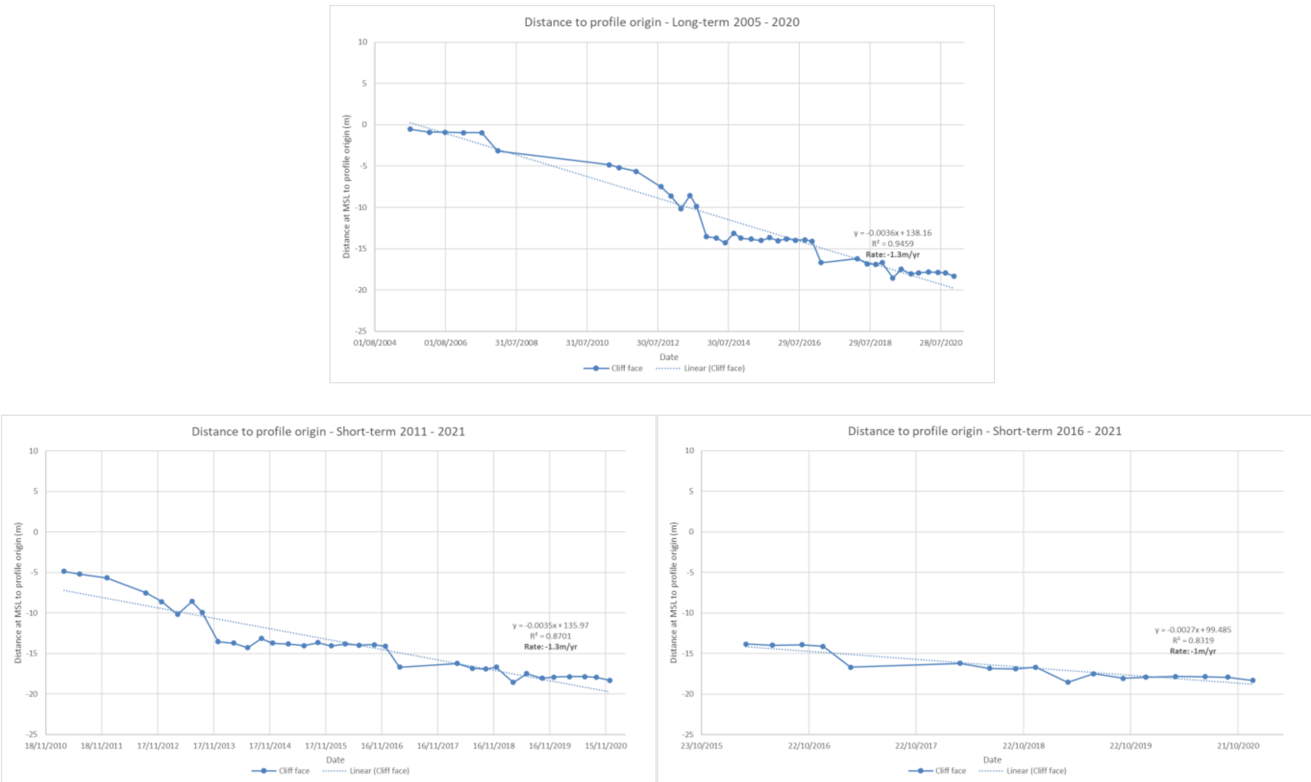


Figure B 13: Regression analysis at beach profile 3b01468 GY30 – North Corton Cliffs, Church Farm South.

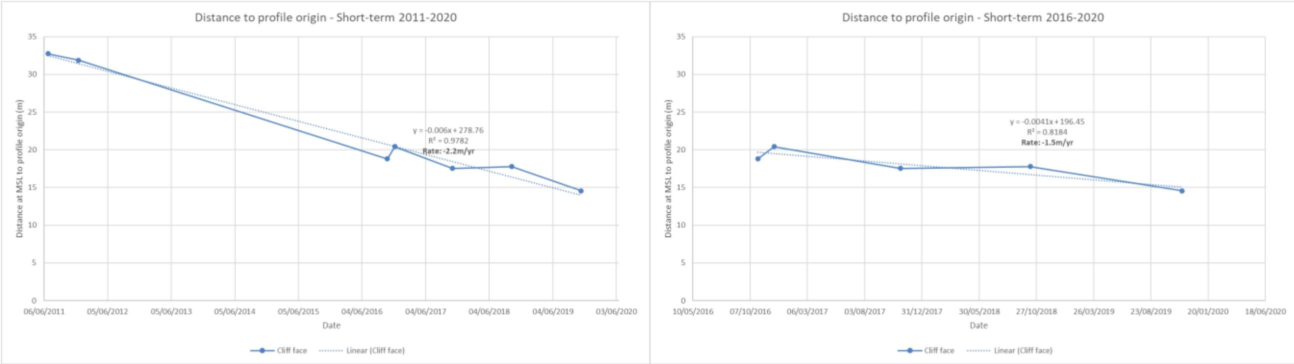


Figure B 14: Regression analysis at beach profile 3b01465 GO102 – North Corton Cliffs, at Church Farm.

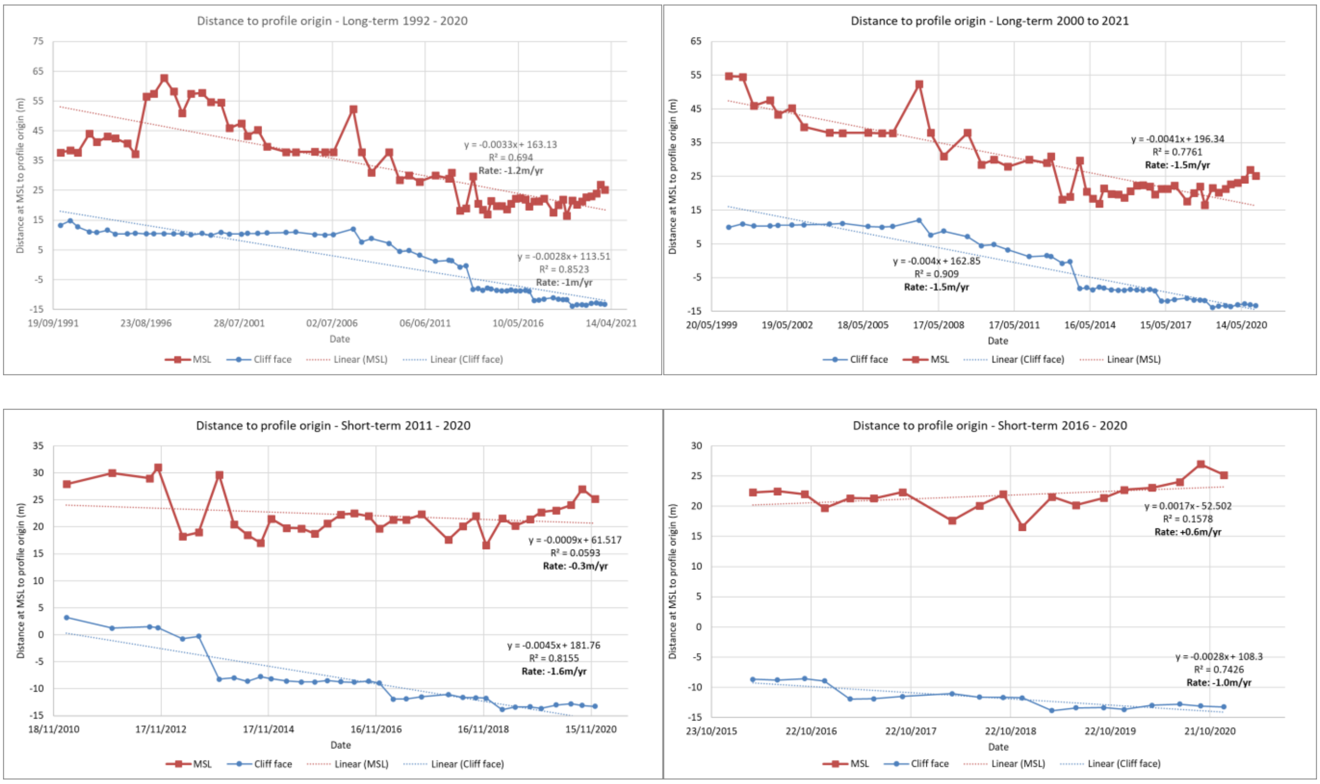


Figure B 15: Regression analysis at beach profile 3b01459 N118 – Corton Cliffs, at Broadland Sands Holiday Park.

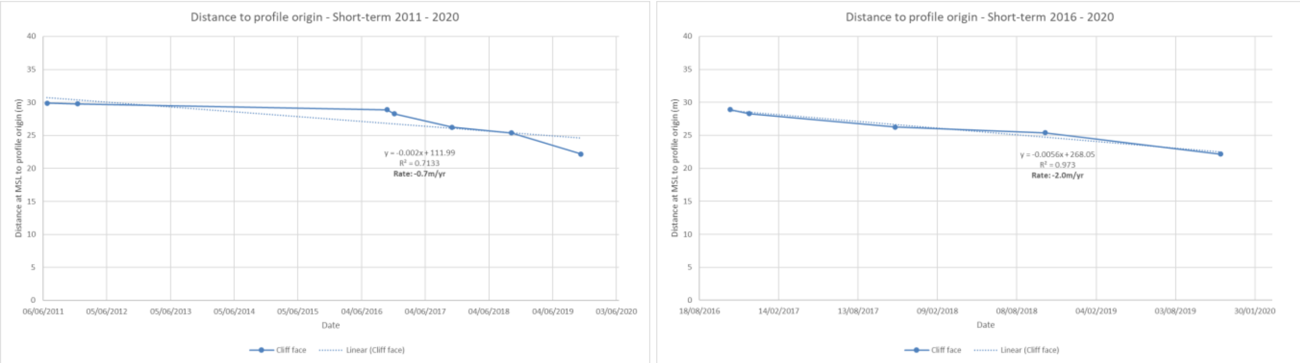


Figure B 16: Regression analysis at beach profile 3b01453 GO91 – North Corton cliffs, south of RAF Hopton (failed defences)

Figure B 17: Regression analysis at beach profile 3b01449 GO87 – North Corton: RAF Hopton

Annex C. Offshore bathymetry

C.1 Difference plots

The figure below (Figure C 1) shows the configuration of the offshore bathymetry between Great Yarmouth and Lowestoft in 1999 (left), 2017 (middle) and the difference in depth between 199 and 2017 (right). In the right hand difference plot, red shades represent a deepening whereas blue shades indicate a shallowing of the bed levels.

The right hand difference plot shows that Holm Sands, located some 2 km offshore of Corton-Gunton frontage, accreted vertically (becoming shallower) between 1999 and 2017, whilst the channels of North Corton Road and Lowestoft North Road (middle) deepened over the same period.

The sandbanks and their intervening channels have been extensively studied over time, but there remains residual uncertainty over the drivers of observed changes in form and position. As such, predicting future behaviour is difficult, particularly as changes are not linear in nature, for example the opening and closing of Holm Channel (left).

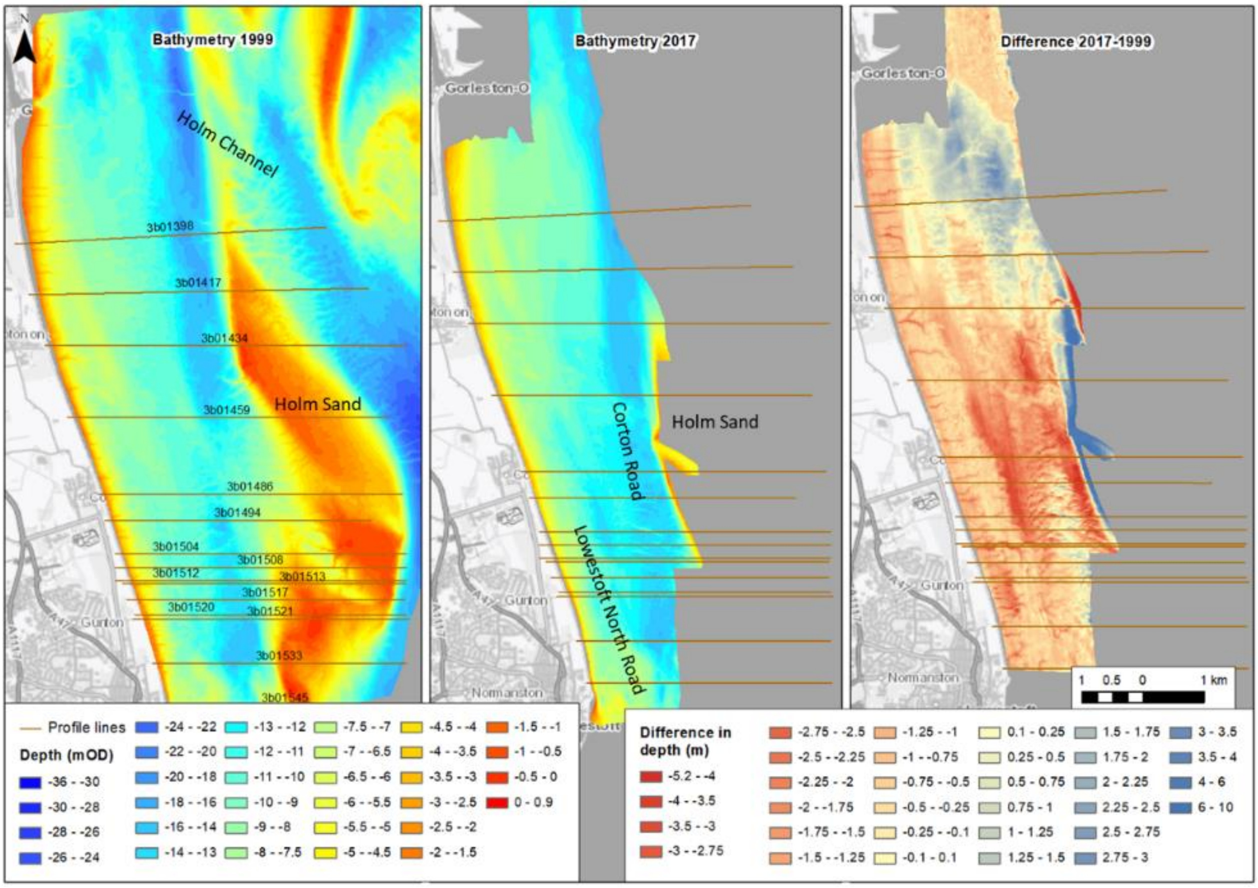


Figure C 1: Offshore bathymetry between Great Yarmouth and Lowestoft in 1999 (left), 2017 (middle) and the difference in depth between 1999 and 2017 (right).

The figure below (Figure C 2) shows the difference in depth of the bed levels between 2014 and 2017. Red shades represent a deepening from 2014 to 2017, whereas blue shades indicate a shallowing of the bed levels in this same time period. At the southern end of the figure between the most southern point of the figure and beach profile 'N120', it is evident that there are sand waves migrating northwards close to the shore, shown by the alternating red and blue shaded areas.

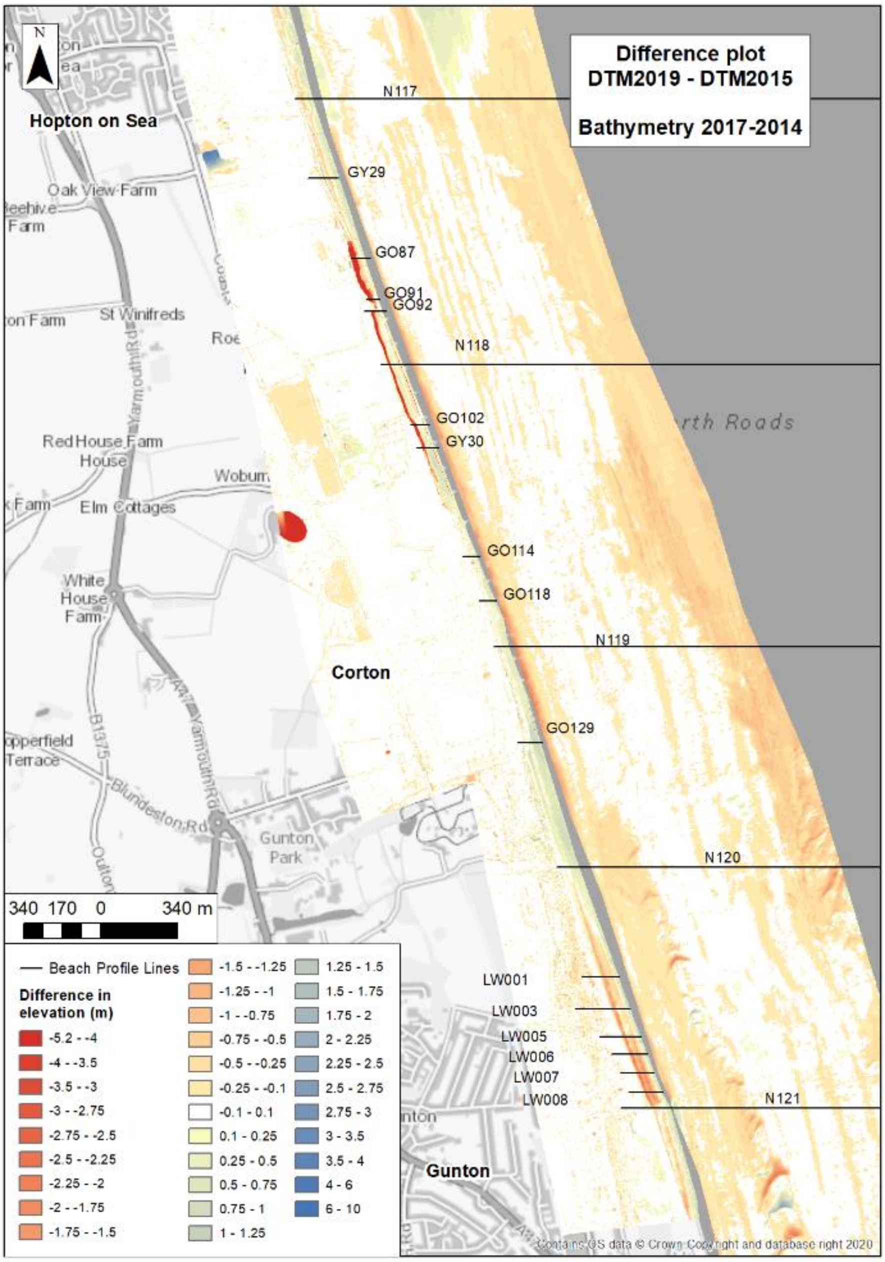


Figure C 2: Offshore bathymetry difference plot along the Corton-Gunton frontage, comparing bed levels from 2014 and 2017. Red shades indicate a deepening whereas blue shades represent a shallowing of bed levels from 2014 to 2017.

Alongside the bathymetry difference plots above (Figure C 1 and Figure C 2), at each of the locations shown on these figures, cross sections have been extracted and beach profile analysis has been undertaken. The analysis is described in the sections below.

C.1 Lowestoft North Denes (Links Road)

The graph below in Figure C 3 shows the changes in bathymetry from 1991-2017 at beach profile 3b01521 N121 at Links Road. Summary of bathymetry changes:

- Since 1999, a small landward retreat of the -5mOD contour has been observed, at an average rate of around -0.4 m/yr.

- A general lowering of the seabed has occurred between 150 m and 550 m chainage, with up to 1.7 m change since 2005. Further offshore, the seabed been stable since 2005.

Profiles	Retreat of -5m contour
3b01521 N121	**Average since 1999: -0.4m/yr** 2005-2014: -0.9m/yr 2014-2017: -0.3m/yr

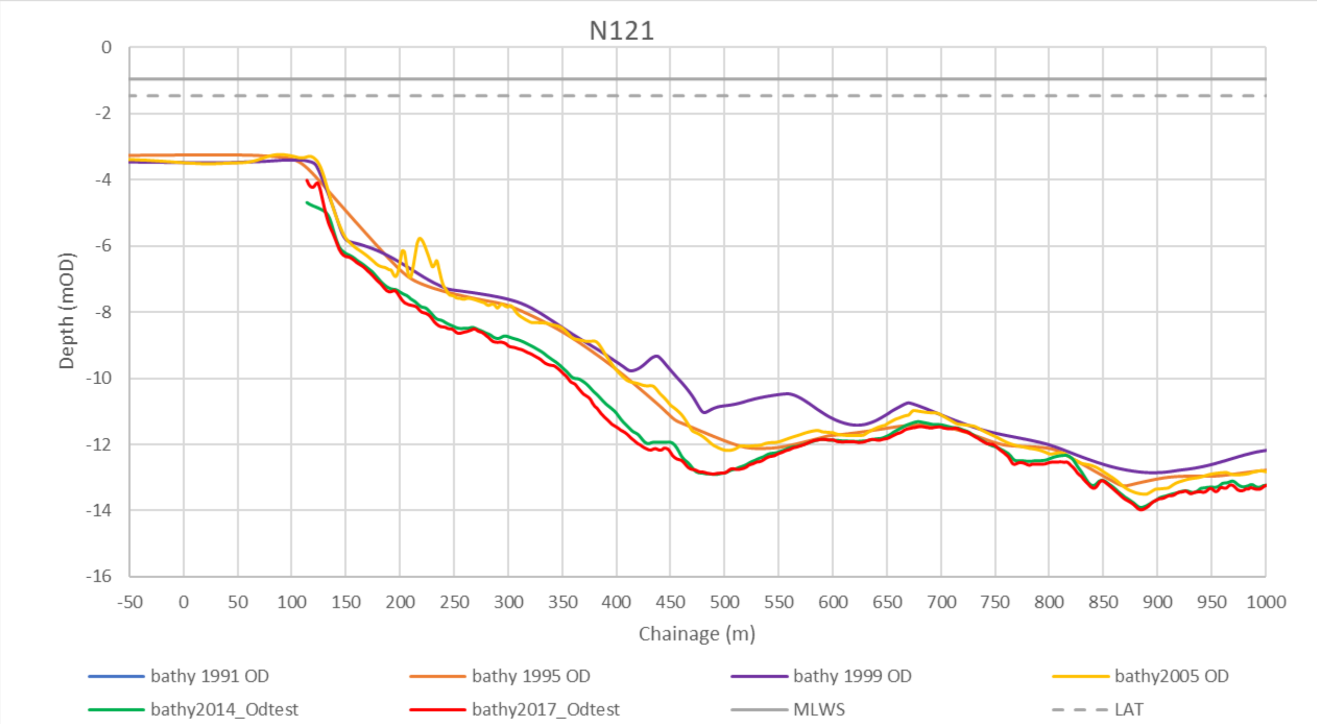


Figure C 3: Bathymetric changes over time (1991-2017) at beach profile 3b10521 N121 – Links Road.

C.2 Southern Gunton Warren: undefended section

The graph below in Figure C 4 shows the changes in bathymetry from 1991-2017 at beach profile 3b01513 LW001, north of Links Road. No data are available for -5 mOD contour for 2014 and 2017. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -6 m OD contour has been observed, at an average rate of around -2.5 m/yr.
- A general lowering of the seabed has occurred between 200 m and 500 m chainage, of up to 1.5 m since 2005.

Profiles	Retreat of -6m contour*
3b01513 LW001	**Average since 1999: -2.4m/yr** 2005-2014: -5.3m/yr 2014-2017: -1.7m/yr

* No data for 2014 and 2017 at -5 mOD contour

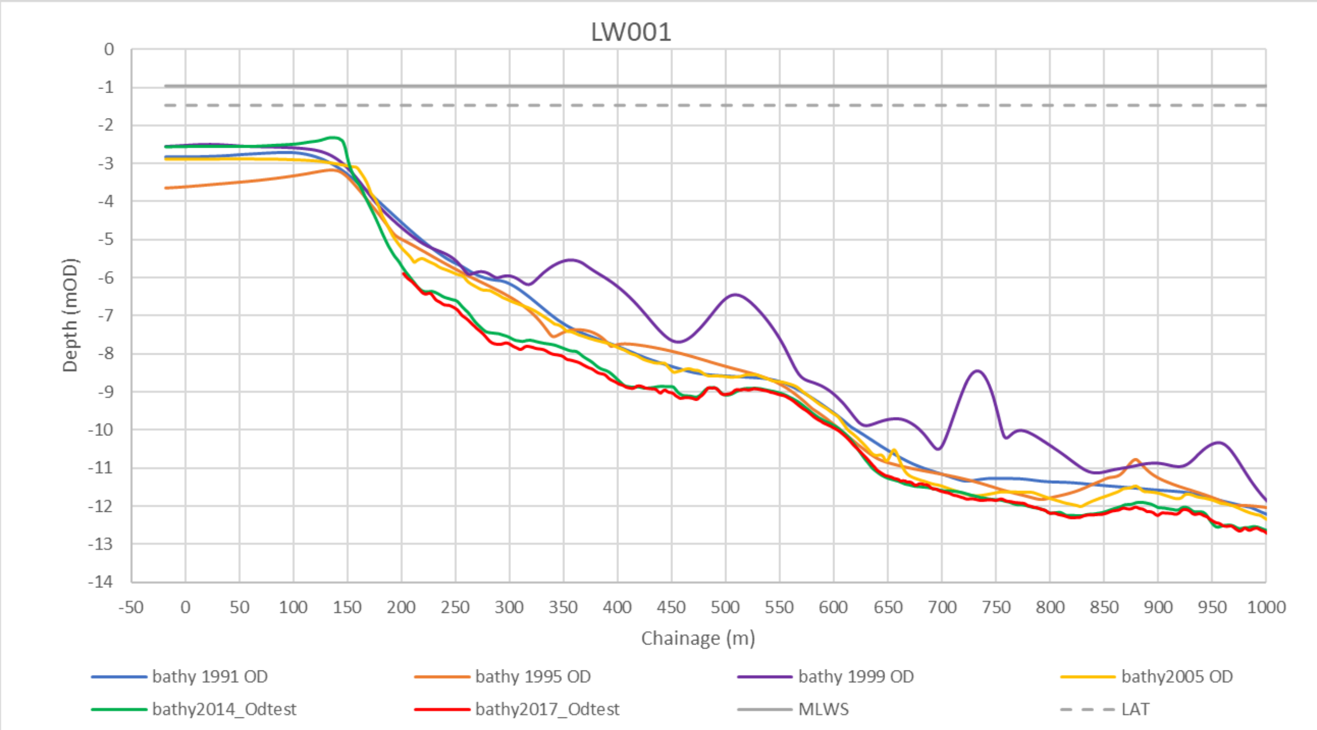


Figure C 4: Bathymetric changes over time (1991-2017, no data for 2014 and 2017 at -5mOD contour) at beach profile 3b10513 LW001 – North of Links Road.

C.3 Northern Gunton Warren (Corton Woods): defended section

The graph below in Figure C 5 shows the changes in bathymetry from 1991-2017 at beach profile 3b1504 N120 at Tramp's Alley, northern Gunton Warren. No data are available for -5 mOD contour for 2014 and 2017. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -6 mOD contour has been observed, at an average rate of around -4 m/yr.
- A general lowering of the seabed has occurred between 150 m and 500 m chainage, up to 0.8 m since 2005. Further offshore than this, the seabed has lowered less, by only around 0.3 m (from 500 m offshore).

Profiles	Retreat of -6m contour*
3b01504 N120	**Average since 1999: -4m/yr** 2005-2014: -4.6m/yr 2014-2017: -3m/yr

* No data for 2014 and 2017 at -5 mOD contour

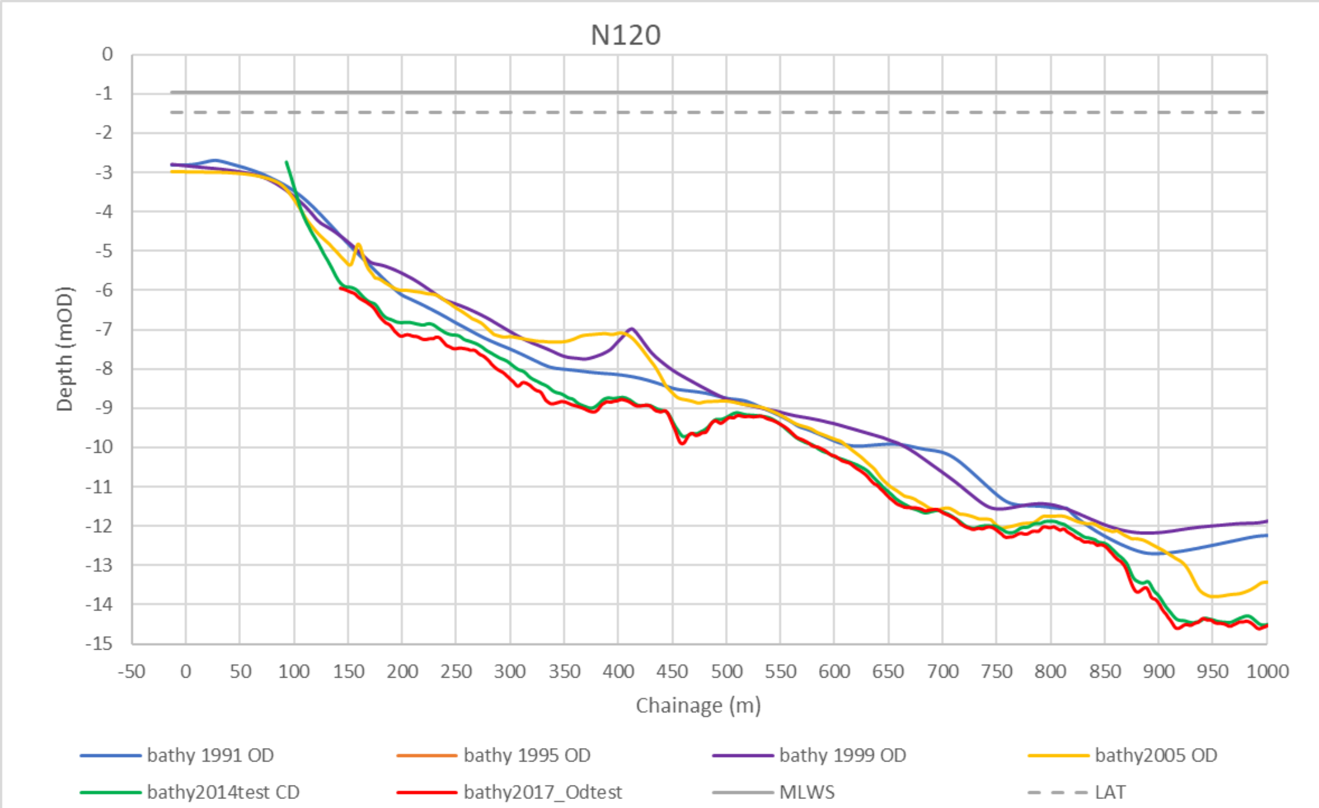


Figure C 5: Bathymetric changes over time (1991-2017, no data for 2014 and 2017 at -5 mOD contour) at beach profile 3b01504 N120 – northern Gunton Warren (Corton Woods) at Tramp's Alley.

The graph below in Figure C 6 shows the changes in bathymetry from 1991-2017 at beach profile 3b01494 GO129 at Corton Long Lane, northern Gunton Warren. No data are available for -5 mOD contour for 2014 and 2017. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -6 mOD contour has been observed, at an average rate of around -2 m/yr.
- A general lowering of the seabed has occurred between 200 m and 900 m chainage, of up to 0.5 m. Further offshore there has been greater lowering of the seabed (from 900 m), by up to 1.5 m.

Profiles	Retreat of -6m contour*
3b01494 GO129	**Average since 1999: -1.9m/yr** 2005-2014: -1m/yr 2014-2017: -1.3m/yr

* No data for 2014 and 2017 at -5 mOD contour

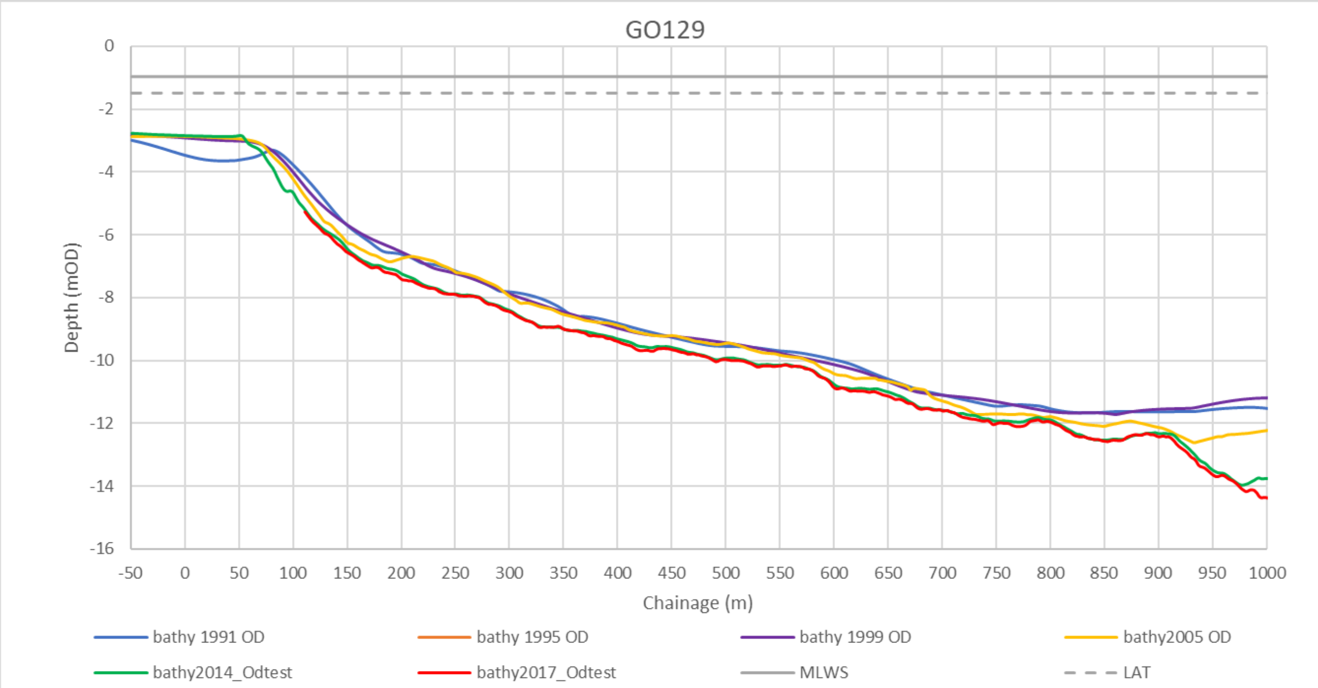


Figure C 6: Bathymetric changes over time (1991-2017, no data for 2014 and 2017 at -5mOD contour) at beach profile 3b01494 GO129 – northern Gunton Warren at Corton Long Lane.

C.4 Corton village

The graph below in Figure C 7 shows the changes in bathymetry from 1991-2017 at beach profile 3b01486 N119, at Tibbenham's Score. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -5 mOD contour has been observed, at an average rate of around -2 m/yr.
- A general lowering of the seabed has occurred between 200 m and 600 m chainage by up to 0.5 m since 2005.

Profiles	Retreat of -5m contour
3b01486 N119	**Average since 1999: -1.9m/yr** 2005-2014: -1m/yr 2014-2017: -1.7m/yr

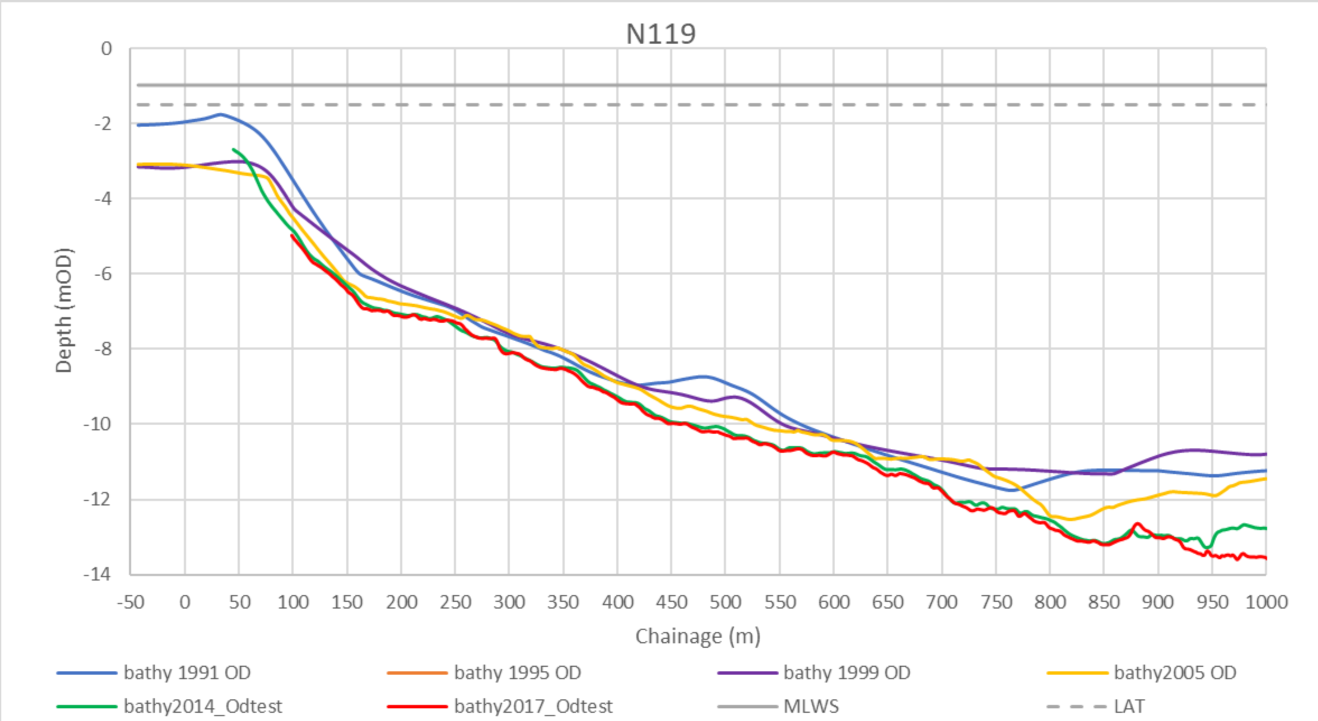


Figure C 7: Bathymetric changes over time (1991-2017) at beach profile 3b01486 N119 – Corton, at Tibbenham's Score.

C.5 North Corton cliffs

The graph below in Figure C 8 shows the changes in bathymetry from 1991-2017 at beach profile 3b01459 N118, at Broadland Sands Holiday Park, North Corton cliffs. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -5mOD contour has been observed, at an average rate of around - 3 m/yr.
- A general lowering of the seabed has occurred between 500 m and 1000 m chainage, up to 0.8 m since 2005.
- Between 2014 and 2017, profiles were stable.

Profiles	Retreat of -5m contour
3b01459 N118	**Average since 1999: -3m/yr** 2005-2014: -2.5m/yr 2014-2017: -1m/yr

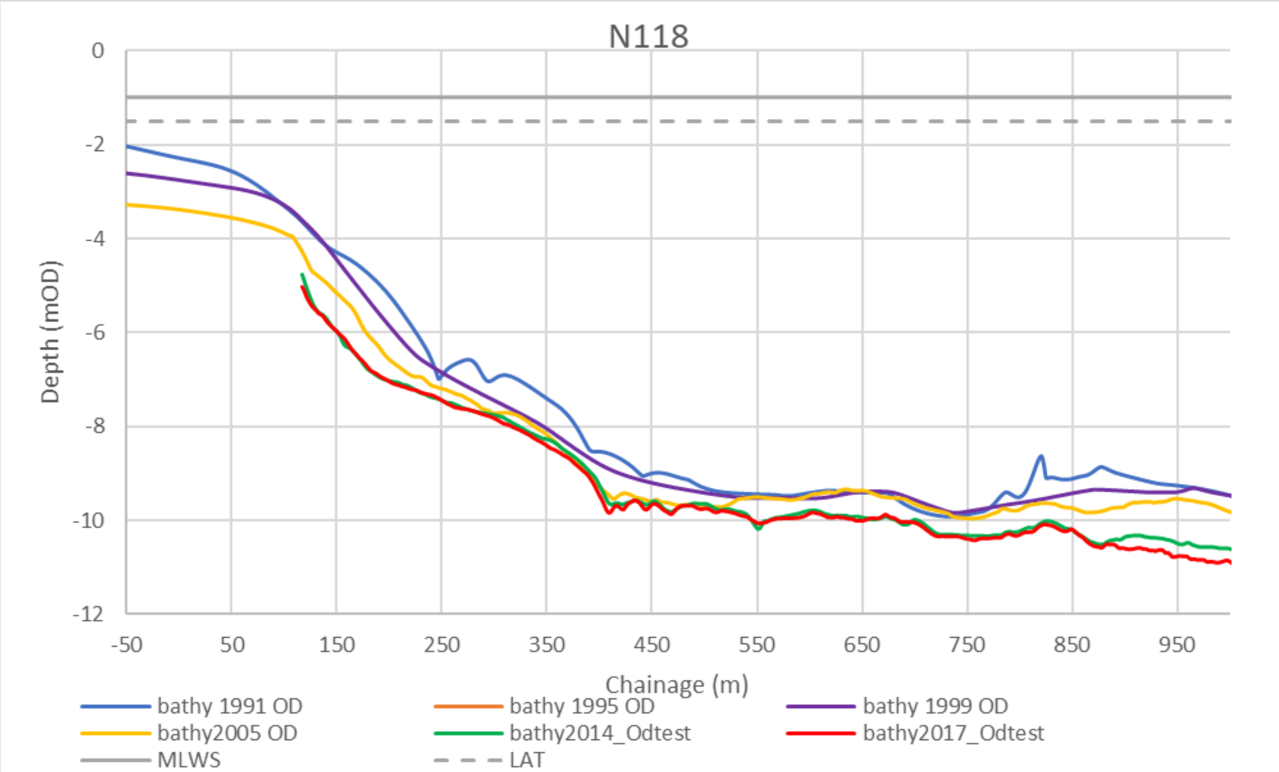


Figure C 8: Bathymetric changes over time (1991-2017) at beach profile 3b01459 N118 – North Corton cliffs at Broadland Sands Holiday Park.

C.7 South of Hopton-on-Sea

The graph below in Figure C 9 shows the changes in bathymetry from 1991-2017 at beach profile 3b01434 N117, at the southern end of Hopton. Summary of bathymetry changes:

- Since 1999, a landward retreat of the -6 mOD contour has been observed, at an average rate of around - 2 m/yr.
- A general lowering of the seabed has also occurred between 350 m and 1000 m chainage, with a change of up to 1 m since 2005.

Profiles	Retreat of -6m contour*
3b01434 N117	**Average since 1999: -1.9m/yr** 2005-2014: -3m/yr 2014-2017: -2m/yr

* No data for 2014 and 2017 at -5 mOD contour

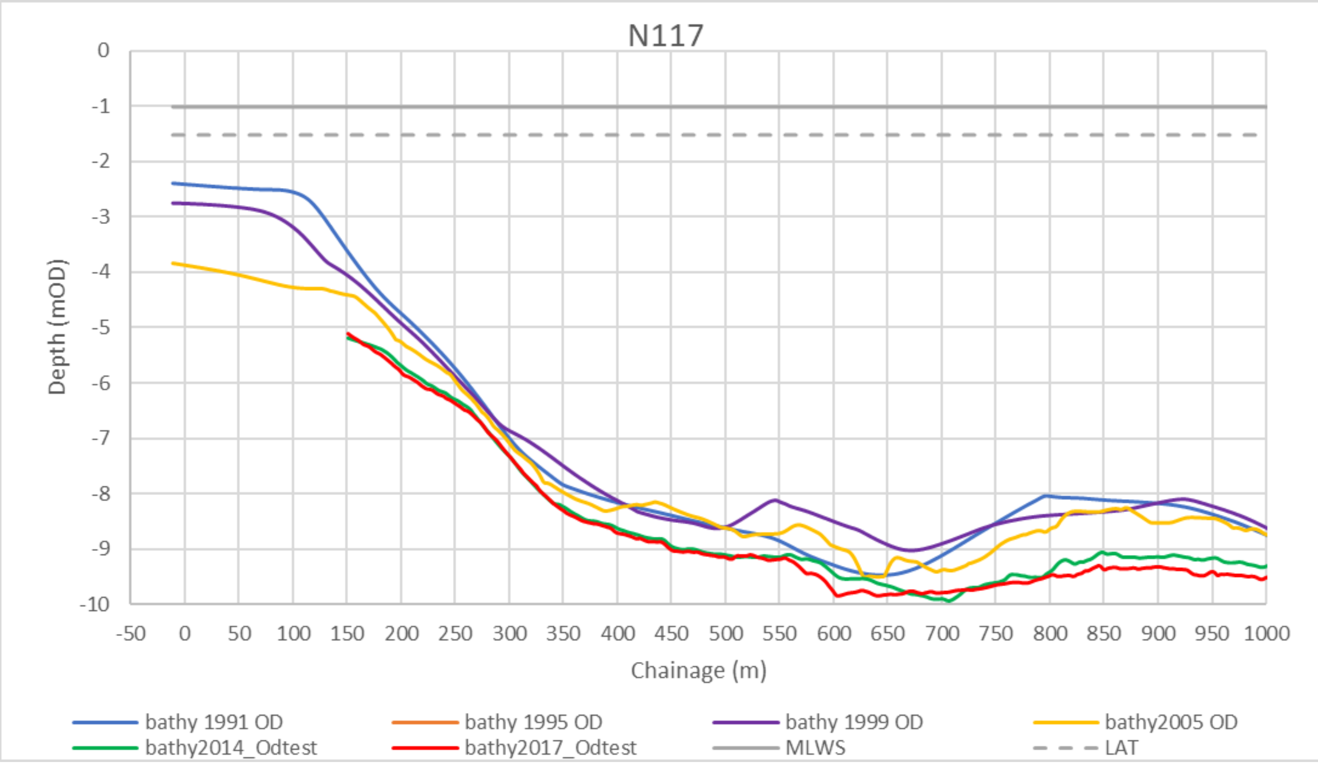


Figure C 9: Bathymetric changes over time (1991-2017) at beach profile 3b01434 N117 – Southern end of Hopton.

Annex D. Wave assessment

Analysis of wave data from Lowestoft wave buoy between 2016 and 2020, as collected as part of the Anglian Coastal Monitoring Programme, is presented in the table below. The location of the buoy is shown in the figure beneath.

It is evident from Figure D 1 and Figure D 3 that the wave climate was not consistent at this location between 2016 and 2020. Particularly looking at the dominant and secondary wave directions in Figure D 1, it is clear that there has been a net change in dominant wave direction. In 2016, the dominant wave direction in summer was SSE-S and the secondary wave direction was NE-ENE. After 2016 (2017-2020), the dominant wave direction changed to between NNE and ENE. Similarly, in 2016 the dominant wave direction in winter was NE-ENE, whereas after this the dominant wave direction was SSE-S. In both seasons there has been a clear change in dominant wave direction after 2016, as shown in Figure D 1 and Figure D 3.

Period		Season	Wave height			Wave period		
Start	Finish		Magnitude (m)	Direction	Max	Magnitude (s)	Direction	Max
20/04/2016	23/09/2016	Summer	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 165-180 (SSE-S) Secondary: 45-60 (NE-ENE)	Between 2-2.5m mainly from NE-ENE. Tp of these waves is between 7.1s and 8.3s and happened in May and June 2016	Dominant: 5.5-6 Secondary: 5-5.5	Dominant: 165-180 (SSE-S) Secondary: 45-60 (NE-ENE)	Up to 14.5s from NE only. Wave heights of these long periods vary between 0.7 and 0.9m. These waves occurred in August 2016
22/03/2018	23/09/2018	Summer	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 45-60 (NE-ENE) Secondary: 165-180 (SSE-S)	Between 2.5-3m mainly from SSE-E. Tp of these waves is around 7s	Dominant: 5-5.5 Secondary: 4.5-5	Dominant: 45-60 (NE-ENE) Secondary: 165-180 (SSE-S)	up to 13s from NE only. Wave heights of these long periods are around 0.7m. These waves occurred in September 2016
22/03/2019	23/09/2019	Summer	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 30-60 (NNE-ENE) Secondary: 165-180 (SSE-S)	Between 2.5-3m mainly from SE. Tp of these waves is around 6s	Dominant: 5-6 Secondary: 4-4.5	Dominant: 30-60 (NNE-ENE) Secondary: 165-180 (SSE-S)	Up to 17s mainly N and NE. Wave heights of these long periods are around 0.1 and0.2m. These waves occurred in March and August 2019
22/03/2020	23/09/2020	Summer	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 30-60 (NNE-ENE) Secondary: 165-180 (SSE-S)	Between 3-3.5m from NE. Tp of these waves is around 8s and 10s	Dominant: 5.5-6 Secondary: 5-5.5	Dominant: 30-60 (NNE-ENE) Secondary: 165-180 (SSE-S)	Up to 14.5s from N - NE only. Wave heights of these long periods are around 0.2 and 0.7m. These waves occurred in April and May 2019
24/09/2016	21/03/2017	Winter	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 45-60 (NE-ENE) Secondary: 165-180 (SSE-S)	Between 3.5-4m mainly from SE and S. Tp of these waves is around 6s and occurred in November 2016	Dominant: 5.5-6 Secondary: 5-5.5	Dominant: 45-60 (NE-ENE) Secondary: 165-180 (SSE-S)	Up to 15.5s from NE only. Wave heights of these long periods vary between 0.5 and 0.8m. These waves occurred in December 2016
24/09/2018	21/03/2019	Winter	Dominant: 0.5-1 Secondary: 0-0.5	Dominant: 165-180 (SSE-S) Secondary: 30-45 (NE)	Between 3.5-4m mainly from SE. Tp of these waves is around 7s. These occurred in december 2018.	Dominant: 5-5.5 Secondary: 6.5-7	Dominant: 165-180 (SSE-S) Secondary: 30-45 (NE)	Up to 18.5s mainly NE but a couple also from SE. Wave heights of these long periods vary between 0.2 and 0.8m. These waves occurred in January and February 2019
24/09/2019	21/03/2020	Winter	Dominant: 0.5-1 Secondary: 1-1.5	Dominant: 165-180 (SSE-S) Secondary: 150-165 (SSE)	Between 4-4.5m mainly from SE. Tp of these waves is around 6 and 7s and occurred in december 2019 and february 2020	Dominant: 5.5-6 Secondary: 5-5.5	Dominant: 165-180 (SSE-S) Secondary: 150-165 (SSE)	Up to 17s mainly N and NE. Wave heights of these long periods vary between 0.4 and 0.8m. These waves occurred in October 2019 and January 2020
24/09/2020	31/12/2020	Winter (part)	Dominant: 0.5-1 Secondary: 1-1.5	Dominant: 165-180 (SSE-S) Secondary: 150-165 (SSE)	Between 3.5-4m mainly from SE. Tp of these waves is around 9s and occurred in dec 2020	Dominant: 5.5-6 Secondary: 5-5.5	Dominant: 165-180 (SSE-S) Secondary: 150-165 (SSE)	Up to 17s mainly NE. Wave heights of these long periods vary between 0.3 and 0.4m and occurred in December 2020. Waves around 1m occurred in November 2020.

Figure D 1: Wave climate analysis summary table, including wave height and wave period analysis of magnitude (m), wave direction and max height waves.

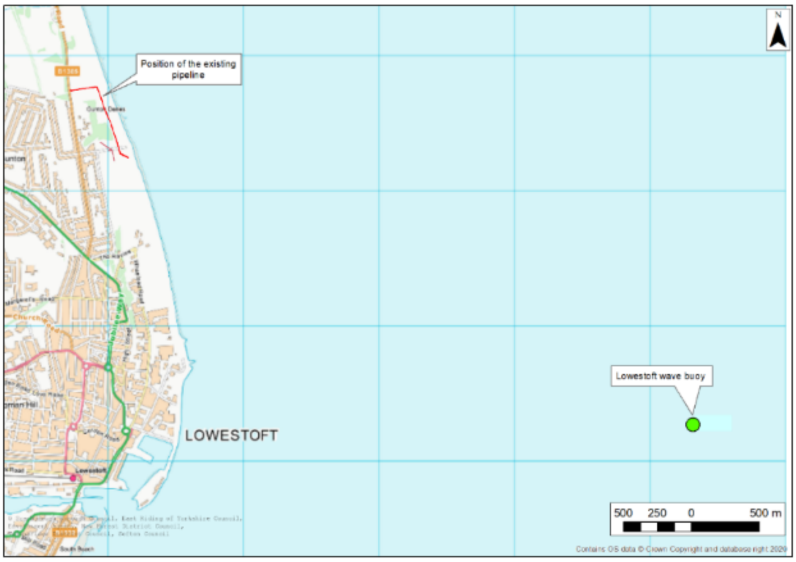
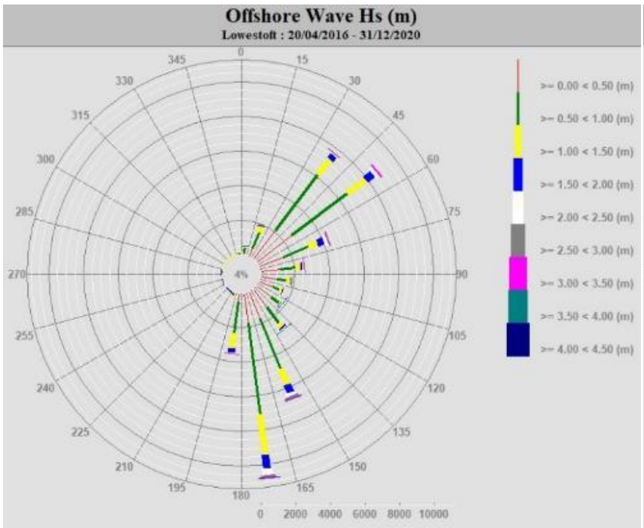


Figure D 2: Location of wave buoy used for wave climate analysis.

Below are wave roses for the Lowestoft wave buoy, between 20/04/2016 and 31/12/2020, for Significant Wave Height (Hs – left) and Peak Wave Period (Tp – right).



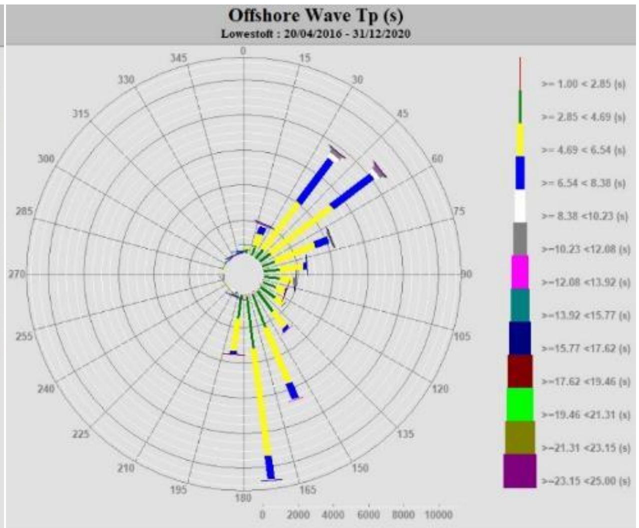


Figure D 3: Wave roses for offshore Significant Wave Height (Hs – left) and Peak Wave Period (Tp – right) period between 20/04/2016 and 31/12/2020

Annex E. Reference information from earlier studies

This Annex E compiles coastal processes analysis and findings from previous studies as described in the Strategy.

E.1 Historical change in shoreline position

The 1999 Strategy (Halcrow, 1999a, b and c) provided a comprehensive review of historical changes in coastal processes along the Gunton to Corton frontages. Table E 1 shows historical change in shoreline position between Gunton and Corton frontage analysed by the 1999 Strategy.

Table E 1: Historical change observed from Ordnance Survey maps. Information taken from the original Strategy (Halcrow, 1999) – it should be noted that measurements of beach retreat or advance (based on the position of mean low water) would have been fairly high-level.

Period	Gunton Denes	Corton	Hopton to Corton
1883 to 1904	Beach retreat.	Minimal change.	Beach retreat, but less than along Gorleston to Hopton.
1904 to 1938	Beach retreat – change in MLW typically 50m to 125m	Beach retreat – change in MLW typically 50m.	Beach retreat – change in MLW typically 50m.
1938 to 1967	Up to 25m retreat of MLW at northern end of frontage. Overall net beach advance elsewhere - change in MLW of around 75m.	300m stretch of seawall and groynes built 1960 in northern half of frontage. Northern end: beach retreat - change in MLW of around 25m Southern end: limited accretion - change in MLW of around 25m.	Minimal change.
1967 to 1971	Seawall and groynes built 1967-1971 in response to accelerated erosion downdrift of the Corton defences. Beach retreat – change in MLW typically 40m.	Extension of seawall southwards. Northern end: beach accretion - change in MLW of around 25m Southern end: beach retreat - change in MLW of around 50m.	Beach retreat – change in MLW typically 40m.
1971 to 1992	Beach accretion – change in MLW typically 60 - 75m.	Beach accretion – change in MLW typically 60 - 75m.	Beach accretion – change in MLW typically 25m.

Further analysis of shoreline changes was undertaken by the Environment Agency Coastal trends reports (2007, 2008 and 2013). These report on analysis of the twice-yearly topographic beach surveys collected by Environment Agency at 1 km intervals along this coastline. Results from the 2008 and 2013 reports are included here (Table E 2) for completeness, but there is little additional information included in the 2007 report.

Table E 2: Observations made in the EA Coastal trends Reports 2008 and 2013

Profile ref (old/new)	Place name	2008 report	2013 report
SWF4/ N0120	Gunton Cliffs	A period of modest erosion up to 2001 followed by some degree of accretion. No significant foreshore rotational trend apparent.	A cycle of erosion to 1999 is followed by uniform accretion at all levels to 2012. There is no beach rotation. Overall trend of accretion is 1.1 m/yr.
SWF3/ N0119	Corton Village	A strong erosion trend with significant foreshore steepening occurring.	A relatively wide foreshore in 1992 of 25m is subjected to a strong erosion trend to 2007 where beach levels then remain stable. More significant erosion at low water has led to steepened profile with mean trend of -1.2 m/yr. The current foreshore width is around 8m.
SWF2/ N0118	Corton Cliffs	Data shows some accretion prior to 1997 with subsequent erosion since. Little or no beach present in front of defences. Strong beach steepening trend apparent.	Little movement at high water with erosion trends at MSL and low water. Water levels accreted to 1997 and then sharply retreated to 2012. The foreshore is very narrow at 9m in width. The mean trend is -0.5 m/yr with a steepened profile.

E.2 Sediment input

An assessment was undertaken in 1996 of the sediment composition and likely sediment yield from the cliffs (British Geological Survey (BGS), 1996). This analysis (Table E 3 indicated that the cliffs are predominately composed of sand, which constitutes between 71 and 99% of the sediment. The proportion of gravel and mud varies, with a higher proportion of gravel found in the cliffs at the southern end of the frontage, whilst along the Corton frontage the percentage of fines is considerably higher. The proportion of fines affects both the likely input of sediment from the cliffs and also the way in which the cliffs are likely to fail.

The table also shows total sediment volume and mud, sand and gravel volume between the two EA profile markers; this takes account of the cliff height as well as the composition. This is also shown graphically in Figure E 1. It should be noted that these are potential yields: up to recently the cliffs along this coastline have not been subject to any erosion, meaning that this volume has not been field-tested in any way. The table provides data for Lowestoft Denes (SWF5 to SWF6), however at this location the coastal hinterland is low-lying. Therefore, the data must respond to the cliffs that lie around 250 m inland. Similarly, at Gorleston the cliffs are currently set back behind the promenade and sea wall and have been re-graded in the past, therefore it would some time before these began reactivated, even under a scenario of no future management (‘no active intervention’).

Table E 3: Cliff sediment and potential yield (m^3 per metre of recession) – taken from BGS (1996)

Location	EA markers	Revised location names*	Mud		Sand		Gravel %		Total
			%	m^3	%	m^3	%	m^3	m^3
Hopton to Corton	SWF1-SWF2	N117-N118	10.2	753	88.2	6,479	1.6	115	7,346
Corton Cliffs	SWF2-SWF3	N118-N119	25.8	4,235	71.3	11,687	2.9	475	16,297

Corton Woods & Corton	SWF3-SWF4	N119-N120	30.4	5,847	66.0	12,710	3.6	689	19,246
Gunton Denes	SWF4-SWF5	N120-N121	5.3	657	86.8	10,849	7.9	983	12,490
*Since the report was written, the profile locations have been renamed, therefore these have been added to the table and are shown in Figure E 1.									

It is predominately the sand and gravel fractions of the cliffs which will contribute to beach-building. Figure E 1 and Table E 3 indicate that cliffs to the south of Corton would potentially yield higher volumes of sediment than those further north, although a higher proportion of mud would be released. Excluding the frontages of Gorleston and Lowestoft where the cliffs are set back from the coast, the cliffs from Gunton Denes up to South Gorleston could potentially yield around 55,000 m^3 of sand and gravel for every metre of landward retreat. To put this volume into context, a crude estimate of volume change along this frontage suggests that compared to 1992 the beaches (in December 2013) may have reduced in volume by around 35,000 m^3 of sediment.

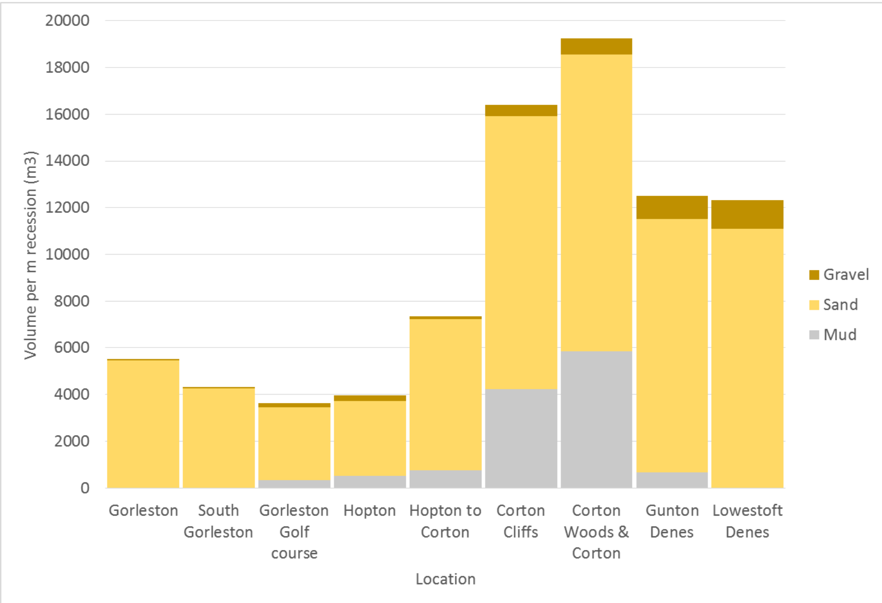


Figure E 1: Graphical representation of the BGS (1996) volume data

Currently, much of the frontage is protected by some form of defence and there is only one area of coastline that is actively eroding, which lies between Hopton and Corton. Here, defences have failed leaving the cliffs exposed to wave action. Erosion will be releasing sand, but there is little evidence of this being retained on the fronting beaches

E.3 Cliff Erosion

There is only one section along the Strategy frontage where cliffs are currently eroding, which lies between Hopton and Corton (see Table E 4). There is one EA profile that relates to this stretch of shoreline, namely N118; although there are additional profiles now available, the longest of these only extend back to 2008 and many of the profile locations only contain two survey sets, both of which were taken in 2011.

The data for N118 indicates that there may have been some cliff cut back between the surveys of August 1992 and 1996, but there is only one other data set available between these two dates to substantiate this. Data since 1996 shows that cliff erosion was initiated by failure of the timber revetment and erosion of the beach which had been retained by the revetment. Onset of cliff erosion was around July 2008 and between 2008 and summer 2013 the cliff retreat appears to have been a gradual trend, but there was a significant cut back between July

2013 and December 2013. It is likely that this was the result of the extreme storm event in early December 2013, which affected much of the East Coast of England.

From the data available, which records position of the cliff toe and cliff top, estimates of cliff erosion can be calculated for N118. This in turn can be used to derive broad estimates of the volumes of sediment released, based upon the following assumptions:

- the length of eroding cliff is around 820 m (this is based on the latest aerial image and additional profile data);
- there is a linear rate of retreat;
- around 74% of the sediment released is likely to be sand and gravel, i.e. beach-building materials (according to the BGS 1996 cliff composition data; see Section E.3).

Table E 4: Calculations of cliff retreat using EA profile N118

Date	Retreat of cliff top at N118	Retreat of cliff toe at N118	Average rate of retreat at N118	Average annual rate at N118	Calculated change in CSA at N118	Estimated volume of sand/gravels released along frontage
30/7/2008 – 09/7/2009	0.14 m	2.67 m	1.41 m	1.1 m/year	14.8 m^2	9,000 m^3
09/7/2009 – 23/7/2010	2.21 m	2.47 m	2.34 m	2.3 m/year	16.9 m^2	10,300 m^3
23/7/2010 – 28/6/2011	2.63 m	0.32 m	1.48 m	1.6 m/year	17.1 m^2	10,400 m^3
28/6/2011 – 31/7/2013	2.36 m	4.69 m	3.53 m	1.7 m/year	29.2 m^2	17,700 m^3
31/7/2013 – 12/2013	7.63 m	9.21 m	8.42 m	22.3 m/year	61.4 m^2	

The data show that, albeit based on a relatively short period of time, usually the annual rate of cliff retreat at N118 ranges between 1 and 2.3 m per year, however, during extreme events, such as that experienced in December 2013, over 8m recession can occur. Excluding the extreme erosion, this rate of erosion would be expected to contribute between 9,000 and 17,700 m^3 sediment.

E.4 Sediment Transport

Coastal area modelling of sediment transport under combined waves and currents has been undertaken by HR Wallingford (1998), ABPmer (2013) and again by HR Wallingford in 2013, as reported in SMP (2013), and HR Wallingford, on behalf of Great Yarmouth Port Company (GYPC) (HR Wallingford, 2013 a, b). The most comprehensive modelling study is that reported in HR Wallingford (1998), which considered different bathymetries.

Information from these have been used to produce an average annual sediment volume for comparison with earlier studies, as shown below in Table E 5.

Table E 5: Potential annual littoral transport volumes from HR Wallingford (1988 and 2013b): Corton

	Average annual wave climate			UK MO wave climate	1993 wave climate	Nearshore wave climate (2005-2011)*
	1996 bathymetry	**1986 bathymetry**	**1970 bathymetry**	**1996 bathymetry**	**1996 bathymetry**	**2005 - bathymetry**
Northward drift	27,770	84,540	121,140	26,710	34,400	301,070
Southward drift	128,550	116,110	250,710	144,750	240,200	232,580
Net drift	100,790 S	31,570 S	129,570 S	118,060 S	205,800 S	68,490 N

* These volumes have been derived by using the plots produced by HR Wallingford (2013b) for SWF3, and averaging the components of drift across the 7 years of data.

Further analysis of the data indicates that it is the northward component of drift that is so different at GY30 (between Hopton and Corton), compared to other locations between Gorleston and Corton. Here the northward drift is much lower and therefore the location is more sensitive to changes in wave climate that result in more southward drift. A similar conclusion was reached in the previous Strategy, which also found that at COR 5 (Corton) the gross northward drift was equal or greater than the southward drift.

The cross-shore transport of sediment was not specifically addressed by HR Wallingford (HR Wallingford, 2013a, b), although COSMOS modelling was undertaken, this was used to look at the cross-shore distribution of alongshore transport, not beach response during storm conditions. Similarly there is little discussion of cross-shore transport within the reports produced by Shoreline Management Partnership (2013).

Although the monitoring reports undertaken for the GYOH identify the cross-shore movement of beach material from upper parts of the beach to lower regions from beach profile analysis, there is no quantification of this mechanism.

As part of their work looking into different defence options, ABPmer (2013) undertook modelling of beach response and cross-shore sediment transport. Key conclusions from their study, which focused on Hopton were:

- Fine sand (with a median grain size of 0.25 mm) can potentially be transported up to 90 m (around -5 m OD) offshore from the MHW shoreline during a storm event;
- Storm response did not seem to depend upon storm direction, for the 1 in 35 year event considered. (However, this is for Hopton only (GY28) and may differ along the shoreline due to the varying orientation of the shoreline to the incoming waves).
- Sediment eroded from the upper and lower beach profile does not move more than 20 m further offshore, and the amount of material transported to greater than -5 m OD was less than 3% of the loss from the upper beach.

E.5 Summary from the Strategy report

In summary, the data sets examined indicate how the over time the beaches along this shoreline have experienced reversals in erosion/accretion trends. These changes do not occur simultaneously along the frontage, instead there appears to be a progressive impact along the shoreline. The data also illustrate that changes along this coast can occur fairly rapidly following a trigger, which highlights the need for continual monitoring to detect when a change in trend occurs, such that an appropriate action can be identified.

There are locations where currently beach material is not being retained, namely in front of Corton Cliffs, at Corton itself, and along Lowestoft North Beach. The beach profile data shows that where erosion is experienced, the timber revetments are successful in retaining sediment for some time, until a point is reached at which beaches seaward of the revetment drop to a critical level, resulting in failure of the revetments and erosion of material to landwards of the structures.

As observed by HR Wallingford (2013b) and Shoreline Management Partnership, changes in the beach appear to be driven by sudden losses or gains of sediment, i.e. 'step changes'. The trigger for these step changes is not distinguishable from the data sets, but the data illustrate that changes along this coast can occur fairly rapidly following a trigger. This highlights the need for continual monitoring to detect when a change in trend occurs, such that an appropriate action can be identified.

Although the changes in beach volume at any one location have been significant over time, the net change in overall volume across the frontage is much smaller, suggesting that the system is close to being in balance, with material moving from one location to another and limited net gain or loss from the system. The cliff erosion at Corton Cliffs is a contemporary input to the beach system; there is little evidence to suggest material released is being retained locally, therefore material is either feeding adjacent beaches or being lost offshore. The distance between the profile data makes it difficult to track the movement of any sediment released and it is not possible to identify any beach gains elsewhere that can be directly attributed to the cliff erosion.

E.6 Future changes from the Strategy report

The beach profile data indicate that trends in beach trends have changed and/or reversed between 1992 and 2014

Recent cliff erosion data from Corton give an indication of the extent of cliff retreat that could be expected elsewhere along this coast, should beach levels diminish sufficiently to result in failure of defences and activation of cliff erosion. This shows that rates of between 1 and 2.5m per year might be expected, but also that the cliffs are vulnerable to extreme events, such as that which occurred in December 2013 around the East Coast and that as a result of such conditions, cliff retreat can exceed 8m.

A range of between 1 and 2.5m per year would result in much higher rates of retreat than predicted by previous studies, such as the original Strategy, Futurecoast (Halcrow, 2002) of the SMP for the Strategy area, if erosion were to commence immediately. At the time of these studies there was no contemporary data relating to cliff erosion for this coastline.

It is, however, difficult to determine from the cliff data whether the current cliff erosion is a 'spring back' mechanism resulting from the shoreline being held forward of its natural position and therefore whether rates may slow once the cliff line reaches a position more commensurate with the prevailing wave and tidal levels. However, as current material from the cliffs is not being retained locally and therefore beach levels at the cliff toe continue to remain low, thereby promoting further erosion due to wave attack.

E.7 References

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