The Great Grid Upgrade

Sea Link

Sea Link

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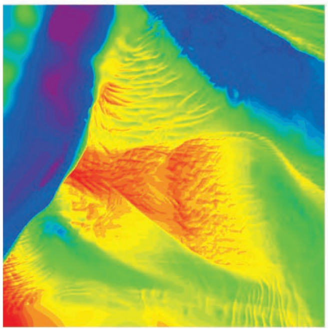
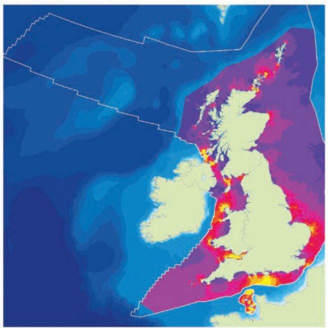
NGET

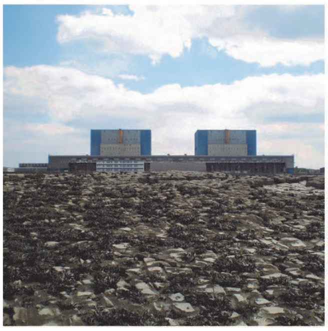
Landfall Assessment at Aldeburgh

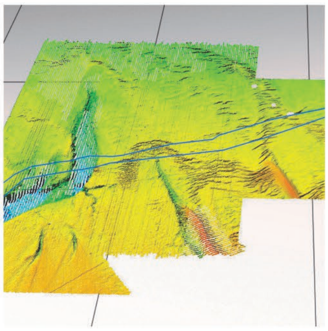
Sea Link Project – Landfalls sediment modelling

October 2024









Innovative Thinking - Sustainable Solutions

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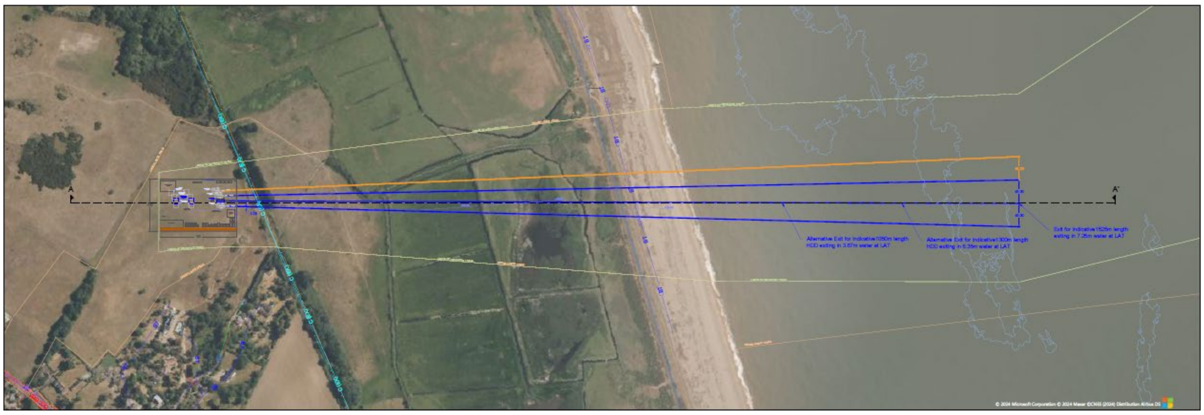

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1 Introduction

1.1 Overview

The Sea Link Project is a network reinforcement link proposed by National Grid Electricity Transmission Plc (NGET) to reinforce the electrical transmission network in the South East of England and East Anglia. The network reinforcement link makes landfall at Aldeburgh in East Suffolk, and at Pegwell Bay, Kent. The installation methodology at the landfalls are trenchless solution exit points for the HVDC (High-voltage direct current) cable.

This report deals with the landfall at Aldeburgh in East Suffolk and the accompanying report, R4575, with the landfall at Pegwell Bay, Kent.

The risk for cable landfalls can be summarised as:

- Short to medium term nearshore/beach variance: the risk can be assessed by comparing historical topographic profiles or maps, to determine the range of short to medium term variance in beach level, including daily, seasonal and interannual timescales if possible.
- Long term nearshore/beach level variance: the risk is assessed by comparing historical topographic profiles or maps, identifying if long term patterns are accretionary, stable or erosional; and
- Shoreline stability: whether the frontage is advancing or retreating. This will be primarily dependent upon whether the frontage is protected by coastal defences and if the short, medium and long-term Shoreline Management Plan (SMP) policies are to maintain these defences. Where there are no defences, data is gathered on the long-term stability of the natural shoreline and if other shoreline management measures are in place.

The project deliverable is this factual report which includes:

- Description of data utilised, models implemented and methodology.
- Description of the hydrodynamic flow and sediment circulation at each landfall
- Presentation of the results of the modelling on the beach profiles and strandlines development, for the different storm return periods and the effects of eustatic and climatic change during the planned lifetime of the asset
- Assess the impacts of the different storm events at each landfall during the planned lifetime of the asset
- North-up charts of the modelled bathymetric changes at the landfalls and trenchless solution exit points
- Profiles along line of the proposed cable route for the modelled events for Aldeburgh up to the -10m Lowest Astronomical Tide, LAT.
- Results of the analysis of the effects on the Coralline Crag, of the location of conceptual horizontal directional drilling HDD exits in close proximity.

1.2 Construction methodology

The cable route and location of the HDD exit points are shown in Figure 1 below which shows the latest option of the HDD exit at -7.3m LAT. The position of the coralline crag outcrop and the Haven Local Nature Reserve and the RSPB North Warren Reserve is also indicated in the profile view, as well as geological boundaries extrapolated from boreholes.

The route from the HDD entry to the exit (in thick blue line in the profile view) is 1525m long and gets to a maximum depth of 25.59 m Ordinance Datum Newlyn (ODN). Although three alternative HDD exits are shown on this drawing, the preferred one is the one with the HDD exit at -7.3m LAT.

The baseline year used within this assessment has been 2027.
The lifetime expectancy considered has been 50 years.

Figure 1. Landfall Concept Drawing (see page below)

Source: NGET

PLAN VIEW

PLAN VIEW

NOTES

1. ALL DIMENSIONS, LEVELS AND CHAINAGES ARE IN METRES UNLESS OTHERWISE STATED. PROPOSED BOREHOLES ARE INDICATED BY YELLOW MARKERS.
2. LAND ELEVATIONS FROM PROJECT SURVEY DATA
3. LAT CORRELATION TO OD NEWLYN IS TAKEN OFFSHORE SURVEY DATUM
4. GEOLOGY IS BASED ON INTERPRETATION OF AVAILABLE BGS MAPPING, BGS BOREHOLE LOGS AND ONSHORE GROUND INVESTIGATIONS THAT MAY BE SOME DISTANCE AWAY. OFFSHORE GROUND INVESTIGATIONS MAY CHANGE THE INTERPRETATION.
5. DRAWING IS PROVIDED FOR INFORMATION AND IS NOT A DESIGN

DO NOT SCALE

Rev	Date	Description	By
C	26/04/2024	Updated with Order Limits & Limits of Deviation	TR
B	19/03/2024	Changes to Winch Pads	TR
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2 Methodology and Data Sources

2.1 Introduction

The study has been undertaken using existing data sources along with a number of different analysis tools to understand the potential variability at the landfall. This section outlines the methodologies and data sources used to deliver the study.

The landfall assessment focus mainly upon the intertidal and nearshore areas where the cable will make landfall. The subtidal HDD exit for Aldeburgh is presently expected to be at a depth of approximately -7m LAT.

2.2 Units and datums

The following units and vertical datum details are used for all submitted datasets:

- Horizontal positions are provided as Universal Transverse Mercator UTM Zone 31, WGS84.
- Bathymetric information is given as metres above Lowest Astronomical Tide (LAT) (using UK Vertical Offshore Reference Frames VORF rev2 method of reduction), therefore, subtidal bathymetry has a negative value.

Where needed, the vertical datum of historical data has been adjusted from Ordnance Datum to LAT using the UK VORF rev2 data layers. The conversion from ODN to LAT used throughout the study is 1.5 m as per VORF data and to be consistent with the value used throughout the project. Data sets obtained with positive depth values have been inverted as needed.

The VORF model / app is available via: https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/apps/2d71688069744cc6873768d39e0c2f2e/explore

2.3 Direction conventions

During this study, the following conventions are used when describing directions:

- Waves – wave directions are FROM, so that for example a Northerly wave comes from the North and a 90° wave direction represents a wave coming from the East
- Currents – currents are TOWARDS, so that for example a Northerly current goes towards the North and a 90° current direction represents a current going to the East

2.4 Data sources

The study has used a combination of project specific and publicly available data, studies and reports to inform the investigation. The following data sources have been used in the analysis, Table 1. The data providers listed are:

- Channel coastal observatory (CCO): https://coastalmonitoring.org/
- UK Hydrographic Office (UKHO): https://seabed.admiralty.co.uk/
- Anglian Coastal Monitoring (ACM): https://environment.maps.arcgis.com/apps/webappviewer/index.html?id=d26827c087d54546925c37161e751dde
- SEASTATES North Atlantic wave hindcast (ABPmer 2013) and SEASTATES NorthWest European Shelf Tide and Surge hindcast (ABPmer, 2018)

Reports and other literature are referenced throughout the document and provided in the reference list.

Table 1. Data sources

Data	Data Type	Year Collected	Description	Comment	Source
Metocean Data					
ABPmer SEASTATES Tide and Surge Model	Tide and water level	1979-2023	Tide surge hindcast model providing flow parameters for a >40 year period		ABPmer SEASTATES hindcast database
ABPmer SEASTATES Wave Model	Wave data	1979-2023	Spectral wave hindcast model providing wind and wave parameters for a >40 year period		ABPmer SEASTATES hindcast database
Topographic Data					
LIDAR	Topography	Yearly, 2015 to 2020	OSGB36, mODN Resolution: 1m grid		CCO
LIDAR	Topography	2023	EPSG:25831 mLAT Resolution: 20cm grid	Data was acquired in 2023, but was integrated into the integrated report in 2024.	NGET
Topographic profiles		from 1991 to 2022.	Profile numbers S038, S039, S040, S041 and S042 OSGB36 mODN Resolution: 2 to 5m spacing		CCO
Bathymetric data					
Bathymetry	Bathymetric survey	1984	WGS84 (CD) Resolution: 80m Single beam sonar	Used to identify long term historic trends in bed level Data are collected using [multi beam sonar] unless otherwise stated.	UKHO
		2014	WGS84 (CD) Resolution: 2m		
		2017	WGS84 (CD) Resolution: 1m		
		2023	WGS84 (CD) Resolution: 0.5m		
Bathymetry	Bathymetry	2021	EPSG:25831 mLAT Resolution: 0.5m	Nearshore	NGET

Data	Data Type	Year Collected	Description	Comment	Source
Bathymetry	Bathymetry	2024	EPSG:25831 mLAT Resolution: 0.5m	Nearshore	NGET
Bathymetric profiles	Bathymetry	10/08/1997 21/07/2003 24/08/2007	Profile numbers S038, S039, S040, S041 and S042 OSGB36 mODN Resolution: 2 to 5m spacing	These were along same line as topographic profiles, but undertaken from a small boat	ACM
Other Data					
Cable corridor	Shapefile	2022	Cable corridor for the entirety of the project EPSG:25831		NGET
Coralline crag	Shapefile		Extent of the offshore and inshore coralline crag		CEFAS for EDF, supplied via NGET
Isopachs	Shapefile	2021	Isopach of sand thickness	Data acquired 2021, isopachs extracted 2024	NGET

2.5 Shoreline stability

Historical morphological analysis of Aldeburgh beach has been undertaken using:

- Google Earth historical satellite and aerial imagery
- Coastal Channel Observatory topographic surveys
- Anglian Coastal Monitoring bathymetric surveys
- UKHO bathymetric surveys

The wider area was first analysed with the help of the imagery and the topographic and bathymetric surveys (see Figure 2 for location), focusing on the changes observed on the morphology of the beach and the variability of these changes. Further, more detailed analysis, was undertaken for the profile closest to the landfall, S040, see Figure 2. For this one, the data was combined with extracted transect data along the same profile from the UKHO bathymetries in order to have a greater dataset for the sub-tidal region. The range of change at 1m intervals along the chainage of the profile was then calculated and commented on, especially as it provides with an estimation of the depth of closure.

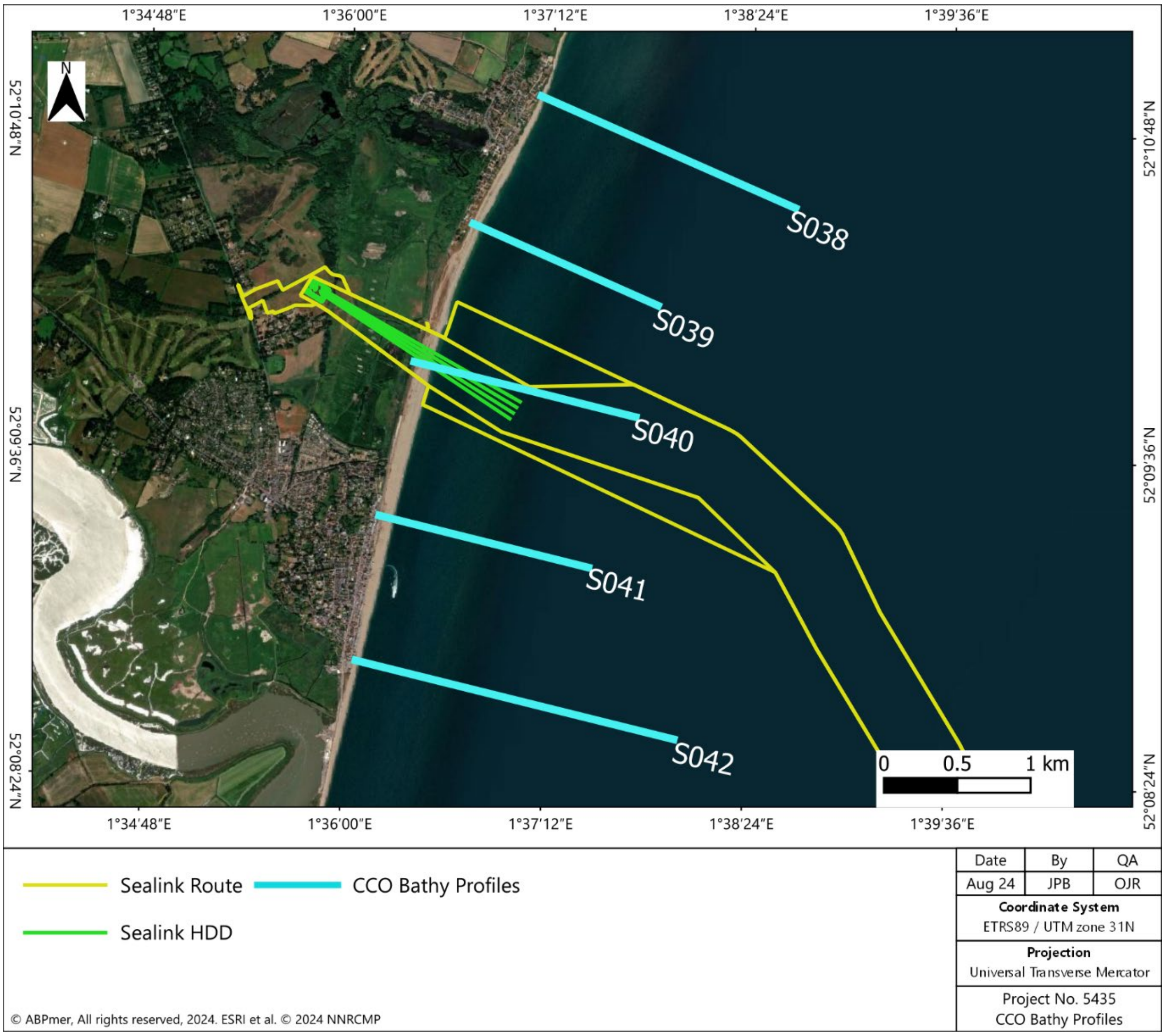


Figure 2. Position of the topographic and bathymetric profiles along the Aldeburgh frontage

Relevant results from the analysis are provided in the report discussion, especially focusing on the results from the profile closest to the landfall. A full series of results are provided as Appendix A.

2.6 Seabed mobility

This section encompasses both seabed mobility (from the bathymetric data) and beach mobility (from the topographic lidar data), as the methodology employed for both is the same.

To allow for the morphological assessment a continuous high-resolution bathymetry surface within the wider area was required. The data used for these have been:

- UKHO bathymetric data (2014, 2017, 2023)
- NGET provided bathymetric data (2021, 2024)
- CCO Lidar data (2015 to 2023, yearly)
- NGET provided Lidar data (2023)

The following process was used:

- The bathymetry data sources are added in the order that they appear in Table 1. Some data sources use spatial coordinates other than UTM Zone 31N (e.g. Latitude/Longitude or Ordnance Survey Eastings/Northings), which have been converted accordingly.
- The vertical datum of all surveys is quoted as either LAT or 'Chart Datum' (CD). There is generally insufficient information more precisely define or differentiate between these similar vertical datum specifications in the offshore environment (difference typically in the order of a few centimetres). It is therefore assumed that all data sets are representative of levels to the same vertical datum (LAT).

Relevant results from the analysis are provided in the report discussion.

2.7 1D parametric modelling

The 1-D parametric model Shingle-B was run for a set of wave and water level conditions to estimate the response of the beach to storms.

Shingle-B (available at https://coastalmonitoring.org/shingle/) was developed as a new parametric model for predicting beach profile response on shingle beaches under bimodal wave conditions (HR Wallingford, 2016c). It is based on using the parametric model of Powell (1990) and it was developed based on extensive 2D physical model data and field work.

The results from the modelling, together with the analysis of the profile data of the area, is used in order to inform of the cross-shore transport that generally happens at short-term scale when storms arrive to the beach. Relevant results from the analysis are provided in the report discussion. A full series of results are provided as part of Appendix A.

2.8 Metocean analysis

ABPmer is currently undertaking a metocean study for NGET, where metocean conditions are being derived for a number of points along the cable route and weather downtime analysis carried out.

For the metocean study, two models have been used, as referenced in Table 1:

- A high resolution hydrodynamic (HD), tide only model covering the cable corridor at 200m resolution. Given the variation in flow conditions along the route it is felt appropriate that the main tidal components of flow are extracted from this model to gain the most accurate representation of tidal currents across the route. This model has been run for 1 year, the baseline year of 2027.
  - The tide only timeseries for locations along the route were then subject to harmonic analysis. Tidal constituents from each location then used to generate a 40+ year timeseries of tidal currents and water levels.
  - Location specific residual components of flow and water level have been extracted from the ABPmer SEASTATES HD tide surge model and combined with the harmonically predicted high-resolution HD model tidal data to produce total current and water level data for each location.
  - Tidal currents from this model have been extracted for the sediment transport analysis.

- The ABPmer SEASTATES spectral wave (SW) hindcast model from which wind and wave parameters have assessed from the for a >40 year period: 1979 to near present. The spatial resolution of this model is approximately 5km near the cost increasing to approximately 10km in the offshore parts of the route.
  - Univariate analysis of the combined tide/surge timeseries along the route has been carried out to calculate the still water level return period of 1:1, 1:10 and 1:100 conditions. For the landfalls and inshore, the Environment Agency's (EA) Coastal Design Sea Levels (Coastal Flood Boundary Dataset CFBD) has been used.
  - Univariate analysis of the wave timeseries along the route has also been carried out to calculate wave return period of 1:1, 1:10 and 1:100 conditions.
  - Extreme water levels from the EA's CFBD have been used for the landfall and extreme wave conditions from the univariate analysis of the wave parameters for this study.

2.9 Assumptions and uncertainty in morphodynamics

Uncertainty can arise when measuring trends of long-term bed level change by the direct comparison of absolute levels in repeat survey data. Uncertainty (differences) in the vertical datum of measurements introduced during data collection and processing can erroneously introduce apparent differences in levels. Such uncertainty is mainly mitigated through consistent and robust methodologies for survey data collection and processing.

The quoted vertical uncertainty for bathymetry collected by a modern high-resolution multibeam system is typically in the order of ±0.30 cm; this is the uncertainty in the absolute level of the surface as a whole, e.g. relative to a geoid or tidal level, and does not imply random uncertainty or 'noise' of this magnitude in every individual data point (uncertainty of 'relative measurements' is discussed below).

Larger uncertainties in absolute levels may occur when comparing datasets with different horizontal spatial resolutions. For example, individual data points from the lower resolution European Marine Observation and Data Network EMODnet data (100m resolution) are likely to be an integrated or averaged value representing a larger area of seabed. In practice, this footprint may potentially include a range of elevations about the average value due to smaller bedforms and parts of larger bedforms, that may have been originally very accurately measured. In comparison, individual data points from higher resolution multi-beam bathymetry (1 to 4m resolution) retain the detail of individual bedforms at this finer scale, and therefore might be considered 'more accurate' over smaller horizontal distances.

Residual uncertainty in absolute levels is accounted for by applying additional caution when the magnitude of a measured trend or difference in levels is less than the combined residual uncertainty of the two data sets being compared.

Uncertainty in relative measurements (i.e. between adjacent bathymetric data points in the spatial grid) is much smaller (likely in the order of <0.1m). Measurements of the height of bedforms based on the difference in levels from trough to crest, or length based on the distance from crest to crest, will likely be much more accurate.

Uncertainty is inherent in the assumption that present-day conditions and trends will persist into the future. This uncertainty is mitigated through a robust understanding of regional as well as local scale processes and systems, which should ideally explain both historical and present-day observations, and support any assumptions being made about the future. Uncertainty becomes greater as trends identified over a relatively short term are applied further into the future.

Short term beach levels will vary in response to the local wave climate and storm events but long-term patterns are heavily influenced by beach and coastal defence management within the wider coastal Sediment Cell. The shoreline recession score is based upon the SMP policy, but these are subject to regular review and funds being available and long-term sediment availability may be affected by human activities both updrift and downdrift.

3 Baseline Understanding

3.1 Overview of study area

The Aldeburgh frontage is an eastward facing open coast with an exposed shingle beach that extends for over 30 km from Lowestoft to Orford Ness, see location map in Figure 3. The shingle bank is about 100 m wide extending about 400 m (APEM, 2024) and highly mobile both in terms of location, shape and sediment composition as it responds naturally to the metocean conditions.

Geomorphologically speaking this stretch of coast contains numerous controlling headland and foreland features, including a ness (Thorpeness) and the complex sediment transport processes between the nearshore and the offshore bank systems (Aldeburgh Napes and Aldeburgh Ridge, see Figure 10 for their position). The interaction between coastal and estuarine processes is also strong with a potential breach at the coastal barrier at Slaughden would mean a major reconfiguration of the Alde/Ore estuary.

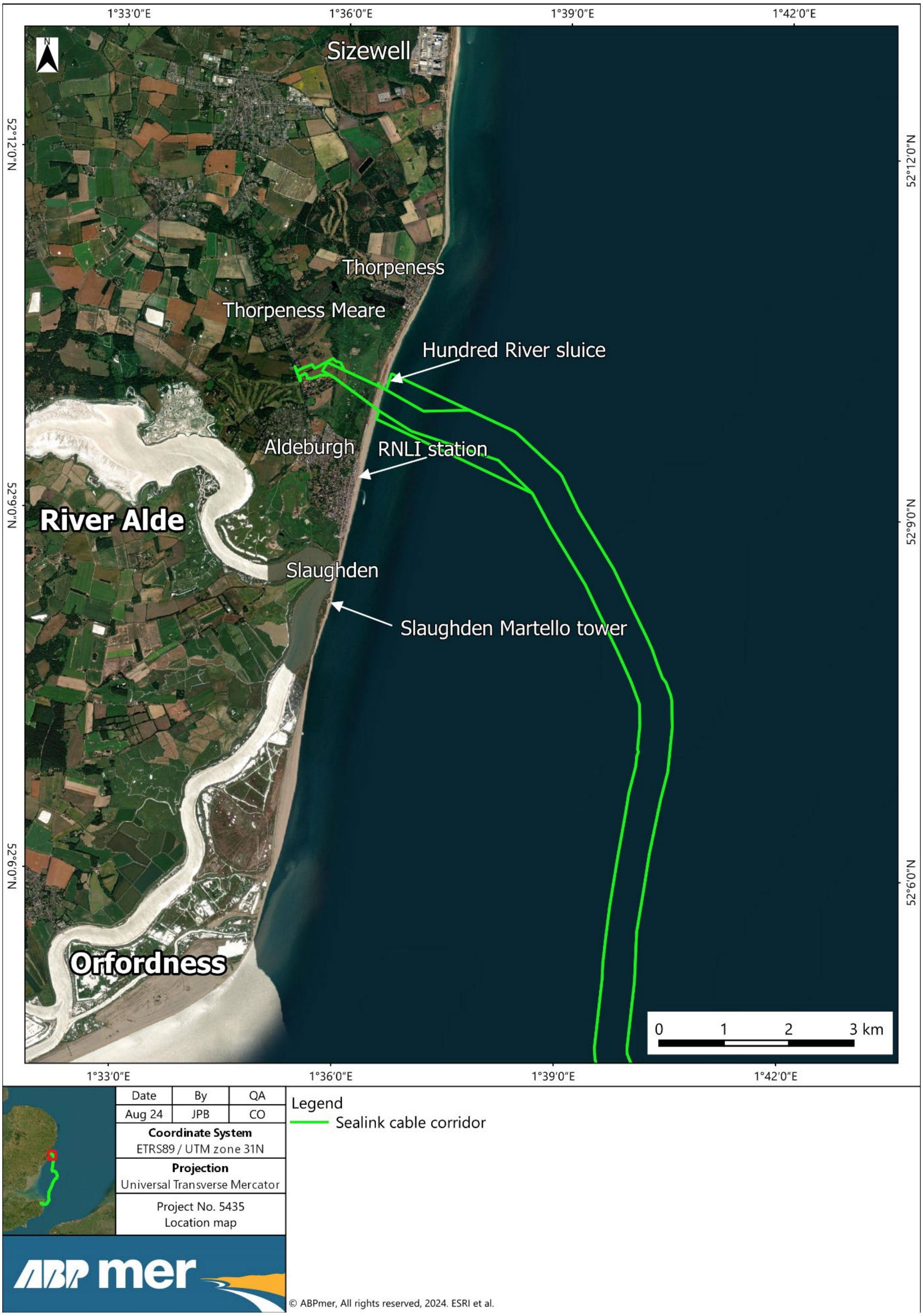
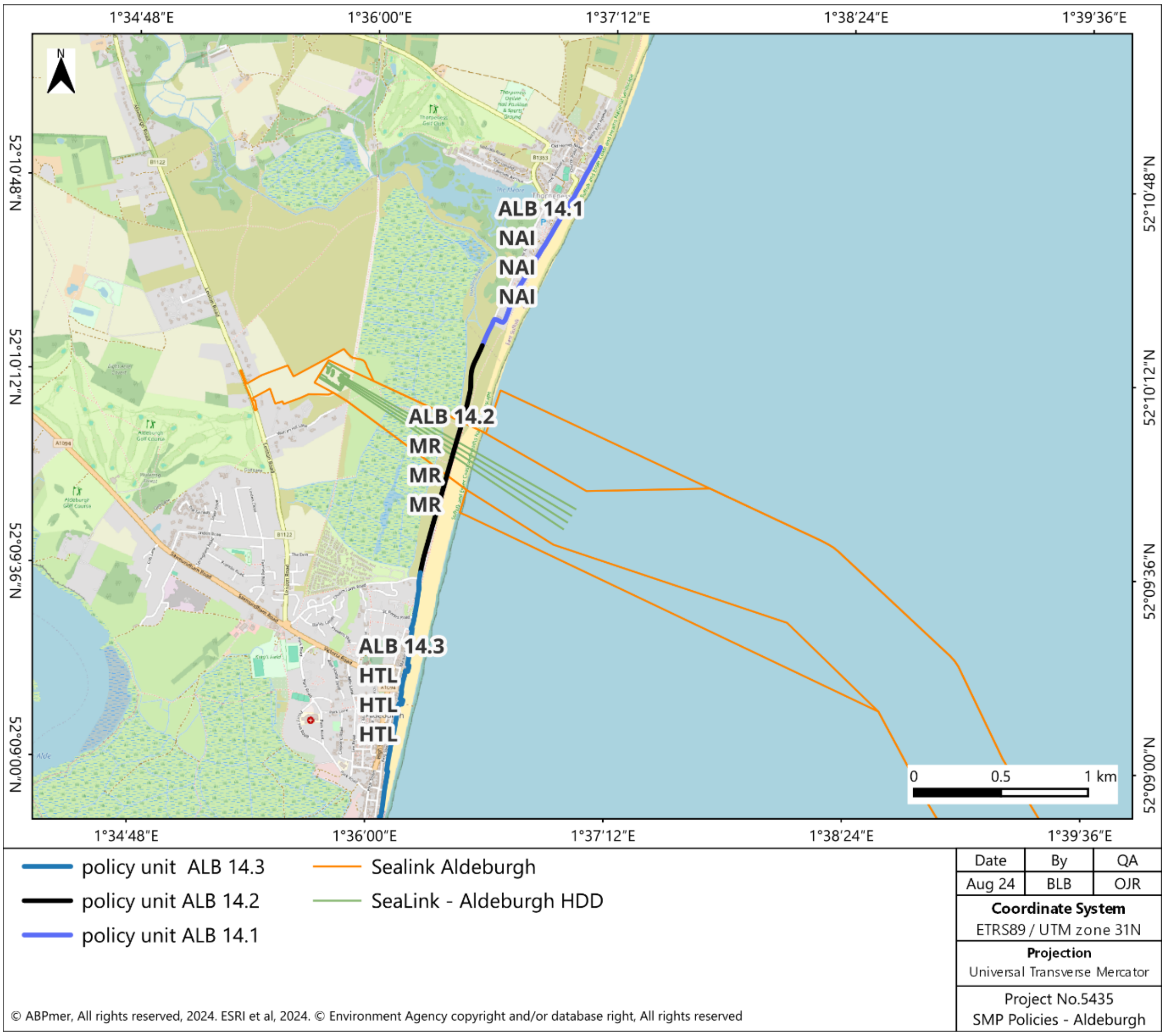


Figure 3. Location map

3.2 Flood and coastal erosion risk

3.2.1 Shoreline Management Plan Policy

The study frontage lies within Policy Development Zone 5 Thorpeness to Orford Ness, Management Area ALB14, Policy Unit 14.2 (Thorpeness Haven Beach). The Policy Units for the area are shown in Figure 4, together with their policy (SMP2 Royal Haskoning, 2010).



Source: SMP2 Royal Haskoning, 2010

Figure 4. Shoreline Management Plan policy units and policies (short term, medium term and long term in rows under the policy unit)

The Shore Management Plan (SMP) was superseded by SMP2 (Royal Haskoning, 2010) and can be accessed through the East Anglian Coastal Group (https://www.eastangliacoastalgroup.org/assets/img/1443012.pdf). The policy for Thorpeness Haven Beach is managed realignment (MR) for all epochs (see Table 2). The Coastal Partnership East (https://www.coasteast.org.uk/shoreline-management-plans) provides a list of SMP reviews for certain policy units and the documents to support those; there have not been any reviews to the policies in Aldeburgh.

Table 2. Shoreline Management Plan Policies

Policy Unit	2025	2055	2105	Notes
PU14.1 Thorpeness Haven Property	No active intervention	No active intervention	No active intervention	This would not preclude minor works to sustain property, subject to impact assessment.
PU14.2 Thorpeness Haven Beach	**Managed realignment**	**Managed realignment**	**Managed realignment**	Consider allowing flooding with secondary defence but maintain the road.
PU14.3 Aldeburgh	Hold the line	Hold the line	Hold the line	Control at Fort Green

Source: SMP2 Royal Haskoning, 2010

3.2.2 Coastal Erosion Risk

The potential baseline erosion rates for the frontage from the SMP2 are provided in Table 3. Base rates were assessed from monitoring and historical data so that the range of potential erosion was assessed in terms of variation from the base rate and sensitivity in potential sea level rise. It is important to note that these potential erosion rates were derived with data available till 2010; recent rates vary from these as explained in Appendix A and within the assessment in the report.

Table 3. Potential Baseline erosion rates from the SMP2

Location	Base rate (m/yr)	Notes	100 yr Erosion Range (m)
Thorpe Ness	0.1	Influenced by nearshore feature	10 to 30
Thorpeness	0.1	Influenced by exposure of the headland to the north	10 to 10
Thorpeness Haven	**0**	**Still affected by SLR**	**10 to 20**
Aldeburgh	**0.2**	**Area generally protected by beach and control to the south**	**10 to 20**
Slaughden	0.5	Held by defences or erosion through to estuary	0
Orford North	0.7	Protected by Benacre Bess and Progression of Ness	30 to 120
North of Ness	0.3	Helf by bank	10 to 25
Orford Ness	1	Dependent of occasional feed from the north	33 to 186
Note: Sea Level Rise assumed rates: 0.06m to year 2025; 0.34m to year 2055; 1m to year 2105			

Source: SMP2 Royal Haskoning, 2010

The National Coastal Erosion Risk Mapping, NCERM, shows the coastal baseline (https://www.data.gov.uk/dataset /7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021).

This baseline is split to ‘frontages’, which are defined as lengths of coast with consistent characteristics based on the cliff behaviour characteristics and the defence characteristics. This database is intended as an up-to-date and reliable benchmark dataset showing erosion extents and rates for three periods:

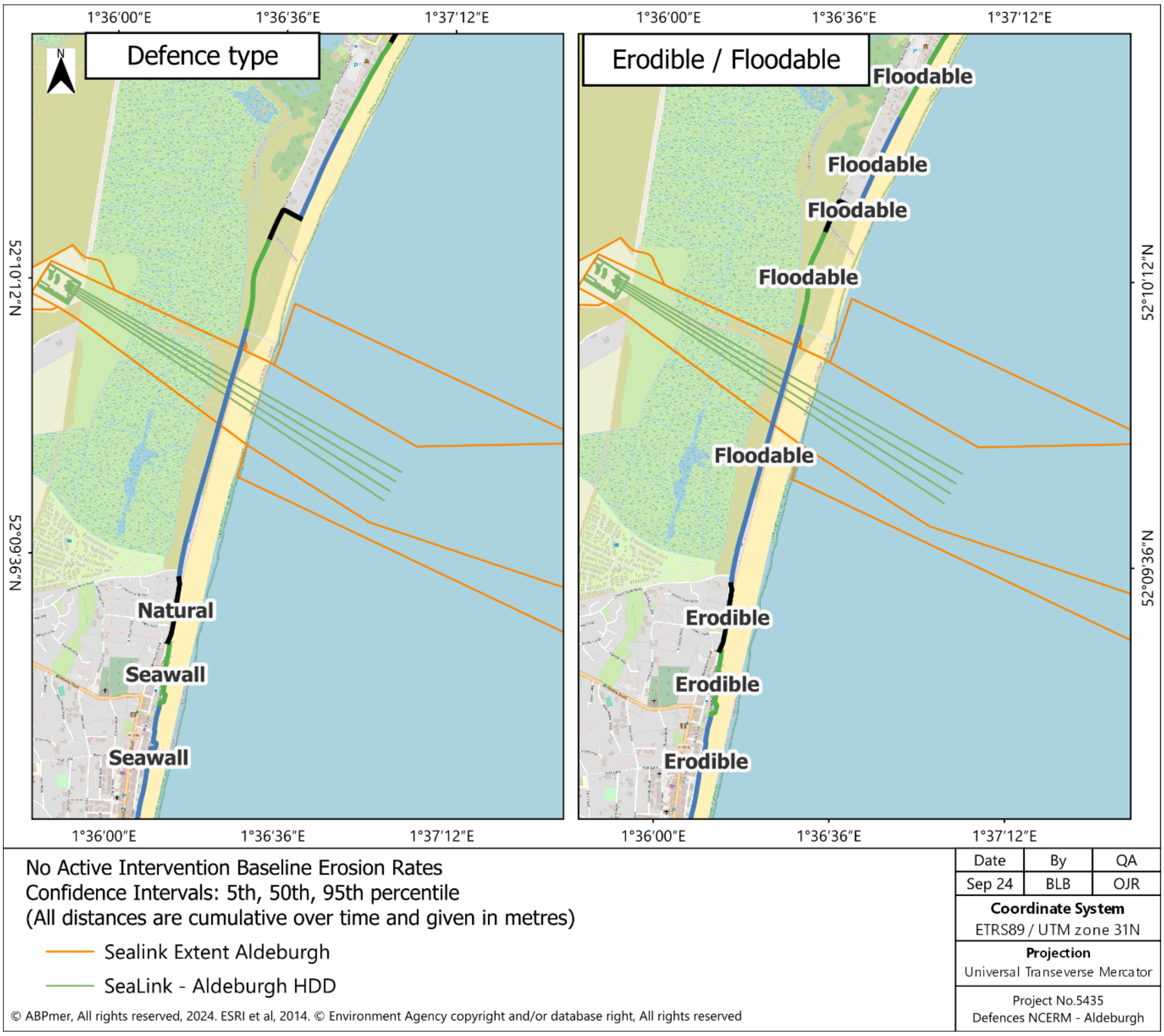
- Short Term (0 – 20yr);
- Medium Term (20 – 50yr); and
- Long Term (50 – 100yr).

These erosion extents are provided for the 5th, 50th and 95th percentile confidence levels for two different scenarios (all distances are cumulative over time and given in metres):

- No Active Intervention, NAI, Policy Scenario; and
- With the implementation of Shoreline Management Plan 2 Policies. Defence type and SMP policies for each of the three periods described above are included.

The NCERM information considers the predominant risk at the coast, although flooding and erosion processes are often linked, and data on erosion of foreshore features are, in general, not included.

Figure 5 shows the defence types of the features along the coast as well as the predominant risk at the coast per feature. The area of the cable corridor does not contain information on the defence type and it is classified as floodable as the predominant risk to the coast. However, to the south of it the area is classified as erodible. The area of the cable corridor at the coastline will be at risk of both erosion and floods, the latter being of greater importance to the former.



Source: NCERM (https://www.data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021)

Figure 5. NCERM information: defence type along the coastline and predominant risk at the coast

The NCERM data for the two scenarios (NAI and SMP policy) for the three different periods and for the three confidence level intervals (5th, 50th and 95th percentile) is provided in Figure 6 and Figure 7 for NAI and SMP policy respectively. The Representative Concentration Pathway or RCP is not mentioned, but believed to be 8.5.

The data describes the upper and lower estimates of erosion risk at a particular location, within which the actual location of the coastline is expected to lie. The data does not estimate the absolute location of the future coastline. Details of geologically complex areas, known as "complex cliffs" are, in general, not included within the dataset due to the inherent uncertainties associated with predicting the timing and extent of erosion at these locations.

As the area of the cable corridor at the coastline is classified as Floodable, the erosion rates shown in these figures is 0 m/yr for both scenarios, the three periods and the three confidence intervals. It is important however to consider that to the south of our area, Area 14.3 Aldeburgh, the coastline is prone to erosion, especially for the No Active intervention case. For the 50th percentile confidence interval, this area is given a baseline erosion of 6 m/yr short term, 15 m/yr for the medium term and of 30 m/yr for the long term. These are 0 m/yr with the implementation of SMP2 policies (in this case, Hold the Line) for the three periods and the three confidence intervals.

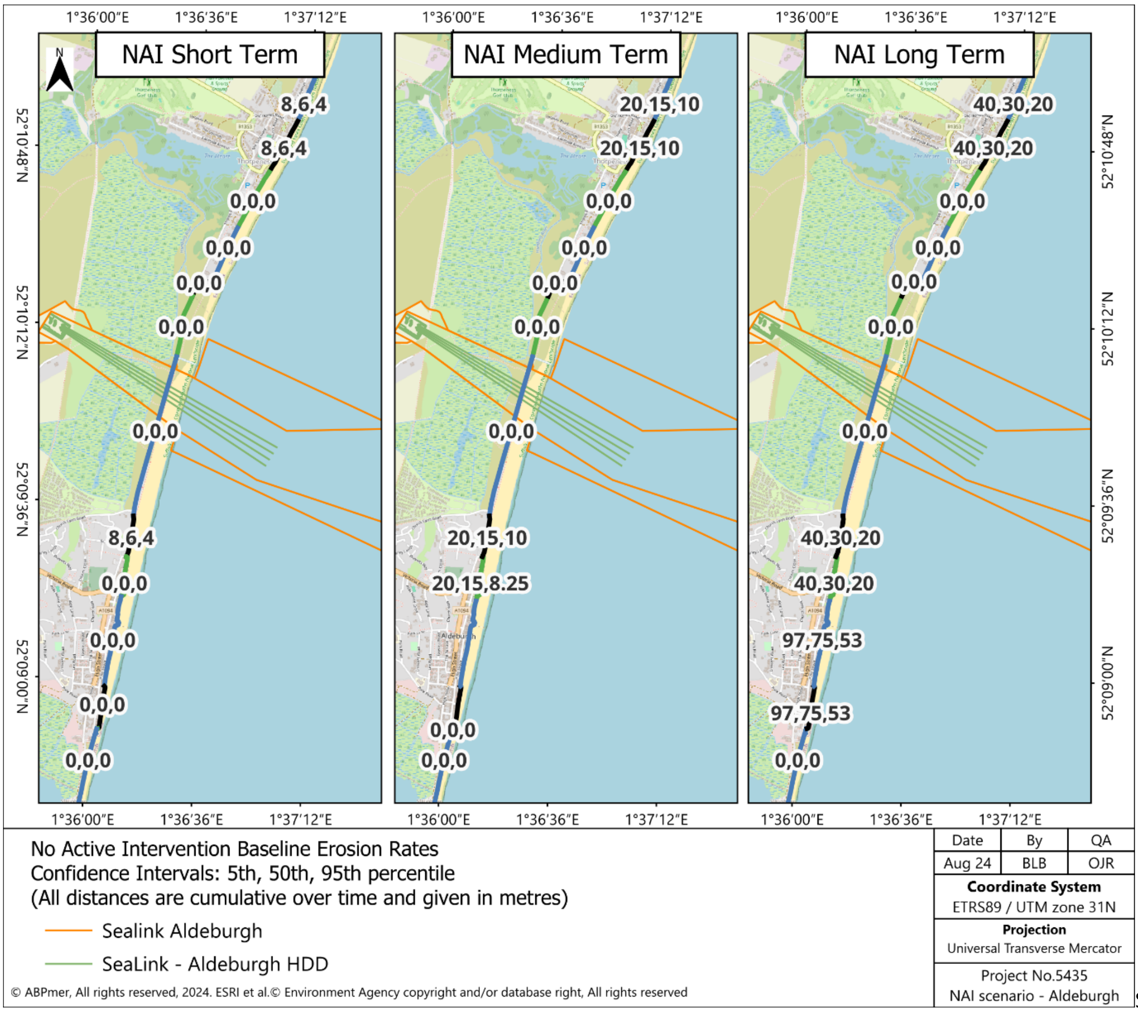


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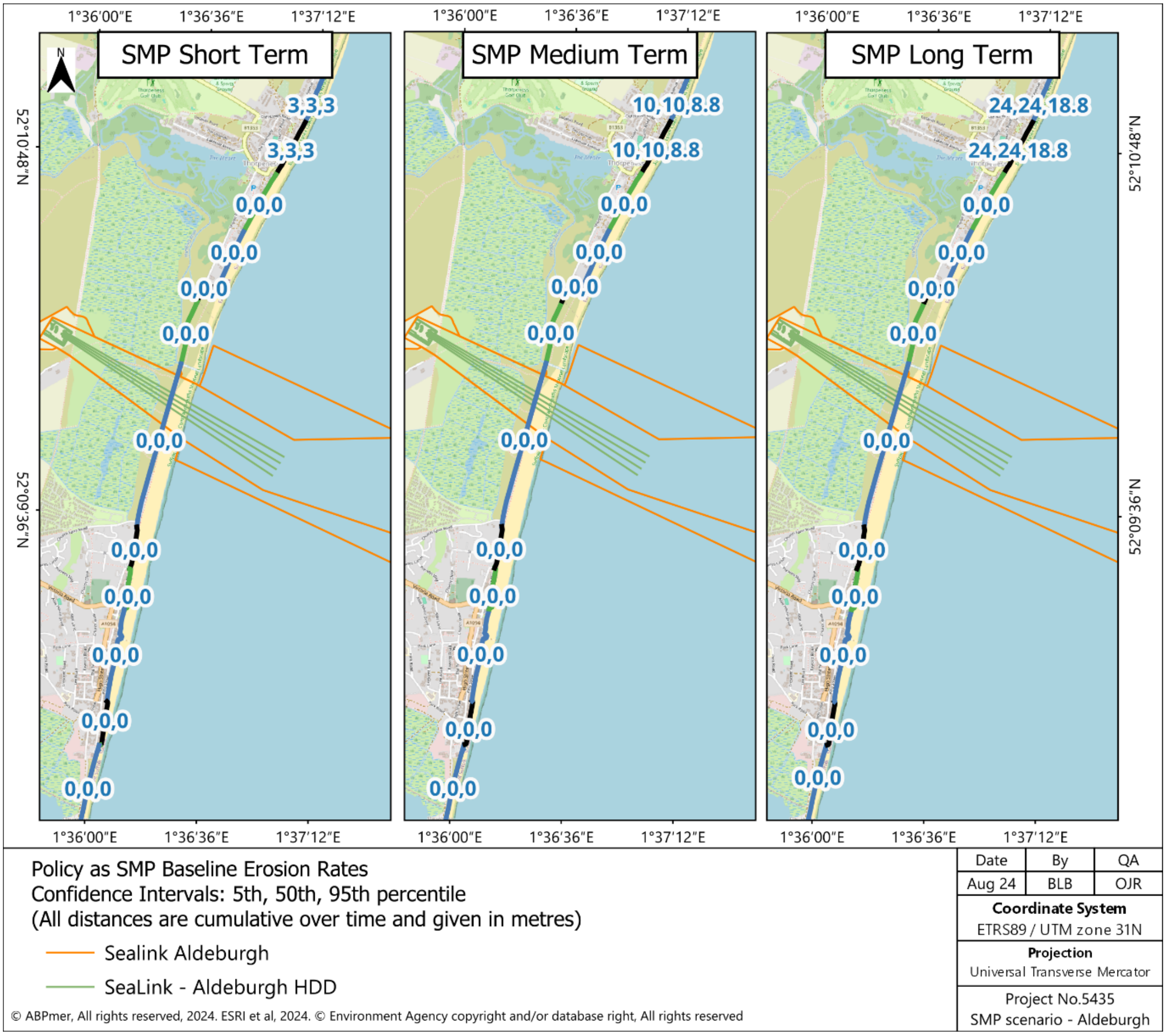
Figure 6. No Active intervention Scenario Baseline erosion rates for short, medium and long term for three confidence intervals (5th, 50th and 95th percentile)



Source: NCERM (https://www.data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021)

Figure 7. With the implementation of SMP2 Policies Baseline erosion rates for short, medium and long term for three confidence intervals (5th, 50th and 95th percentile)

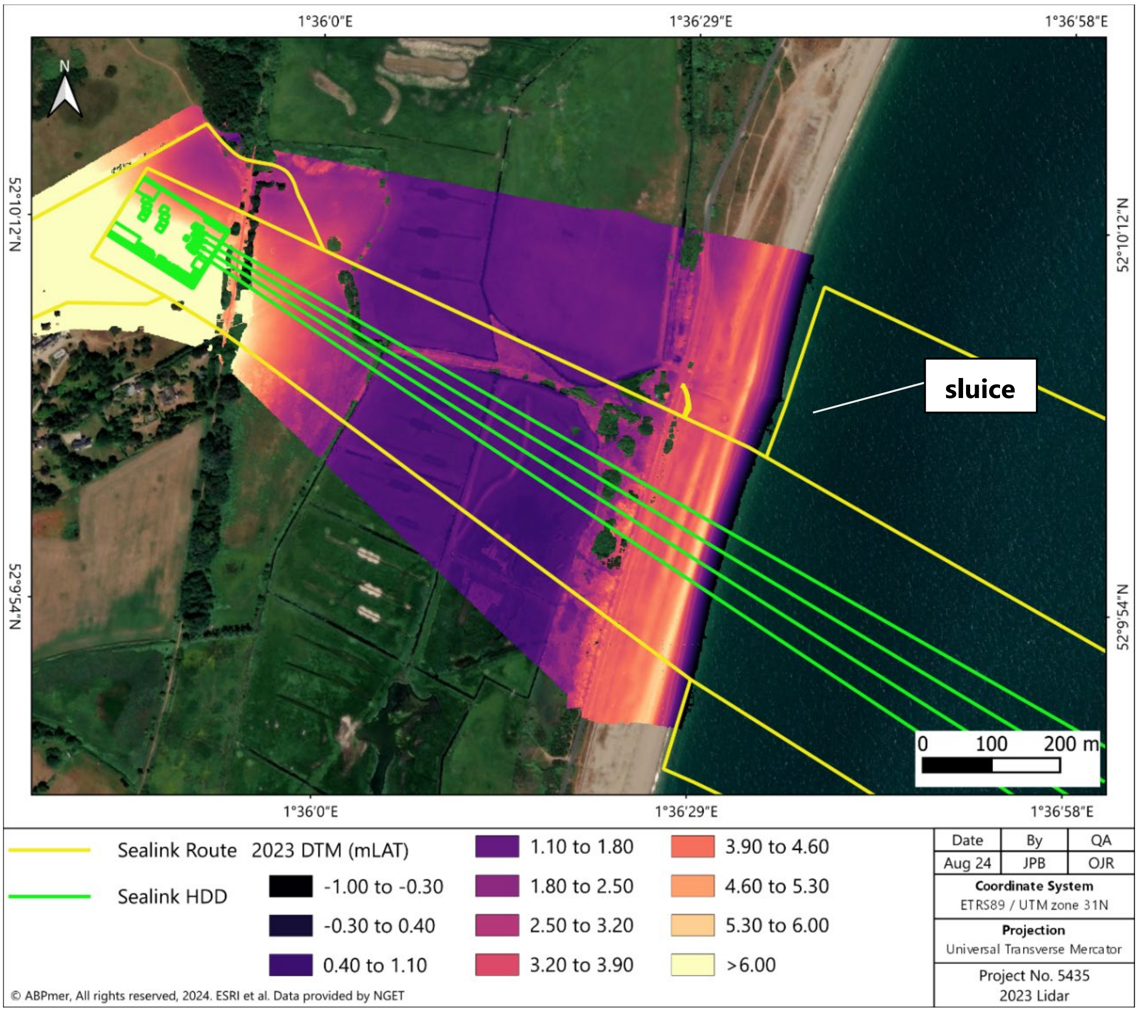
3.2.3 Flooding risk

The area of study is at risk of flooding as the area behind the shingle bank at the back of the foreshore is low-lying, remnants of the old Hundred River valley. The latest topographic data from 2023 is shown in Figure 8. This shows how the hinterland behind the beach and the road has lower levels than the beach itself. The 1:200 return period extreme water level for 2018 (provided in Table 6) is 4.64 m LAT[1]. The land level in the hinterland in Figure 8 in purple is at a level of 1.8 m LAT, less than the 1:200 extreme water level, and therefore prone to flooding. As for the proposed Construction Compound / Transition Joint Bay, most of it is at levels higher than 6 m and therefore less than the 1: 200 extreme water level.

[1] Note that this is the level for 2018 and sea level rise should be applied to take this value to 2027. However, the difference in levels (from 2018 to 2027) will be of the order of 5 to 6 cm and therefore considered insignificant for this high-level assessment.

This area is actively managed with a sluice (see location in Figure 8) that drains the hinterland, so that when there is flooding the sluice gets open and discharges to the sea. Therefore, at present, there are no concerns with the flooding of the area, although this will have to be reviewed in the future if the management strategy changes. Maintaining the road against flooding should be a priority.

Moreover, in the future, with sea level rise (see Section 3.4.2), the risk of flooding will increase. At present, the transition point is in an area of high elevation and at no risk of flooding. A major flooding event in the area is both possible and unpredictable.



Source: NGET provided

Figure 8. **Topography of the study area**

3.2.4 Defences and other works

As seen in Figure 5, there are no defences along the cable corridor, just a seawall located in Aldeburgh village. Shingle recycling works to recharge the neck at Slaughden (even further south) continued until 2015. This scheme used sediment from the neighbouring Sudbourne beach on Orfordness since the 1980’s to add sediment to beaches further north around the Martello Tower and at the neck where beach levels were receding. Since cessation, the average rate of change in that area has been 0.00m/yr (EA, 2021).

No other renourishment, recycling or bypassing works have been identified in the area from Thorpeness to Orfordness.

3.2.5 Nature conservation

The Alde/Ore Estuary together with the shingle ness is designated as a Ramsar site. This area is also part of the Orfordness-Shingle Street SAC and is covered by SPA designation (the SPA extending beyond the former designations) as the Sandlings SPA at the head of the estuary and inland of the low lying land behind Thorpeness around the valley of the Hundred River. Most of the area north of Aldeburgh is an SSSI, part of the Leiston-Aldeburgh designations. The whole coast lies within the Suffolk Coast and Heaths AONB.

3.3 Wave conditions

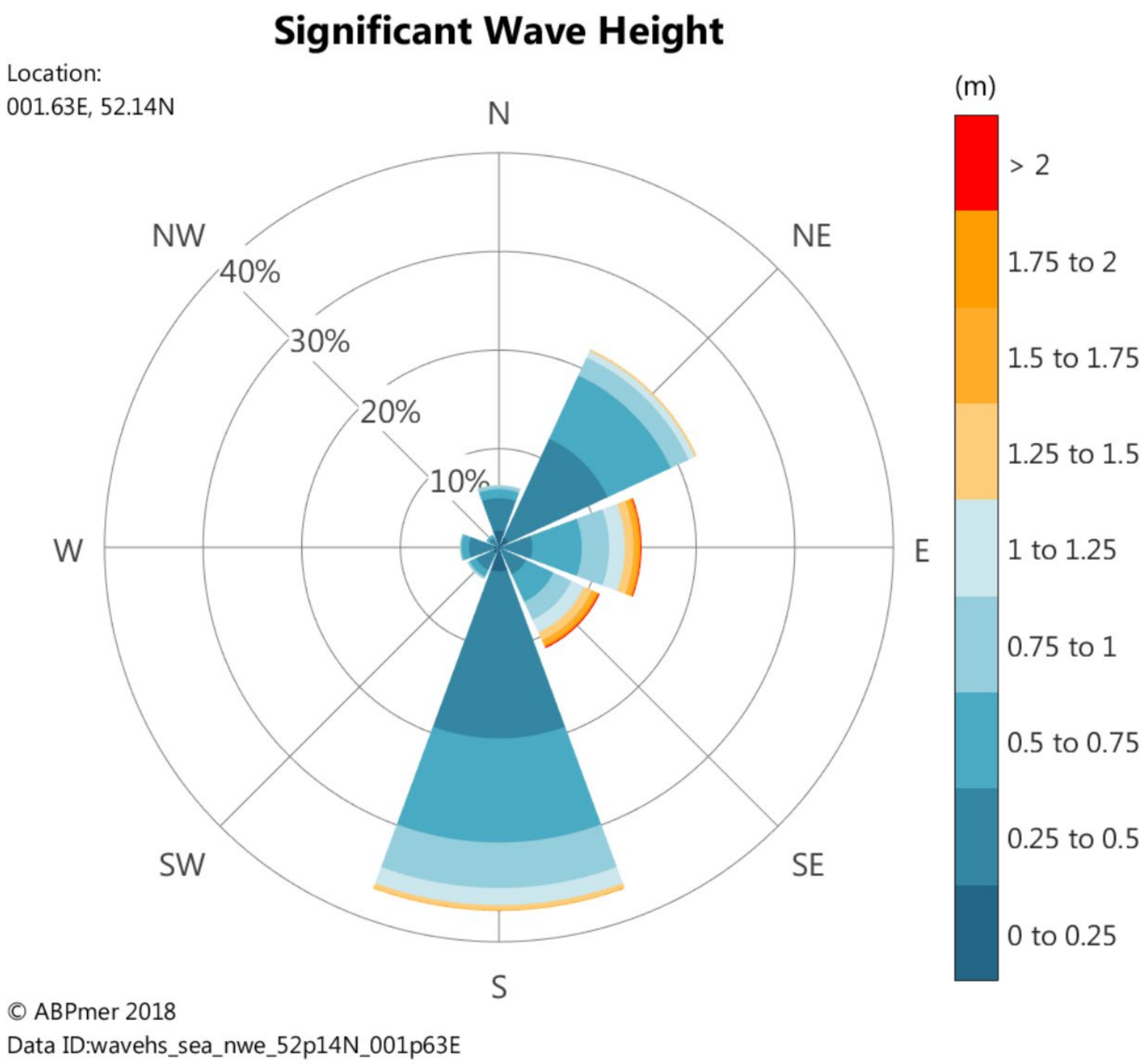
The offshore wave climate for the Aldeburgh frontage is illustrated as Figure 9 below. The dominant offshore wave directions are from the Northeast and the South. The nearshore banks: Aldeburgh Napes immediately offshore, Sizewell Bank to the North and Aldeburgh Ridge to the south (shown in Figure 10) and the nearshore bathymetry in general modify the wave energy, both in terms of wave height and wave direction, so that the waves approaching nearshore would be different from those offshore.

BEEMS TR311 (undated) reported the EA deployed nearshore Acoustic Wave and Current Profilers (AWACs) in c. 5 m water depth around the East Anglian coast for three years (2006 — 2009), five of which were on the Lowestoft Felixstowe coast. In Figure 11, the AWACs' locations are presented along with the wave roses that highlight the typical bidirectional wave climate of the Suffolk coast, the balance of which varies with location although most sites are fairly evenly balanced. Covehithe shows an almost symmetrical bimodality, whereas just 6 km to the south the bimodality is asymmetric with a slight dominance from the northeast / east north-east. Further south at Slaughden, the waves approach almost equally from the two directions but for significant wave heights (Hs) > 1.5 m, the wave climate is unidirectional with almost all waves approaching from the east north-east sector; this could be due to the Aldeburgh Ridge attenuating the larger waves coming from the southeast. The wave energy levels south of Orford Ness are significantly less than those experienced along the central Suffolk coast.

Work carried out previously at Aldeburgh and Bawdsey in 2015-16 (HR Wallingford, 2016a and 2016b) describe the bimodality of the waves as complicating the behaviour of the shoreline: the difference in persistence and strength of waves from each of these directions governed the evolution of the beaches in the area studied. The very strong winds during the winters of 1989/90 and 2014/15 resulted in considerable damage over much of the UK and it is expected that substantial changes in the shoreline were observed and measured during these winters. Such variations are documented in the Sea Link Ecological Survey report (APEM, 2024).

The BEEMS studies (BEEMS Technical Report TR311, undated) concluded that change from the energetic north-easterly unidirectional wave climate of the 19th century to the present more balanced north-east to south-east bi-directional one.

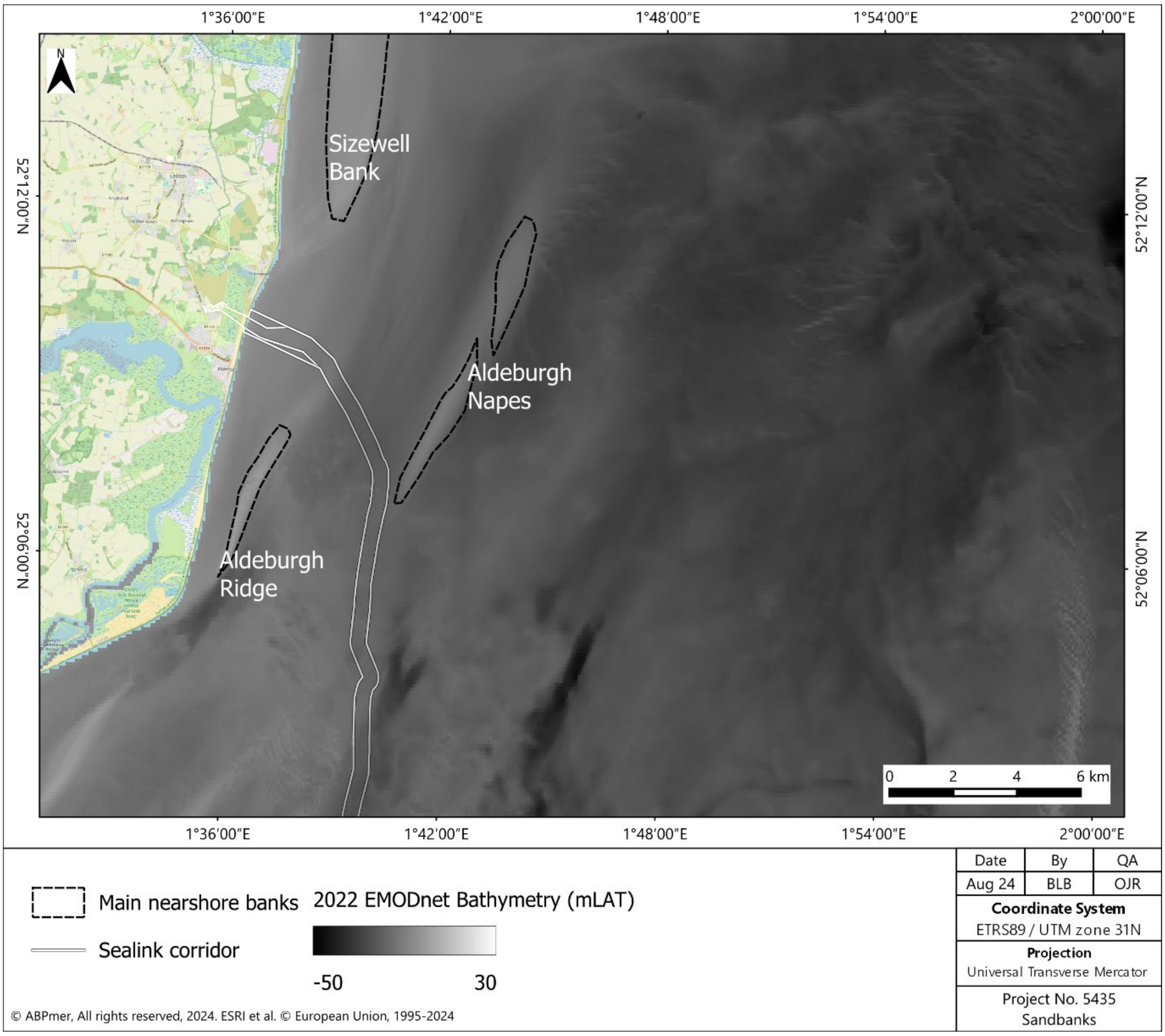
Further analysis carried out during the study revealed that during these winters, the proportion of waves approaching from the south almost doubled and many fewer waves arrived from the northern sectors. Both the increased intensity of large waves and the change in their direction seem to be linked to an increased value of the North Atlantic Oscillation (NAO) index which meteorologists use to characterize (high-altitude) atmospheric pressure and wind patterns over that ocean (in the way that the El Nino / La Nina weather patterns occur over the Pacific Ocean).



Source ABPmer's SEASTATES[2]

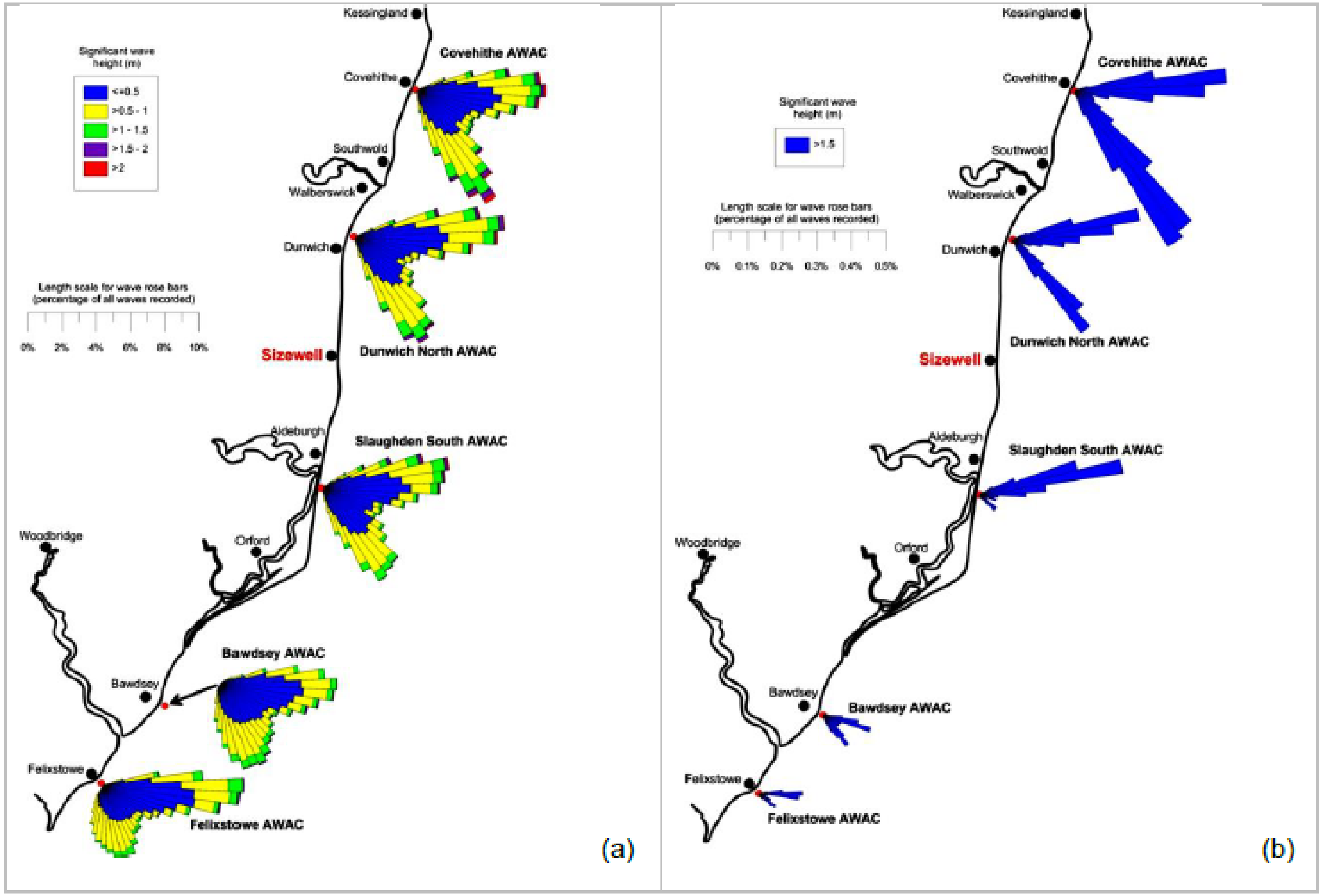
Figure 9. Wave climate offshore of Aldeburgh 40 year wave hindcast)

[2] www.seastates.net



Bathymetric data source: Emodnet, 2022

Figure 10. **Bathymetry of the wider area, showing the most important sandbanks and other features in the seabed affecting the wave propagation**



Source: BEEMS Technical Report TR311, undated

Figure 11. **Regional inshore wave roses from EA AWAC deployments. Wave roses for: a) all data and b) Hs>1.5m. Data collected by AWAC gauges for the period October 2006 and September 2009.**

3.3.1 Extreme wave conditions

Univariate analysis from the SEASTATES wave data has been carried out for the metocean study for NGET at different locations along the cable rote.

Values at KP3 (see location in Figure 12) for five different return periods from the analysis are given here in Table 4 for all directions. An example of the directionality of this data is provided in Figure 13, where the directional extreme wave heights for a 1:50 year return period have been plotted. The relative directional distribution of all (45 years of) available wave data are shown by the underlying scatter points where colour indicates the relative density of the data (relative frequency of occurrence of joint wave height/direction occurring) the resulting 1:50 year return period extreme wave height estimate for each directional sector is overlaid as a black solid line shape and value. In this case, for the 1:50 return period, the most extreme wave height is from SSE at 2.9 m, followed by Easterly one at 2.6 and ESE at 2.4 m. These wave heights are representative of nearshore approaches to the landfall, however, very local modification of waves might be expected at and around the exact landfall position, due especially to the shoals at Aldeburgh Ridge. The effect of such sheltering and shoaling is expected to be a slightly reduced wave height, especially from ESE to SSE.

Figure 12. Position of KP3

Table 4 Omnidirectional extreme wave results at KP3 for five different return periods

Wave Parameter	Return Period (years)				
	1:1	1:5	1:10	1:50	1:100
Hs (m)	2.4	2.7	2.7	2.9	2.9
Tp (s)	7.5	7.9	8.1	8.2	8.3

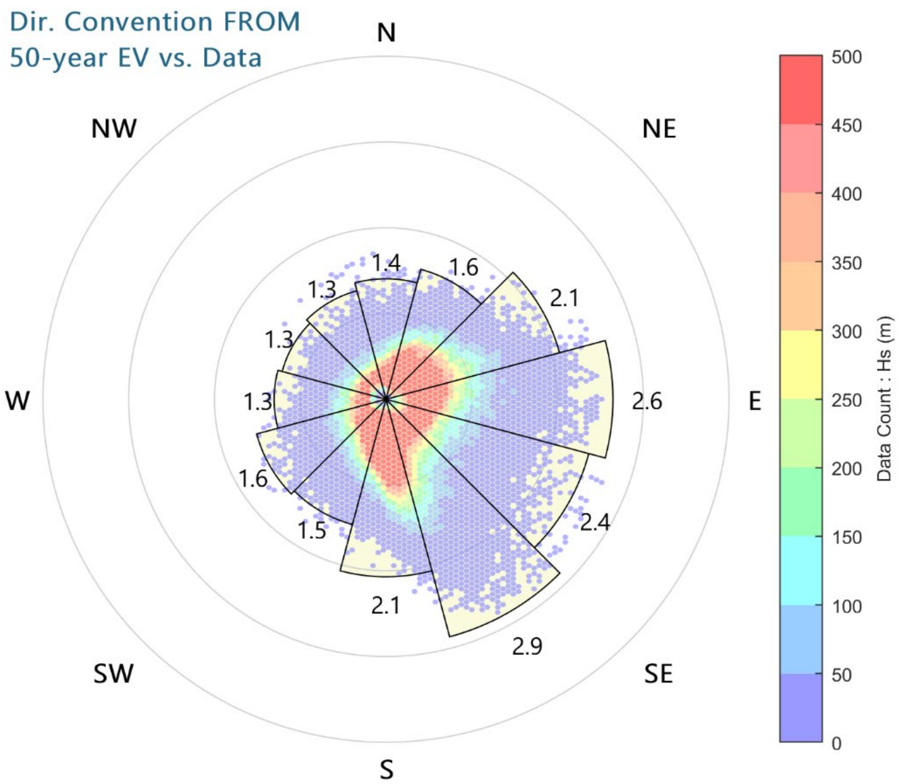
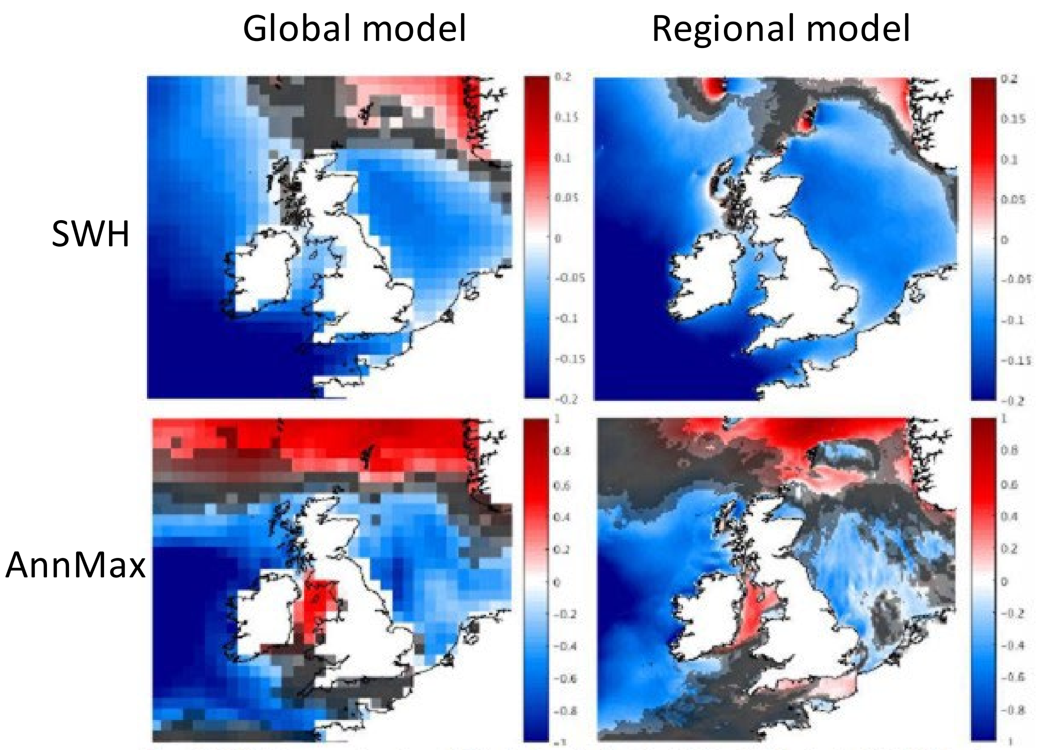


Figure 13. **Wave rose of extreme wave heights at 1:50 return period for KP3, showing the amount of wave height data per sector and in black the exteme wave height per direction sector.**

3.3.2 Climate change

The UKCP18 Marine Projections report (MetOffice, 2018) provides with regional wave model projections where significant wave heights (SWH) and mean annual maximum (AnnMax) are provided for the UK for the end-21st century period 2081-2100. Their results are reproduced here in Figure 14 as maps of change in SWH between the end-21st century RCP8.5 projection, and the present-day conditions. The area of the proposed landfall shows an absolute change in significant wave height of maximum 0.1 m. As for the mean annual maximum, the area is within that where the changes are hidden by the natural variability.



Source: MetOffice, 2018

Figure 14. RCP8.5 end century change in mean SWH (top) and mean AnnMax (below). Global model (left) and regional (right). All plots show an absolute change, in metres. Grey masking indicates where natural variability is high. Where there is no masking, there is higher than a 75% chance that the future wave conditions are different to the historical conditions, rather than masked by natural variability

3.3.3 Storm surges

UKCP18 found no evidence for significant changes in future storm surges.

3.4 Tides and water levels

Predicted tide levels for Aldeburgh are presented in Table 5 which have been taken from Admiralty Total Tide data (2024) for the secondary Port 0139 – Aldeburgh. The conversion from mCD to mODN is -1.50. Tides are semi-diurnal with approximately two tides a day.

Table 5. Predicted tidal levels at Aldeburgh

Level	Tide Level (mCD)	Tide Level (mODN)
HAT	3.4	1.9
MHWS	2.7	1.2
MHWN	2.3	0.8
MSL	1.66	0.16
MLWN	0.9	-0.6
MLWS	0.3	-1.2
LAT	-0.2	-1.7
Mean neap tide range (m)	1.4 m	
Mean spring tide range (m)	2.4 m	

Note that the conversion from ODN to LAT used throughout the study is 1.5 m (and not 1.7m as per table above) as per VORF data.

3.4.1 Extreme water levels

Estimated, present day extreme water levels from the 2018 Coastal Flood Boundaries Dataset (CFBD) are presented in Table 6 (Environment Agency, 2019). The location of points of this dataset is given in Figure 15. In the table t1 for example refers to the 1 in 1 return period, where return period provides an estimate of the probability of exceedance of a given level in this case. For example, t100, a 100-year return period corresponds to a level that has an exceedance probability of 0.010 or a 1% chance that the level will be exceeded in one year[3].

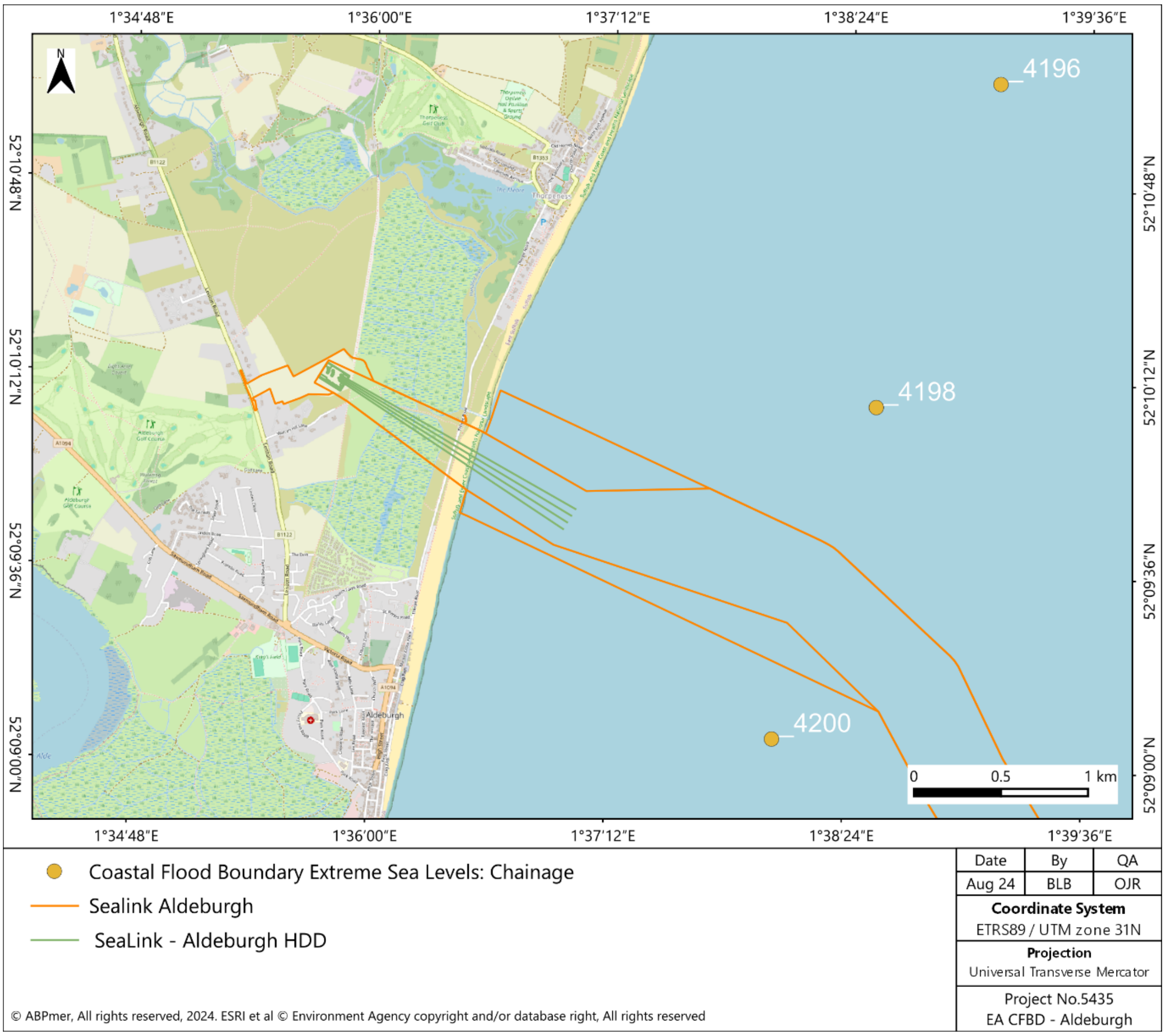
Table 6. Extreme water levels for 2018 (Chainage 4198)

Return Period	Level (mODN)	Level (m LAT)
HAT	1.8	3.3
t1:	2.03	3.53
t2:	2.18	3.68
t5:	2.38	3.88
t10:	2.53	4.03
t20:	2.68	4.18
t25:	2.73	4.23
t50:	2.86	4.36
t75:	2.95	4.45
t100:	3.01	4.51
t150:	3.09	4.59
t200:	3.14	4.64
t250:	3.18	4.68
t300:	3.22	4.72
t500:	3.33	4.83
t1000:	3.46	4.96
t10000:	3.92	5.42

Note: Some return periods have been highlighted for ease of reading the table

Source: Environment Agency, 2019

3 The most common misconception about return periods, for example, the 100-year return period is that the extreme water level will only occur once in 100 years. It is essential to understand that if an extreme water level with a 100-year return period occurs now, it does not mean that another extreme water level of this magnitude will not occur in the next 100 years.



Source: Environment Agency, 2019

Figure 15. Location of the Coastal Flood Boundary Extreme Sea Levels points

3.4.2 Climate change

The Environment Agency provides climate change guidance in their website (https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#offshore-wind-speed-and-extreme-wave-height-allowance).

The sea level allowances provided by the EA for the Anglian region are provided in Table 7. They are provided based on two percentiles (a percentile describes the proportion of possible scenarios that fall below an allowance level). These are:

- Higher central allowance is based on the 70th percentile: an allowance based on the 70th percentile is exceeded by 30% of the projections in the range.
- Upper end allowance is based on the 95th percentile: an allowance based on the 95th percentile it is exceeded by 5% of the projections in the range.

This data has been plotted for both the higher central and the upper end allowances, from the baseline year of 2027, for 50 years. It can be inferred from the table or the graph that, for our site, the following sea level rise should be considered:

- For 40 years from 2027: a sea level rise of 0.33 to 0.43 m needs to be considered.
- For 50 years from 2027: a sea level rise of 0.45 to 0.58 m needs to be considered.

The EA does not mention the RCP considered in these allowances, although it is believed to be RCP 8.5.

Table 7. Sea level allowances for Anglian region for each epoch in mm for each year (based on a 1981 to 2000 baseline) – the total sea level rise for each epoch is in brackets

Allowance	2000 to 2035 (mm)	2036 to 2065 (mm)	2066 to 2095 (mm)	2096 to 2125 (mm)
Higher central	5.8 (203)	8.7 (261)	11.6 (348)	13 (390)
Upper end	7 (245)	11.3 (339)	15.8 (474)	18.1 (543)

Source: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#offshore-wind-speed-and-extreme-wave-height-allowance

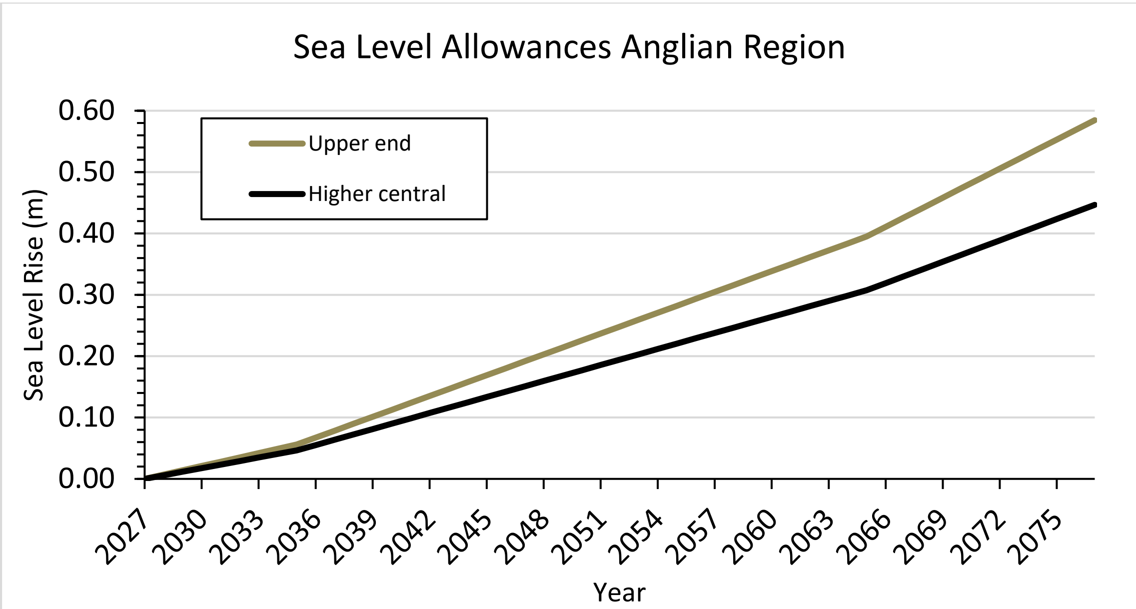


Figure 16. Sea Level allowances for Anglian Region from baseline year of 2027 for 50 years.

3.5 Geology and geomorphology

The headland of Thorpeness and the high ground at Aldeburgh are backed by the valley of the Hundred River (see Figure 3) and low-lying area situated behind the shingle bank at the back of the foreshore. The nearshore area of this section is relatively shallow, sloping out to the 10m Chart Datum (CD) contour some 1km offshore. Thorpeness is held seawards of the rest of the coastline by the presence of relatively-resistance coralline crag. The shingle backed bay forms a shallow curve from Thorpeness to Aldeburgh where it is aligned north-south. This bank is quite substantial with an extensive back face and shallow front slope.

During the 1953 storm[4] it was not fully breached, although overtopped with local fans of sediment distributed behind. It was near the open fresh water Meare (see Figure 3) that the most northern of the 1953 shingle fans developed. Evidence of the fans can be seen along the frontage cutting across the road that runs behind the shingle ridge. The road is at a level of approximately 4m ODN with the general scrub grazing land beyond lying lower at some 2m ODN.

The shingle ridge runs south into the progressively more forward line of properties making up the sea front of Aldeburgh. At the southern end of Aldeburgh this line of properties and the seawall fronting them is actually exposed to the active front beach face. Further north the line runs some considerable distance behind the beach face with a wide expanse of flat shingle berm between. This berm is used by fishermen to store boats and fishing gear. The whole frontage has in the past been groyned, demonstrating that in the last century there were occasions when this shingle was not present., In the past, Aldeburgh apparently lost some five rows of properties forward of the current line. The current width of shingle is around 60m. Buildings such as the War Memorial and the RNLI station protrude slightly over the back beach area.

To the south of this area is Slaughden, a narrow neck of land only 50m to 75m wide, separating the coast from the estuary. The Slaughden Martello Tower sits on the narrow neck of land between sea and estuary. The seaward face of this neck is heavily defended by rock and timber groynes, and by a concrete seawall. Until recently (Royal Haskoning, 2010) this area has also received recharge with material taken from further south. The potential for continued recharge is being reviewed. Further south the shingle ridge becomes slightly wider as the estuary turns slightly inland and then considerably more so as the Orfordness curves slightly seaward.

3.5.1 Seabed sediment composition

The seabed over the study area contains a mix of sands and muddy sands as shown in Figure 17. Aldeburgh Ridge is located on the sandy gravel area, whereas Aldeburgh Napes is mainly on the gravelly sand.

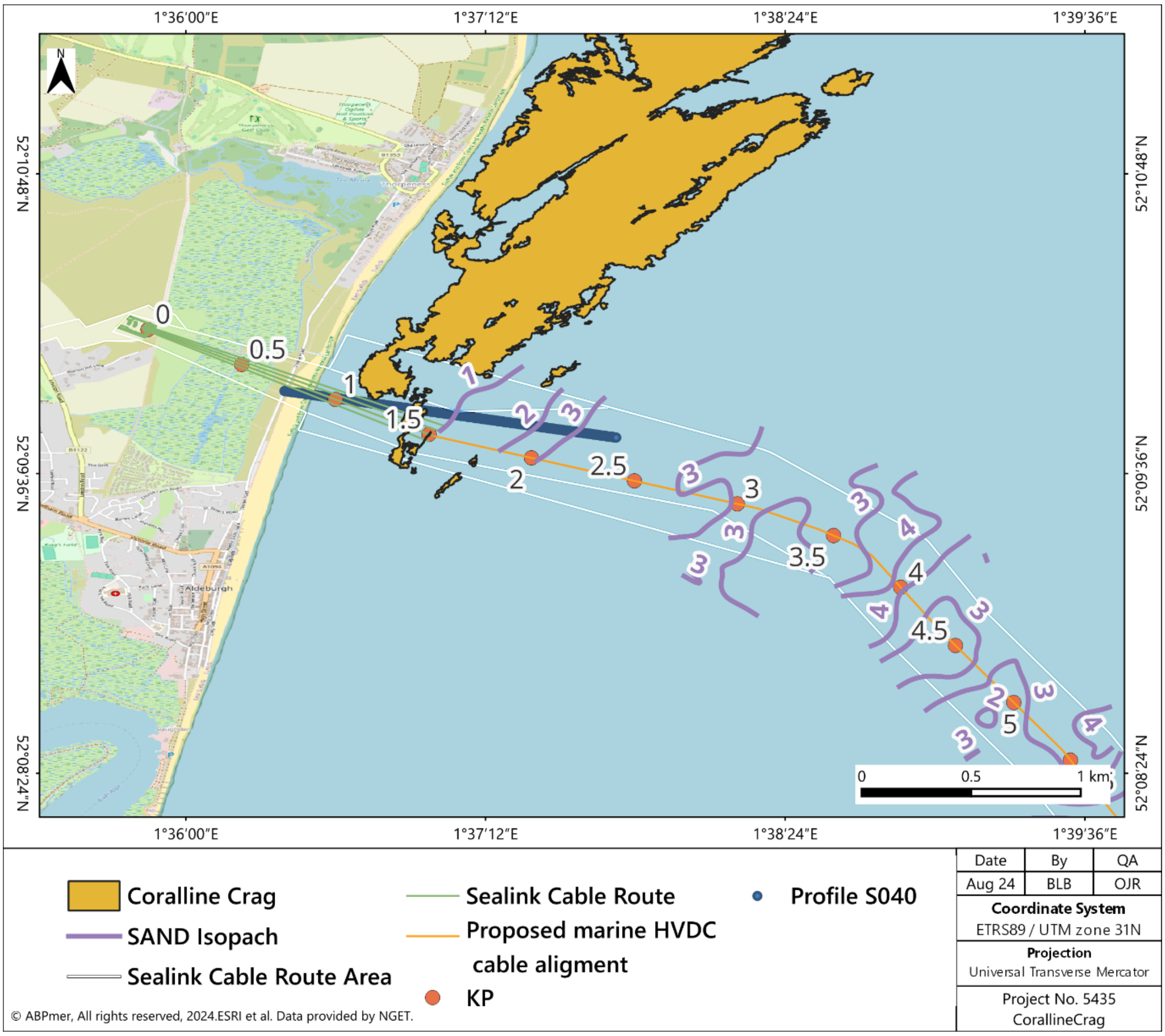
Source: BGS GeoIndex Offshore viewer (https://mapapps2.bgs.ac.uk/geoindex/home.html)

Figure 17. Seabed sediments according to BGS GeoIndex Offshore viewer

[4] The 1953 North Sea flood was a major flood caused by a heavy storm surge that struck the England, among others. Most sea defences facing the surge were overwhelmed, resulting in extensive flooding. A combination of a high spring tide and a severe European windstorm caused a storm tide of the North Sea. The combination of wind, high tide, and low pressure caused the sea to flood land up to 5.6 metres above mean sea level.

3.5.2 Coralline Crag

The important geological feature is the ridge of Coralline Crag composed of cemented iron-stained Pliocene shelly sand formed of bryozoan and mollusc microfossil debris that extends north-eastwards from Thorpeness beneath the modern beach sediments. The Coralline Crag bedrock outcrops are a series of hard substrate ridges extending from below the surface north of Aldeburgh to the coastal headland of Thorpeness and continuing at the seabed in a SW-NE direction offshore, east of SizewellI. It is of greater resistance to erosion compared with other deposits and this bedrock provides an unusual area of hard substrate in an area where the coastal seabed is dominated by soft mobile sands. It has been suggested that the position of the Ness to the north of Thorpeness is comparatively fixed by this geological unit, which also serves to anchor the Sizewell-Dunwich Bank Complex. They can protrude 1-2 m from the surrounding seabed (BEEMS Technical Report TR087, 2009). An area of exposed Coralline Crag bedrock, approximately 4km^2, is present off the coast of Thorpeness, and an area of sand over mud/clay occurs to the east of this. The position of the coralline crag near the site as well as the sand isopaches, which denote the thickness of the sand layer, are given in Figure 18.



Source: Isopachs, coralline crag data and cable route provided by NGET

Figure 18. Position of the coralline crag area and the thickness of the sand layer along cable route

The Coralline Crag habitat is a dynamic environment and the extent protruding from the seabed is affected by migration of adjacent sandwaves (BEEMS Technical Report TR087, 2009).

3.6 Sediment transport regime

3.6.1 Introduction

There are several forcings to the sediment transport in this area:

- Oblique waves that cause longshore drift along the coast
- Tidal currents that will cause longshore transport along the coast
- Storm events that will mostly work in the cross-shore dimension moving sediment at shorter time-scales

All of these are influenced by the bathymetry of the area, and in particular to the complex banks present, shown in Figure 10.

These forcings are all detailed below, together with a summary of the movement of the banks.

3.6.2 Longshore drift due to oblique waves

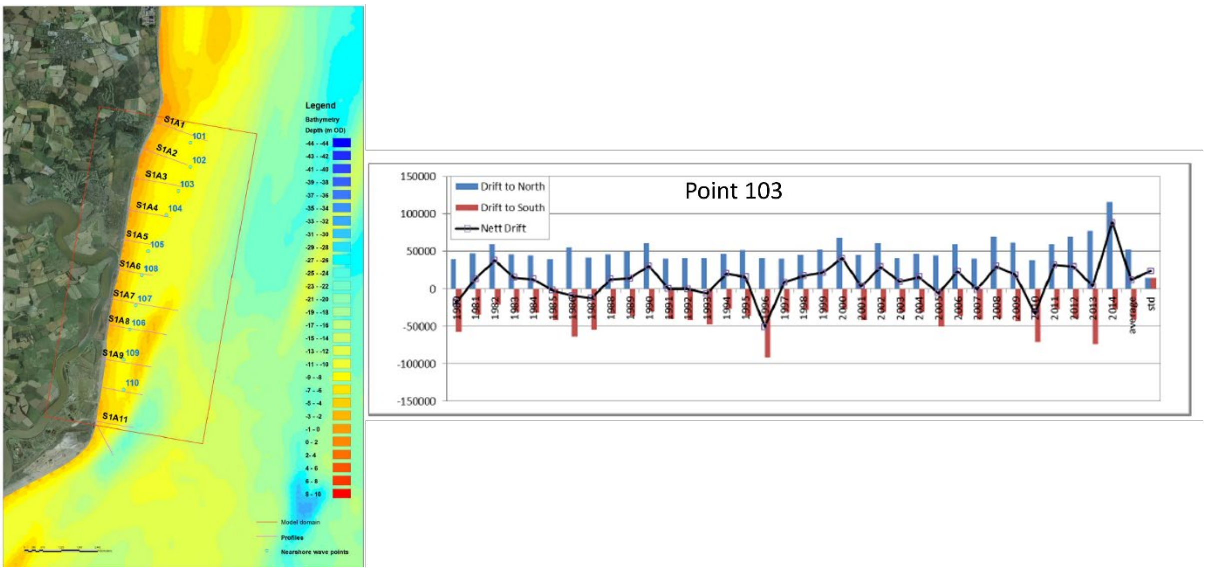
The 'traditional' view of the longshore drift regime, based on studies going back some 70 years, was that the long-term net drift direction along this part of the Suffolk coastline is southwards, but with periods of a reverse drift both along the spit that extends south from Orfordness as well as along almost the whole frontage between the Ore/Alde and the Deben. This old-fashioned view of the drift regime generated maintenance problems in the artificially-maintained headland at East Lane, Bawdsey and is likely to have caused confusion over the years in many of the locations along the East Anglian Coast. It is expected that net northward transport of shingle would occur in other locations in some years, depending on the climate. This switch in northerly and southerly transport as a result of the wave climate is also recorded along the study frontage as reported by Atkinson & Esteves 2019.

In order to make historical estimations of the longshore drift on the site, nearshore waves which take into account the nearshore banks and bathymetry are required. As we saw in the Wave conditions section, Section 3.3, the Aldeburgh Ridge has an influence on the Southeasterly waves, as the larger waves break over the ridge and they are dissipated, see Figure 10. If the estimation of the longshore drift was to be made with the offshore waves, the northerly drift will be over-predicted.

According to the SMP2 (Royal Haskoning, 2010) over the northerly section of the zone the frontage is quite stable. There is a weak supply of sediment past Thorpeness which is likely to continue. South of Thorpeness, the drift is still relatively low with a suggested net drift to the north over the northern section and a weak net southerly drift across the Aldeburgh frontage. As over much of the SMP coast, these net drift rates are developed from the balance between higher drift rates under different conditions from north to south and from south to north. The rates determined, given the inherent inaccuracy of sediment modelling, suggest low throughout over the bay. There seems little to suggest that there is a drift divide and the significant degree to which the outfall in the centre of the bay tends to draw out the low water contour indicates a high degree of stability. The shingle ridge will still tend to roll back and the ridge is vulnerable over the centre and south to overtopping on a major storm. Retention of sediment is controlled at the southern end by the end section of defence at Aldeburgh.

The sediment transport due to the longshore drift is due to the differences in longshore drift along the beach, so that in simple terms at a certain location if there is more longshore drift coming in that coming out that will be prone to accrete and conversely if there is less longshore drift coming in that coming out it will be prone to erode. These differences in drift alongshore are due to the differences in the wave energy alongshore and therefore will be influenced by the nearshore bathymetry.

As well as the alongshore variability of the longshore drifts, how these drifts vary from year to year (as well as seasonally) is important for the sediment transport they might produce. Historical longshore drifts were estimated with nearshore waves for a project near the site in HR Wallingford (2016a). Figure 19 shows the variation of the potential longshore drift to the north, south and net drift at a point, named 103, north of our site. These can help understand the annual variability of the longshore drift expected in our site, even though this point shows a mark bimodality in the directions of the sediment transport as it is away of the area of influence of Aldeburgh Ridge. The variability of both the northerly drift and the southerly drifts is very high, and some years present a potential drift that is double the average drift. The effect of the longshore drift can be readily seen on the accumulation to other side or the other (depending on the drift direction) of the wooden casing of the sluice, see Figure 19.



Source: HR Wallingford, 2016a

Figure 19. Variability of the potential longshore drift at a point north to the area of study

Figure 20. Effects of the longshore drift: accumulation either side of the wooden structure covering the sluice acting as a small groyne on the beach

3.6.3 Tidal currents

The SMP2 (Royal Haskoning, 2010) describes the tidal flows as peak flow on the flood of the order of 1.3m/s tending to set in towards the coast and therefore tending to be captured by the channel between the shore and the offshore bank. On the ebb, the flow in the offshore area is of the order of 1.5m/s, tending to flow slightly to the north northeast.

ABPmer has extended the grid of their high-resolution hydrodynamics model and run it for the whole year of 2027 to extract high resolution tidal currents along the cable route. The model grid near the Aldeburgh landfall is shown in Figure 21, together with its bathymetry and it is observed how both the Aldeburgh Napes and the Aldeburgh Ridge are included within the resolution of the mesh.

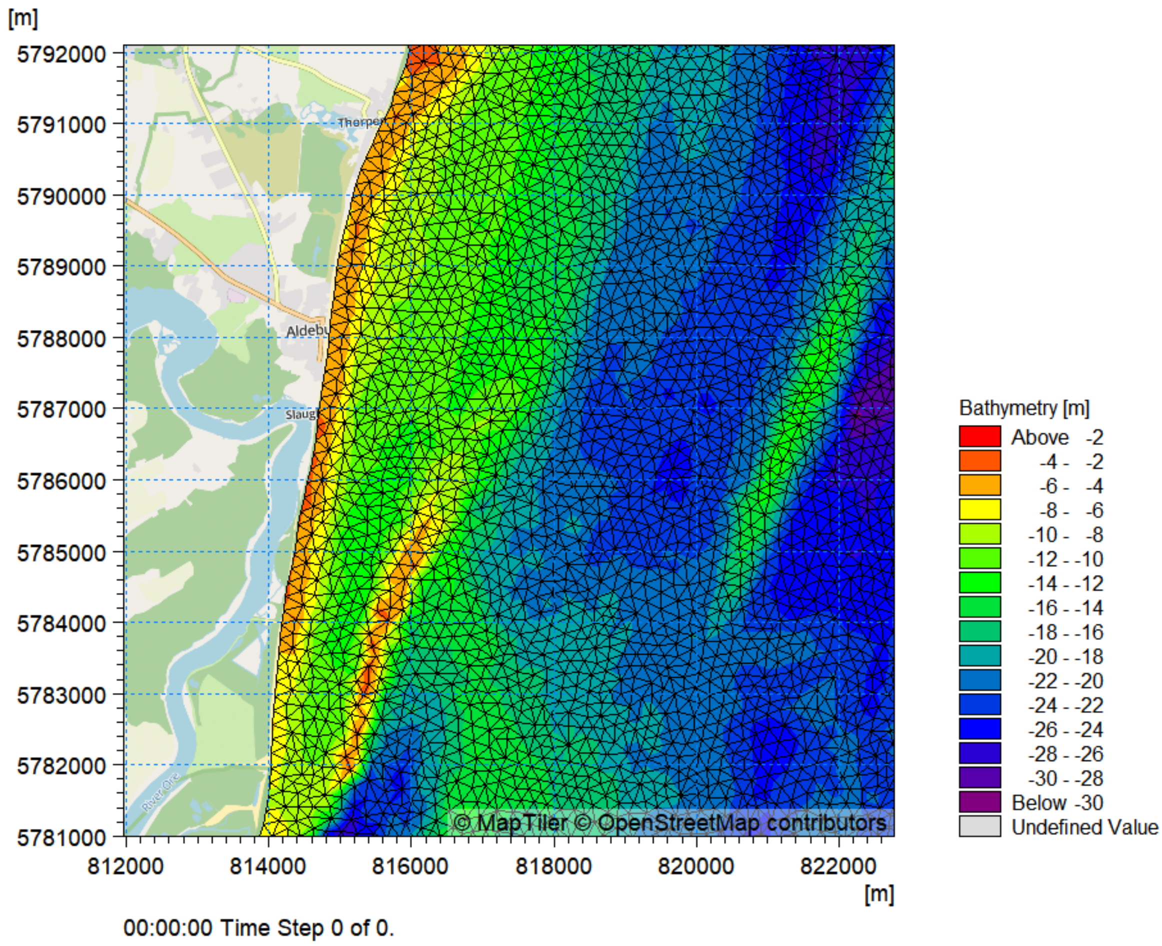


Figure 21. Mesh and bathymetry for Hydrodynamics high resolution model

Figure 22 shows the tidal currents in the area of the larger area of interest, at four states of the tide; Low Water (LW), Mid Flood (MF), High Water (HW), and Mid Ebb (ME) during a large spring tide in March 2027 (the KP points along the cable route shown are at 0.5 km intervals). Each sub-plot shows in a small insert the surface elevation at KP3.0 at the time of the snapshot and the black outlines are the positions of the sandbanks as per Figure 10. The results are for the largest tidal range typically experienced in a year and illustrates a potential annual maximum flow regime; lower flow speeds will be experienced over a typical tide.

During low water, the currents are minimal and inshore of KP3 they are zero. As mid flood, the tidal currents are generally towards SSW and offshore of KP3 the current speeds are up to 1m/s; inshore of KP3 the current speed decreases gradually to 0.2 m/s closest to the shoreline. At high water the tidal currents are still considerable and going towards SSW also. At mid-ebb the currents are now mostly towards NNE and offshore of KP3 they are of the order of up to 1m/s. Inshore of KP3, the current speed decreases gradually up to 0.2 m/s near the coastline. The effect of the Aldeburgh Napes on the tidal current can be observed at mid-ebb, so that it creates an area of lower currents speeds on its shadow (Northwest of it).

The tidal currents and the longshore drift due to oblique waves will be acting on the beach at the same time:

- It can be that both are operating at the same depth across the beach, so that for example at mid flow the tidal currents will be generally towards the SSW. If this coincides with NE waves, the longshore drift from the waves will be enhanced by the tidal currents so the transport towards the South will be greater or if it coincides with SE waves the tidal currents will be counteracted by the littoral drift. Similar situations might happen during mid ebb, so that during these NNE tidal currents if there are North easterly waves the transport will be diminished, but if the waves are coming from the Southeast, the longshore transport will be enhanced.
- It is known that in this area of the UK, both the tidal currents and the wave induced littoral drifts might be operating at the same time but in different depths across the beach; in these cases, a different sediment transport pattern from the one described above will happen. The littoral drift might be greatest in shallower waters, due to smaller wave heights, and the tidal currents are at deeper water, so that if both of them are towards the same direction, the sediment transport occurs over a wider area on the beach profile. However, if these two transport mechanisms are in opposite direction (for example during mid flow with tidal currents towards the SSW and SE waves that create a northeasterly drift), they will both be happening on the beach at the same time, so that over shallower depths the sediment transport is being moved towards the northeast by the littoral drift and deeper in the profile it is being moved towards the southeast by the tidal currents.

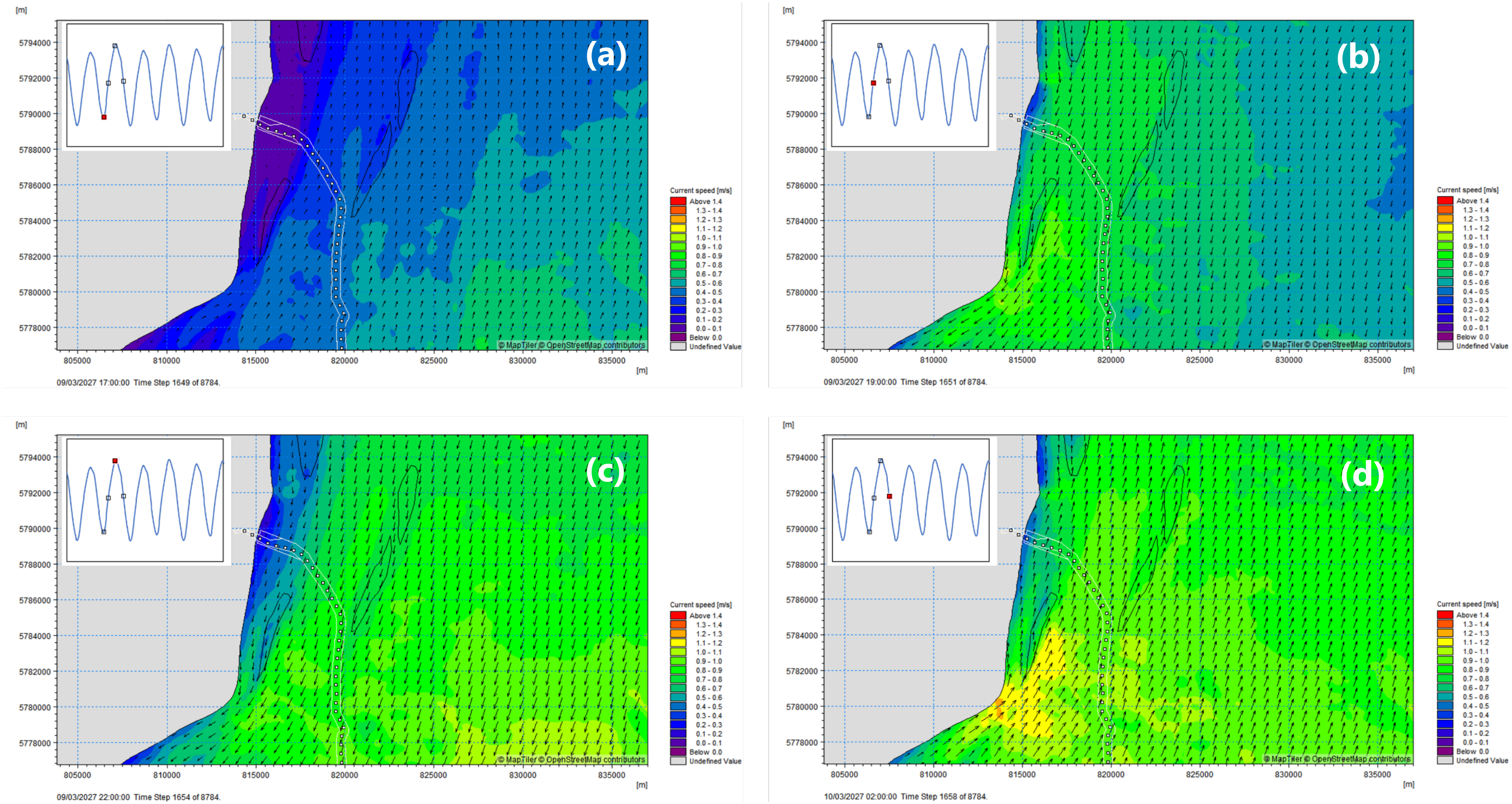


Figure 22. **Tidal currents at four states of the tide: (a) Low Water, (b) Mid Flood, (c) High Water and (d) Mid Ebb (the outlines in the figure show the position of the main sand banks in the area and the small insets the water elevation at KP3). The insets are used as a general reference to the state of the tide, therefore units/vertical scale are omitted. The red dot on the insets indicate the state of the tidal cycle displayed in the image.**

3.6.4 Depth of closure

The depth of closure is the depth beyond which no significant longshore or cross-shore transports takes place due to littoral processes, so that it defines the seaward boundary of the littoral zone. The depth of closure can be inferred from a long record of bathymetric beach profiles.

Previous authors (HR Wallingford, 2016a) suggest a depth of closure of 6m. The bathymetric profiles of the area combined with transects along the bathymetry have been analysed in order to derive a depth of closure for the area the landfall (see Appendix A for details of analysis) based on the data for Profile S040, location in Figure 2. The range of change across the profile has been calculated for every 1m, taking into account that the coverage of the profiles is different (the derived ones from UKHO bathymetry start at LAT and each of them finalise at different depths) and therefore sometimes the range would be calculated from six values and others from less, even just from two values. This range of change across the profiles is shown in Figure 23 where the top figure shows the actual profiles along S040 and the bottom figure the range of change. From this analysis, the depth of closure would be around -6 to -7m LAT.

This estimated depth of closure is for the most mobile sediment. The coralline crag, which exists in the area, has a greater resistance to erosion and this depth of closure would not apply.

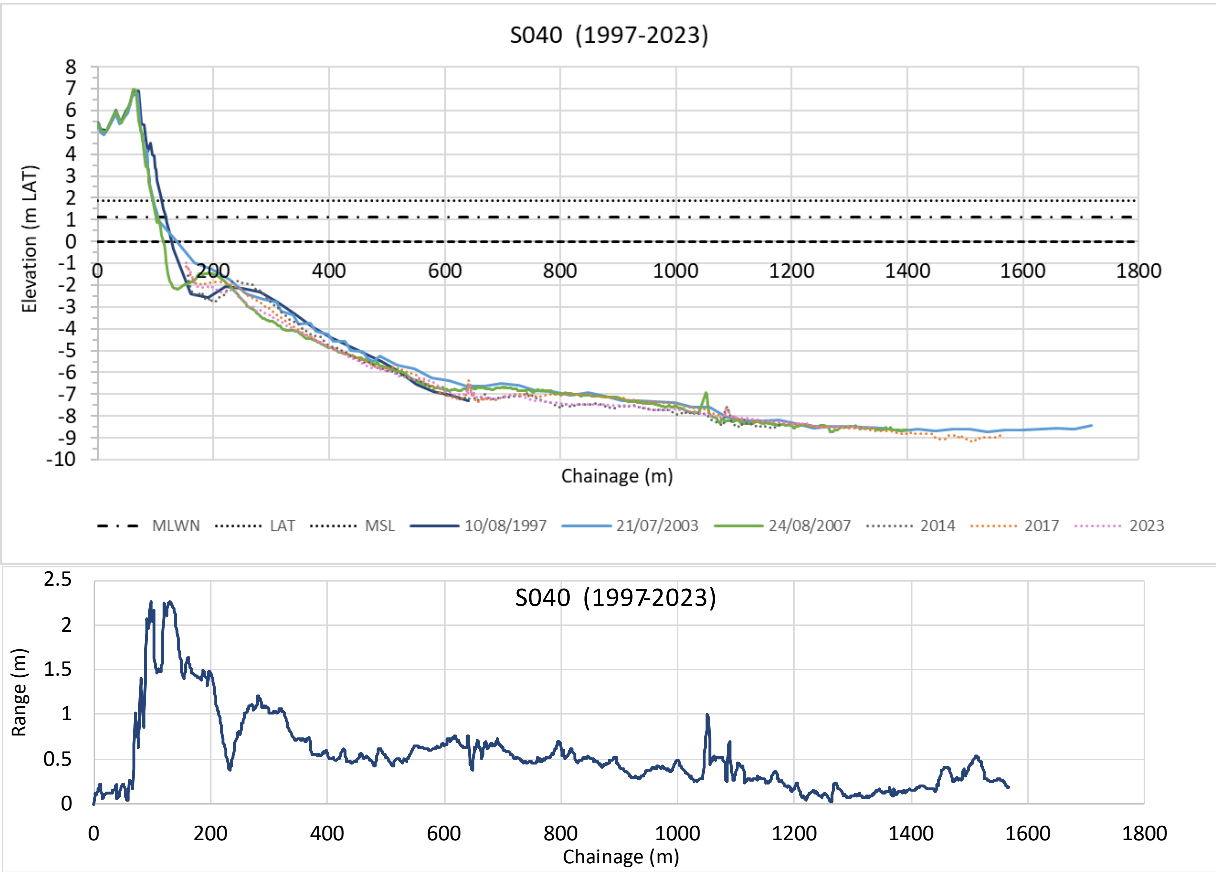


Figure 23. Range of change across S040 profile (location in Figure 2)

3.6.5 Response to storms

Appendix A contains details for this assessment. During a storm, mixed gravel and shingle beaches response is very different due to the higher permeability: this makes a fast and considerable percolation of the water through the beach face the key physical process. The main implication is the weakening of the backwash flow and therefore there is a resulting reinforcement of the onshore transport. In terms of the beach profile after a storm, the gravel moves across-shore towards the back of the beach, creating a very steep crest. A step has been formed below the water level where the sediment has eroded to form the crest.

The permeability of mixed beaches is lower than that of gravel beaches and therefore the percolation is smaller and so is the onshore transport. As a result, mixed beaches response is similar but with a smaller and less steep crest and a smaller step.

Aldeburgh beach is a mixed beach and this behaviour of storm response has been seen in the data for Profile S040 (location in Figure 2). Figure 24 shows two consecutively following profiles, in summer of 2019 and winter of 2020 where the difference between a "summer" and "winter" profile for Aldeburgh beach can be appreciated. The beach in the winter shows the characteristic steep berm formed by the gravel; the face of the berm presents a steepness of 1:2. The "summer" profile presents the typical steepness of a gravel/ mixed beach of 1:7.5. This profile only covers the accretionary part of the beach, so what it is not appreciated is the step formed below low water, due to the material transported from there to form said crest. The run-up limit of the storm that formed this crest would be at the start of the crest, at around chainage 85 m. It can be observed that there have been morphological changes in the area behind this chainage since the summer; this is probably due to preceding extreme events with higher water levels and/or higher wave heights which built a crest higher up the beach.

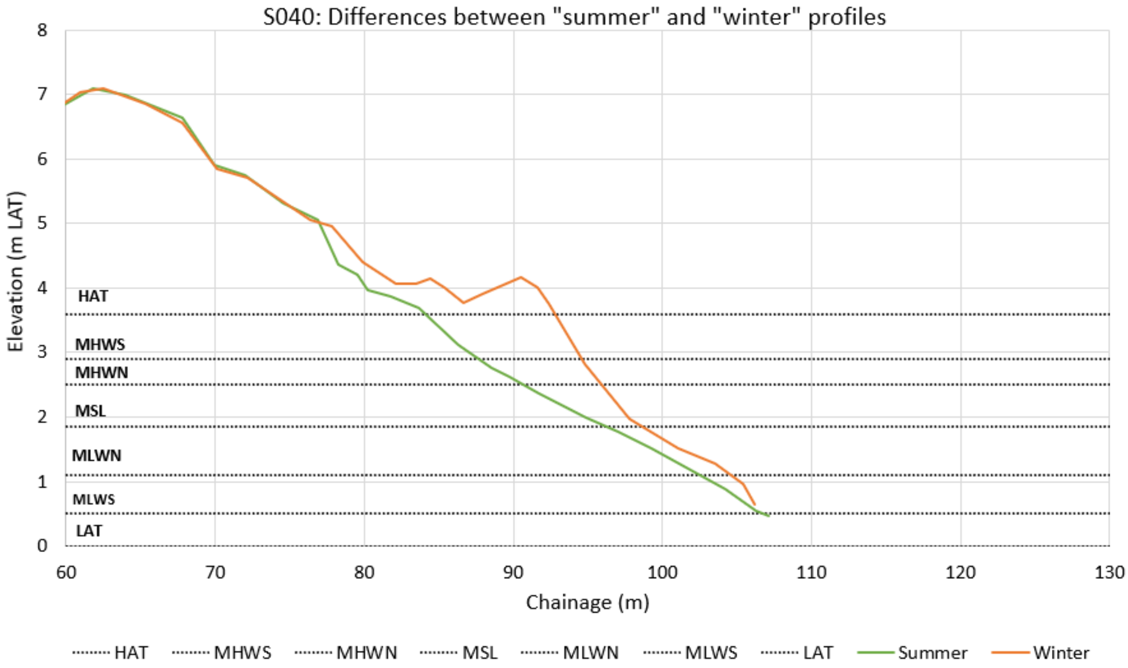


Figure 24. Differences between a "summer" profile from August 2019 and the following "winter" profile in February 2000.

The 1-d model Shingle-B was run for a series of conditions representative of nearshore conditions in the area. The results from the tests are shown in Figure 25. The figure shows also the initial profile used for the model and the composite profile (August 2018 for the intertidal part and August 2007 for the deeper part) in which this plane profile was based on.
The results are most-likely over-predicting how far in the backshore the beach crest is and how high the crest is because the model was derived for gravel beaches and not mixed beaches. The area in the profile between MSL and -2m LAT in reality is steeper than the initial profile used in the model: this area is not well represented by the model and it is probably driven by more complicated sediment transport (wave driven and tidal induced combined) than the cross-shore transport that this model represents. But, in all cases, the important result is that the model does not show any morphological changes beyond the -4m LAT. Due to the limitations expressed above, there is probably some cross-shore transport due to storms beyond the -4m LAT with more extreme water levels and storms; however, this will be within the estimated depth of closure of -6 to -7m LAT.

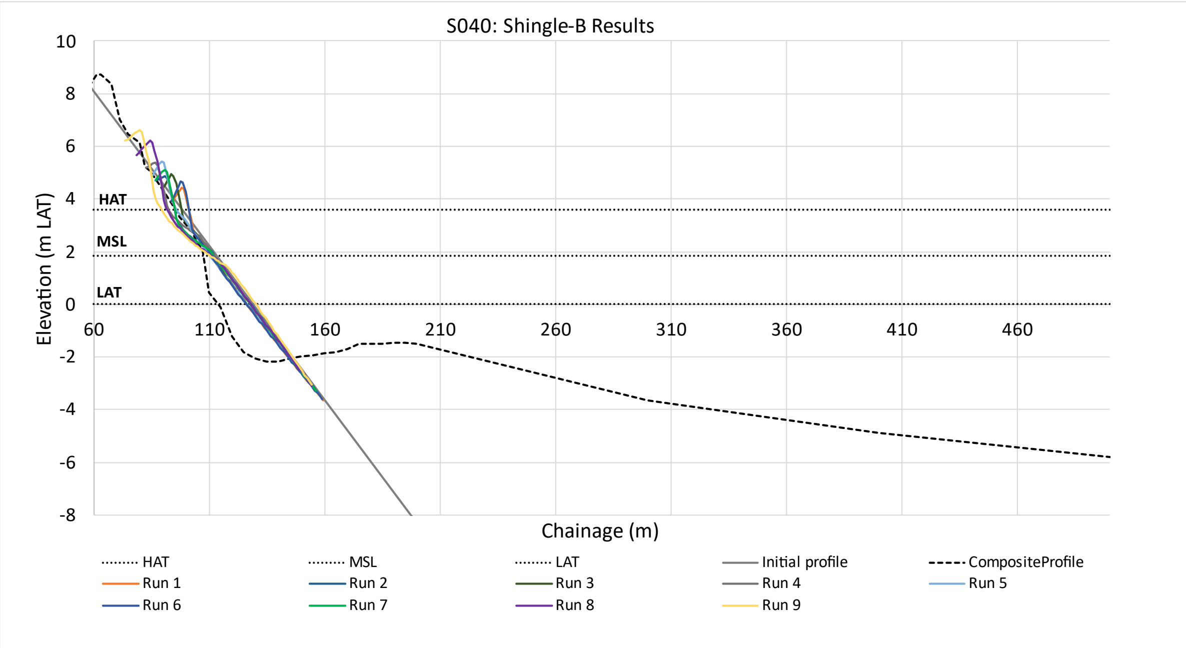


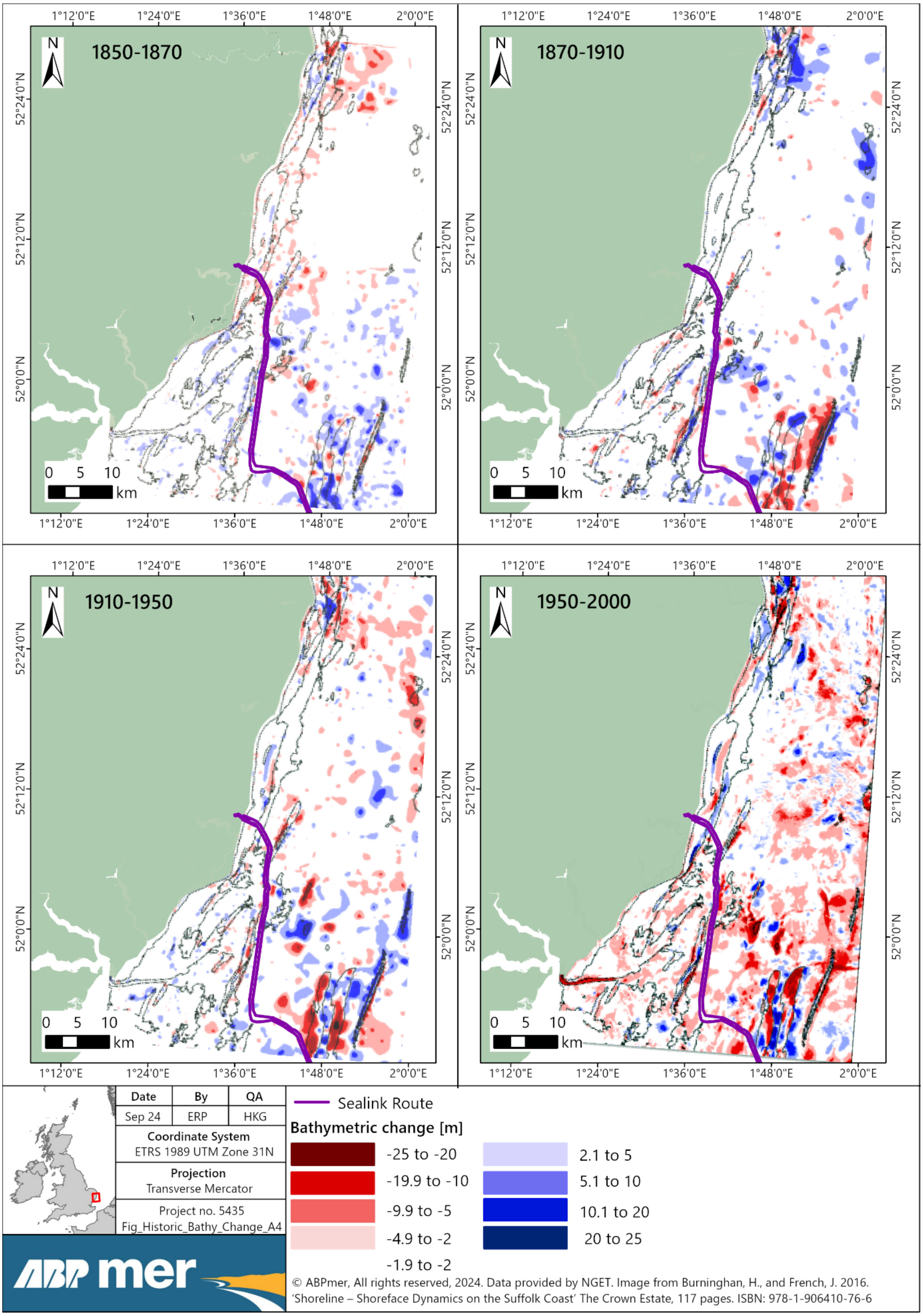
Figure 25. Shingle-B results

3.6.6 Offshore banks

The offshore bank system is extremely complex and studies have shown migration of the different features over time. Figure 26 show the historic bathymetric changes derived by Burningham and French, 2016, which indicated that there has been significant changes to the shoals and bars offshore of the frontage over the past century, including changes to Aldeburgh Ridge and Aldeburgh Napes. Although caution should be given to some of these results due to the likely accuracy of some of the older data sets, it appears that the Aldeburgh ridge shoal has realigned and grown immediately off Orford Ness. As explained in previous sections, this shoal has a significant impact on the waves and tidal currents reaching the coast and the variability in wave climate along the frontage which in turn leads to the variability in the drift rates.

The changes observed over past 25 years (1992-2007) from bathymetric profiles (HR Wallingford, 2016a) appear to show the Aldeburgh ridge shoal realigning/migrating shoreward whilst also growing north. Over the shallow parts of the shoal, the height of the shoals appears to remain constant over this time, although to the north the shoal height has grown by around 2m. To the south, where the shoal is non-existent there has also been some erosion of the bed. If these changes were to continue, they would significantly affect the sheltering afforded by the shoal to different aspect of the frontage under different incident wave conditions.

The BEEMS studies concluded an overall reduction in inshore wave energy due to growth of the Sizewell – Dunwich Bank (elevation, width and extent), which is thought to have been a sink for some of the material eroded from Minsmere – Dunwich Cliffs during its 19th Century erosive phase (BEEMS Technical Report TR223, undated).



Source: Burningham and French, 2016

Figure 26. Historical bathymetric changes on the offshore banks and shoals over different epochs

3.6.7 Conclusion on the sediment transport regime

The sediment transport in the area is a combination of several forcings, such as the longshore drift caused by waves breaking at an oblique angle and coming predominantly from the northeast and southwest. On top of this, the tidal currents that flow southwest or northeast also might enhance or diminish the longshore drift. The longshore drift in this area is very variable alongshore due to the shoals that influence the wave transformation processes, but there is also high variability over the years.

The beach at Aldeburgh is a mixed beach, which is also influenced by shorter term changes (mostly in the cross-shore) due to severe storms. To the north and south of the Aldeburgh are two nesses, Thorpeness in the north and Orfordness, in the south, which have been changing over the years. The morphodynamics of the nesses are not well understood at the moment and is an area where research has been scarce over the last decades.

There are no existing numerical models that deal with the sediment transport of mixed beaches, as these are very complicated due to the temporal and 3D variation of their sediment. Standard practice is to model them either with a numerical model for sandy beaches or one for gravel beaches or even both and qualitatively extend the results to mixed beaches, supporting it with measurements and observations.

Moreover, the nearshore shoals and banks in the offshore region have been migrating and this in turn influences the forcings onto the beach.

All of these make this area very difficult to be modelled successfully in a sediment transport numerical model and therefore the morphological changes in the future will be better implied by the assessment of the historical data of morphological changes instead. This is what has been carried out in this study, presented in the next section.

4 Morphological Changes Near the Landfall Area

The morphological changes near the landfall area have been separated into three regions: hinterland, intertidal and sub-tidal, which are specified below.

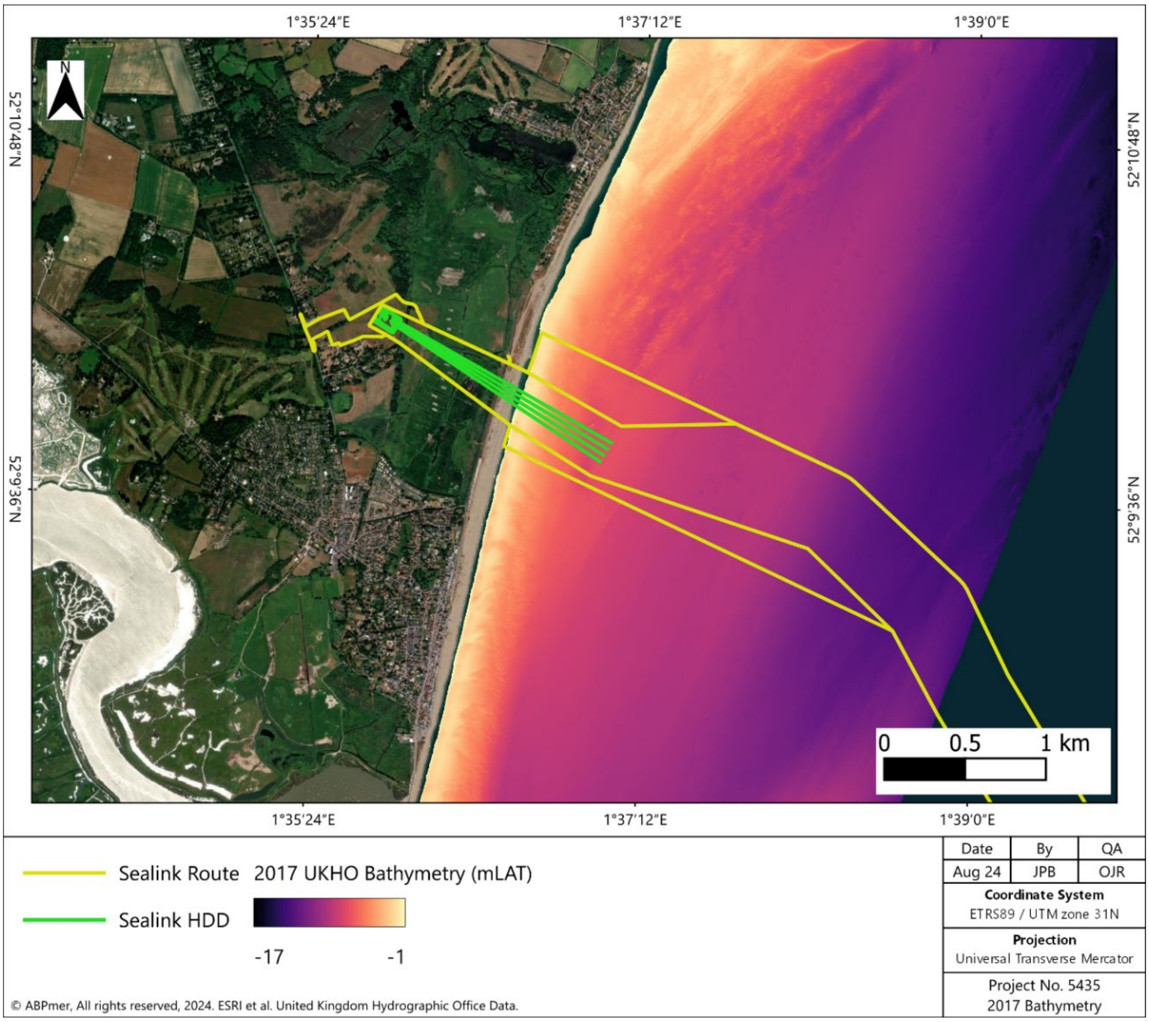
4.1 Morphological changes in the sub-tidal region

4.1.1 Historic trend

Historical analysis of the seabed near the HDD exit point has been undertaken using a number of bathymetries available:

- UKHO bathymetric data (2014, 2017, 2023)
- NGET provided bathymetric data (2021,2024)

An example of one of these bathymetric datasets is provided in Figure 27 where the bedforms present in the nearshore are well characterised within the bathymetric data.



Source: UKHO, 2017

Figure 27. Bathymetry over the area of interest for 2017

These bedforms are aligned NW-SE to the prevailing sediment transport at the time, in this case from the southwest; other bathymetric sets show a different alignment of the bedforms (to a prevailing sediment transport from the northeast) and other show no sand waves at all, exposing the variability of the nearshore dynamics.

An envelope of the differences of these bathymetries between 2014 and 2023 at a resolution of a pixel has been presented in Figure 28, where the areas in yellow show no change, the changes shown in orange, pink, purple (as they are greater). The figure shows how the greatest changes are very close to the coastline, on the beach. Moving offshore, the change becomes very small, possibly enhance by the fact that his is the area where the coralline crag is. Towards the end of the bathymetric extents the changes are slightly greater, of the order of 0.5 m. The differences in the bedforms from survey to survey are appreciated close to the shore.

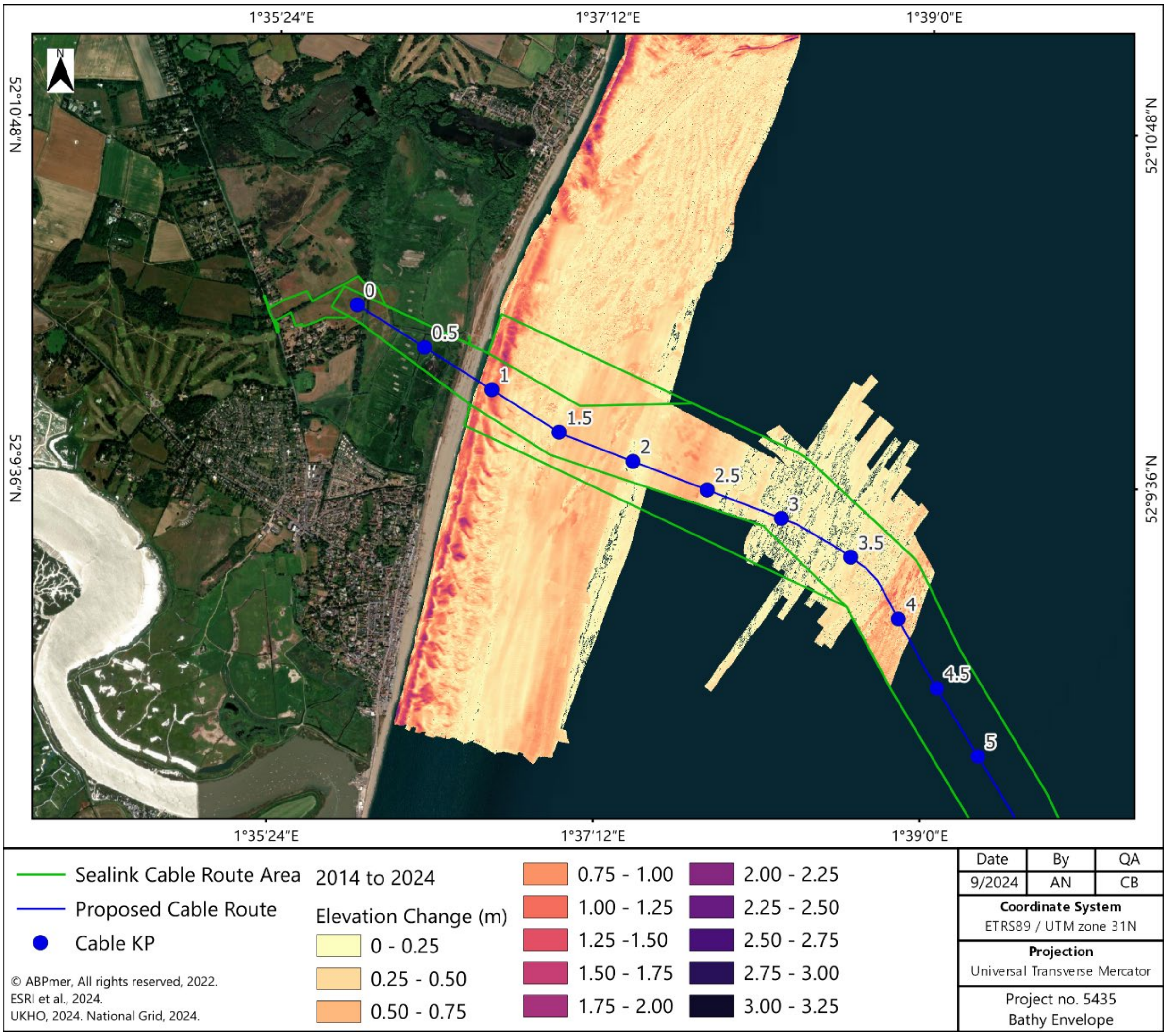


Figure 28. Envelope of the differences of available bathymetries between 2014 and 2024.

4.1.2 Response to storm events

There is insufficient data available to quantify the response of the sub-tidal area to any individual storms.

4.2 Morphological changes on the beach

4.2.1 Historic trend

Historical morphological analysis of Aldeburgh beach has been undertaken using:

- Google Earth historical satellite and aerial imagery,
- Environment Agency LiDAR topographic surveys; and
- Coastal Channel Observatory topographic surveys.

The detail analysis and results are presented in Appendix A. Here, a summary of the area near the landfall, represented by Profile S040 (location in Figure 2) is provided.

Figure 29 shows the profile changes for three different time periods: in each of these graphs the data for that period is in colours, whereas the data for the other two periods is greyed out. The three periods considered are: 1991 to 2000, 2001 to 2011 and 2012-2022. The evolution of the beach over the last three decades is emphasized in these graphs: the healthiest beach is the oldest measured and the beach retreated slowly up until about 2006. Since then, the beach has more or less stabilised and even advance slightly, but not to the levels of three decades ago.

From the whole profile data record (1991-2022), the intersection of the Mean Sea Level, MSL level and the profile along the years can be calculated for each of the years in order to produce a time series of MSL chainages. This is shown in Figure 30. These figures show long term variations on the beach, profile S040 shows two different rates of erosion: up until about 2006, the erosion was about -1.2 m/yr. However, since then, the beach has stabilised and is even showing some very small accretion.

The high variability of this profile (and others close to it) and their erosional and accretional trends over the years emphasize the highly dynamic area of the study and the value of long-term measurements to produce historical ranges of change that might be used to infer potential future changes.

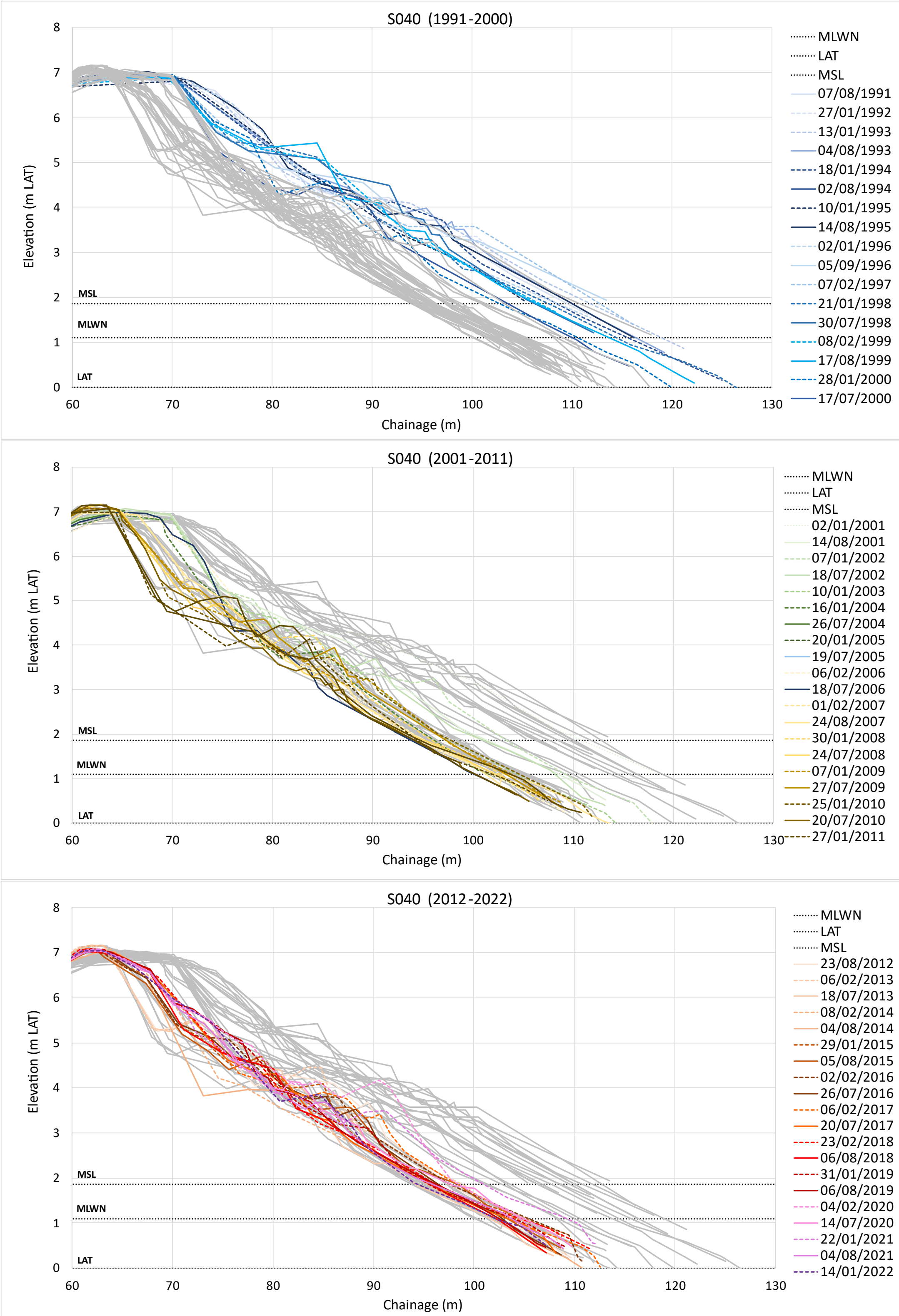


Figure 29. Profile S040: Top- changes 1991-2010; Middle- 2001-2011; Bottom- 2012-2022

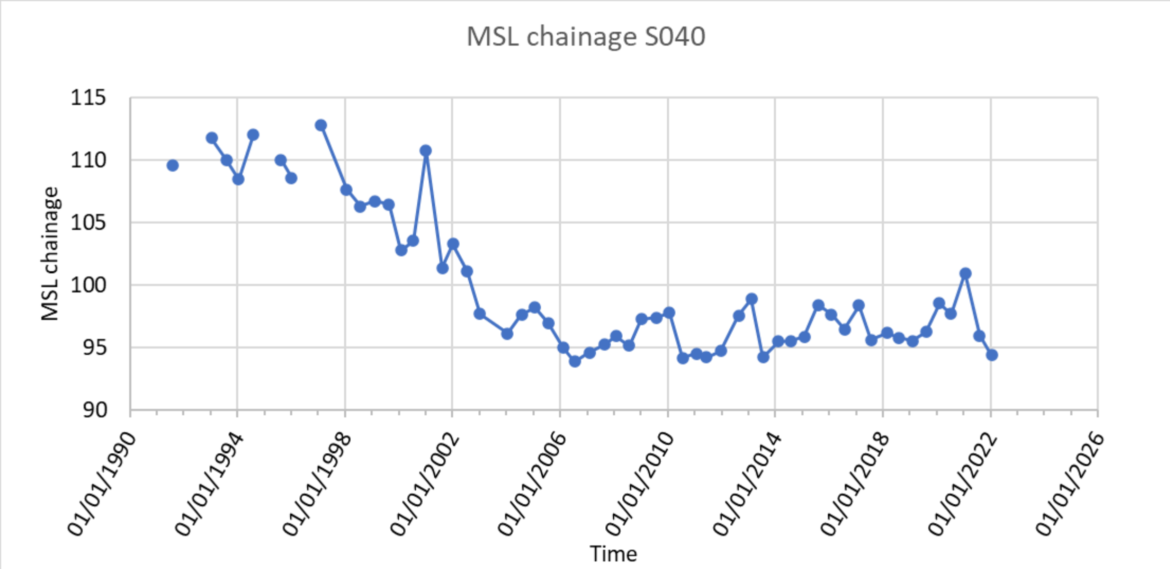


Figure 30. Timeseries of MSL chainage at Profile S040 over the past three decades

The bathymetric profiles of the area combined with transects along the bathymetry have been analysed in order to quantify changes along the whole beach profile (including the subtidal region) and derive a depth of closure for the area the landfall (see Appendix A for details of analysis). These changes have been shown in Profile S040 (Figure 23) in terms of the range of change across the profile, which was seen to be highest in the intertidal zone, the highest value being above 2m; this range then decreases up until the -5m LAT. From about -5m LAT, the range of movement is very low, around 0.5 to 0.75 m with some peaks that might be due to spurious data.

4.2.2 Response to storm events

The response to storm events was analysed with the available data and with a 1-D parametric model, as described in Section 3.6.5 and Appendix A. Although the data does not contain post-storm profiles taken right after an extreme event, the three decades of measurements present enough variability to believe that the changes due to storm events are within the variability seen in the measured data.

This dataset contains the storms of the winters of 2013 and 2014, which were devastating in many parts of the UK, due to both intensity and persistence; the wave height from the SEASTATES SW model has been plotted in Figure 32 from 2010 to 2018, where in the winter of 2014 more peaks can be observed and more higher ones also.

The effect of these storms on the beach is observed in the MSL chainage timeseries (Figure 30) where one of peaks is in the winter of 2014; the data shows how the beach recovered afterwards.

The storm events are likely to influence the beach mostly on the intertidal area and just below. The morphological changes of the beach sediment will be within the estimated depth of closure of -6m to -7m LAT.

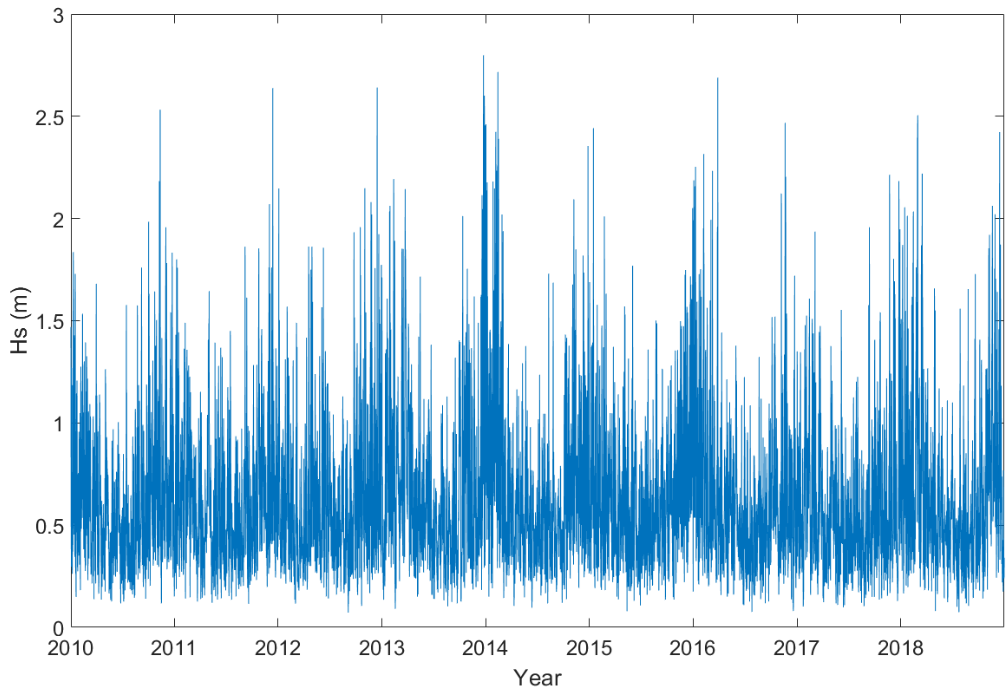


Figure 31. Timeseries of wave height at KP3 from 2010 to 2018

4.3 Morphological changes of the hinterland

Historical analysis of the available LIDAR data in the area has been undertaken using a number of datasets available:

- CCO Lidar data (2015 to 2023, yearly)
- NGET provided Lidar data (2023)

An envelope of the differences of these topographies between 2015 and 2023 at a resolution of a pixel has been presented in Figure 32, where the areas in yellow show no change, the changes shown in oranges, pinks, magentas and black (as they are greater). As with the bathymetric data, the greatest changes seen in this figure are near the coastline, in this case in the intertidal area, where changes of up to 2 m maximum are calculated for these seven years. This is consistent with the morphological changes observed within the beach data, which is a longer dataset.

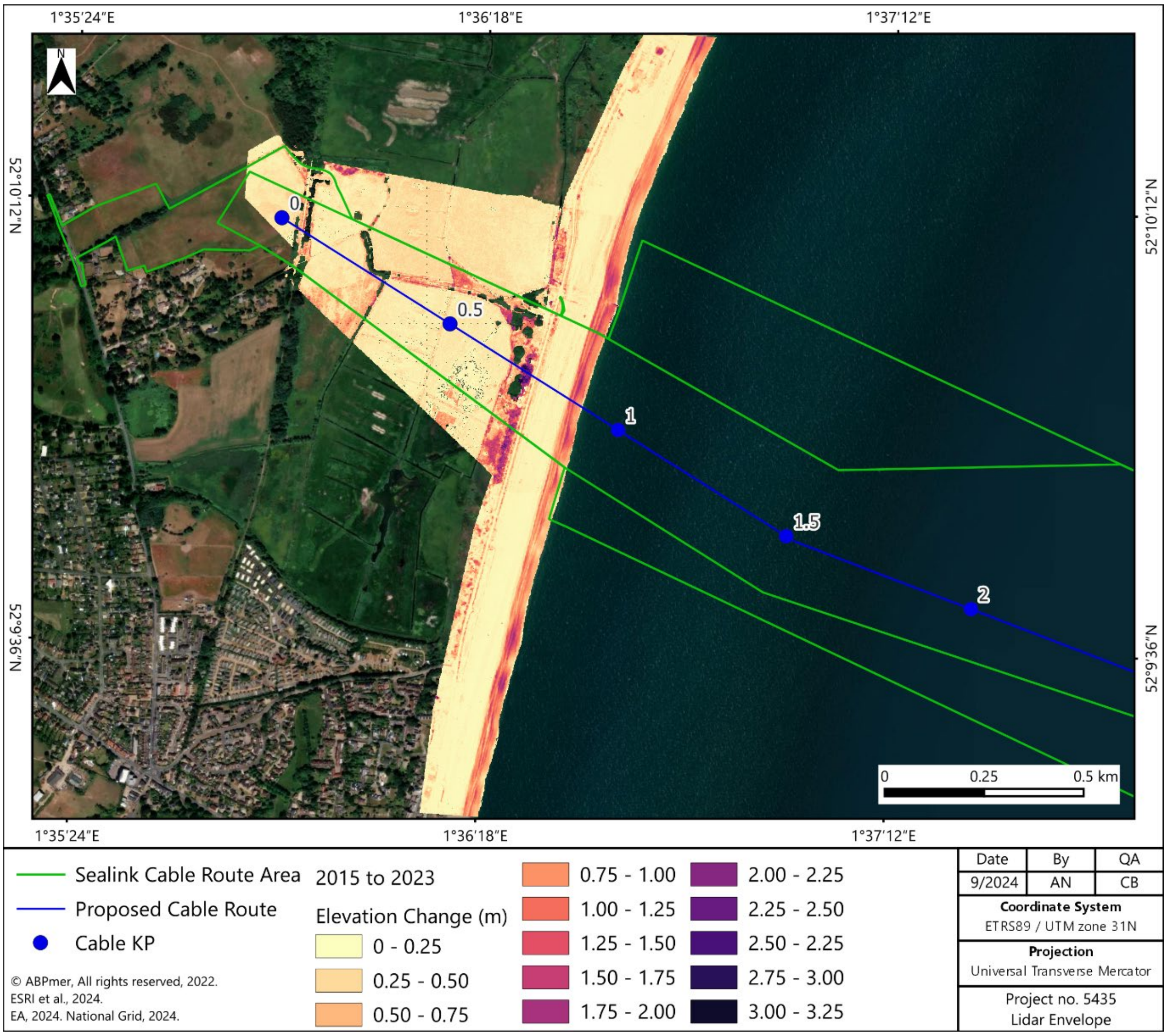


Figure 32. Envelope of the differences of available LIDAR data between 2015 and 2023.

4.3.1 Response to storm events

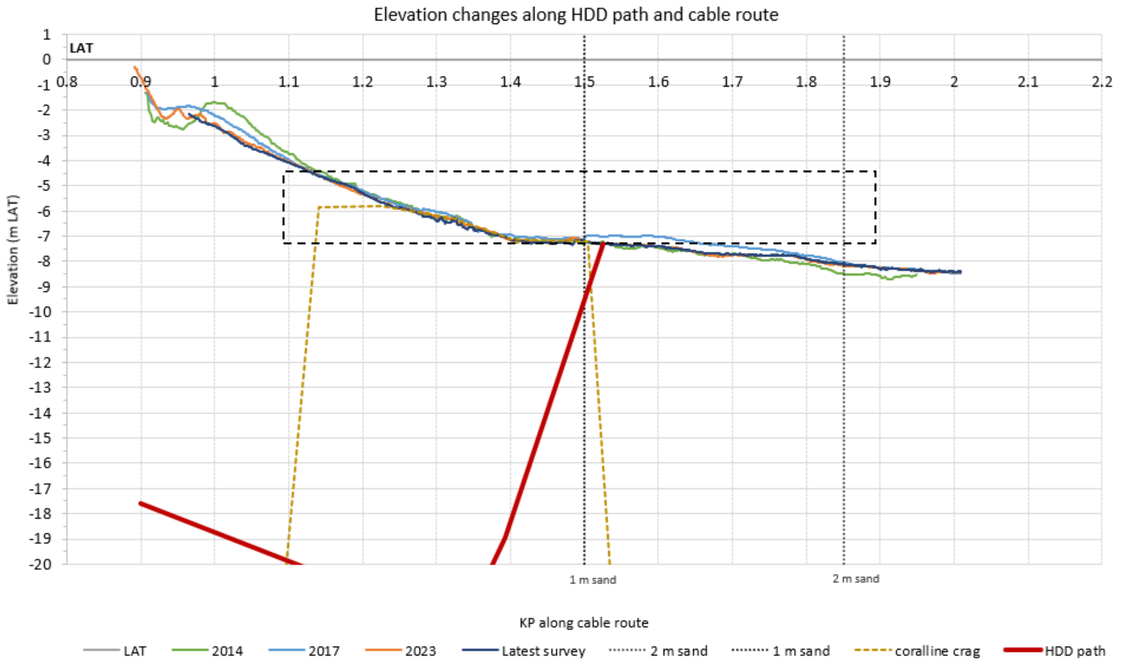
There is insufficient data available to quantify the response of the hinterland area to any individual storms.

4.4 Variability along the cable route

The variability of the morphology along the cable route has been analysed with the bathymetric data available:

- UKHO bathymetric data (2014, 2017, 2023)
- NGET provided bathymetric data (2021), named latest survey

These are shown in Figure 33, where the position of the isopaches of sand along the route, the approximate position of the coralline craig and the proposed HDD path has also been marked.



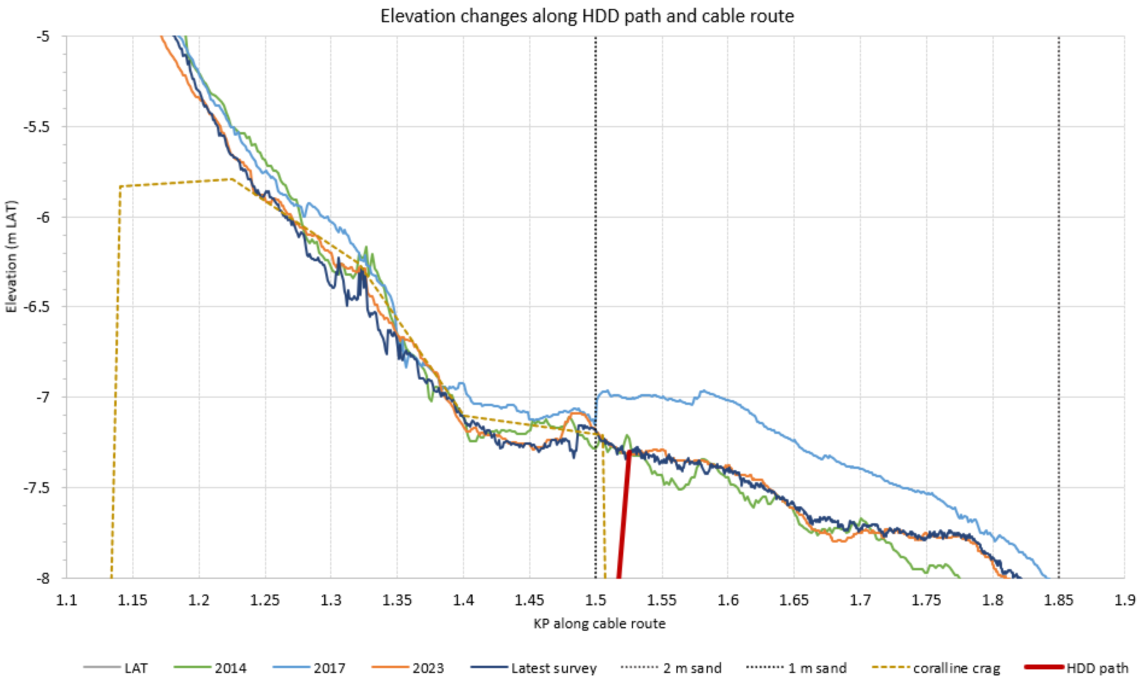


Figure 33. Elevation changes along the HDD path and cable route (top: whole profile from LAT up to -9 m LAT, bottom: zoomed from -5 to -8 m LAT)

From this it can be deduced that most of the morphological changes have occurred within the beach, so that the greatest changes are up to -4 m LAT. Changes up until -6 to -7 m, of smaller quantity, of the order of maximum 0.5 m have also occurred.

4.5 Prediction of future evolution

Future changes in the morphology up until the exit point are likely to be within the changes observed in the historical data:

- No changes in the future are expected in the hinterland. If the flooding management changes in the area, the risk of flooding should be re-assessed.
- Changes of the order of up to 1 to 2 m are realistically possible to be expected in the inter-tidal area, which is away from the landfall and therefore of no influence.
- Changes of the order of 0.5 m are to be expected in the subtidal area up to the depth of closure estimated at -6 m to -7 m LAT. This area between -6m to -7m LAT is where the outcrops of coralline crag are. This coralline crag is more resistant to erosion and is not expected to erode under normal circumstances. If the change was for deposition on top of the coralline crag instead of erosion, this will not pose any damage to the cable. It is not expected that this deposition will be larger than 0.5 m in any way and therefore not posing a risk to the thermal characteristics of the cable.
- If the beach rolls back, this will move the active beach (enclosed within the depth of closure) backwards and therefore will not pose a risk to the pipeline exit.

5 Discussion and Conclusions

The Sea Link Project is a network reinforcement link proposed by National Grid Electricity Transmission Plc (NGET) to reinforce the electrical transmission network in the South East of England and East Anglia. The network reinforcement link makes landfall at Aldeburgh in East Suffolk, and at Pegwell Bay, Kent.

This report deals with the landfall at Aldeburgh in East Suffolk and the accompanying report, R4575, with the landfall at Pegwell Bay, Kent.

This report provides an assessment of the potential morphological changes around the cable corridor at the landfall position of Aldeburgh. For this, an assessment of historical changes based on a number of datasets, together with a conceptual understanding of the coastal processes in the area have been used in order to estimate potential morphological changes in the future.

The study has used a combination of project specific and publicly available data, studies and reports to inform the investigation. The following data sources have been used in the analysis, Table 1. The data providers listed are:

- Channel coastal observatory (CCO): https://coastalmonitoring.org/
- UK Hydrographic Office (UKHO): https://seabed.admiralty.co.uk/
- Anglian Coastal Monitoring (ACM): https://environment.maps.arcgis.com/apps/webappviewer/index.html?id=d26827c087d54546925c37161e751dde
- SEASTATES North Atlantic wave hindcast (ABPmer 2013) and SEASTATES NorthWest European Shelf Tide and Surge hindcast (ABPmer, 2018)

Key findings from the assessments presented in this report are summarised below:

- **Risk of flooding**: The area of study is at risk of flooding as the area behind the shingle bank at the back of the foreshore is low-lying, remnants of the old Hundred River valley. However, the area is actively managed with a sluice that manages the flooding of the hinterland and therefore, at present, there are no concerns with the flooding of the area, although this will have to be reviewed in the future if the management strategy changes. Moreover, in the future, with sea level rise, the risk of flooding will increase. At present, the proposed Construction Compound / Transition Joint Bay is in an area of high elevation and at no risk of flooding. A major flooding event in the area is both possible and unpredictable.

- **Sediment transport:** The sediment transport in the area is a combination of several forcings, such as the longshore drift caused by waves breaking at an oblique angle and coming predominantly from the northeast and southwest. On top of this, the tidal currents that flow southwest or northeast also might enhance or diminish the longshore drift. The longshore drift in this area is very variable alongshore due to the shoals that influence the wave transformation processes, but there is also high variability over the years.

  The beach at Aldeburgh is a mixed beach, which is also influenced by shorter term changes (mostly in the cross-shore) due to severe storms. To the north and south of the Aldeburgh are two nesses, Thorpeness in the north and Orfordness, in the south, which have been changing over the years. The morphodynamics of the nesses are not well understood at the moment and is an area where research has been scarce over the last decades.

There are no existing numerical models that deal with the sediment transport of mixed beaches, as these are very complicated due to the temporal and 3D variation of their sediment. Standard practice is to model them either with a numerical model for sandy beaches or one for gravel beaches or even both and qualitatively extend the results to mixed beaches, supporting it with measurements and observations.

Moreover, the nearshore shoals and banks in the offshore region have been migrating and this in turn influences the forcings onto the beach.

All of these make this area very difficult to be modelled successfully in a sediment transport numerical model and therefore the morphological changes in the future will be better implied by the assessment of the historical data of morphological changes instead. This is what has been carried out in this study.

- **Morphological changes in the sub-tidal region**: an envelope of the differences in high resolution bathymetric data between 2014 and 2023 at pixel resolution has been presented, showing that the greatest changes are very close to the coastline, on the beach. Moving offshore, the change becomes very small, possibly enhance by the fact that his is the area where the coralline crag is. Towards the end of the bathymetric extents the changes are slightly greater, of the order of 0.5 m. The differences in the bedforms from survey to survey are appreciated close to the shore. There is insufficient data available to quantify the response of the sub-tidal area to any individual storms.

- **Morphological changes on the beach**: the profile changes in an area near the landfall represented by Profile S040 are analysed from 1991 to 2022. The evolution of the beach over the last three decades is emphasized in these graphs: the healthiest beach is the oldest measured and the beach retreated slowly up until about 2006. Since then, the beach has more or less stabilised and even advance slightly, but not to the levels of three decades ago. From the whole profile data record (1991-2022), the intersection of the MSL level and the profile along the years can be calculated for each of the years in order to produce a time series of MSL chainages. These figures show long term variations on the beach, giving two different rates of erosion: up until about 2006, the erosion was about -1.2 m/yr. However, since then, the beach has stabilised and is even showing some very small accretion.

  The high variability of this profile (and others close to it) and their erosional and accretional trends over the years emphasize the highly dynamic area of the study and the value of long-term measurements to produce historical ranges of change that might be used to infer potential future changes.

  The bathymetric profiles of the area combined with transects along the bathymetry have been analysed in order to quantify changes along the whole beach profile (including the subtidal region) and derive a depth of closure for the area the landfall. The range of change across the profile, which was seen to be highest in the intertidal zone, the highest value being above 2m; this range then decreases up until the -5m LAT.

  From about -5m LAT, the range of movement is very low, around 0.5 to 0.75 m with some peaks that might be due to spurious data. From this analysis, the depth of closure would be around -6 to -7m LAT. This estimated depth of closure is for the most mobile sediment. The coralline crag, which exists in the area, has a greater resistance to erosion and this depth of closure would not apply to it.

Historical data and a parametric model (Shingle-B) has been used to investigate the response to the storm events: the storm events are likely to influence the beach mostly on the intertidal area and just below. The morphological changes of the beach sediment will be within the estimated depth of closure of -6m to -7m LAT.

- **Morphological changes of the hinterland**: historical analysis of the available LIDAR data in the area has been undertaken using a number of datasets available. An envelope of the differences of the topographies between 2015 and 2023 at a pixel-resolution has been presented. As with the bathymetric data, the greatest changes seen in this figure are near the coastline, in this case in the intertidal area, where changes of up to 2 m maximum are calculated for these seven years. This is consistent with the morphological changes observed within the beach data, which is a longer dataset. There is insufficient data available to quantify the response of the hinterland area to any individual storms.

- **Variability along the cable route**: the variability of the morphology along the cable route has been analysed with the bathymetric data available, showing that most of the morphological changes have occurred within the beach, so that the greatest changes are up to -4m LAT. Changes up until -6 to -7 m, of smaller quantity, of the order of maximum 0.5m have also occurred.

- **Future morphological evolution**: Future changes in the morphology up until the exit point are likely to be within the changes observed in the historical data:

    - No changes in the future are expected in the hinterland. If the flooding management changes in the area, the risk of flooding should be re-assessed.
    - Changes of the order of up to 1 to 2 m are realistically possible to be expected in the inter-tidal area, which is away from the landfall and therefore of no influence.
    - Changes of the order of 0.5 m are to be expected in the subtidal area up to the depth of closure estimated at -6 m to -7m LAT. This area between -6m to -7m LAT is where the outcrops of coralline crag are. This coralline crag is more resistant to erosion and is not expected to erode under normal circumstances. If the change was for deposition on top of the coralline crag instead of erosion, this will not pose any damage to the cable. It is not expected that this deposition will be larger than 0.5 m in any way and therefore not posing a risk to the thermal characteristics of the cable.
    - If the beach rolls back, this will move the active beach (enclosed within the depth of closure) backwards and therefore will not pose a risk to the HDD exit.

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7 Abbreviations/Acronyms

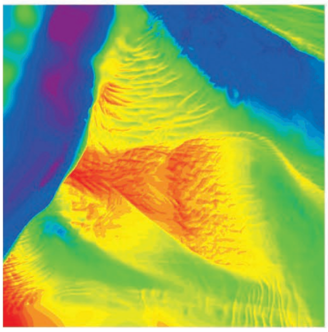
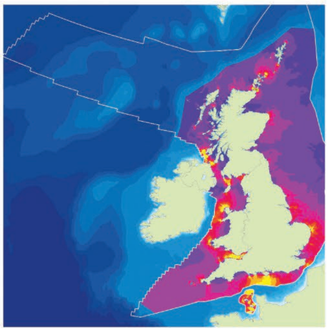
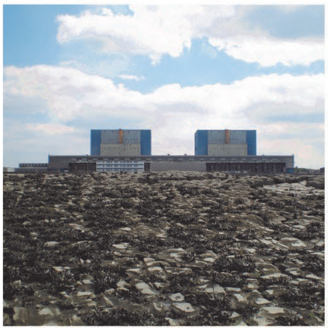
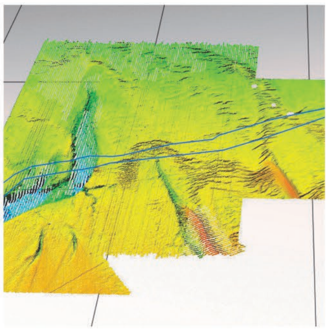
ABP	Associated British Ports
ACM	Anglian Coastal Monitoring
ALB	Aldeburgh
AnnMax	mean annual maximum
AONB	Area of Natural Beauty
AWAC	Acoustic Wave and Current Profiler
BEEMS	British Energy Estuarine & Marine Studies
BGS	British Geological Service
CCO	Channel coastal observatory
CD	Chart Datum
CEFAS	Centre For Environment Fisheries & Aquaculture Science
CFBD	Coastal Flood Boundary Dataset
D50	Median particle size
DTM	Digital Terrain Model
EA	Environment Agency
EDF	Electricité de France
EMODnet	European Marine Observation and Data Network
G	Gravel
GS	Gravelly Sand
HAT	Highest Astronomical Tide
HD	Hydrodynamic
HDD	Horizontal Directional Drilling
HVDC	High-voltage direct current
HW	High Water
KP	Kilometric Point
LAT	Lowest Astronomical Tide
LIDAR	Light Detection and Ranging
LW	Low Water
MBES	Multibeam Echo Sounding
ME	Mid Ebb
MF	Mid Flood
MHW	Mean High Water
MHWL	Mean High Water Level
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLW	Mean Low Water
MLWL	Mean Low Water Level
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Springs
MR	Managed realignment
MSL	Mean Sea Level
NAI	No active intervention
NAO	North Atlantic Oscillation
NCERM	National Coastal Erosion Risk Mapping
NGET	National Grid Electricity Transmission Plc
ODN	Ordinance Datum Newlyn
RCP	Representative Concentration Pathway
RNLI	Royal National Lifeboat Institution

RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SMP2	Shoreline Management Plan second generation
SPA	Special Protection Area
SSSI	Sites of Special Scientific Interest
SW	Spectral Wave
SWH	Significant Wave Height
SWL	Still Water Level
UKCP18	UK Climate Projections 2018
UKHO	UK Hydrographic Office
UTM	Universal Transverse Mercator
VORF	Vertical Offshore Reference Frames

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices

Innovative Thinking - Sustainable Solutions

ABP mer

A Shoreline Stability

Historical morphological analysis of Aldeburgh beach has been undertaken using:

- Google Earth historical satellite and aerial imagery,
- Environment Agency LiDAR topographic surveys; and
- Coastal Channel Observatory topographic surveys.

The following review aims to characterise the level, extent and character of the intertidal and nearshore areas within and nearby the export cable corridor.

A.1 Morphological changes in the area of study

A number of historical satellite and aerial images covering the period 1945 to 2022 are available from Google Earth (shown in Figure A1). For each of the images, a line following the beach berm has been digitised and is presented here as a proxy to the shoreline. These lines might have been affected by the tide and the storms leading to the date of the image, but in general terms they are useful to draw conclusions on the orientation of the shorelines over those years. The images show that:

- To the North of the cable corridor, not much change has occurred throughout this period;
- In the area of the cable corridor, the main change over the years is due to the wooden casing of the sluice of the Hundred river on the beach, which acts as a groyne and sediment accretes either side of it depending on the direction of the longshore transport;
- In the area south of the cable corridor up to the village of Aldeburgh, the orientation if the shoreline has been changing so that the shoreline has been moving anti-clockwise

Figure A1. Satellite and aerial images of the shoreline covering the period 1945 to 2022

A.2 Topographic surveys

The EA and CCO have been surveying beach profiles in this area since 1991 bi-annually, in the summer and winter, in low tide up to approximately the LAT mark. Five profiles have been analysed for this study: S038 to S042, see location in Figure A2.

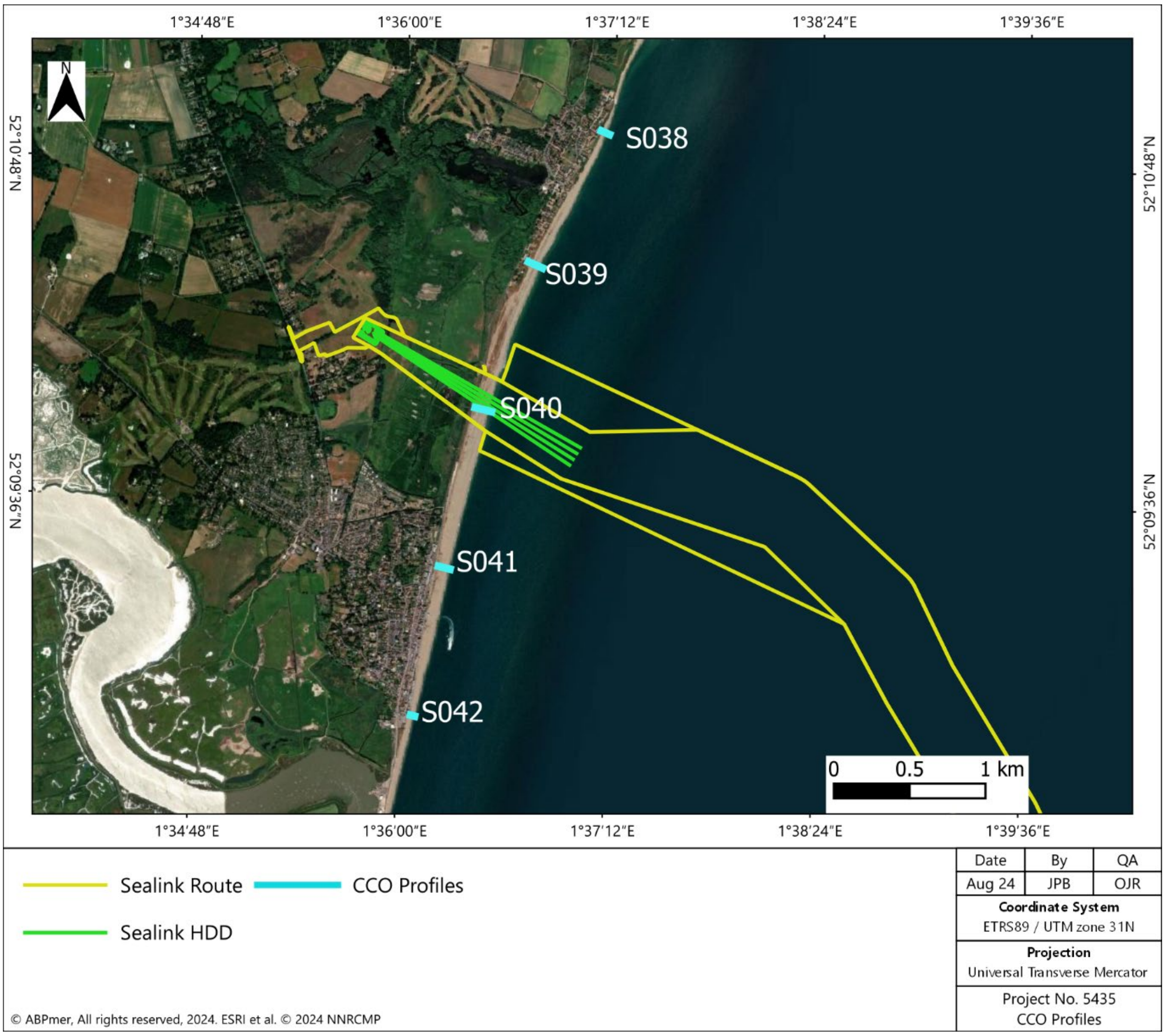


Figure A2. Position of the topographic profiles along Aldeburgh beach

The EA (2011) published the mean trends of these profiles, see Table A1. Similar rates were used in the SMP2 (Royal Haskoning, 2010). The profile in the area of interest, S040, was described with a mean trend of -1.0 m/yr. The profiles to the South of it both have an accretionary trend, as it was observed in the aerial images. However, the behaviour of these profiles changed from about 2006, as explained below.

Table A1. Changes in beach morphology 2001 to 2011 (EA, 2011)

Profile Old Reference	Profile New Reference	Behaviour from 2001 to 2011 (EA, 2011)	Mean Trend 2001 to 2011 (EA, 2011)
S1A1	SO38	Very dynamic beach showing overall accretion to 2001 followed by a period of relative erosion to 2010 with beach levels returning to landwards of their 1991 position	0.1 m/yr
S1A2	SO39	Moderate rates of erosion at all levels with no beach rotation	-0.8 m/yr
S1A3	SO40	Moderate erosional trend with no foreshore steepening	-1.0 m/yr
S1A4	SO41	Slight accretion at all levels, greater at MHWS to give a slightly steepened profile.	0.2 m/yr
S1A5	SO42	High accretion trend to 1997 at all levels. The beach is very dynamic with subsequent years showing periods of erosion and accretion	0.4 m/yr

The whole dataset for each of the profiles is shown in Figure A3 to Figure A7.

From this data, the intersection of the MSL level and the profile along the years can be calculated for each of the years in order to produce a time series of MSL chainages; the same can be done for MLWS, MHWL and HAT. This is shown in Figure A8 to Figure A12 for Profiles S038 to S042. These figures show long term variations on the beach:

- Profile S038 shows very high variability over the years, with the lowest, narrowest beach in winter 2013, where recovery time to pre-storm positions took 2 years. The erosion rate in recent years is from -0.6m/yr to -2.0m/yr.
- Profile S039 shows the lowest, narrowest beach was measured in summer 2011, but recovered to its former width by the following winter. Here, during the recent years the mean rate of shoreline retreat has recently doubled.
- Profile S040 shows two different rates of erosion: up until about 2006, the erosion was about -1.2 m/yr, similar to that stated in EA (2011). However, since then, the beach has stabilised and is even showing some very small accretion.
- Profile S041 shows a high variability: accretional until about 2001, a low and narrow beach in the Winter of 2013 and then slowly accreting till about 2013, from when it stabilises.
- Profile S042 shows slightly simpler trends: accretional till 2002 and then it stabilises.

The high variability of these profiles and their erosional and accretional trends over the years emphasize the highly dynamic area of the study and the value of long-term measurements to produce historical ranges of change that might be used to infer potential future changes.

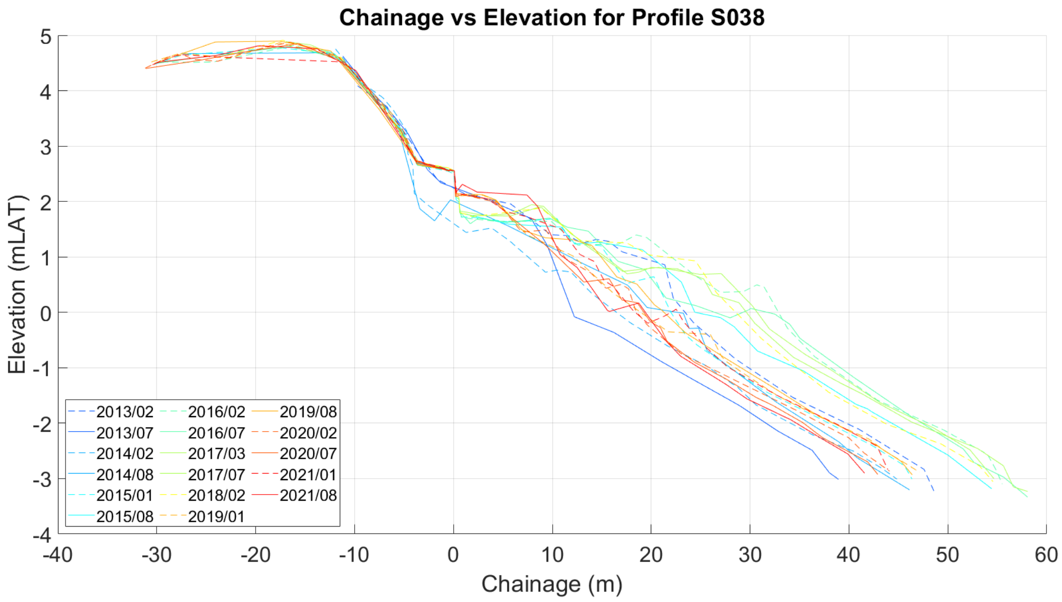


Figure A3. **Profile changes 2013-2021 – Profile S038**

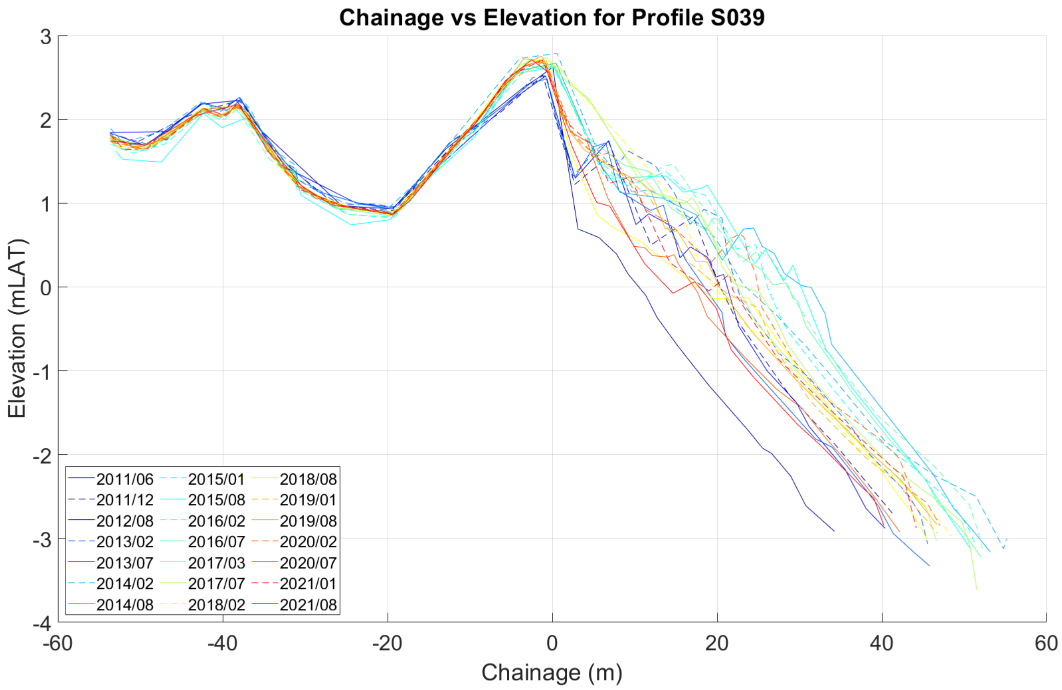


Figure A4. **Profile changes 2011-2021 – Profile S039**

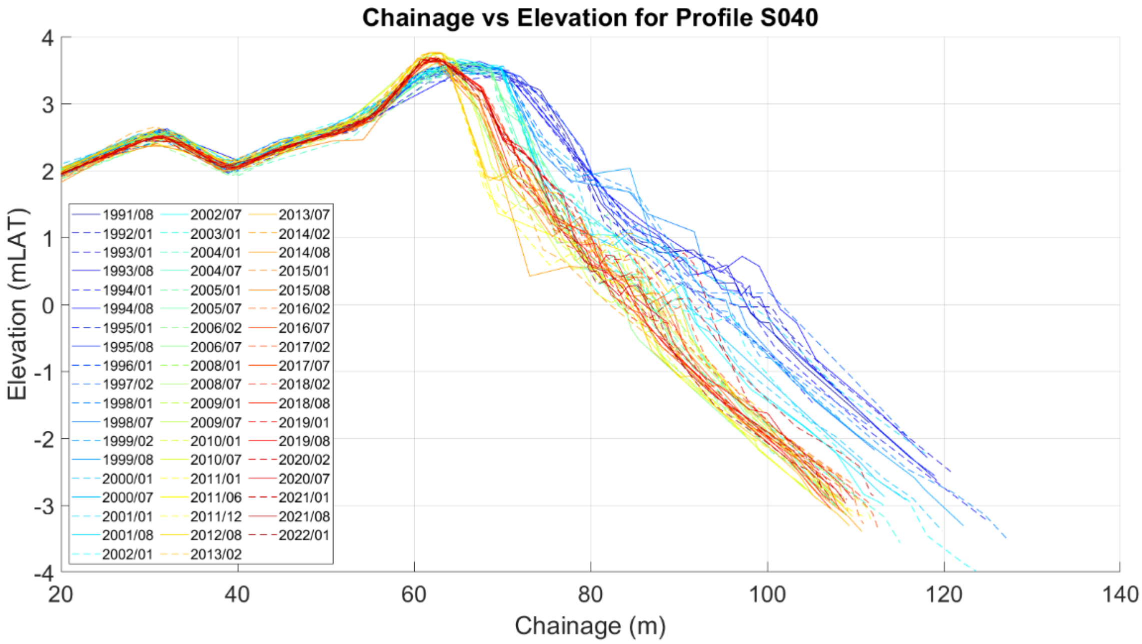


Figure A5. **Profile changes 2013-2021 – Profile S040**

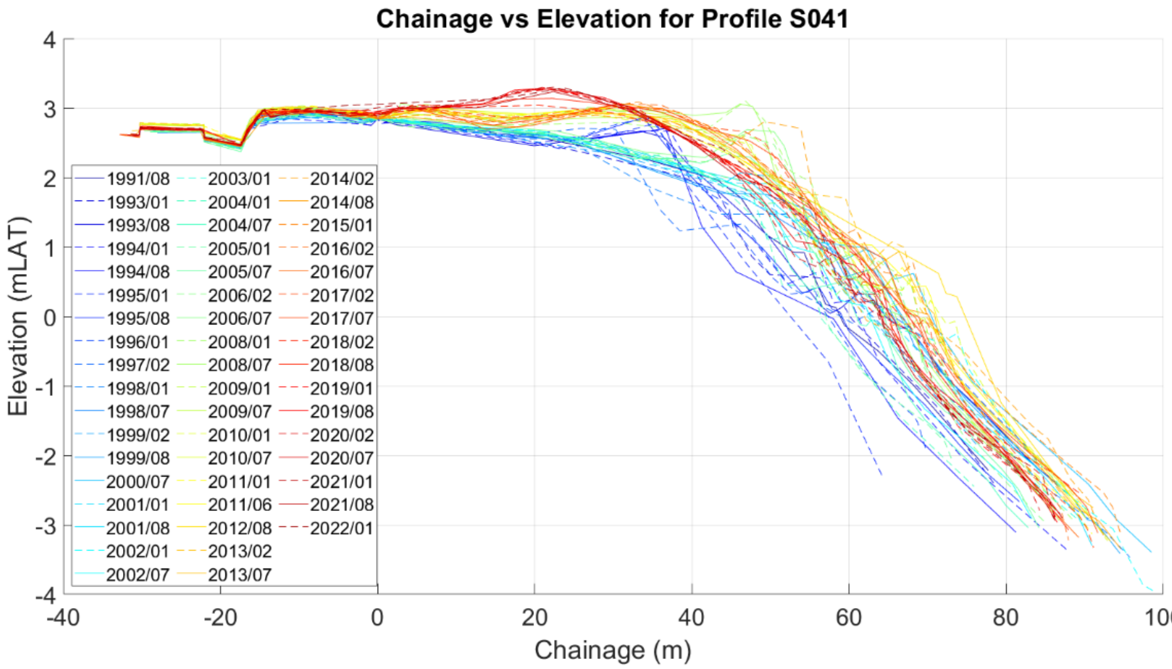


Figure A6. **Profile changes 2013-2021 – Profile S041**

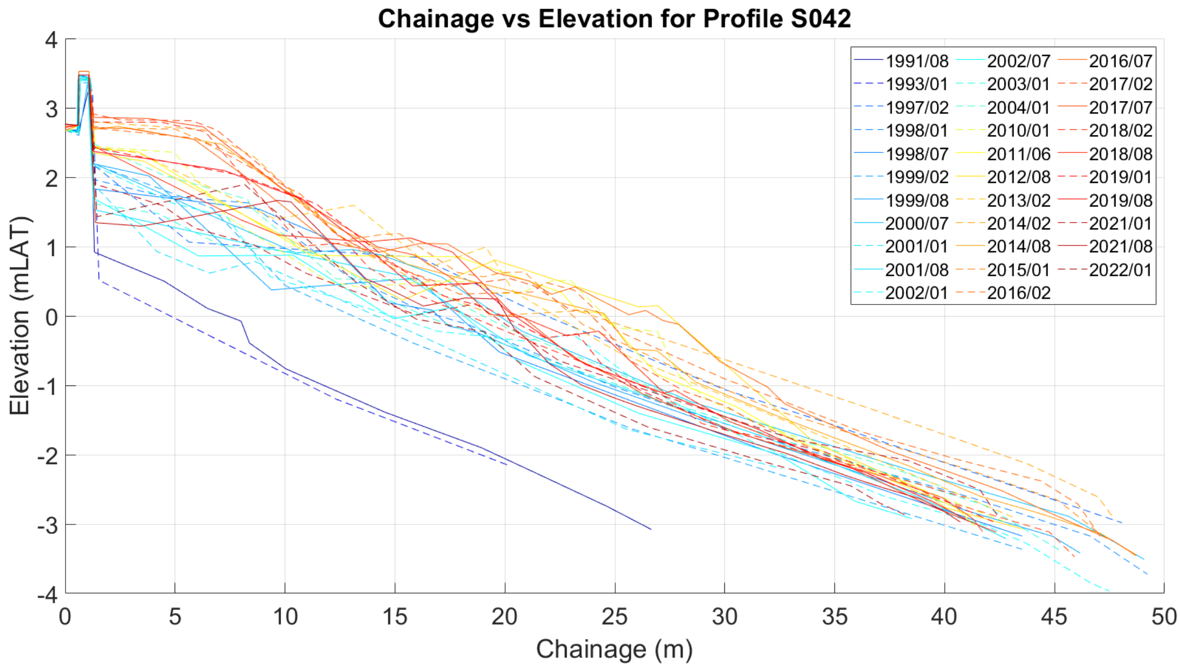
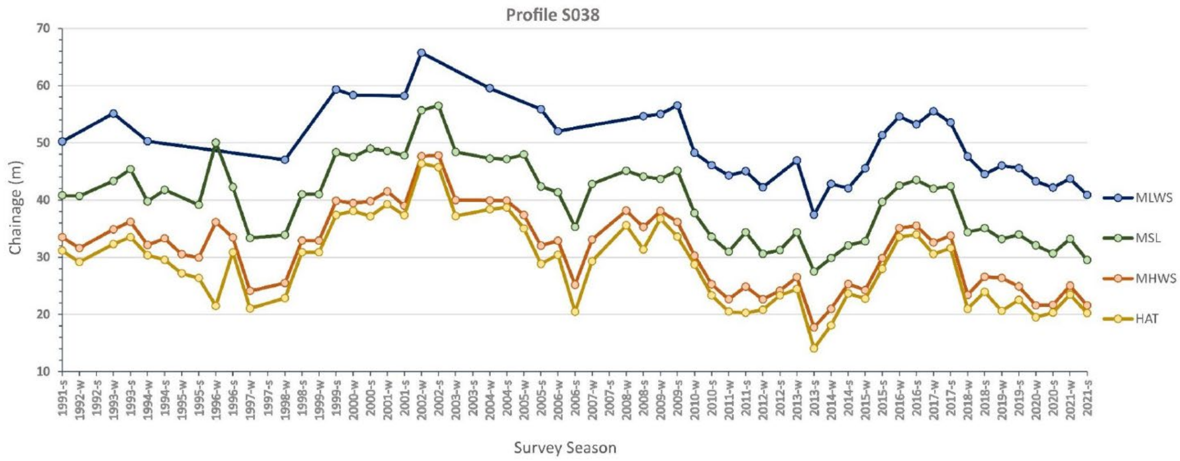
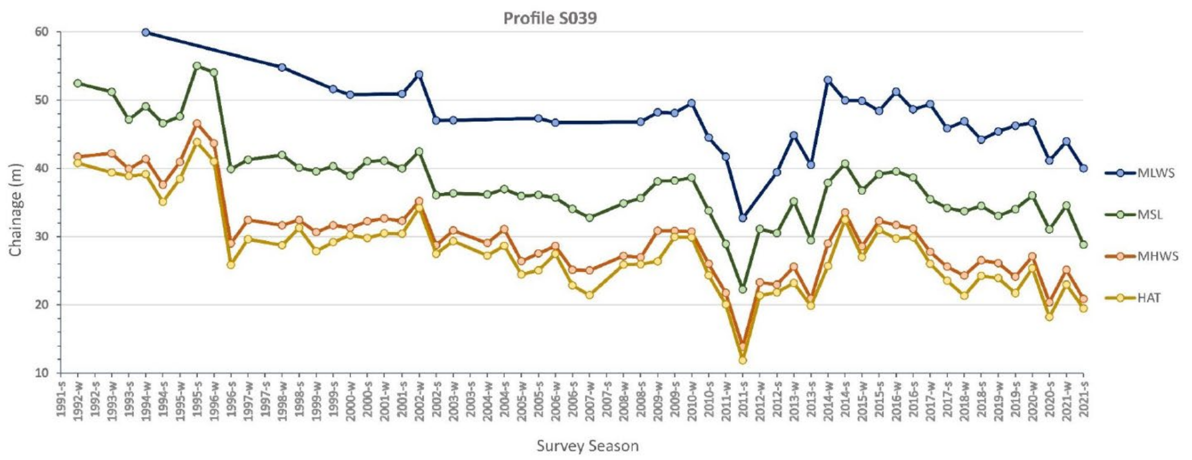


Figure A7. Profile changes 2013-2021 – Profile S042



Source: EA (2021)

Figure A8. Timeseries of MSL, MHWL, LAT and MLWL chainages– Profile S38

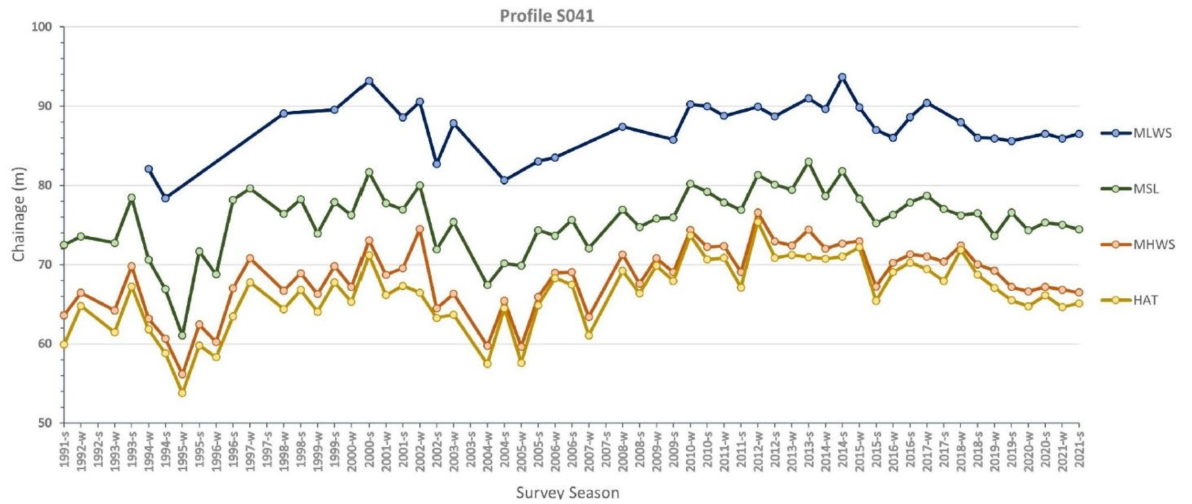


Source: EA (2021)

Figure A9. Timeseries of MSL, MHWL, LAT and MLWL chainages– Profile S39

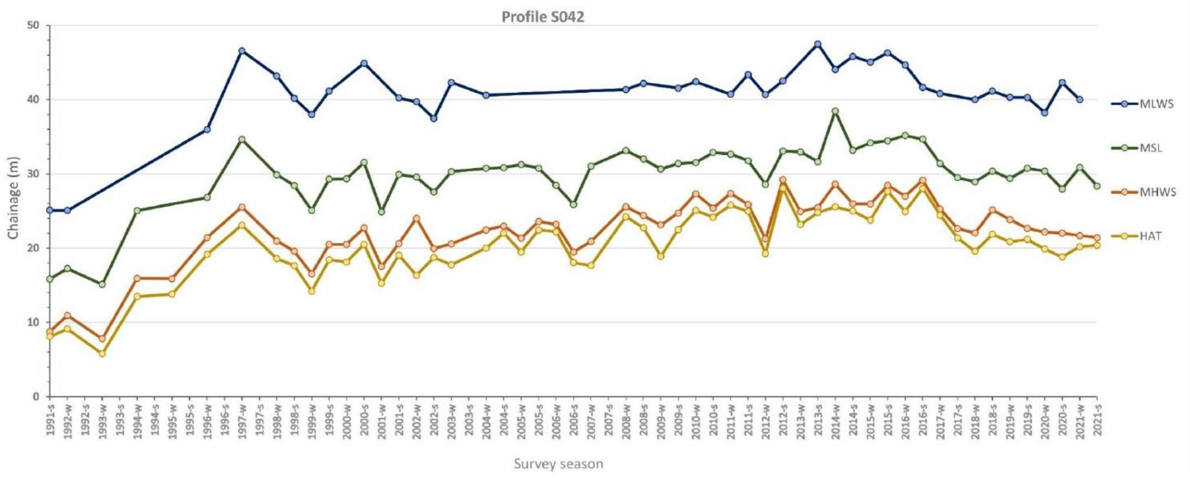
Source: EA (2021)

Figure A10. Timeseries of MSL, MHWL, LAT and MLWL chainages– Profile S40



Source: EA (2021)

Figure A11. Timeseries of MSL, MHWL, LAT and MLWL chainages– Profile S41



Source: EA (2021)

Figure A12. Timeseries of MSL, MHWL, LAT and MLWL chainages– Profile S42

A.2.1 Profile S040

The data for the profile closest to the landfall, S040, has been analysed in more detail. Figure A13 shows the profile changes for three different time periods: in each of these graphs the data for that period is in colours, whereas the data for the other 2 periods is greyed out. The three periods considered are: 1991 to 2000, 2001 to 2011 and 2012-2022. The evolution of the beach over the last three decades is emphasized in these graphs: the healthiest beach is the oldest measured and the beach retreated slowly up until about 2006. Since, the beach has more or less stabilised and even advance slightly, but not to the levels of three decades ago.

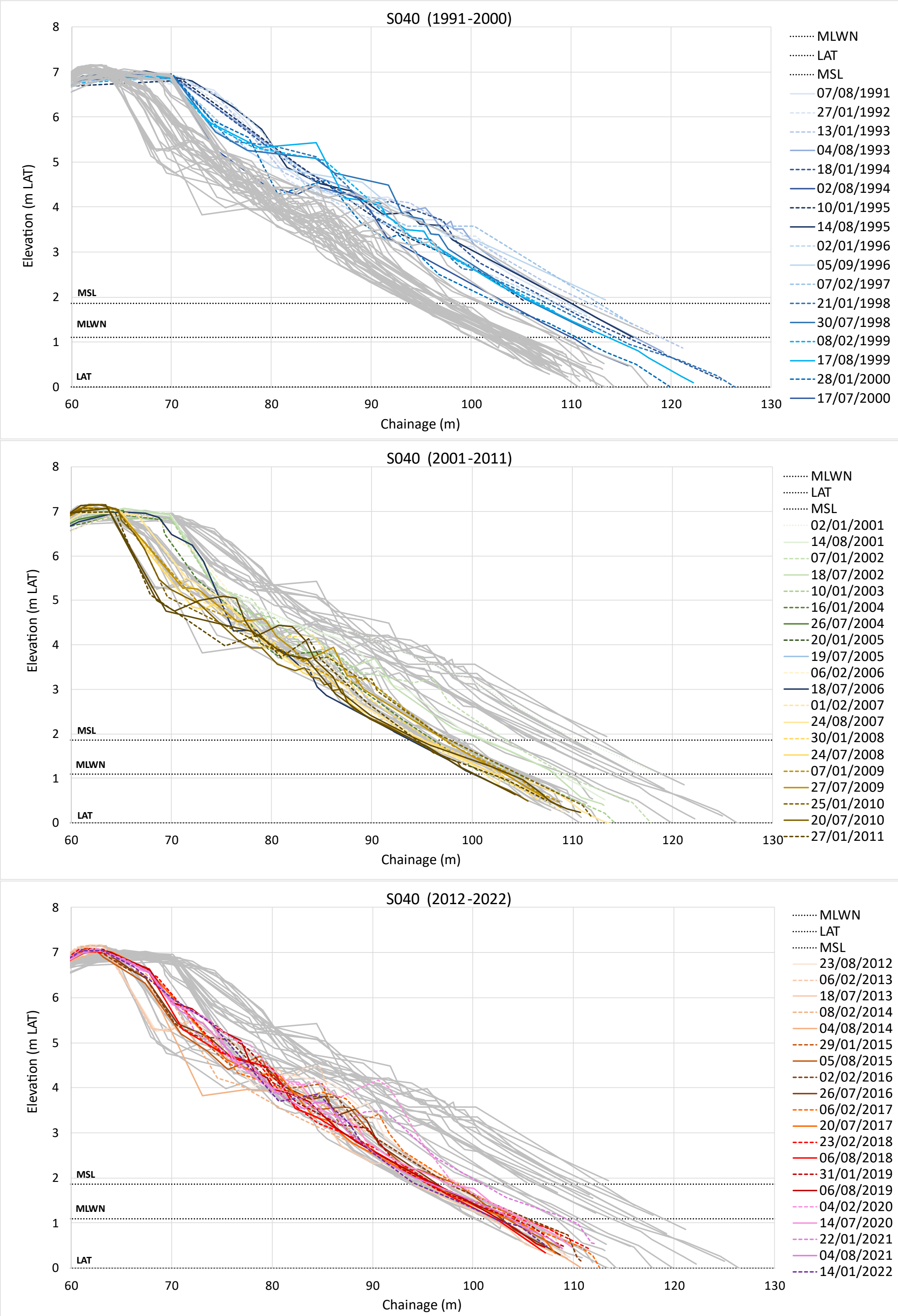


Figure A13. Profile S040: Top- changes 1991-2010; Middle- 2001-2011; Bottom- 2012-2022

A.3 Bathymetric profiles

In three occasions the five profiles shown previously, S038 to S042 were extended to the -10mLAT with a small boat. This data has been acquired from the Anglian Coastal Monitoring and the positions of these profiles shown in Figure A14. The data is plotted in Figure A15 to Figure A19. These figures show the presence of a nearshore bar in most profiles at about -4m to -7m LAT. This bar gets deeper as you move south, so that it is around -4m LAT in Profiles S038 and S039, -6m in Profile S040 and -7m in Profile S041 and S042. As expected, the variability of the beach is largest in the upper beach and it gets smaller as it gets deeper. However, there are likely inaccuracies involved in bathymetric surveying using small boasts in often choppy water close to the coast and therefore these bathymetric surveys have higher uncertainty than the topographic surveys.

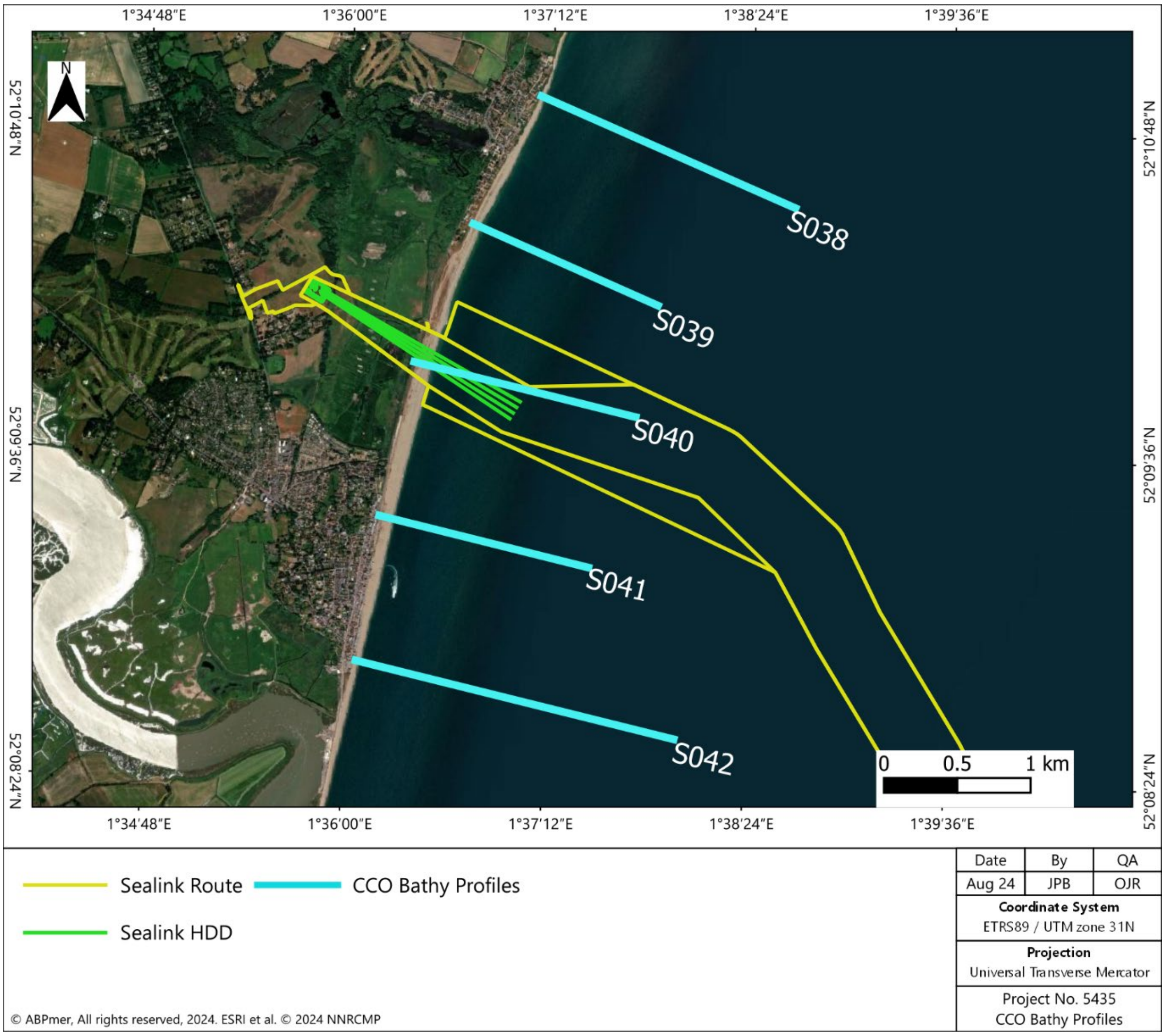
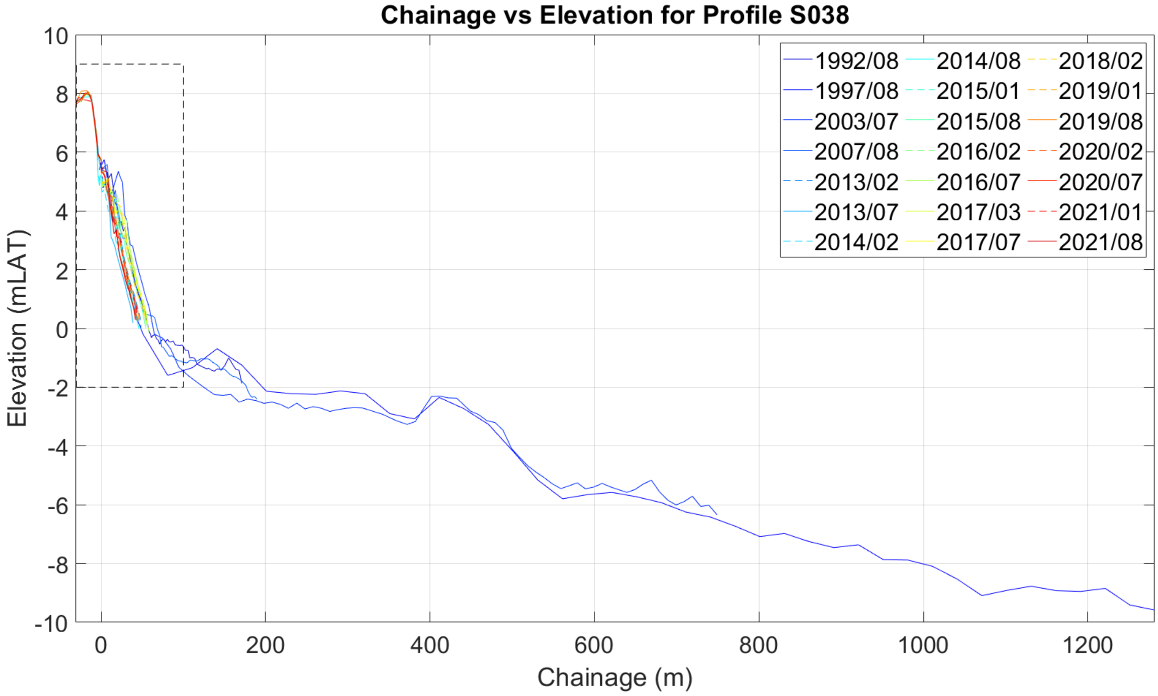


Figure A14. Position of the topographic and bathymetric profiles



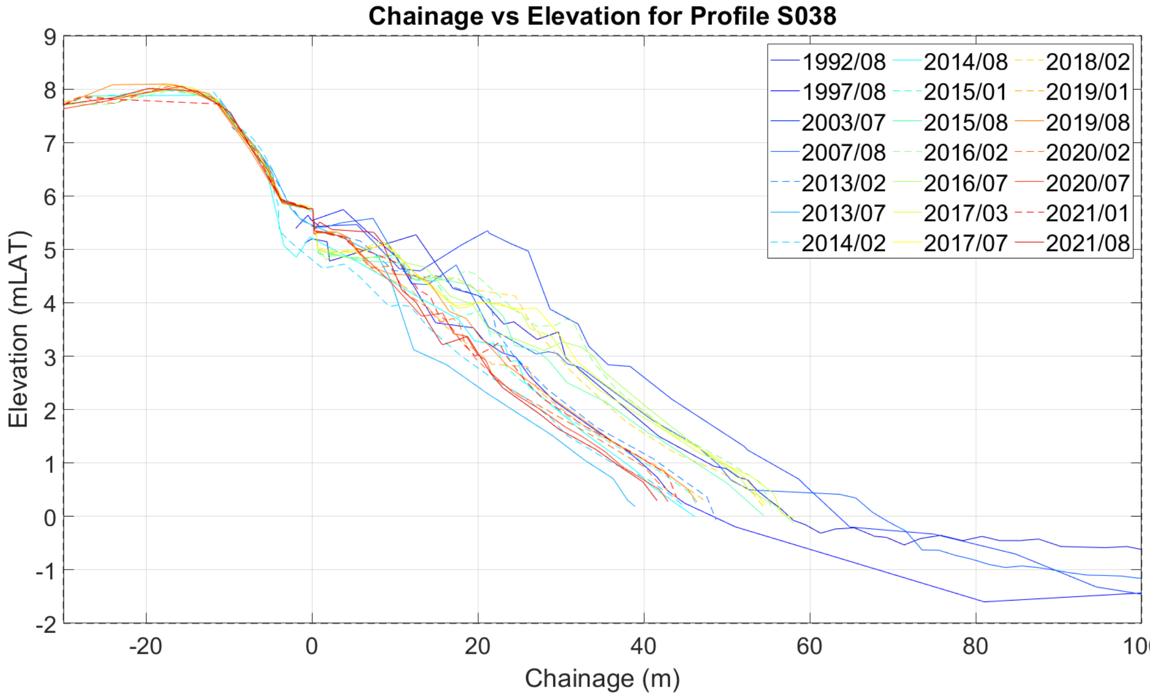


Figure A15. **Profile S038 elevation change including bathymetric profiles to -10m LAT (Top) and zoomed to -2m LAT (Bottom).**

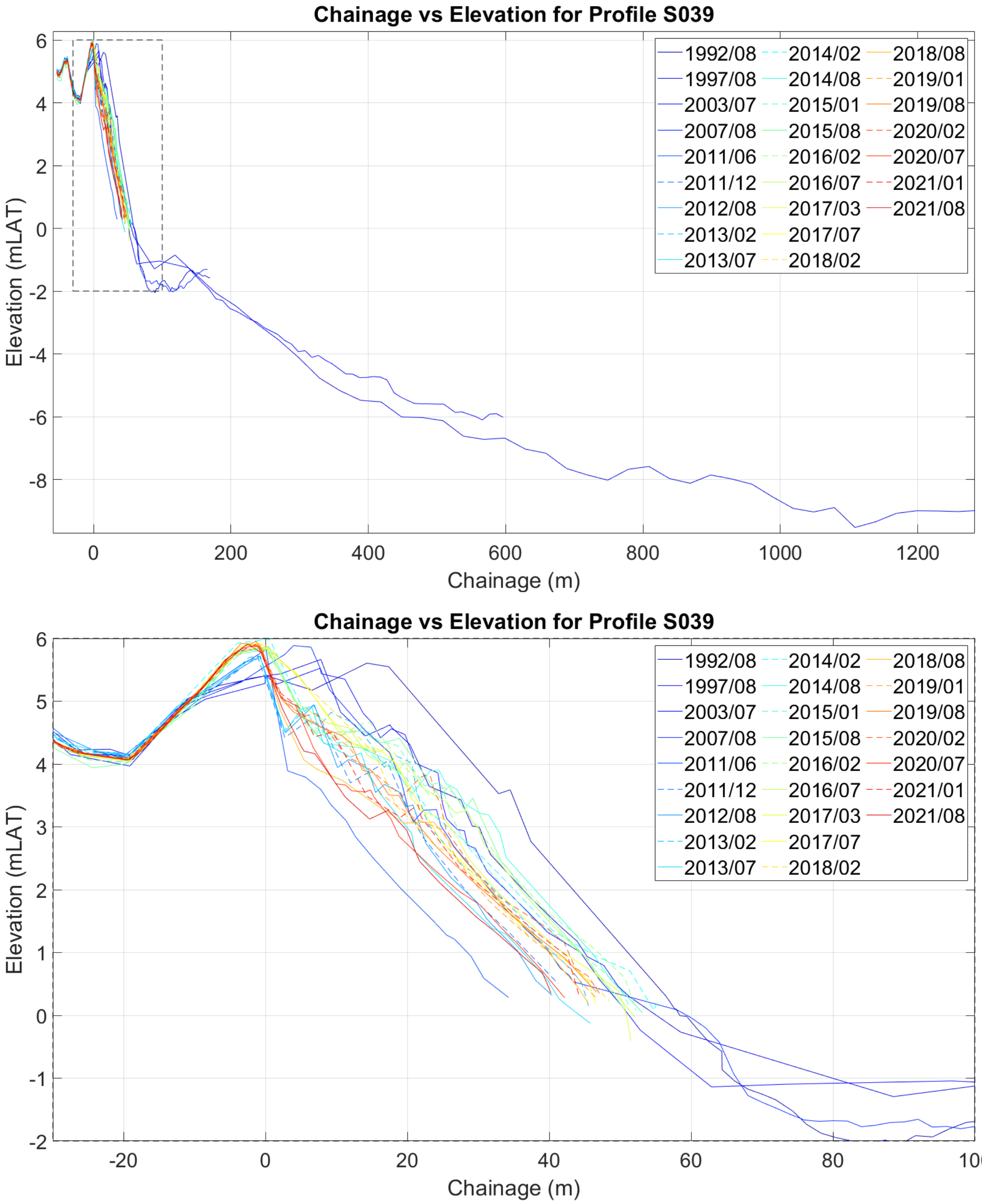


Figure A16. Profile S039 elevation change including bathymetric profiles to -10m LAT (Top) and zoomed to -2m LAT (Bottom).

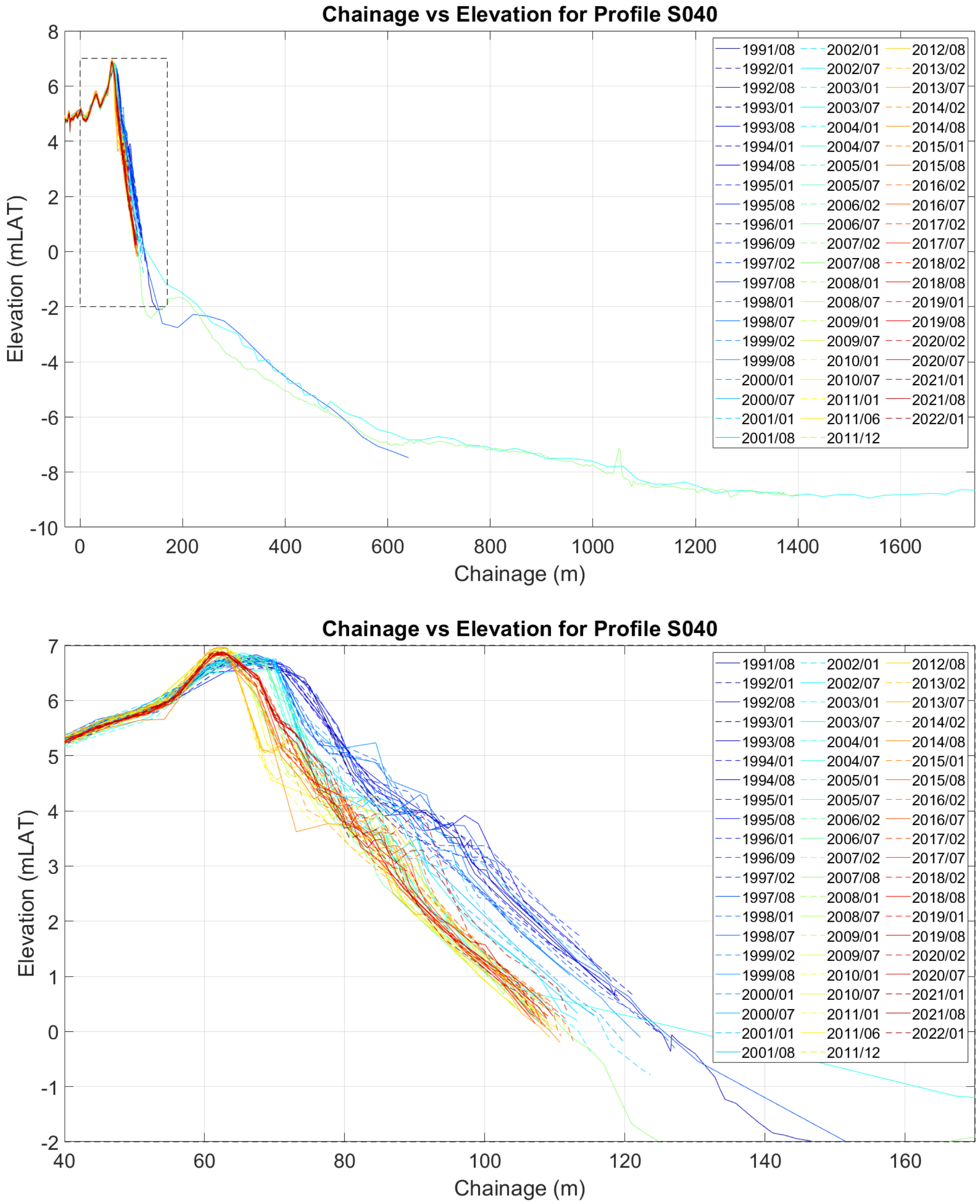
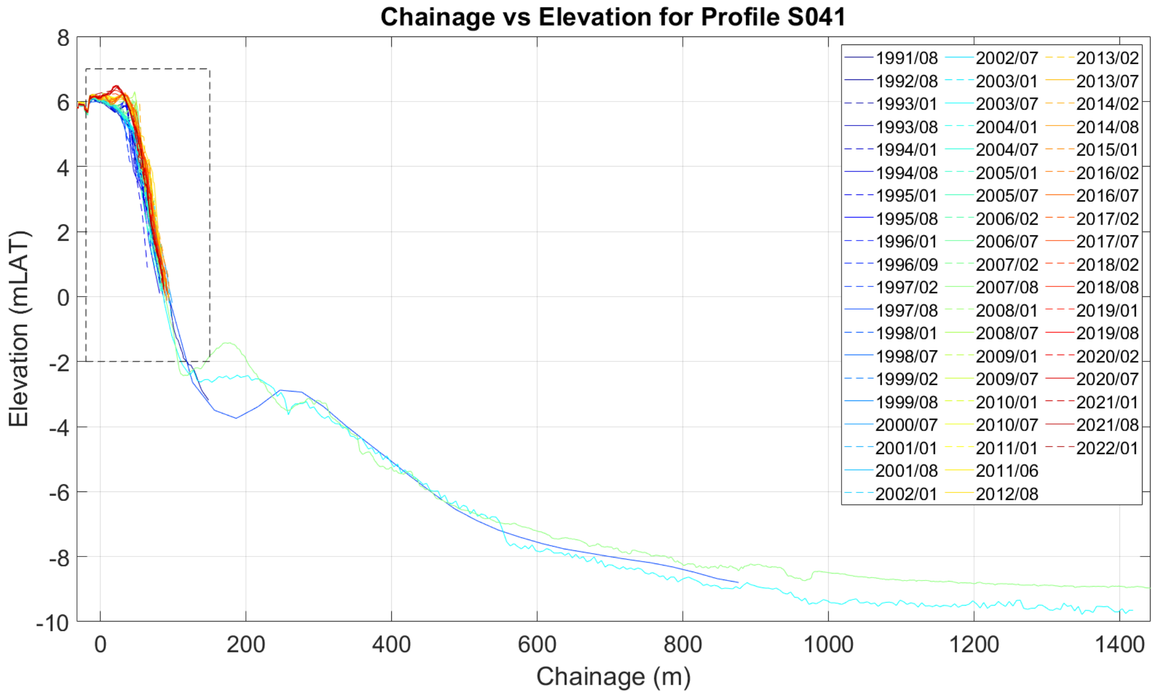


Figure A17. **Profile S040 elevation change including bathymetric profiles to -10m LAT (Top) and zoomed to -2m LAT (Bottom).**



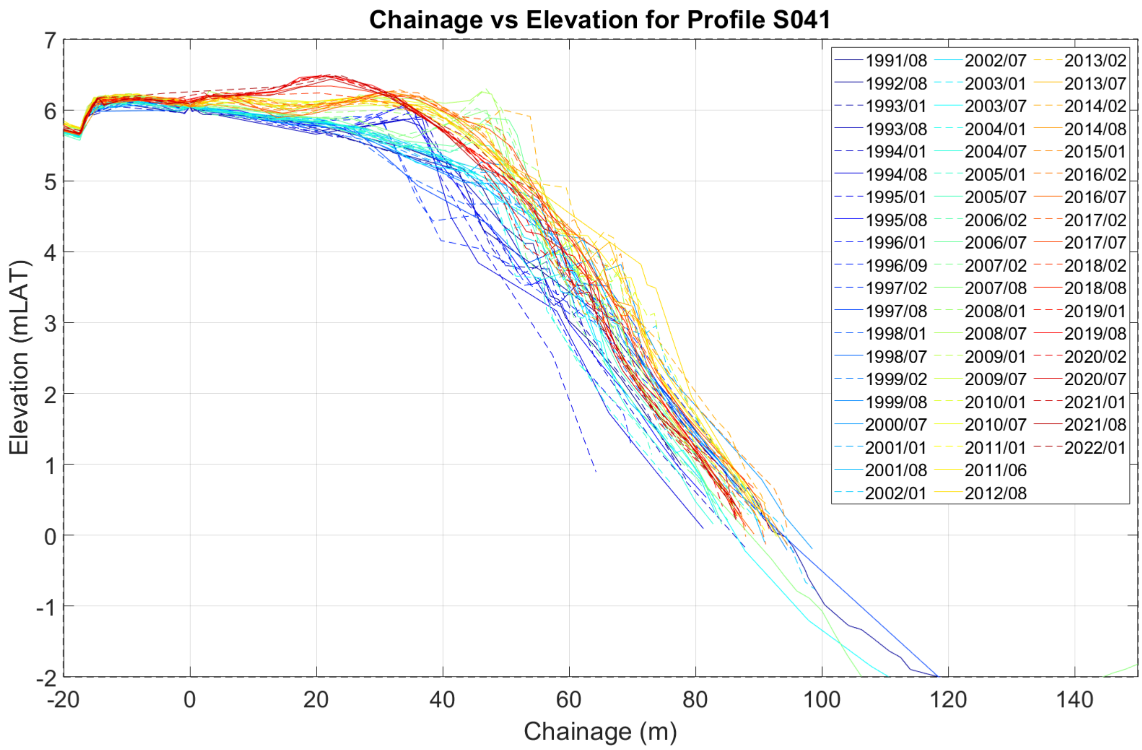


Figure A18. Profile S041 elevation change including bathymetric profiles to -10m LAT (Top) and zoomed to -2m LAT (Bottom).

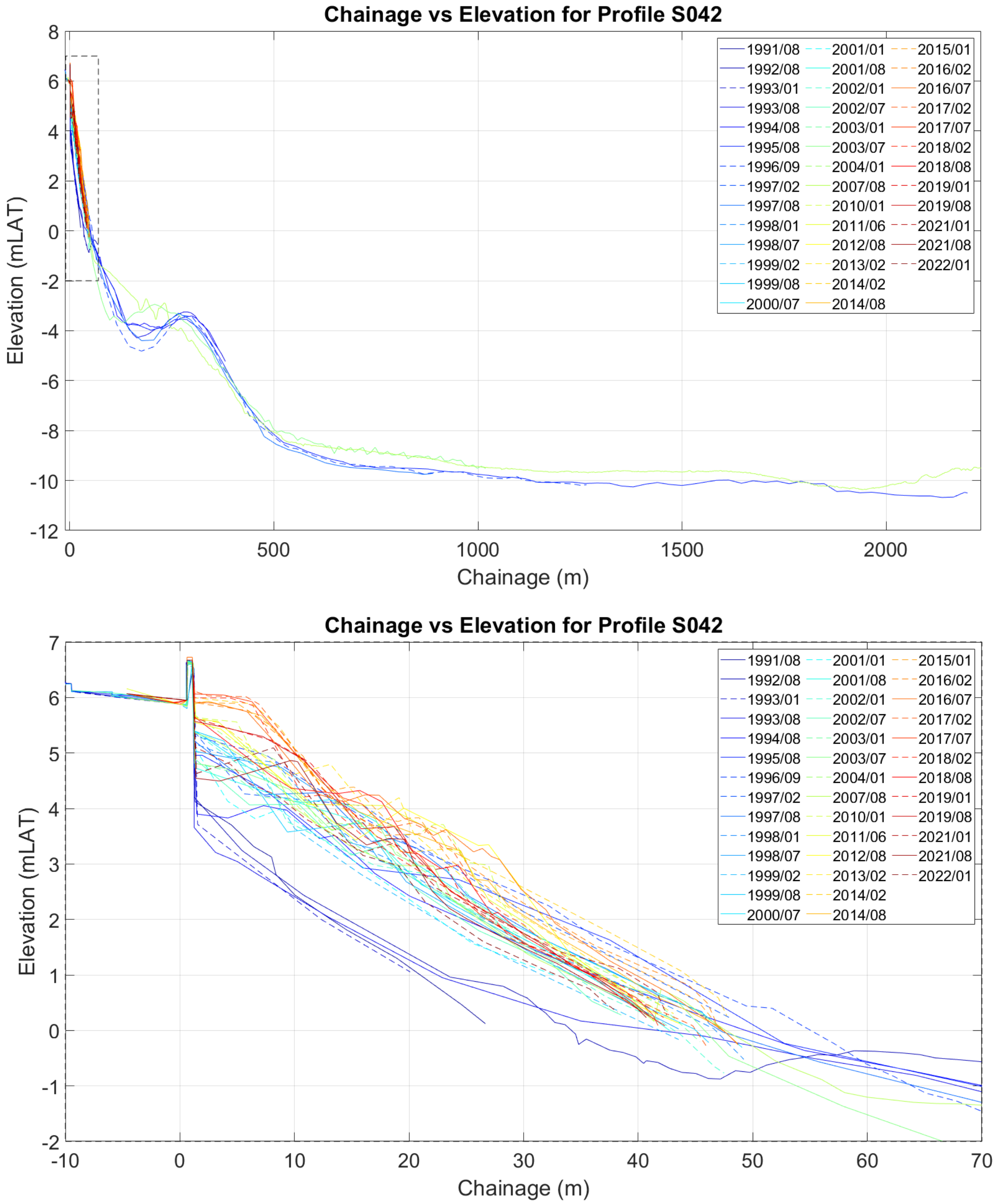


Figure A19. **Profile S041 elevation change including bathymetric profiles to -10m LAT (Top) and zoomed to -2m LAT (Bottom).**

A.3.1 Profile S040

The bathymetric profiles from the Anglian Coastal Monitoring have been combined with transects derived from the UKHO available bathymetry for the area. The latest MBES bathymetry from NGET however, has not been used as it does not cover the entire profile S040.

Figure A.20 shows these profiles: the three from the Anglian Coastal Monitoring are shown in solid lines whereas the ones derived from the UKHO bathymetry have been shown with dotted lines.

The range of change across the profile has been calculated for every 1m along the chainage, taking into account that the coverage of the profiles is different (the derived ones from UKHO bathymetry start at LAT and each of them finalise at different depths) and therefore sometimes the range would be calculated from six values and others from less, even just from two values. This range of change across the profiles is shown in Figure A.20 where the top figure shows the actual profiles along S040 and the bottom figure the rate of change. The range of movement is highest in the intertidal zone, the highest value being above 2m; this range then decreases up until the -5m LAT. From about -5m LAT, the range of movement is very low, around 0.5 to 0.75 m with some peaks that might be due to spurious data. From this analysis one can deduce that the depth of closure, i.e. the depth beyond which no significant longshore or cross-shore transports takes place due to littoral processes so that it defines the seaward boundary of the littoral zone, would be around -6 to -7m LAT.

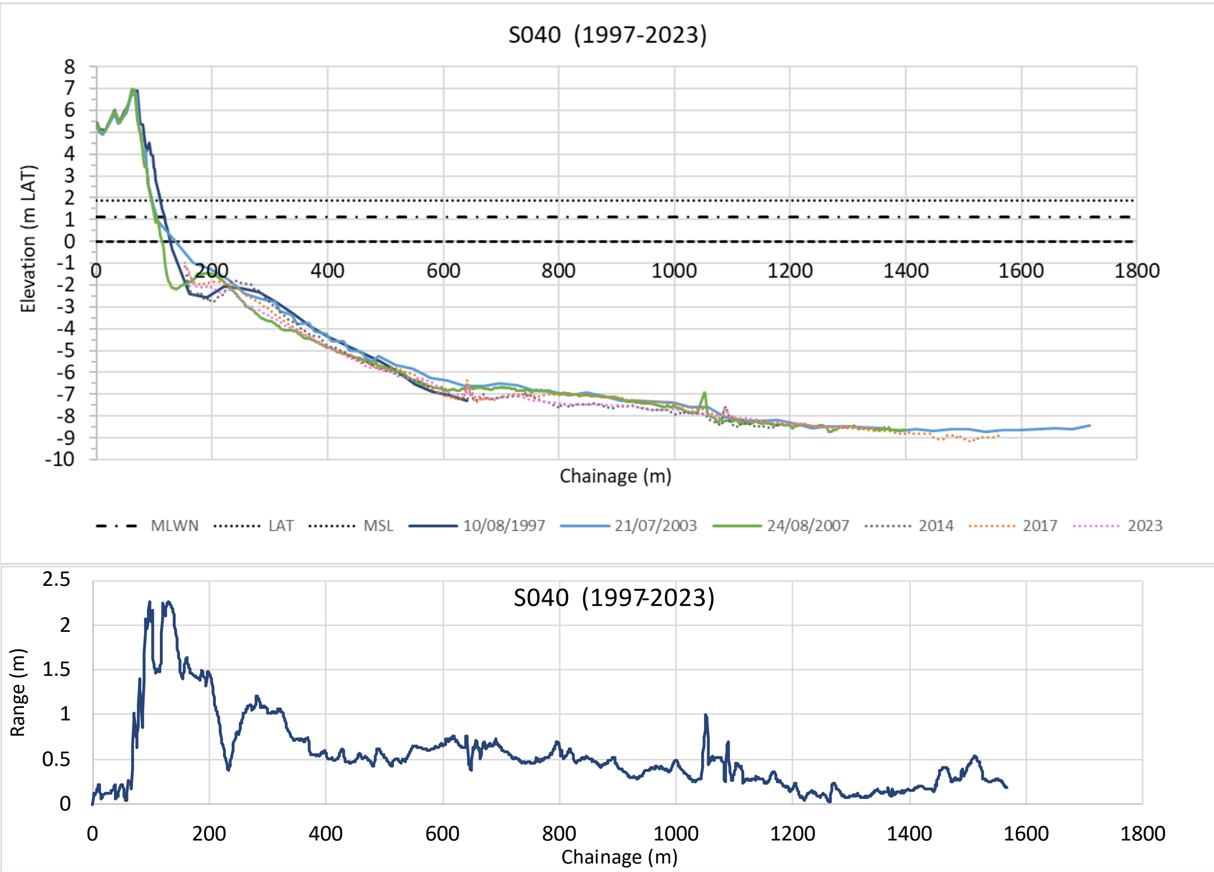


Figure A.20. Range of change across S040 profile

A.4 Response to storms

As waves move onshore, they are modified by a number of processes such as shoaling and refraction. There is a consequent spatial variation in the fluid motions at the bed. This is reflected in changes in the mode, magnitude and direction of sediment transport, so that different regions within the nearshore can be identified in terms of the hydrodynamics. The sediment processes in these regions result in changes in beach profiles in response to wave conditions. For example, the creation of different "summer" and "winter" profiles in response to changing wave heights and periods during a year. The beach profile will then have a feedback role in modifying the subsequent shoaling waves. Cross-shore transport occurs at smaller time scales than longshore transport, so that the beach profile changes, sometimes, dramatically, as a result to a single severe storm. Beach profile changes during milder conditions are slower and will allow the beach to recover many times to its original profile, the beach profile changes showing seasonal variations. These changes will normally occur within the depth of closure, although in some beaches in very extreme storms some of the sediment might be transported offshore, beyond this depth of closure and unable to return in milder conditions to the beach.

The response of gravel only and mixed (gravel and sand) beaches to storm is very different to that of the sandy beaches. This is summarised below:

- *Sandy beaches*: During winter, storm-related high water levels and energetic breaking waves transport sand from the backshore to the foreshore and even further offshore to the upper shoreface. The upper beach profile (and/or dune face) is steepened and the lower beach profile is flattened, implying an onshore shift of the shoreline. During summer, low-energy swell waves carry the sand deposited on the upper shoreface back to the subaerial beach.
- *Gravel beaches*: during a storm, gravel and shingle beaches response is very different due to the higher permeability: this makes a fast and considerable percolation of the water through the beach face the key physical process. The main implication is the weakening of the backwash flow and therefore there is a resulting reinforcement of the onshore transport. In terms of the beach profile after a storm the gravel moves across-shore towards the back of the beach, creating a very steep crest. A step has been formed below the water level where the sediment has eroded to form the crest. This has been schematised in Figure A23.

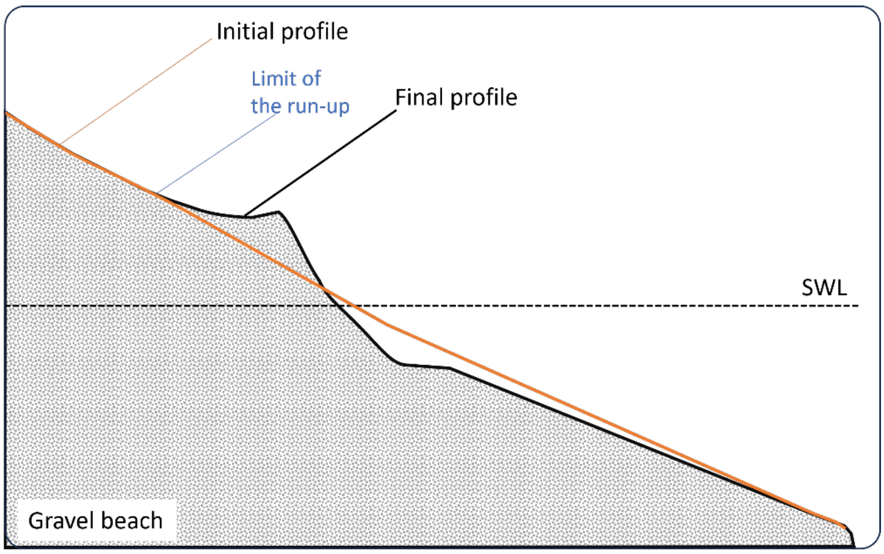


Figure A21. Typical response of a gravel beach to a storm.

- *Mixed* beaches*:* the response of these beaches is similar to gravel ones, however the permeability of mixed beaches is lower than that of gravel beaches and therefore the percolation is smaller and so is the onshore transport. As a result, mixed beaches response is similar but with a smaller and less steep crest and a smaller step.

  In terms of the sediment composition after a storm, for an initially equally mixed beach the following was observed in a series of experiments at 1:1 scale (Blanco *et al*, 2006): the berm is composed solely of gravel, a layer of sediment located below this berm and across most of the profile contains a higher proportion of sand than the initial mixture. This is shown in Figure A22.

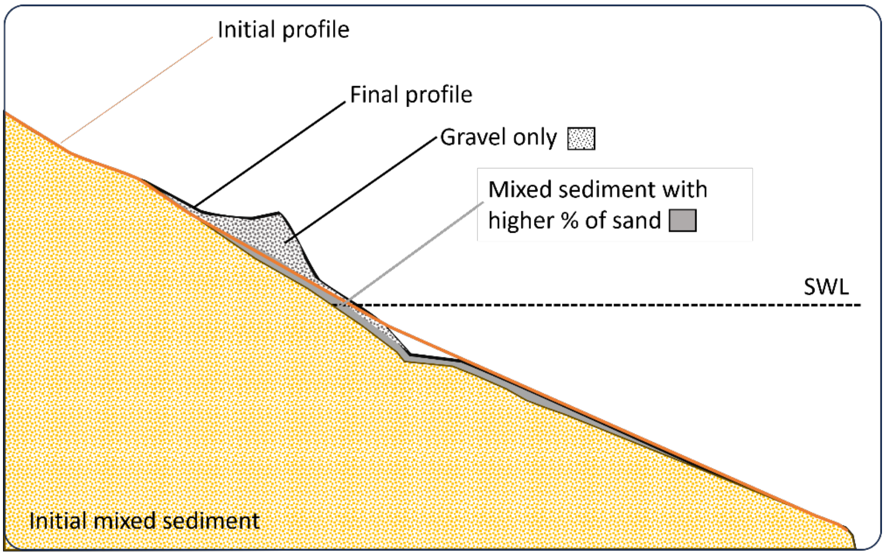


Figure A22. Typical response of a mixed sand and gravel beach to a storm.

A.4.1 Aldeburgh beach as a mixed sediment beach

Many of the beaches across the UK are mixed beaches but not equally mixed across the profile; the majority contain gravel on the foreshore and a core of sand or gravel and sand underneath. When moving offshore, these beaches normally contain more sand.

The profiles from the CCO from 1993 contain information about the surficial composition of the sediment at each point surveyed. In most cases, the sediment is defined as Gravel, with several occasions where closer to the lower water marks, the sediment is defined as Gravel Sand, as can be seen in the example provided in Figure A23. For all survey dates, 85% of the points are characterised as gravel, 12% of them as Gravelly Sand and 3% as Sand. Although Aldeburgh beach is defined as a gravel beach, the fact that there is sand near the low water mark is a sign that there might be sand or gravel and sand below the gravel, so that most likely the beach is more a mixed than a pure gravel beach. APEM (2024) describe the variability of the sediment found on the beach on different survey dates and provide photographs of the lower foreshore as mainly sand and shingle with sand patches (reproduced here in Figure A24). APEM also provide results of their particle size analysis on the beach where all samples were found to be bimodal, with the percentage of sand is around 20 to 40%, see Figure A25.

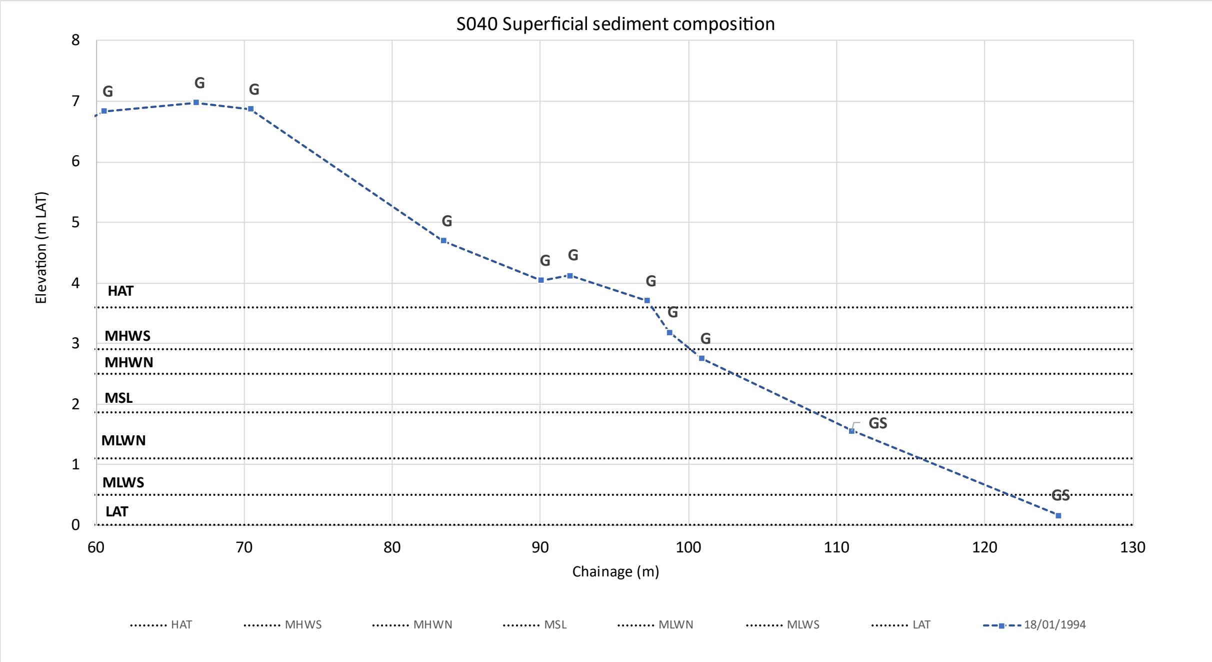
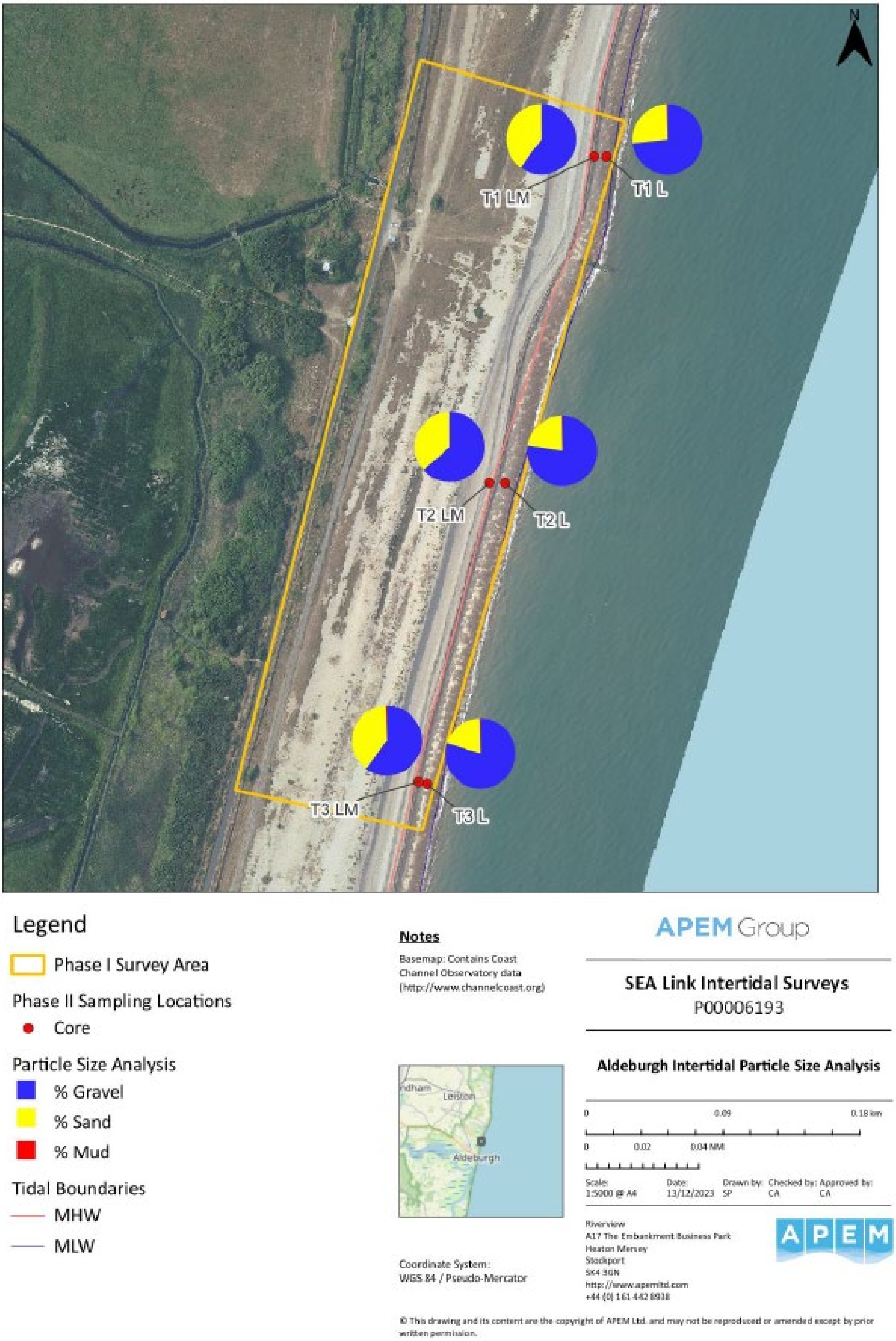


Figure A23. Superficial sediment composition for profile S040 on 18/01/1994. The letters define the composition of the sediment (G for Gravel and GS for Gravelly Sand)

Source: APEM (2024)

Figure A24. Photograps of Aldeburgh beach (looking N towards Thorpness) during APEM surveys (left hand side on 26 July 2023 and right hand side on 12 September 2023), showing the sediment variability on the lower foreshore.



Source: APEM (2024)

Figure A25. Summary of Particle Size Analysis at Aldeburgh

A.4.2 Response to storms based on data available

The morphological response of a beach to a storm is sometimes masked by previous water level conditions and precedent storms, so that it is not unusual to see a crest created on a beach at a lower level than a precedent crest. This makes it difficult to study post-storm profiles unless they have been surveyed immediately after the storm. In the case of the available profiles for the site, they are biannual, so that the morphological shapes of two consequently following profiles will contain six months' worth of water levels and wave conditions, and therefore it is very difficult to see the cross-shore changes described above that happen at shorter scales of time when there is a storm.

Figure A26 shows two consecutively following profiles, in summer of 2019 and winter of 2020 where the difference between a "summer" and "winter" profile for Aldeburgh beach can be appreciated. The beach in the winter shows the characteristic steep berm formed by the gravel; the face of the berm presents a steepness of 1:2. The "summer" profile presents the typical steepness of a gravel/ mixed beach of 1:7.5. This profile only covers the accretionary part of the beach, so that it is not appreciated is the step formed below low water, due to the material transported from there to form said crest. The run-up limit of the storm that formed this crest would be at the start of the crest, at around chainage 85 m. It can be observed that there have been morphological changes in the area behind this chainage since the summer; this is probably due to preceding extreme events with higher water levels and/or higher wave heights which built a crest higher up the beach.

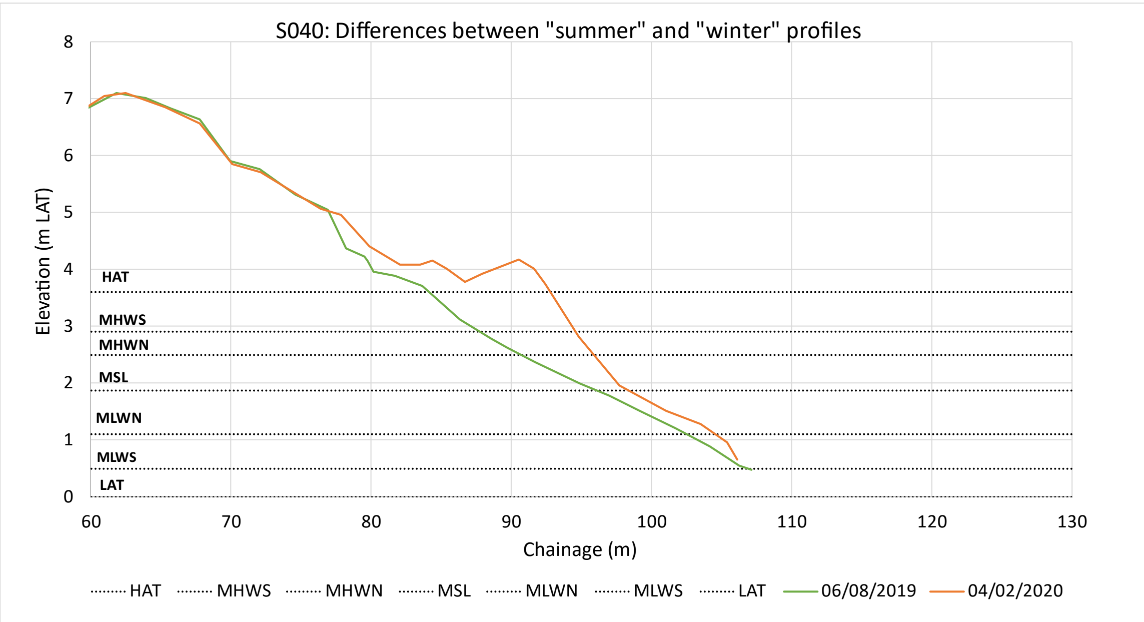


Figure A26. Differences between a "summer" profile from August 2019 and the following "winter" profile in February 2000.

A.4.3 One-Dimensional Parametric Modelling

The 1-D parametric model Shingle-B was run for a set of wave and water level conditions to estimate the response of the beach to storms.

Shingle-B (available at https://coastalmonitoring.org/shingle/) was developed as a new parametric model for predicting beach profile response on shingle beaches under bimodal wave conditions (HR Wallingford, 2016c). It is based on using the parametric model of Powell (1990) and it was developed based on extensive 2D physical model data and field work. The physical model tests were done with anthracite representing the shingle sediment in order to be able to match the permeability in the physical model.

Shingle-B is an ideal tool to help with the design of gravel beaches subject to bimodal wave conditions. As all models it has its limitations, the most important ones being as a result of the limitations of the physical model tests it was based on, as summarised below (HR Wallingford, 2016):

- The tests were based on a single D50 of 12.5mm and a grading curve. No other gradings were considered. This model is representative of gravel beaches therefore with a similar D50 and grading curve. It is expected that when applied to mixed beaches, the crest height will be overpredicted, as well as how far the crest goes back in the foreshore.
- The initial beach slope was fixed at 1:8 for all tests. Although the effect of the slope was not investigated, different wave conditions were repeated without reshaping the beach to the initial plane profile. These showed good agreement suggesting that the initial profile does not significantly affect the final profile.
- Angle of wave attack: the model was designed for cross-shore sediment transport and does not take into account the influence of the angle of wave attack.
- Underlying impermeable structure: the tests were run with a full thickness of beach material. The presence of an underlying impermeable layer within a shingle beach was investigated by Powell (1990). During this study (Powell 1990) it was observed that if the ratio of effective beach thickness to median material size (D50) is less than 30, the thickness of the beach is usually insufficient to retain material.

Moreover, the model does not take into account the different water levels of the tide, as the physical models were done with a single water levels. The response of the gravel beaches to the forcing conditions is very fast and the movement of the water level up or down during the storm will influence the morphological response of the beach to a storm, which is not captured with this model.

Despite the limitations, the model was run for set water level and wave conditions representative of nearshore conditions in the area, as set out in Table A2. The initial profile was plane one with a slope of 1:7.5 representative of the top of the beach at Aldeburgh. The results from the tests are shown in Figure A27 . The figure shows also the initial profile used for the model and the composite profile (August 2018 for the intertidal part and August 2007 for the deeper part) in which this plane profile was based on. The results are most-likely over-predicting how far in the backshore the beach crest is and how high the crest is, due to the fact that the model was derived for gravel beaches and not mixed beaches. The area in the profile between MSL and -2m LAT in reality is steeper than the initial profile used in the model: this area is not well represented by the model and it is probably driven by more complicated sediment transport (wave driven and tidal induced combined) than the cross-shore transport that this model represents. But, in all cases, the important result is that the model does not show any morphological changes beyond the -4m LAT. In order to be within the ranges of the model and due to the limitations expressed above, there is probably some cross-shore transport due to storms beyond the -4m LAT with more extreme water levels and storms; however, this will be within the estimated depth of closure of -6 to -7m LAT.

Table A2 Shingle-B runs – wave parameters and water level input values used

Run #	Hm0	Tp Wind	Swell %	Tp Swell	Water Level
Run1	2	7.5	10	12.75	0.5
Run2	2.5	7.5	10	12.75	0.5
Run3	2	7.5	10	12.75	1
Run4	2.5	7.5	10	12.75	1
Run5	2	7.5	10	12.75	1.5
Run6	2	8.5	10	12.75	0.5
Run7	2.5	8.5	10	12.75	0.5
Run8	2.5	8.5	60	12.75	0.5
Run9	3	8.5	60	12.75	0.5

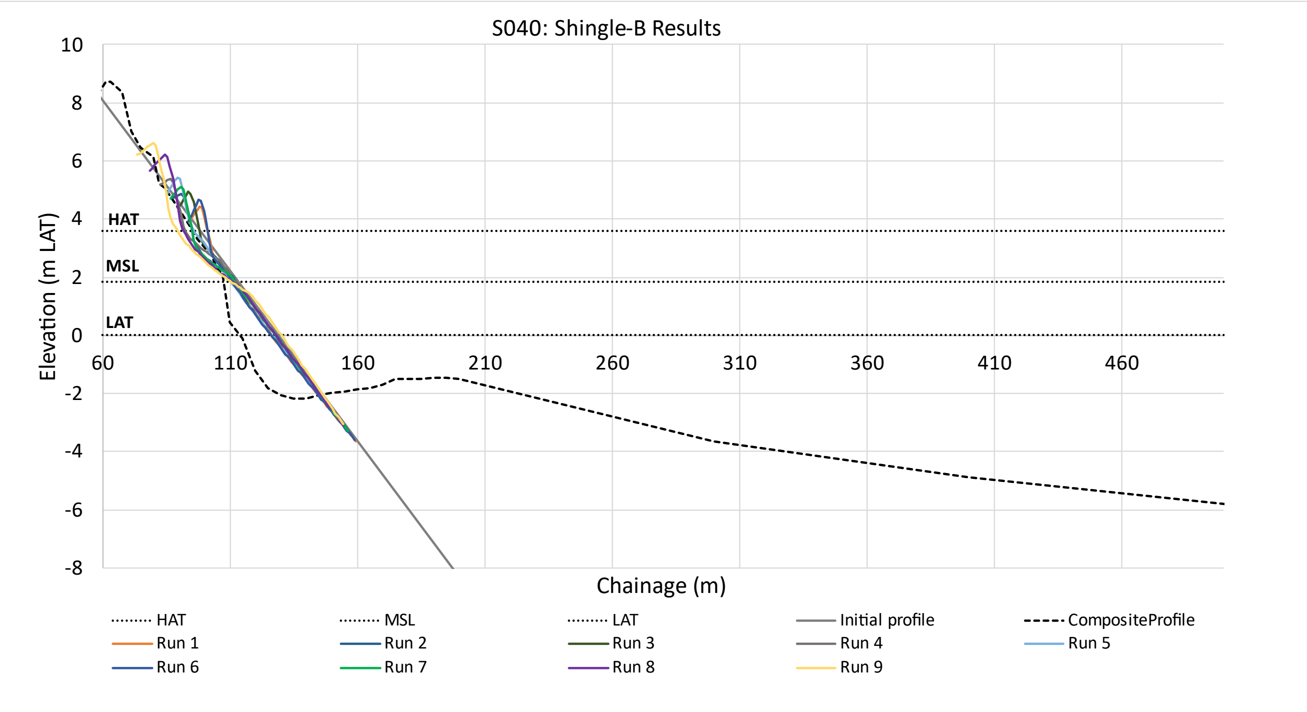


Figure A27. Shingle-B results

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