Jacobs

Technical Note

One Glass Wharf
Bristol
BS2 0FF
0117 457 2500

www.jacobs.com

Subject	**Appendix D - Gunton Coastal Change Assessment for Anglian Water**	**Project Name**	Gunton and Corton Options Appraisal
Attention	Craig Kellard (for Anglian Water)	**Project No.**	B2413600
From	Beatriz Serato and Kevin Burgess, Jacobs		
Date	4 May 2021		
Copies to	Madeline Fallon (East Suffolk Coastal)		

1. Introduction

This technical note presents the findings of the coastal change analysis undertaken along the southern section of the Gunton Warren shoreline corresponding to the location of Anglian Water's (AW) existing pipelines. The analysis has been undertaken as part of the Gunton and Corton Options Appraisal project, commissioned by East Suffolk Council (ESC) and being undertaken by Jacobs. This wider project is re-examining the options for shoreline management proposed in the Gorleston to Lowestoft Coastal Strategy Plan (the 'strategy') (Jacobs, 2017), based upon the latest understanding of coastal processes and shoreline behaviour.

Since the strategy the Gunton frontage has experienced rapid erosion, increasing the risk of exposure to Anglian Water's (AW) pipelines, which are currently located behind the beach within an area of low dunes (Figure 1-1). This has raised concerns regarding the viability of maintaining the current alignment of the pipelines and, in response, AW have considered a series of options for their potential relocation. Their preferred option is to set these further landward withing the backshore area, closer to the base of the former cliff line. To help inform future management decisions, Jacobs have been asked to appraise recent shoreline change as follows:

1) Define the timeframe within which the existing pipe alignment could be affected by erosion;

2) Define the timeframe within which the proposed pipe alignment could be affected by erosion;

3) Consider any potential strategic level management approach to address any risk to the proposed pipeline, and compliance or otherwise with the Shoreline Management Plan (SMP) and Strategy Plan.

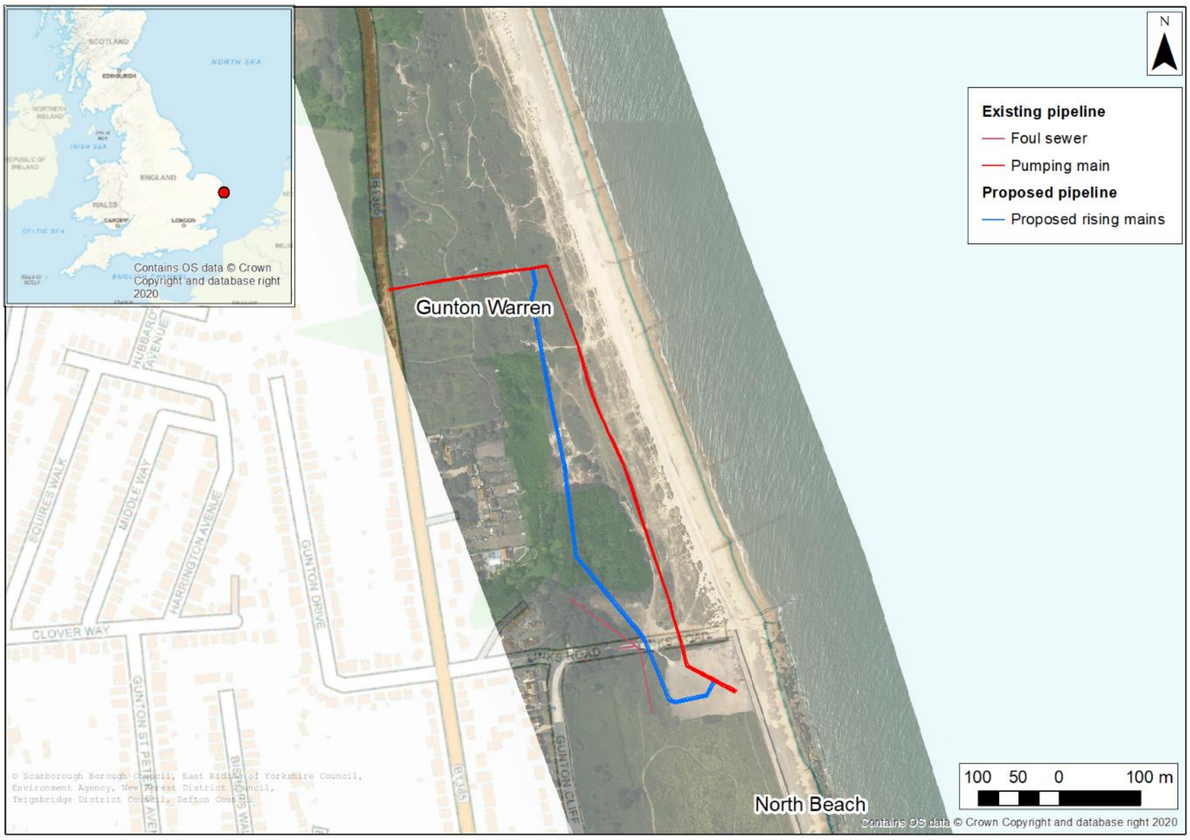


Figure 1-1: Location plan, showing position of both existing and proposed Anglian Water pipelines (based on data provided by Anglian Water).

2. Data used

Table 2-1 lists the datasets used in this coastal change analysis and their sources and Figure 2-1 shows the location of the topographic beach profiles analysed.

With the exception of beach profile LW005, beach surveys are only available from the regional monitoring programme for 2011 (two surveys) and 2016. Therefore, 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.

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

Data type	Source	Details
Topographic beach profiles	Anglian Coastal Monitoring Programme	5 beach profiles were analysed: LW003, LW005, LW006, LW007 and LW008
LiDAR	Environment Agency	Digital Terrain Model (DTM) 1999, 2003, 2015, 2018 and 2019
Bathymetry	UKHO	1999, 2014 and 2017
Drone surveys	Anglian Water	October 2020 and April 2021
Historical aerial photographs	Google Earth	1945, 1999, 2006 and 2019
Wave climate	Anglian Coastal Monitoring Programme	Wave height and direction available from the Lowestoft wave buoy between 2016 and 2020
Existing pipe alignment	Anglian Water	Provided in CAD format
Proposed pipe alignment	Anglian Water	Provided in CAD format
Position and invert levels of existing pipeline	Anglian Water	Provided in PDF format

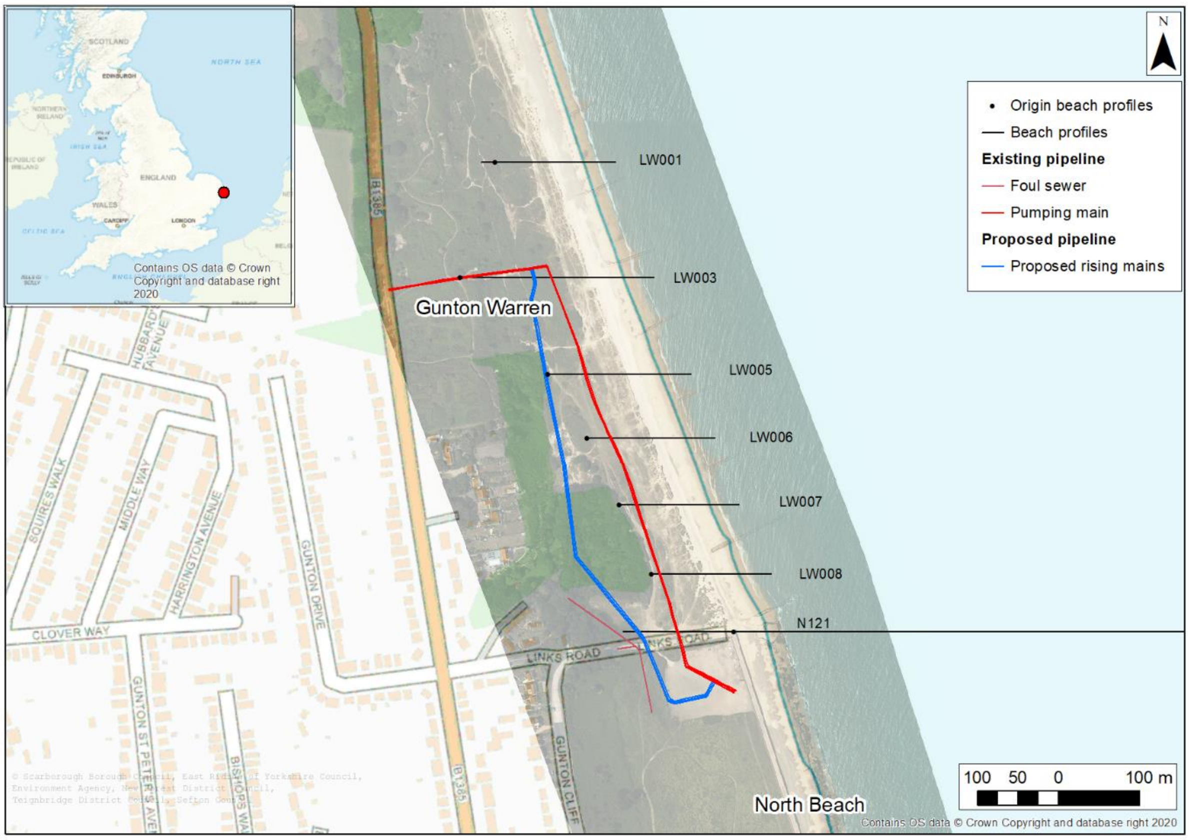


Figure 2-1: Location of the beach profiles used in this analysis (*LW001 and N121 not included*). Beach levels have also been extracted from LiDAR and drone surveys along the same transects.

3. Assessment of shoreline behaviour

3.1 Recent patterns of erosion and accretion

Difference plots using bathymetry, LiDAR and drone surveys have been produced, which compare (i) consecutive survey years and (ii) the most recent to the oldest surveys. These data sets provide an appreciation of changes across the whole beach.

Figure 3-1 shows combined LiDAR (2015 – 2019) and bathymetry (2014 - 2017) difference plots for the frontage. This illustrates the erosional trend along the Gunton frontage and the general accretional trend along the Corton Woods frontage. Figure 3-2 shows the most up-to-date topographic data provided by AW drone surveys and illustrates the difference in beach levels recorded in October 2020 and April 2021. This figure shows how different areas of the beach have changed over that period.

The beach profiles extracted from these data are presented in Appendix A, with further analysis of the changes described in section 4.

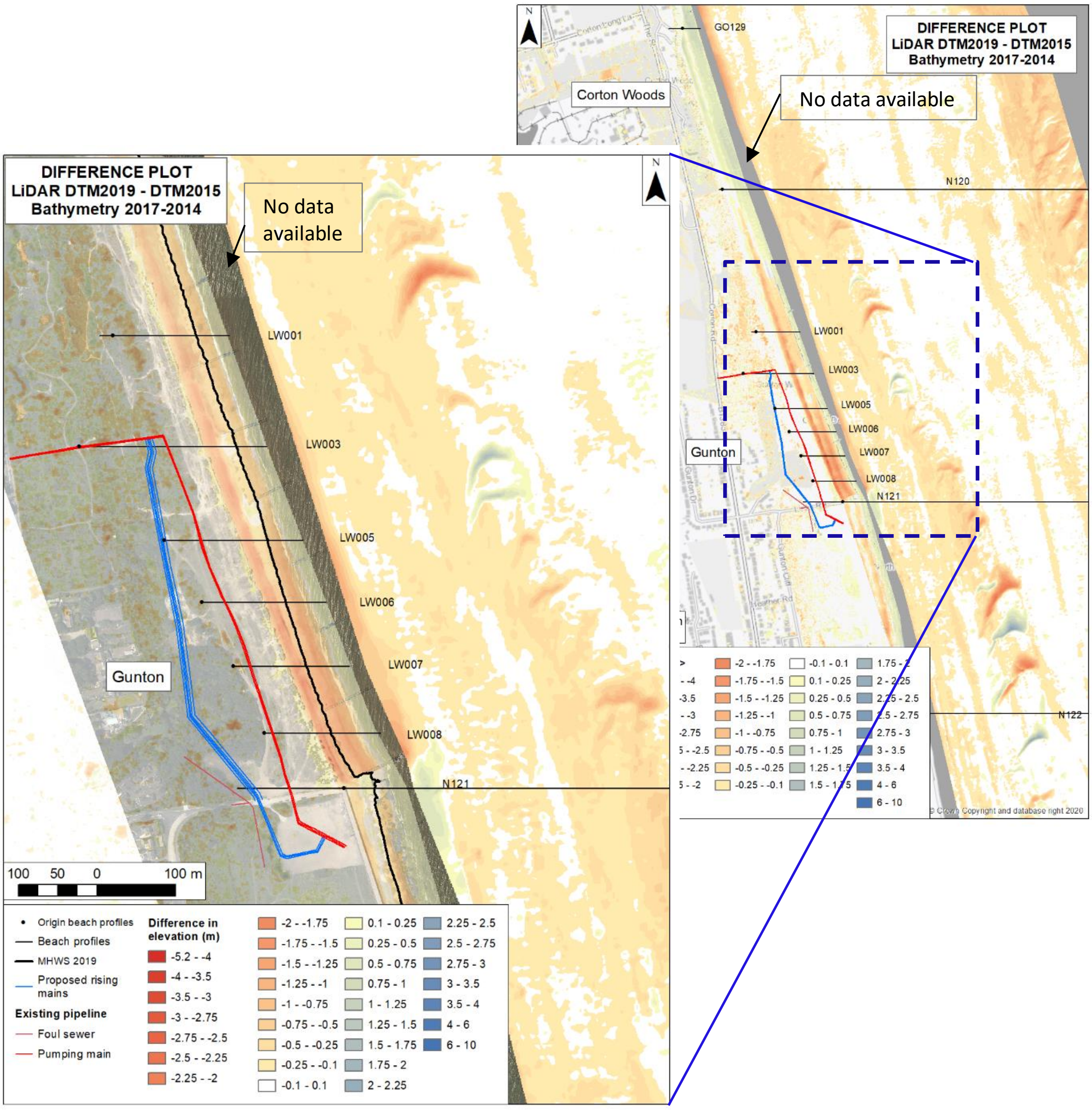


Figure 3-1: Difference plots showing the difference in depth between 2014 and 2017 bathymetry (offshore of the “no data available” area on the plot to the right) and the difference in elevation between 2015 and 2019 DTM LiDAR (inshore of the “no data available” area). The zoomed plot also shows the position of Mean High Water Spring (MHWS) in 2019.

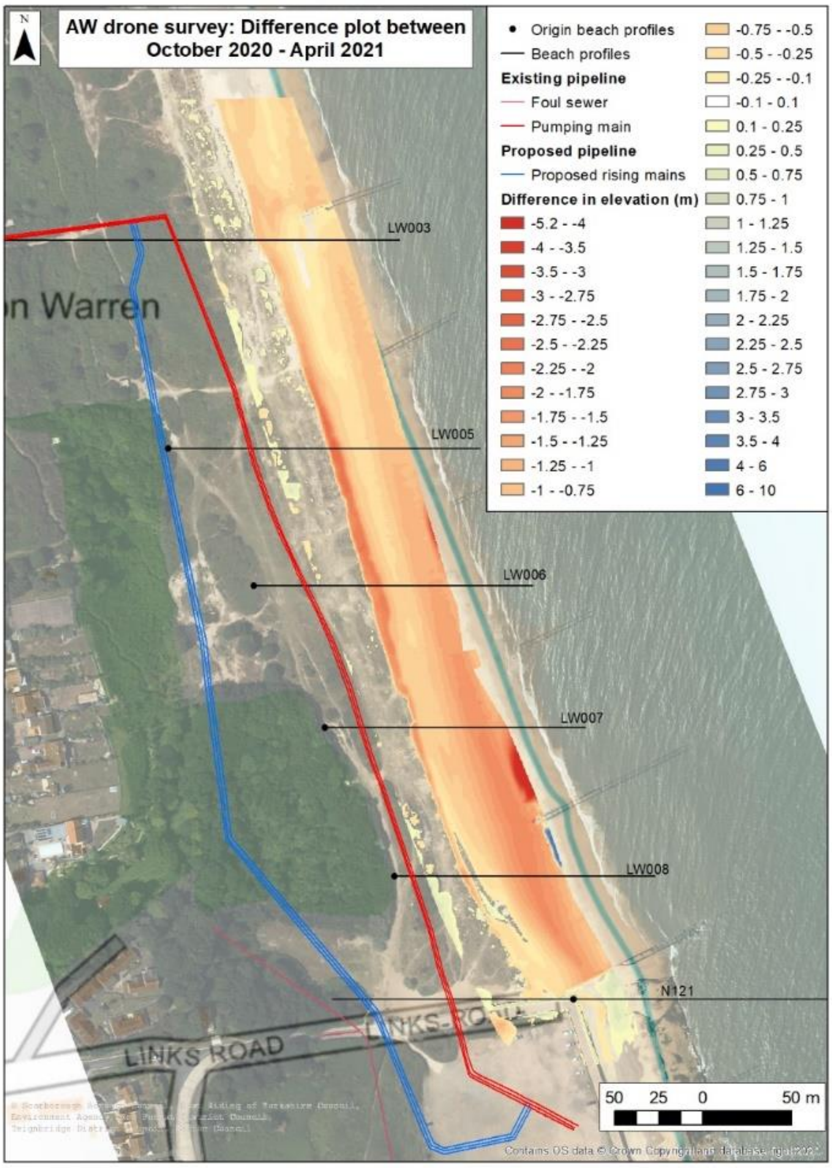


Figure 3-2: Difference plot showing the difference in elevation between AW drone surveys undertaken in October 2020 and April 2021.

3.2 Changes in shoreline alignment

Historical aerial photographs from Google Earth have been examined to assess whether there has been a net shift in plan form over time. Aerials are available for 1945, 1999, 2006 and 2019 and using these the approximate orientation of the beach has been plotted as shown in Figure 3-3 (the entire sequence of images is provided in Appendix B).

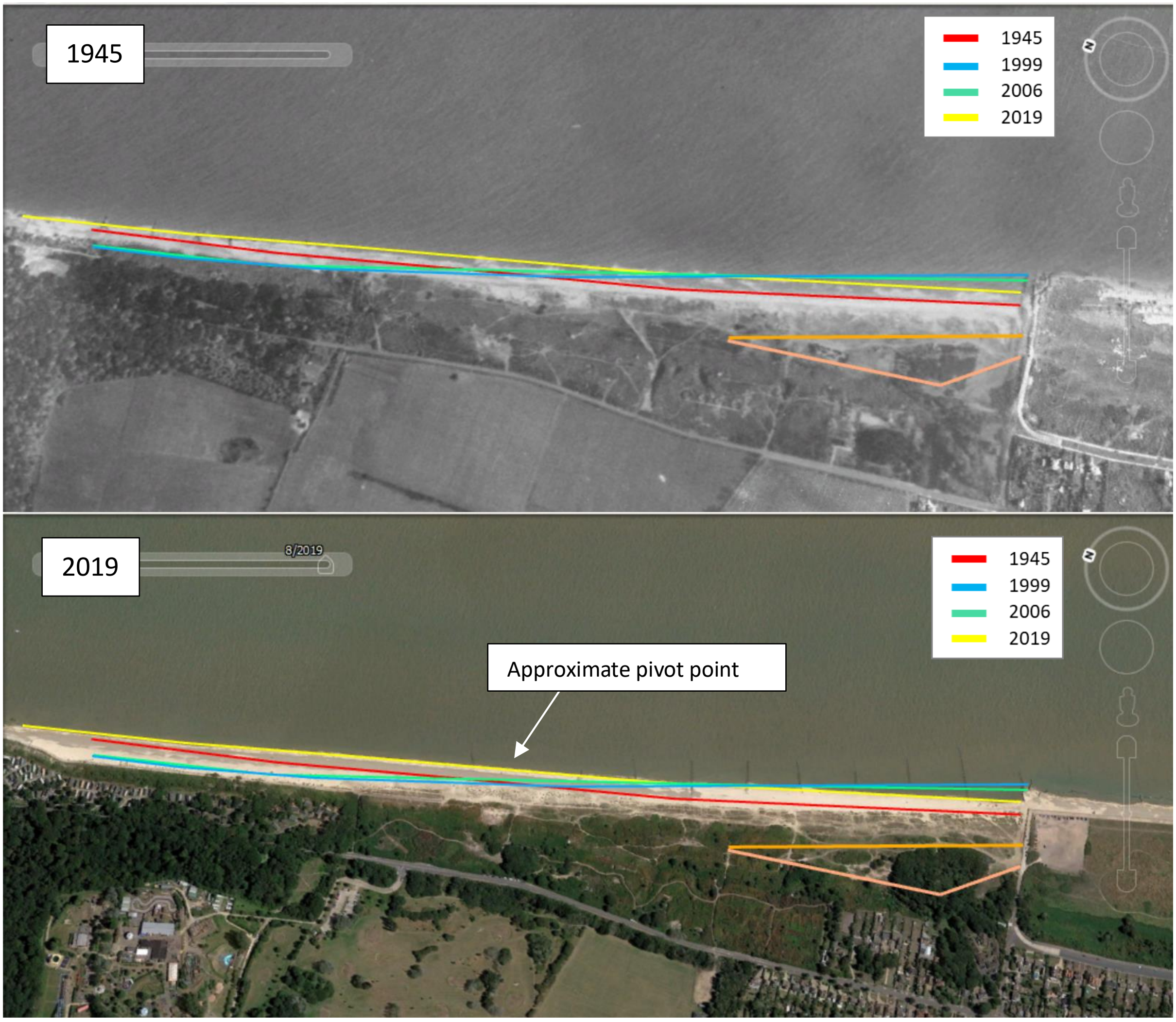


Figure 3-3: 1945 (top) and 2019 (bottom) aerial images overlaid with approximate shoreline position in 1945 (red line), 1999 (blue line), 2006 (green line) and 2019 (yellow line). Orange lines represent the approximate location of both the existing and proposed AW pipelines. Images © Google Earth.

The images show that the beach has both advanced and retreated since 1945, although the overall plan area does not appear to have changes significantly, rather that the whole shoreline between Corton (to the north) and Links Road (to the south) has rotated. Between 1945 and 1999, there was net advancement (offshore movement) of the shoreline at the southern end of the frontage), but corresponding retreat (onshore movement) at the northern end, 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, and advancement to the north.

It is also notable that the 1945 shoreline was further inland than in 2019, suggesting that the location of the existing pipeline may be within what was previously the active beach zone, and could therefore be so again.

Over time, it seems that the shoreline alignment has rotated by up to 5 degrees, with the pivot point located midway along the Gunton frontage. This orientation is postulated to most likely reflect the predominant wave direction during those periods, indicating this has also altered over time as discussed below in section 3.3.

The changes that have occurred show that this shoreline has changed in alignment in the past and therefore it can be inferred that this could happen again in the future, i.e. the beach along the southern end of Gunton Warren may again cease to recede and begin to advance. However, the complexity of factors which may produce this, make the potential and timing for that unpredictable.

3.3 Offshore influences

There are a number of factors that potentially affect shoreline change along the Gunton frontage and it is likely that a combination of these have resulted in the changes in erosion and accretion patterns that have been observed.

Wave data are available from the Anglian Coastal Monitoring Programme for the Lowestoft wave buoy, located approximately 4km offshore of Lowestoft. Analysis of this (Appendix D) indicates that there has been some change in the dominant direction of wave approach over time. However, the offshore area of the Norfolk and Suffolk coastlines is also 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 a major influence on waves and tidal flows along this and adjacent coastlines. Recent changes in the local bathymetry are included in Appendix C.

Changes in these shallow banks can have a significant effect on waves at the shoreline; waves being heavily refracted as they travel over those banks. Consequently, a change in the banks can translate directly to a change in predominant wave direction at the shoreline. Those morphological changes occur over timescales of years, which could also explain the longer-term underlying re-orientations of the shoreline discussed in section 3.2.

4. Erosion risk to pipelines

4.1 Approach

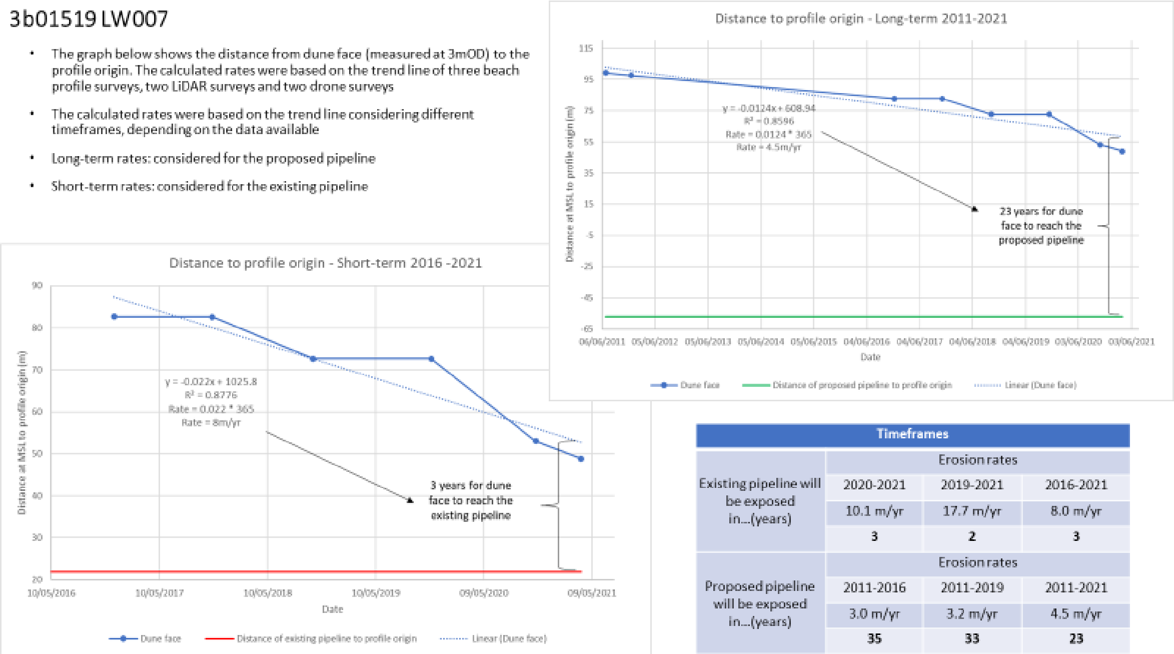
The estimates of erosion risks determined for both the existing pipeline and proposed pipeline are based on the assumption that the trends observed since 2011 will continue in the future. Based on the historical evidence and knowledge that changes to external influences are also important, it is possible that there could be future changes in shoreline orientation leading again to accretion in this area, so these risks may reduce. However, the potential for, and timing of, any such changes is highly uncertain.

Erosion rates have been determined along the beach profiles, using both the topographic data and extracted data from the LiDAR and drone surveys. Using a fixed datum level of +3 mOD, which is representative of the dune face, erosion rates have been calculated as follows:

- For the assessment of erosion affecting the existing pipe, recent short-term rates (1-5 years) have been derived considering 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 derived (5-10 years). These rates have used 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 best reflects the current trends along this frontage.

A linear regression analysis for each time period has been undertaken to predict the rate of change and thus time until the pipe would be reached. An example of the regression analysis undertaken is given in Figure 4-1.



Timeframes			
Existing pipeline will be exposed in...(years)	Erosion rates		
	2020-2021	2019-2021	2016-2021
	10.1 m/yr	17.7 m/yr	8.0 m/yr
	3	2	3
Proposed pipeline will be exposed in...(years)	Erosion rates		
	2011-2016	2011-2019	2011-2021
	3.0 m/yr	3.2 m/yr	4.5 m/yr
	35	33	23

Figure 4-1: Example of the regression analysis undertaken

4.2 Results

Table 4-1 and Figure 4-2 show the erosion rates calculated over different time periods and the estimated time to existing and future pipe exposure, based on those rates.

As described above, risks to the existing pipeline are based upon trends observed over the last 5 years only, these most recent changes considered most appropriate for assessing what may occur over the coming few years and due to the close proximity of the pipe to the present shoreline. However, some caution must be exercised in simply looking at just the past six months between last October and this March, as extrapolation of this alone is less likely to be representative of average annual change given the seasonal differences in erosion, and would not take account of any short-term beach recovery which would most typically occur during the summer.

Projected risks to the future pipe alignment are based upon longer term observations over the past ten years. It is considered to be more appropriate given the further distance to that pipe position and more likely to reflect decadal trends, to effectively 'smoothing out' any individual high (or low) periods of change.

Table 4-1: Erosion rates and timeframe for (a) existing and (b) proposed pipeline to be exposed. As discussed above, different data periods have been used to gain an appreciation of variable erosion rates experienced.

Beach profile	Data period considered	Erosion rates (m/year)	Time to pipeline being exposed (years)	
			(a) existing pipe	(b) future pipe alignment
3b01515 (LW003)	2016-2021	2.8	16	-
	2019-2021	2.6	17	-
	2020-2021	10.4	4	-
	2011-2016	3.0	-	22
	2011-2019	3.4	-	19
	2011-2021	3.2	-	21
3b01517 (LW005)	2016-2021	3.1	14	-
	2019-2020	2.3	19	-
	2020-2021	9.8	4	-
	2011-2020	3.4	-	27
	2011-2021	3.5	-	26
3b01518 (LW006)	2016-2021	6.2	5	-
	2019-2021	12.9	3	-
	2020-2021	21.4	2	-
	2011-2016	2.3	-	43
	2011-2019	2.6	-	38
	2011-2021	3.5	-	28
3b01519 (LW007)	2016-2021	8.0	3	-
	2019-2021	17.7	2	-
	2020-2021	10.1	3	-
	2011-2016	3.0	-	35
	2011-2019	3.2	-	33
	2011-2021	4.5	-	23
3b01520 (LW008)	2016-2021	9.7	3	-
	2019-2021	21.4	1	-
	2020-2021	7.6	4	-
	2011-2016	2.7	-	41
	2011-2019	2.9	-	39
	2011-2021	4.8	-	24

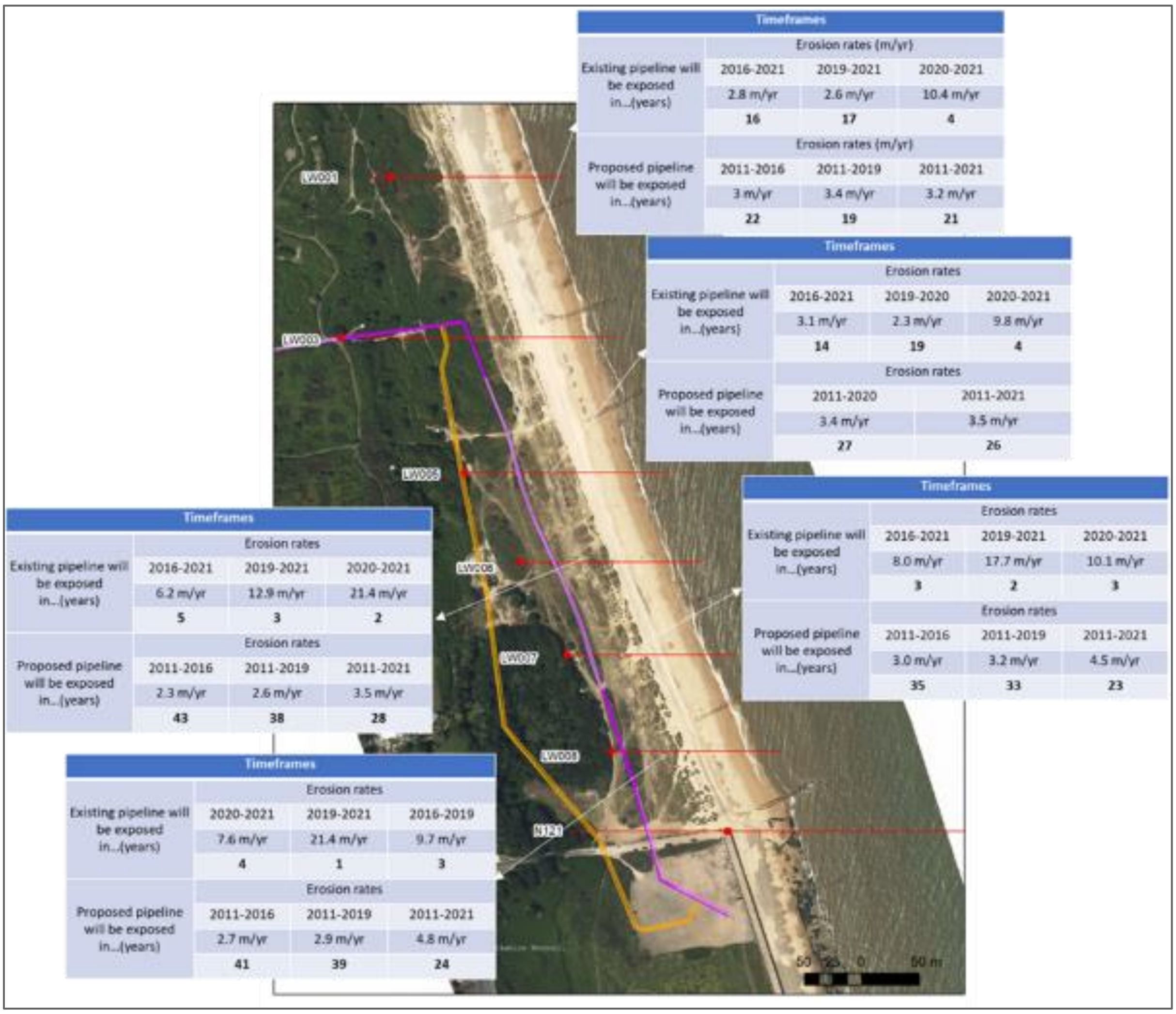


Figure 4-2: Erosion rates and timeframe for both existing and proposed pipelines to be exposed shown per beach profile location

4.3 Erosion risk to existing pipe

The assessments then indicate that, if recent trends continue, the existing pipe alignment could be at risk from erosion within the **next 2 to 3 years**, and even potentially at risk during this coming winter.

4.4 Erosion risk to future pipe

The assessments of beach change indicate that, if recent trends continue, then the future realigned pipe could become at risk from erosion **between approximately 25 and 40 years** from now. The exception to this is at the northern end of the pipeline, where the existing and future pipe alignments converge. All long and short-term trends here indicate that this is likely to become vulnerable **within approximately 20 years** and if the erosion rates seen over this past winter were to continue, that could even be within the **next 5 years**.

However, this review has also identified that the behaviour of this shoreline is non-linear over longer time scales, and it can experience sustained periods of accretion as well as erosion. Although it is not possible to identify any cyclic change, nor predict if and when a switch from one state to another may occur, continued monitoring and reassessment will be essential.

5. Addressing the erosion risk

5.1 Strategic shoreline management requirements

Although this technical note focusses specifically on the 500 m (approximately) of shoreline fronting the Anglian Water pipeline, this is only one part of the Gunton Warren Policy Unit defined in the Shoreline Management Plan (SMP) and Gorleston to Lowestoft Strategy Plan, and any interventions must be considered within that wider strategic context, in particular the potential for those to have wider impact.

5.1.1 SMP Policy

The SMP (AECOM, 2012) sets out the long-term plan for the management of flood and coastal erosion at the shoreline, and policies to apply in the short, medium and longer term towards achieving that plan. It takes account of wider thematic and geographic factors, with the intent of having a holistic sustainable approach to management across the greater area.

At Gunton, the long-term plan (over 100 years) set out in the SMP is for a ‘naturally functioning’ coast between Lowestoft North Denes and Corton, this being one of the very few lengths of shoreline without substantial defences works already. As such, it is also one of the few areas in the area that is able to host a variety of natural habitats.

The ‘present day’ (short term) policy set in the SMP, is to allow retreat through managed realignment, i.e. no longer maintain existing defences (those being the now defunct timber groynes) but allow for their management from a H&S perspective and eventual removal, whilst investigating the potential risks to the oil dump sites and the existing AW pipelines. On the basis that those could be ‘made safe’, for example through removal or relocation, the SMP medium term policy (nominally from 2025 onward) is for ‘No Active Intervention’, i.e. no works to build or maintain defences.

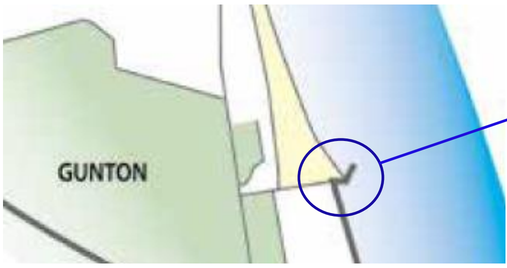
Noting the potential for erosion of the oil dump sites with the associated pollution risk, and exposure of sewage and wastewater return pipes, the SMP does acknowledge that some measures to slow the erosion may be appropriate in the long-term. Those risks do appear to have materialised sooner than originally expected, so there may be some justification to consider those measures now rather than later. But to remain compliant with the intent of the SMP, it is likely that those would need to be approaches that manage the natural movement of beach material and shoreline position rather than approaches that would effectively halt it altogether.

5.1.2 Strategy Plan

The Gorleston to Lowestoft Strategy Plan (Jacobs, 2016) builds upon the SMP, setting out the most appropriate ways to deliver the SMP policies. Again, this is presented in the context of the whole unit between North Denes and Corton, and sets out the vision for Gunton Warren as allowing this area to remain as natural as possible whilst minimising the risk of outflanking to the north (at the boundary with Corton). Actions were primarily around the latter, noting there is a seawall extending down to Tramps Alley, but are also applicable to the AW frontage. A key action was the regular analysis of monitoring data to identify any key areas for concern and to determine any appropriate response accordingly.

Of particular significance, however, is that the strategy does identify actions may be required for the adjacent Lowestoft North Denes unit to encourage higher beach levels at the southern end of Gunton Warren and thus reduce exposure of the east-west section of the seawall alongside Links Road car park, see Figure 5-1. Although this would not fully address the risks to the AW pipeline, it is possible that any proposed options that are consistent with that and incorporate that principle are more likely to be deemed to be working with the SMP management intent for the wider frontage.

Figure 5-1: Illustration of suggested terminal structure at north end of Lowestoft North Denes wall (taken from Gorleston to Lowestoft Strategy Plan; Jacobs, 2016)



5.2 Strategic options for the Anglian Water pipeline

5.2.1 Future pipe alignment

At a high level, the options considered are:

1) Relocation - select a different route altogether for the future pipeline, away from the shoreline.
2) Linear defence (seawall or revetment) - in front of the future pipeline, to prevent further erosion.
3) Beach management - to control the movement of beach sand and ensure sufficient beach width maintained in the area required to prevent future exposure of the new pipeline.

Relocation of the future pipe alignment (1) would potentially negate the requirement for any shoreline intervention, noting that this (and the oil deposits) are the only assets at risk in the near term; properties and other infrastructure assets are highly unlikely to be at threat from coastal erosion for several more decades at worst. It is however understood that this also incurs substantial additional costs and significant disruption, so not currently favoured by AW, and therefore other approaches have been considered here.

The principle function of a linear defence built along the shoreline (2) would be to resist erosion. It will not in any way encourage beach retention; in fact, it could exacerbate beach losses through any structure severing the sediment process link between the foreshore and backing dunes, and by creating higher wave reflection and scour in front. That may in turn require further works to ensure the stability of the defence at a later date, so incur further costs to what could initially be an expensive option. However, given the current estimate of erosion rates, it may not be essential to intervene yet, other than perhaps at the northern end, and future changes in beach behaviour may ultimately render any intervention unnecessary. There is also a risk, if planning on taking this approach, that holding the line in this way may not be permitted when approvals are sought as it would certainly be contrary to the objectives and management intent of the SMP and Strategy Plan.

If a scheme was introduced to manage rather than halt beach movement (3), by working with natural processes, this would be more consistent with the intent of management identified by the SMP and Strategy Plan. There are various methods by which this may be achieved, but the appropriate choice needs to be informed by the appreciation of the ongoing coastal processes and causes of change. For example, beach nourishment alone or the introduction of timber groynes may be ineffective. Numerical modelling would be necessary to determine the most effective approach and configuration of any interventions.

In doing so, consideration should be given to the observed beach behaviour at the macro-scale, i.e. between the 'headlands' created by Corton and Lowestoft North Denes (see Figure 3-3), and seek to mimic this at a local level, i.e. across the AW frontage. For example, it may be that this could be achieved through the construction of mini-headlands at either end of the pipe, i.e. one at the northern point where the existing and new alignments converge, the other at the end of the North Denes seawall. The latter would also be consistent with the Strategy Plan to protect the end of Links Road car park (see Figure 5-1).

The principle would be for sand to still be able to move along the frontage and the shoreline position could still move seaward or landward, corresponding with the wave-induced orientation seen along the entire Gunton Warren frontage. However, the landward extent of that movement would be restricted by the headlands locally holding the beach line in an advanced position and thus not retreating back as far as the new pipe alignment. The northern headland would also provide a fixed-point offering greater protection to that most vulnerable section of the future pipeline. Headlands would almost certainly be designed as rock armour structures. The size, shape and precise location of those would need to be determined based upon likely beach response, and may determine a need for a further structure at the mid-point either initially or as part of a future addition, see Figure 5-2. These are all aspects that would be developed if this option was taken forward for further examination and costing.

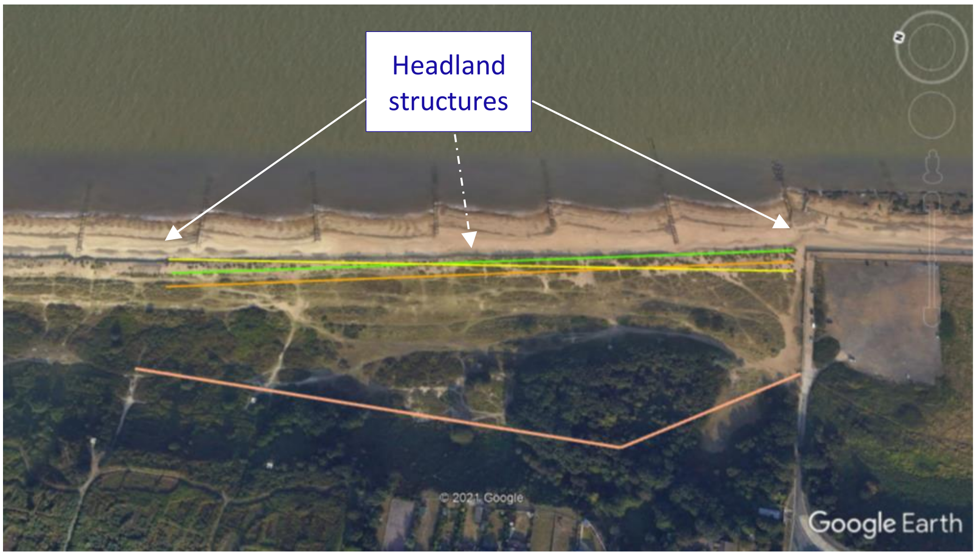


Figure 5-2: Possible locations for mini-headland structures. The dashed line indicates a possible additional structure that may be required.

5.2.2 Interim works for existing pipe alignment

A full (permanent) seawall or revetment along the present line, would not be acceptable under the SMP policy, also having a high potential to have detrimental impacts on the beach processes and natural habitats given the advanced (seaward) location that would be required for that structure.

However, the risks to the existing pipeline may require Anglian Water to seek approval to undertake emergency works until construction of the new pipeline is completed. Given the proximity of the current shoreline to the existing pipeline, options are likely to require some form of linear protection. To comply with the SMP any such works would need to be minimal, temporary, and removed once the new pipe is operational. It might be prudent for the design of that to be developed as soon as possible to give sufficient time for evaluation and approval. Consideration should also be given to use of materials that might also be reclaimed and reused in any subsequent permanent works.

Notwithstanding this, if the long term (permanent) beach management approach was adopted and approved to manage the risk to the new pipeline, it may be advantageous to undertake those works as soon as possible to obtain maximum effectiveness. That may also reduce the extent of any short term emergency measures required, in particular at the northern end of the pipe run.

5.3 Environmental assessment

Any proposed interventions on this section of coast will have to be subject to environmental assessment and consents, as well as planning approvals.

5.4 SMP Policy Change

Any permanent interventions will require a formal revision to SMP Policy. This is more likely to be acceptable as a ‘Managed Realignment’ through the implementation of measures to control beach movements, rather than ‘Hold the Line’ by providing a linear defence.

Although the beach management works might be carried out at the same time as the new pipeline was installed, so fall within the current SMP epoch, the intent would still be to maintain and, if necessary, adapt any structures to ensure the new pipeline remains protected if there were future variations in beach behaviour, for example due to climate change. Consequently, the present ‘No Active Intervention’ policy would have to be altered before any works would be approved.

There is an established review process for this, which would include necessary assessments and consultations on the proposal.

APPENDICES

Appendix A: Beach profiles

Beach profile analysis, using topographic data collected through the Anglian Coastal Monitoring Programme and supplemented by data extracted from LiDAR and drone surveys. Both current and historic names of the profile transects are shown.

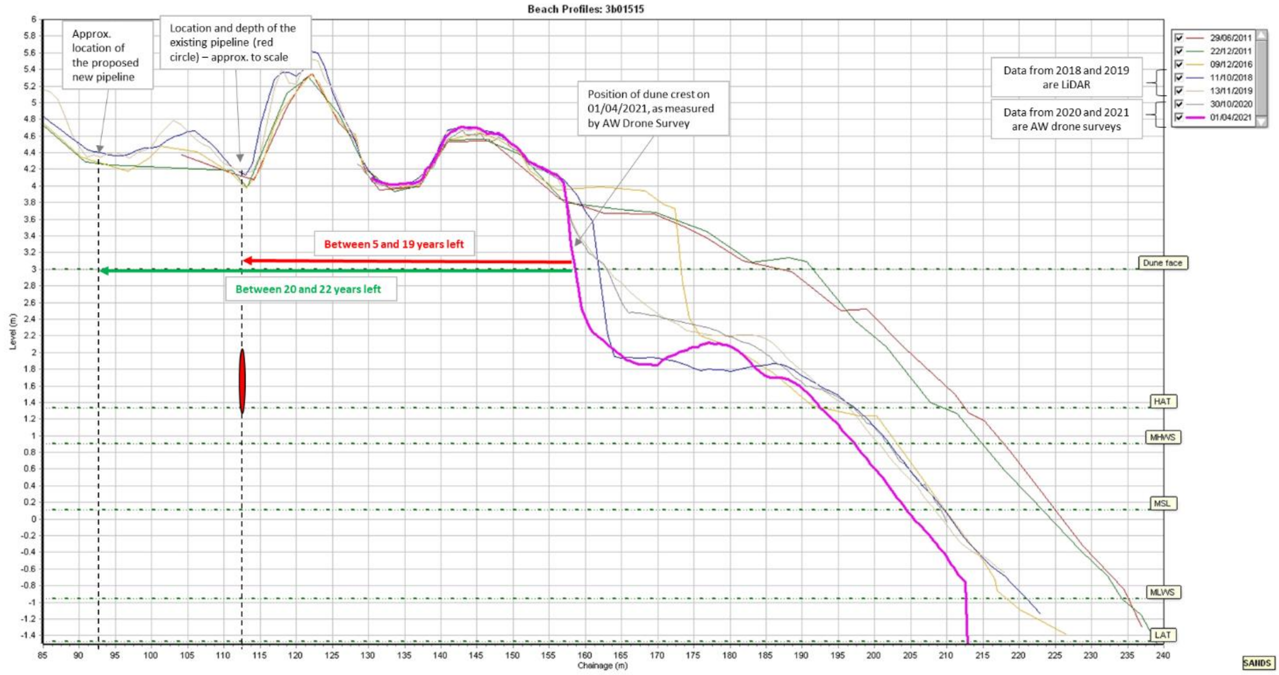


Figure A 1: Beach profile 3b01515 LW003

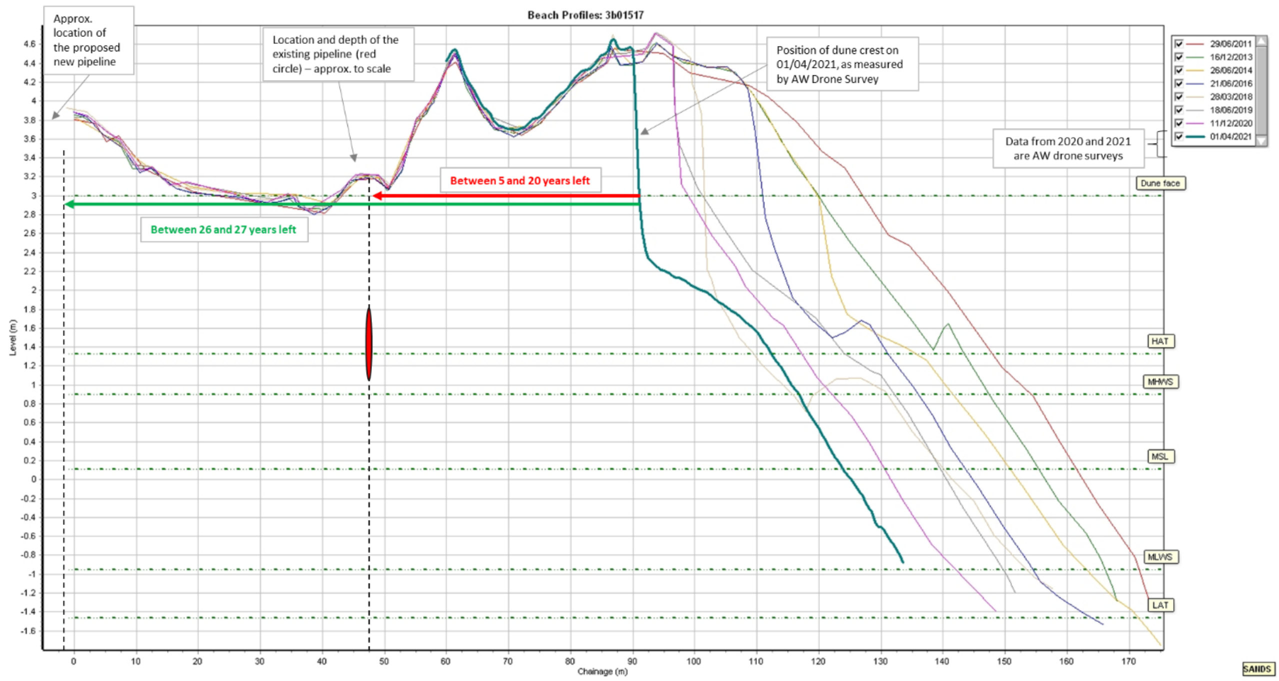


Figure A 2: Beach profile 3b01517 LW005

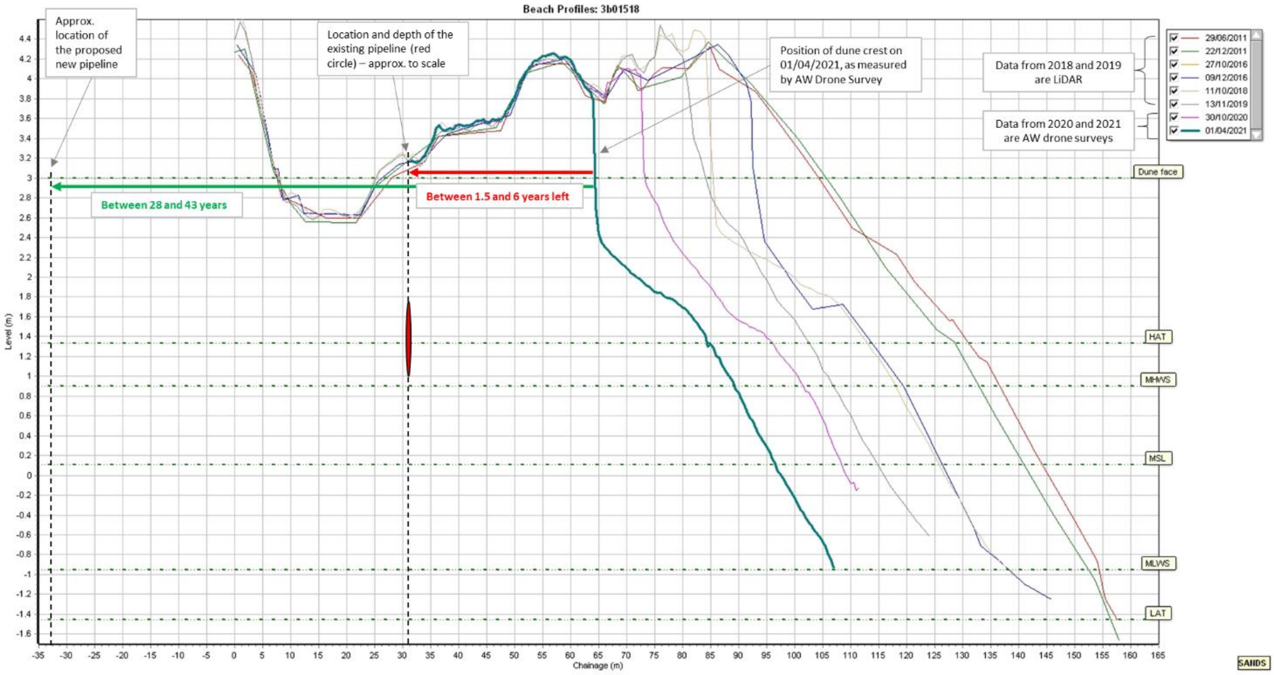


Figure A 3: Beach profile 3b01518 LW006

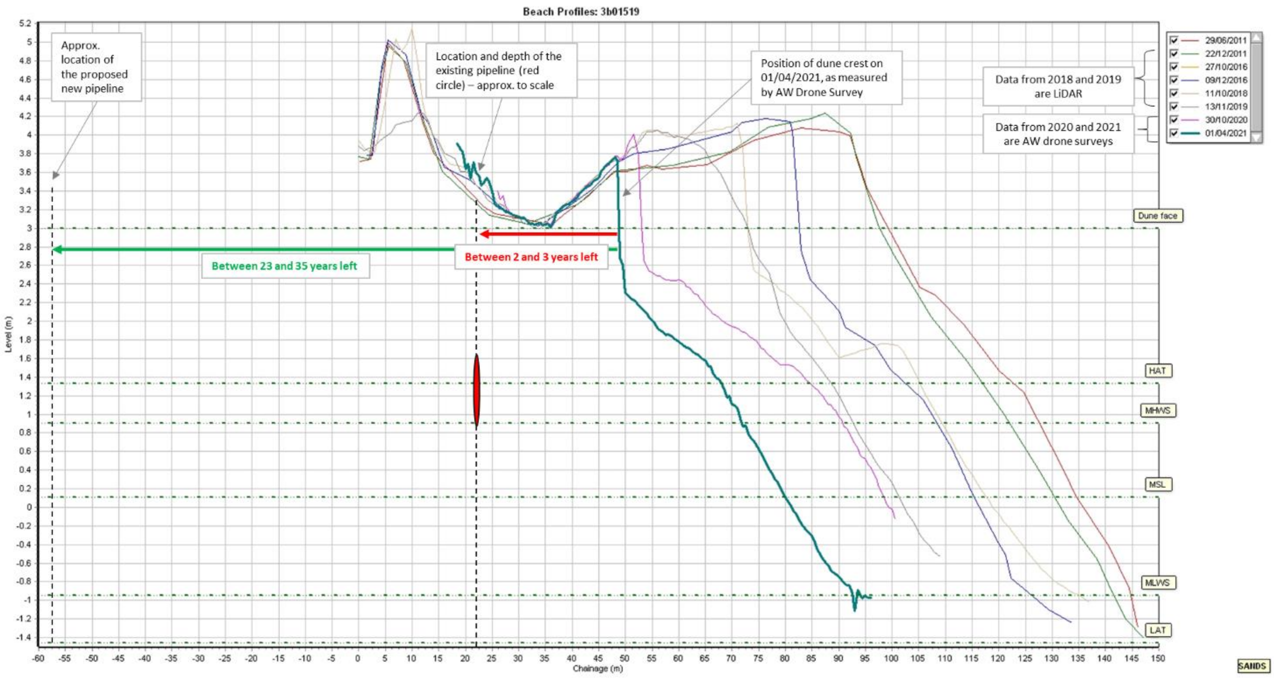


Figure A 4: Beach profile 3b01519 LW007

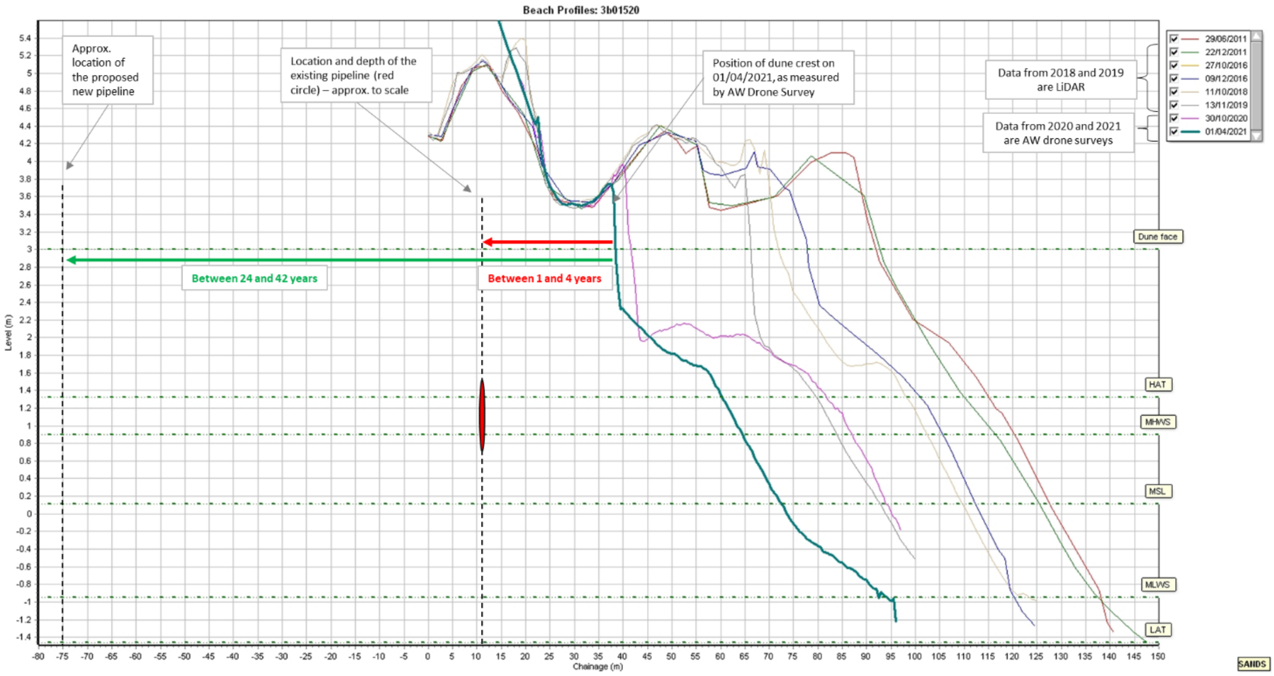
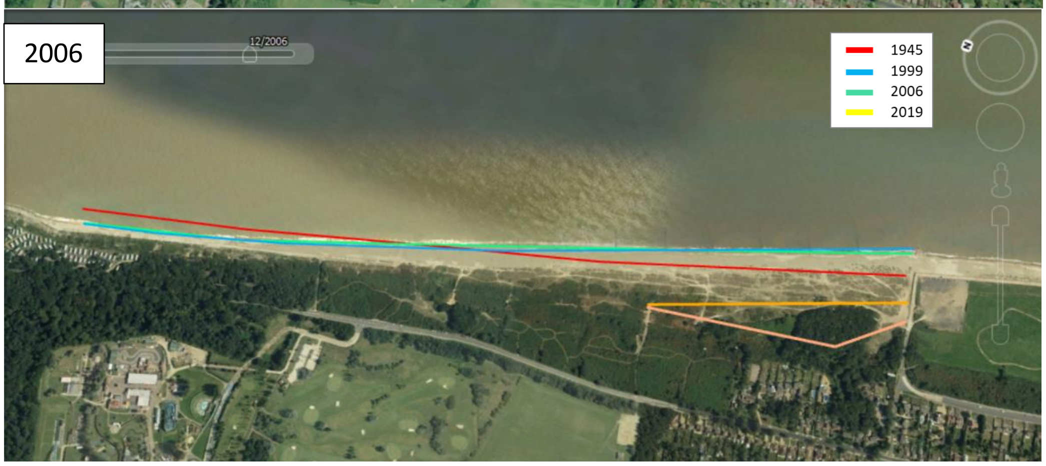
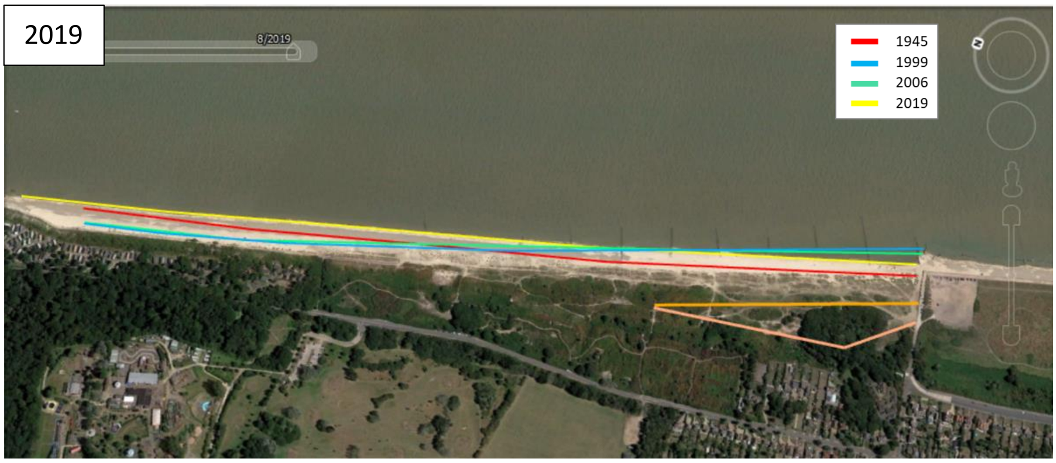


Figure A 5: Beach profile 3b01520 LW008

Appendix B: Historical aerial photographs analysis

The aerial images below are © Google Earth. The estimated position of mean sea level is shown for each time step. Also shown are the existing pipe (orange) and future realigned pipe (light orange).



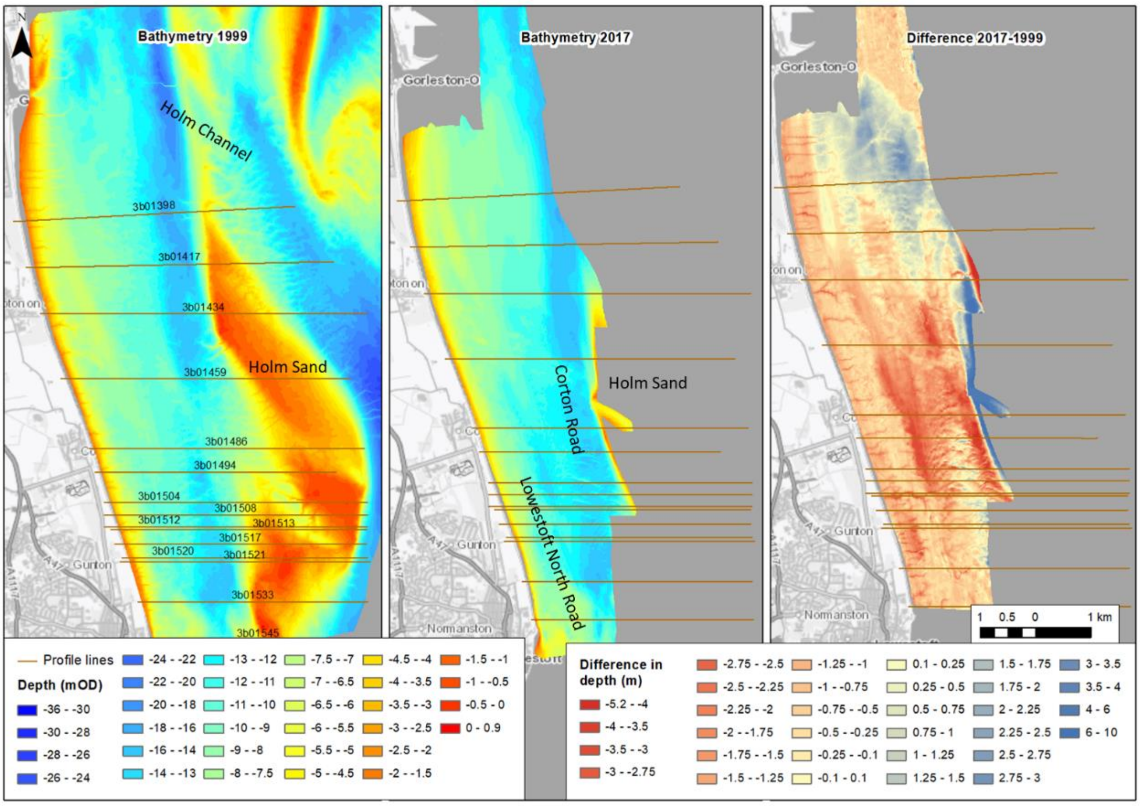

2019
8/2019
1945
1999
2006
2019

Appendix C: Offshore bathymetry

The figure below shows the configuration of the offshore bathymetry between Great Yarmouth and Lowestoft in 1999 (left), 2017 (middle), and the difference in depth between 1999 and 2017 (right); red shades represent a deepening whilst blue shades represent a shallowing of bed levels on the right hand plot.

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).

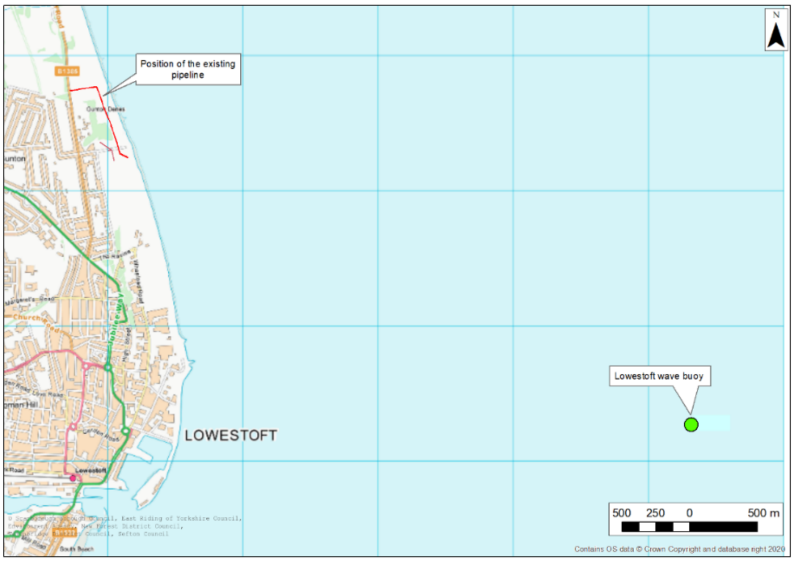


Some indication of the influence of these banks on currents may also be evidenced by the sand ridges that can be seen in Figure 3-1 within the main body of this report (the red “arches” demonstrate an existing sand ridge in 2014 which had moved or disappeared in 2017; whilst the blue “arches” demonstrate new sand ridges in 2017 previously absent from the 2014 bathymetry). These infer strong shore-parallel tidal currents in a northward direction fairly close to the shoreline.

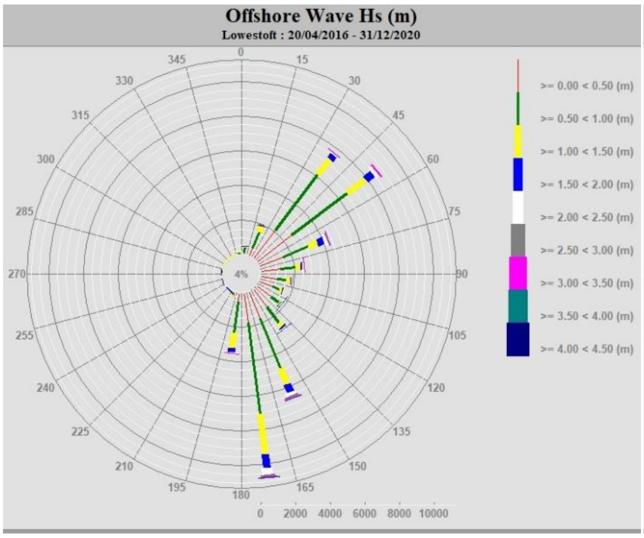
Appendix D: Wave climate analysis

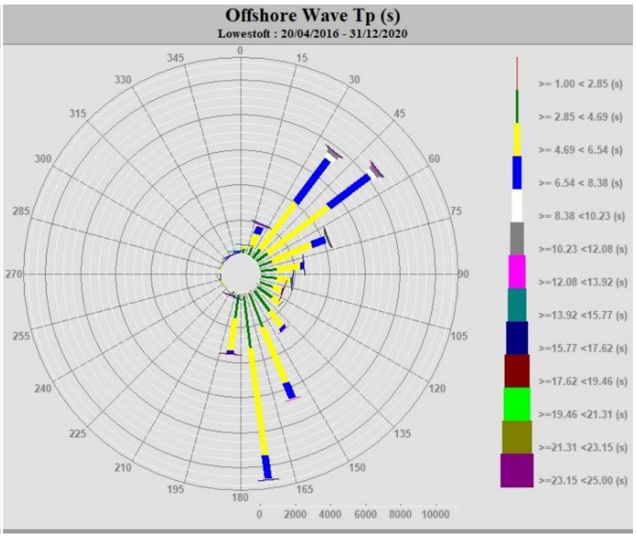
Analysis of wave data from Lowestoft wave buoy between 2016 and 2020, as collected as part of the Anglian Coastal Monitoring Programme, is presented in the table below. The location of the buoy is shown in the figure beneath.

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.



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).


Offshore Wave Hs (m)
Lowestoft : 20/04/2016 - 31/12/2020
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
4%
0 2000 4000 6000 8000 10000
>= 0.00 < 0.50 (m)
>= 0.50 < 1.00 (m)
>= 1.00 < 1.50 (m)
>= 1.50 < 2.00 (m)
>= 2.00 < 2.50 (m)
>= 2.50 < 3.00 (m)
>= 3.00 < 3.50 (m)
>= 3.50 < 4.00 (m)
>= 4.00 < 4.50 (m)


Offshore Wave Tp (s)
Lowestoft : 20/04/2016 - 31/12/2020
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
0 2000 4000 6000 8000 10000
>= 1.00 < 2.85 (s)
>= 2.85 < 4.69 (s)
>= 4.69 < 6.54 (s)
>= 6.54 < 8.38 (s)
>= 8.38 <10.23 (s)
>=10.23 <12.08 (s)
>=12.08 <13.92 (s)
>=13.92 <15.77 (s)
>=15.77 <17.62 (s)
>=17.62 <19.46 (s)
>=19.46 <21.31 (s)
>=21.31 <23.15 (s)
>=23.15 <25.00 (s)