British Geological Survey

Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2023)

Multi-Hazards & Resilience Programme

Commercial Report CR/23/081

BRITISH GEOLOGICAL SURVEY

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COMMERCIAL REPORT CR/23/081

Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2023)

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RGB coloured point cloud for section of 2019 survey.

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Foreword

This report is a published product of the British Geological Survey (BGS) and describes the results of a baseline survey of the cliffs at Hunstanton, Norfolk, for the Borough Council of King's Lynn and West Norfolk.

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Summary

This report is the published product of the **B**ritish **G**eological **S**urvey (**BGS**) and describes the results of the Annual 2023 survey of the cliffs at Hunstanton, Norfolk, for the **B**orough **C**ouncil of **K**ing's **L**ynn & **W**est **N**orfolk (**BCKLWN**).

This report describes the background to the work and discusses the state of the **LiDAR** (**Li**ght **D**etection **A**nd **R**anging) scan provided by the client and collected by the **A**nglian **C**oastal **M**onitoring Programme (**ACM**), covering 2023.

This is an 'annual' report, the objective of which is to derive a series of surfaces for the latest LiDAR scan and to compare it against the earliest (2010) scan and to the previous (2022) scan. A table detailing the amount of erosion, the volume loss and the metres lost over the section surveyed is also included, along with a section detailing the 'Trigger' levels to 2100, and a short survey of the current Fence lines and their life expectancy.

The report provides a brief discussion, with images, of the results of the changes identified, including the year-on-year comparisons.

1 Introduction

The Borough Council of King's Lynn & West Norfolk is currently implementing both annual and post storm LiDAR surveys of the Hunstanton Cliffs over a 4-year monitoring period (likely to be extended), which will potentially be coordinated with the Environment Agency's ACM topographic contractor. The purpose of this is to monitor erosion rates occurring on the cliff line, with long-term monitoring helping to inform when cliff top assets become at risk, in order that planned rock armour can be implemented (likely in 50-60 years' time). The reports would also be made available to residents in the local area, helping to raise awareness of the processes occurring at the cliffs.

In an e-mail, dated November 21, 2019, the Borough Council of King's Lynn & West Norfolk set out the following:

> *A key aspect of the monitoring would be for the data to be placed into an annual report which can present / analyse the terrestrial LiDAR data collected. We would also be looking for some analysis of the terrestrial LiDAR scans conducted by the ACM in 2012, 2017 and 2019 to be analysed and placed into a similar styled report. In particular we would like the report to present any models produced from the data and analysis to focus on the amount of erosional retreat occurring each year, changes in talus at the base of the cliff, major changes on the cliff face and estimations of when cliff top assets are likely to become at risk due to erosion.*

In a Microsoft Teams video meeting on August 29, 2023, the Council asked the BGS to supply them with an annual report, based on data acquired from the 2023 survey, to include the following (Project Code NEE7028R):

- *Change models identifying areas of loss and/or accretion from 'base' year (2010) to 'current' year (2023)*
- *Tables detailing the amount of erosion of the section, the volume loss across the section and the metres per year loss of the section*
- *Discussion and images of the areas where the most significant amount of erosion has occurred and the identification of key changes from 'previous' years (fall events, talus removal etc.)*
- *Analysis of the comparisons*
- *Beach Level changes from 2010 to 2023*
- **Trigger Levels for management implementation to 2100*
- **Fence Line positions and potential lifespan*

***Note**: *Additional content added in meeting with BCKLWN on August 29, 2023.*

2 Data & Extents

The Borough Council of King's Lynn & West Norfolk supplied the BGS with three large georeferenced point cloud data sets (in .las format) from 2023. The area under review is shown in Figure 1 and the data from all years are summarised in Table 1, which shows the date of the survey, the instrument used, including the estimated accuracy, and any additional information stored (Intensity and/or RGB colour). It also shows the number of points attributed to each survey, both initially and after filtering of the cloud. Filtering is necessary in order to facilitate the surface modelling of the point cloud which is required for change analyses.

Figure 1 – Hunstanton cliffs survey area. ***Figure provided by BCKLWN***

Table 1 – Summary of survey data

Survey Year	Instrument Used	*Estimated Accuracy (mm)	Scan Colour	Number of Points			
				Initial	North	Middle	South
2010	Leica Scan Station	+/- 6	None	18184620	454765	535525	181922
2012	Leica Scan Station	+/- 6	None	445526	-	-	102303
2017	Faro Laser Scanner	+/- 3.5	Intensity	180308350	466837	628424	243039
2019	Faro Laser Scanner	+/- 3.5	RGB	59152684	456427	517044	140064
2020	Faro Laser Scanner	+/- 3.5	RGB	10381057	539679	222476	124645
2021	Faro Laser Scanner	+/- 3.6	RGB	34403524	679524	581698	128023
2022	Faro Laser Scanner	+/- 3.4	RGB	16908245	840143	1009386	369921
2023	Leica RTC360 Scanner	+/- 6	RGB	3001579352	19192512	20748446	1022678

Note: *Estimated accuracy is that of the scanner and does not consider the spatial accuracy of the **G**lobal **N**avigation **S**atellite **S**ystem (**GNSS**) position, so is not absolute positional accuracy.

The survey of 2023 was slightly larger than the previous (2019-2022) surveys (in terms of area) and was divided into three smaller sections; North, Middle and South in order to provide a better accuracy for the volume calculations. The sections were split at a gap in the data on the 2010 survey, and at the natural break in the data. These splits are shown in Figure 2 on a 3D illustration and in Figure 3 on a plan. The section extents are given in Table 2.

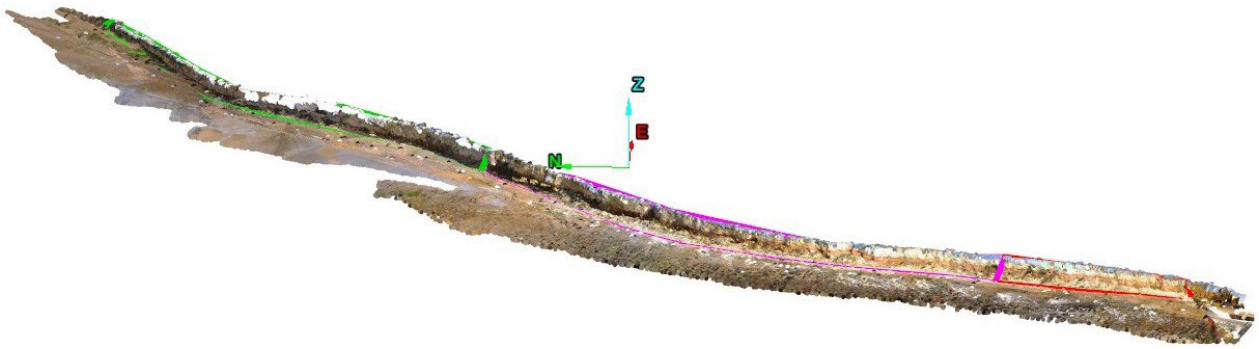


Figure 2 – RGB coloured point cloud of 2021 survey showing sections: Green = North, Magenta = Middle, Red = South (Extents: E 567954 m, N 342450 m to E 567268 m, N 341332 m. Height range = 6.3 m to 18.8 m)

Note: Figure 2 is a 3D illustration of the data and therefore it is difficult to show a representative scale of the Z-value as it varies from ~6 m to ~19 m across the section. This applies to all figures in this report. Therefore, XY extents and Z ranges have been appended to all figures.

Table 2 – Section extents

Section	Start		End		Length	Average
	Easting	Northing	Easting	Northing	(m)	Height (m)
North	567578	342050	567934	342430	515	14.75
Middle	567314	341539	567584	342052	575	17.84
South	567267	341356	567333	341548	185	16.14

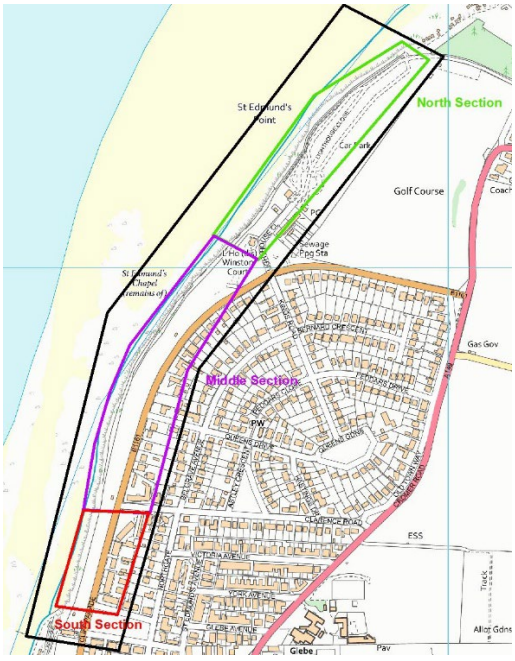


Figure 3 – Plan view of scan area sections: Green = North, Magenta = Middle, Red = South, showing cliff line and property positions

Figure 4 shows the coverage and extents of the scans from the latest (2023) survey. They are displayed as RGB colour values.

Figure 4 – 2023 point cloud data displayed using the RGB colour values (Extents: E 568042 m, N 342490 m to E 567347 m, N 341605 m. Height range = 6.3 m to 18.8 m)

The point cloud data provided, in .las format, for the survey, was imported by BGS into Global Mapper and then into Maptek I-Site Studio, where it was cleaned, removing any artefacts in the data (e.g., bird strikes, anomalous points etc.), and trimmed to equivalent extents, where possible. These data were then trimmed to the cliff-line, leaving a small section of beach, and cut to the section extents shown in Figure 2 and described in Table 2 above.

3 Model Creation

To create a 3D surface model of each section, for each survey year, the point clouds needed to be filtered. This is done to reduce the number of points and to further clean the data. Initially, an *Isolated Points filter* was carried out to remove points that were a large distance from any other points in the scan, helping to remove dust particles and insects which may not have been removed from the earlier cleaning. A *Topography filter* was then carried out to remove unwanted features such as equipment and trees etc. from the scan, retaining only the single lowest point in a defined horizontal grid cell. This has the effect of reducing the data to a more even point distribution. The number of points retained for each section is shown in Table 1.

3.1 FUSION SURFACE MODELS

To best represent the topography of the point clouds a Fusion Surface model was created from a Topographical Triangulation and a Spherical Triangulation. The Topographical Triangulation works in the XY plane, that is, it triangulates straight down, meaning that areas of undercutting will not be modelled correctly. In order to make allowance for this, a Spherical Triangulation, which creates a surface on a sphere, was carried out. As the triangulation grid is spherical from the defined origin point, it allows for overhanging surfaces to be created. The Fusion Surface creates a new surface of evenly sized triangles by following the original surfaces of the two triangulations. Where the surfaces overlap, the Fusion Surface will follow the most detailed triangulation, giving a better combined 3D result. Following the creation of the Fusion Surface de-spiking was carried out, to remove spikes caused by any remaining dust or vegetation, and any small holes (~1 m) in the surface were filled; larger holes, where there were no points, were not.

Based on the sections shown in Figure 2 and described in Table 2, the following Fusion Surface models were created:

- North – 2023 (Figure 5)
- Middle – 2023 (Figure 6)
- South – 2023 (Figure 7)

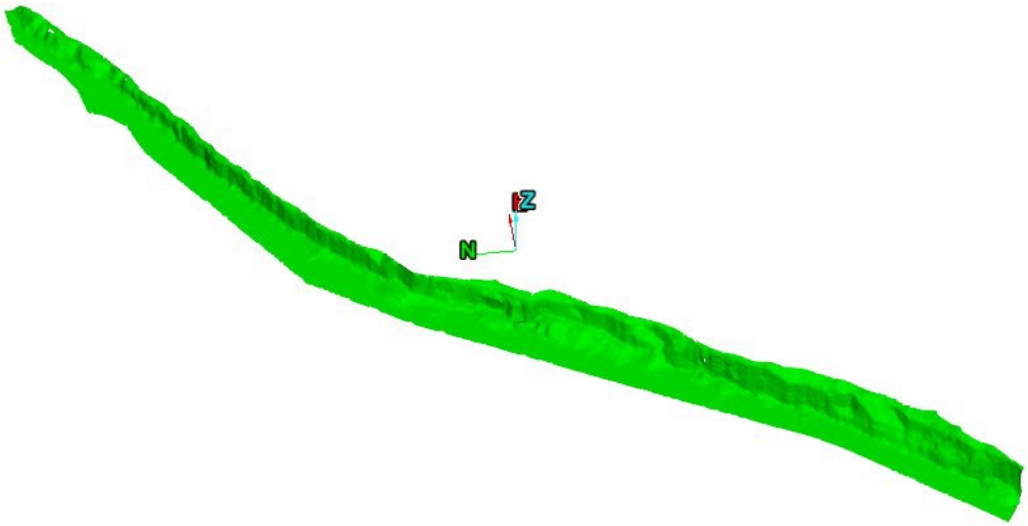


Figure 5 – North Section, 2023 (Extents: E 567934 m, N 342430 m to E 567582 m, N 342049 m)

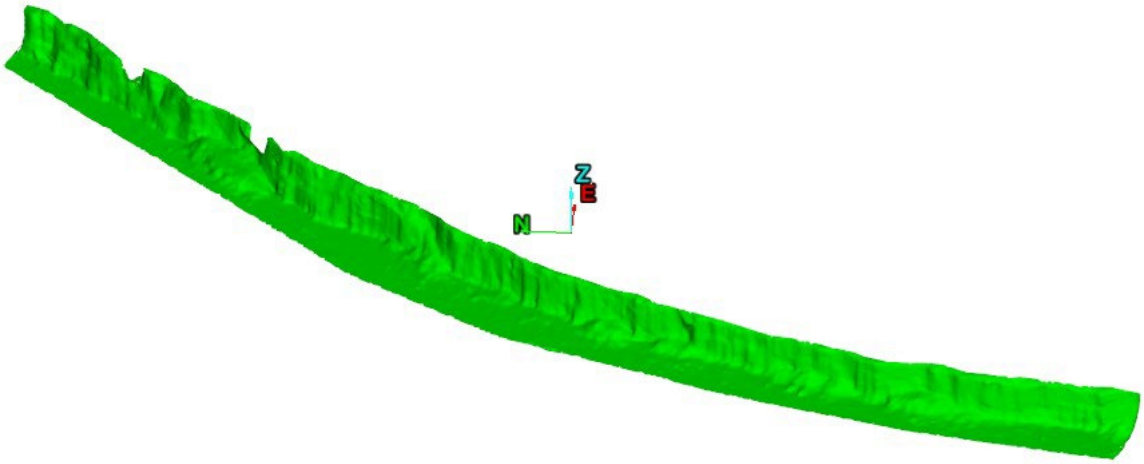


Figure 6 – Middle Section, 2023 (Extents: E 567585 m, N 342045 m to E 567347 m, N 341604 m)

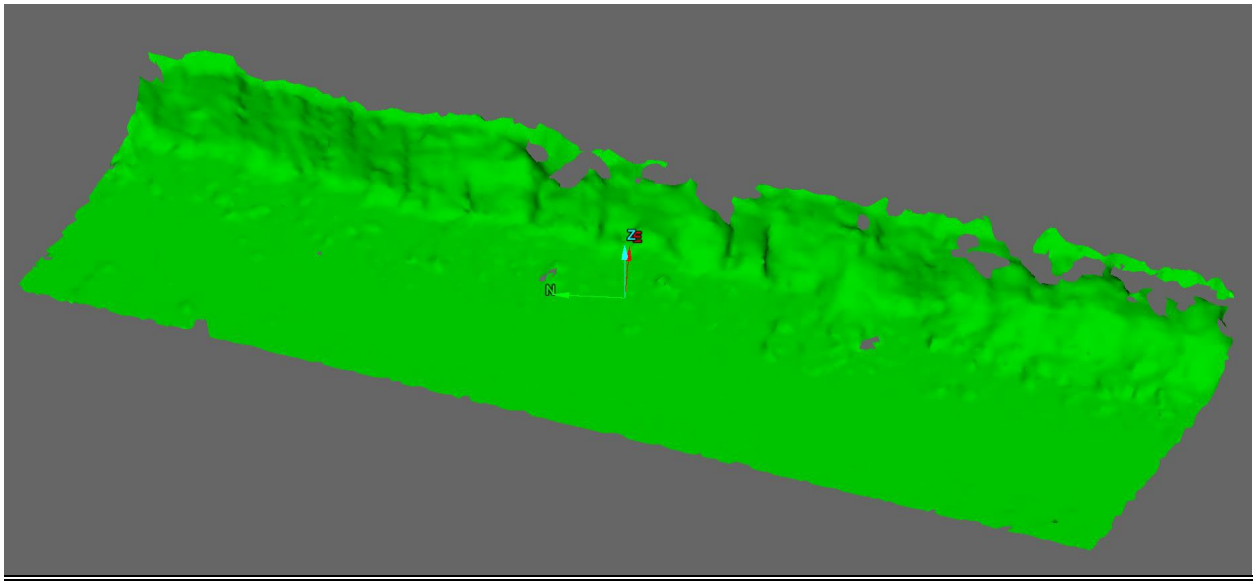


Figure 7 – South Section, 2023 (Extents: E 567312 m, N 341621 m to E 567299 m, N 341429 m)

3.2 CHANGE MODELS

Maptek I-Site Studio was used to create change models between the base year (2010) and the current year (2023) and from the previous year (2022) to the current year (2023), as follows:

- North – 2010 to 2023, 2022 to 2023 (2)
- Middle – 2010 to 2023, 2022 to 2023 (2)
- South – 2010 to 2023, 2022 to 2023 (2)

Change models were created using the *Colour Distance from Objects* tool. The tool is used to visualise areas of change between two triangulated surfaces of the same area. The resulting model is coloured by the distance between the objects according to the colour versus distance relationship specified. This relationship is shown in the legend, which shows a graph displaying the distribution of data in front and behind the surface. Change models for all sections, of all years, can be found in Appendix 1.

4 Volume Calculations

Volumes lost from the cliffs at Hunstanton have been calculated directly from the **T**errestrial **L**iDAR **S**canning (**TLS**) models for the period August 2010 to April 2023 (Table 3). The data shown have been extracted from the two sections previously outlined in Figure 2 and Table 2. To estimate the maximum horizontal movement values of the cliff-line, parallel sections were created at 50 m spacing along the entire 3D model, for the North (Figure 8) and Middle (Figure 9) and South (Figure 10) sections of the cliff. The section lines appear closer together towards the north; this is because of the angle of the image, to make sure all lines are visible.

Table 3 – Cliff recession, derived from TLS

Period		Elaspsed Time	Cumulative Time	North Section			Middle Section			South Section		
Start	End	(days)	(days)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)	Material Loss (m^3)	Cumulative Loss (m^3)	Cumulative Loss/m (m^3)
Aug-10	Oct-12	785	785							200	200	1
Oct-12	Oct-17	1829	2614	1850	1850	4	5500	5500	10	2000	2200	12
Oct-17	Mar-19	522	3136	1200	3050	6	1250	6750	12	150	2350	13
Mar-19	Aug-20	510	3646	2000	5050	10	3500	10250	18	950	3300	18
Aug-20	Mar-21	239	3885	2700	7750	15	500	10750	19	100	3400	18
Mar-21	Apr-22	370	4255	5100	12850	25	150	10900	19	150	3550	19
Apr-22	Apr-23	365	4620	2340	15190	29	2092	12992	23	420	3970	21
Aug-10	Apr-23		*4620*		15190	29		12992	23		3970	21
Loss/Year					1201			1027			314	

North Section			Horizontal	Middle Section			Horizontal	South Section			Horizontal
Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	Movement (m)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	Movement (m)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	Movement (m)
								460	460	2	
4255	4255	8		12650	12650	22		4600	5060	27	
2760	7015	14	*1.5*	2875	15525	27	*1.0*	345	5405	29	*2.5*
4600	11615	23		8050	23575	41		2185	7590	41	
6210	17825	35	*2.4*	1150	24725	43	*1.8*	230	7820	42	*3.0*
11730	29555	57	*3.6*	345	25070	44	*2.5*	345	8165	44	*3.0*
5382	34937	68	*5.0*	4812	29882	52	*5.0*	966	9131	49	
	34937	68	*5*		29882	52	*5*		9131	49	*3*
	2762				2362				722		

The data show a *new* total loss (since 2010) of 32152 m^3 across the 1.275 km combined sections, relating to an estimated mass of approximately 73950 tonnes* of material. These values work out to 2542 m^3/year (up from the previous value of 2343 m^3/year), which is an estimated 5800 tonnes/year (up from the previous value of 5390 tonnes/year). Graphs showing the cumulative loss of material in cubic metres (Figure 11) and the cumulative loss of material in tonnes (Figure 12) are also presented here. These graphs show a consistently steady increase in the amount of material lost from the Middle section throughout the survey period 2012 to 2021 and a rise from 2022 to 2023 and a continued increase in the amount of loss from the North section over the period 2020 to 2023.

Cliff height has not been considered in the calculations (above) as it varies considerably, from ~6.3 m to ~15.7 m in the north section and from ~16.5 to ~18.8 m in the middle section. Across the whole of the surveyed section the cliffs show an average height of ~16 m. A mean recession rate can be calculated by considering the yearly loss (2542 m^3), the cliff length (1275 m) and the cliff height (16 m) giving a total value of 0.125 m/year (up from the previous value of 0.11 m/year).

These results show an increasing rate of recession, albeit a small one, across the time period 2022 to 2023 of 0.015 m/year. This is the same as the previous 2021 to 2022 time period.

Note: *The geology of the cliffs is made up of Carstone (Sandstone) and Chalk. As there is no easy way of differentiating where these layers lie within the scans, the mass calculated is based on the average density value of 2.3 kg/m^3.

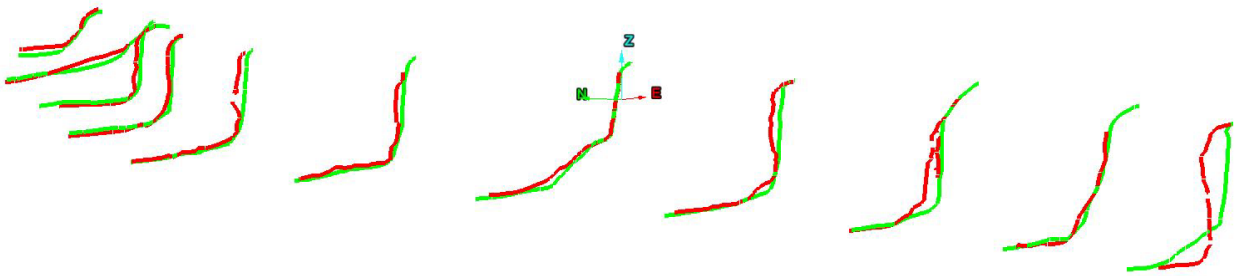


Figure 8 – Cross-sections, at 50 m spacing, for North section: Red = 2010, Green = 2023 (Extents: E 567934 m, N 342430 m to E 567586 m, N 342048 m)

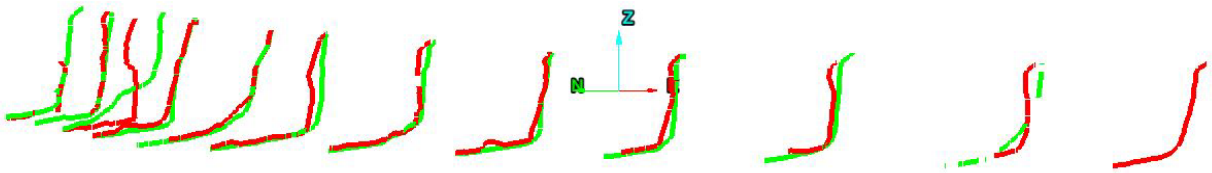


Figure 9 – Cross-sections, at 50 m spacing, for Middle section: Red = 2010, Green = 2023 (Extents: E 567574 m, N 342053 m to E 567348 m, N 341604 m)

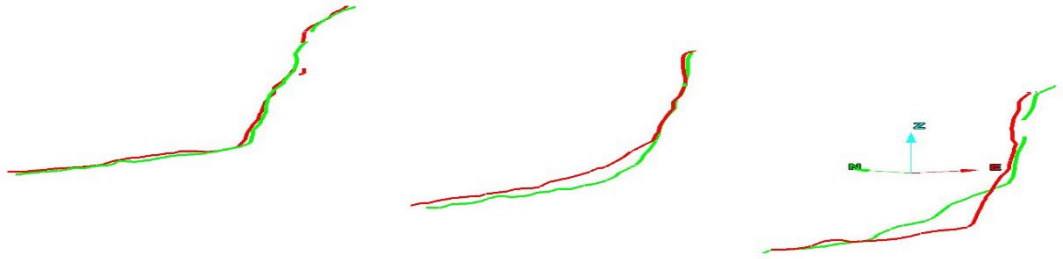


Figure 10 – Cross-sections, at 50 m spacing, for South section: Red = 2010, Green = 2023 (Extents: E 567312 m, N 341621 m to E 567299 m, N 341429 m)

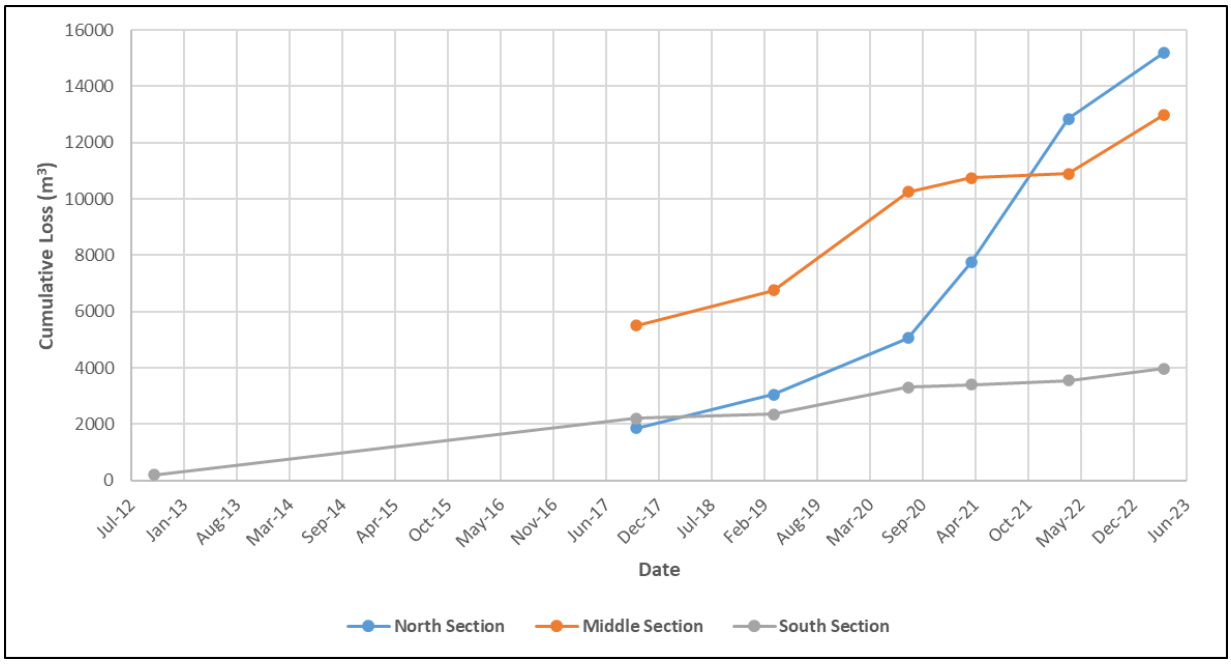


Figure 11 – Cumulative Loss (m^3) v Time

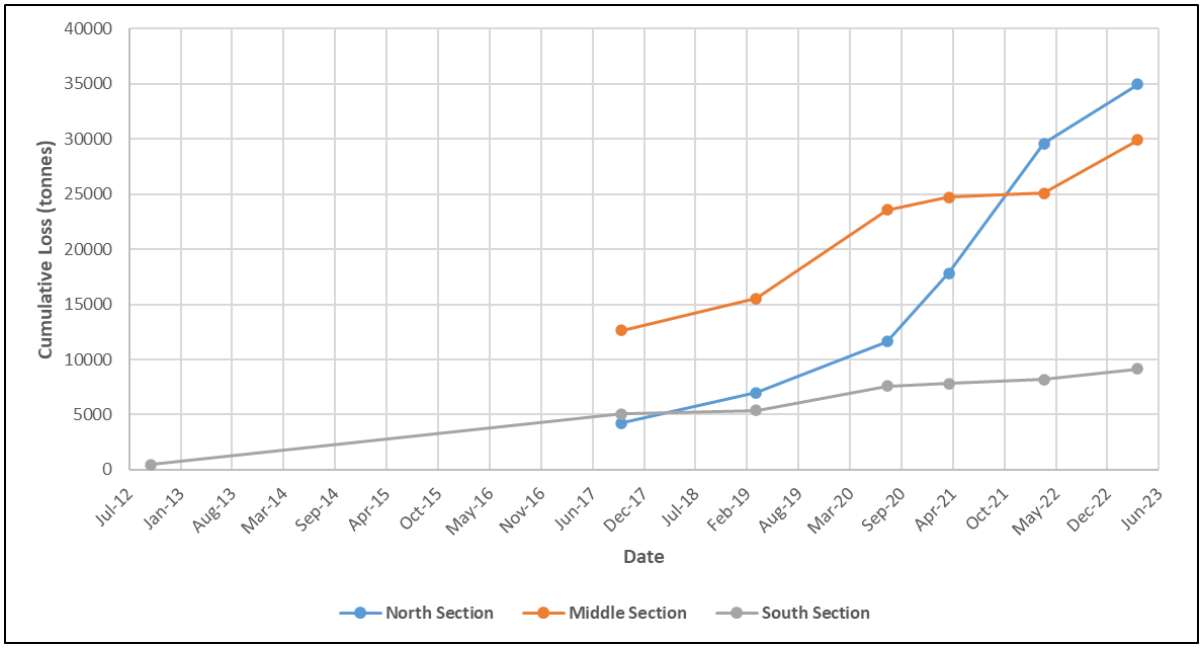


Figure 12 – Cumulative Loss (tonnes) v Time

5 Analysis of Change

This is an annual report, based on the data obtained from the 2023 survey. This discussion of results will refer to the change between the 2010 and 2023 surveys. This discussion will also look at the change between the 2022 and 2023 surveys, as this will provide information on possible changes to the erosion rates. This report will look at the model data by section, giving localised northing co-ordinates, where appropriate; to better delineate the results.

5.1 NORTH SECTION

Areas of major change occur within the north section (Figures 13 & 14) at British National Grid (BNG) 342229 m North to 342325 m North (Figure 15) which show that >4 m of loss has occurred in the cliff face and the accretion that previously followed on the foreshore has begun to erode. At the southernmost part of the section, around 342115 m North (Figure 16), there is a large area of erosion in the cliff face of >4 m, but with no visible accretion on the foreshore. This area sits between the Lighthouse and the Coastguard Lookout. The legend for these figures can be seen in Figure 17, which shows a histogram of the loss/gain distribution.

Figure 13 – Plan view of North section

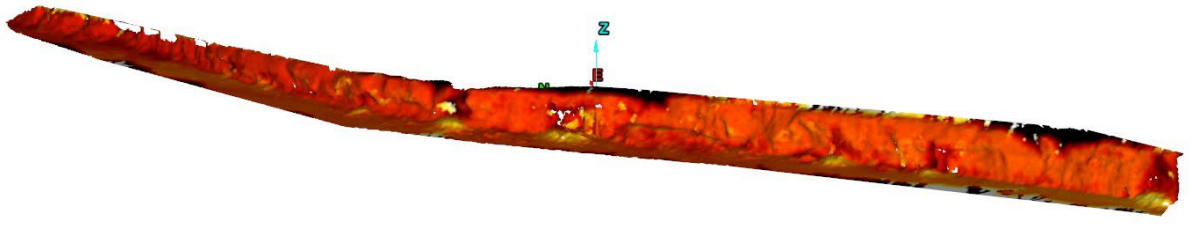


Figure 14 – 3D change model of the entire North section

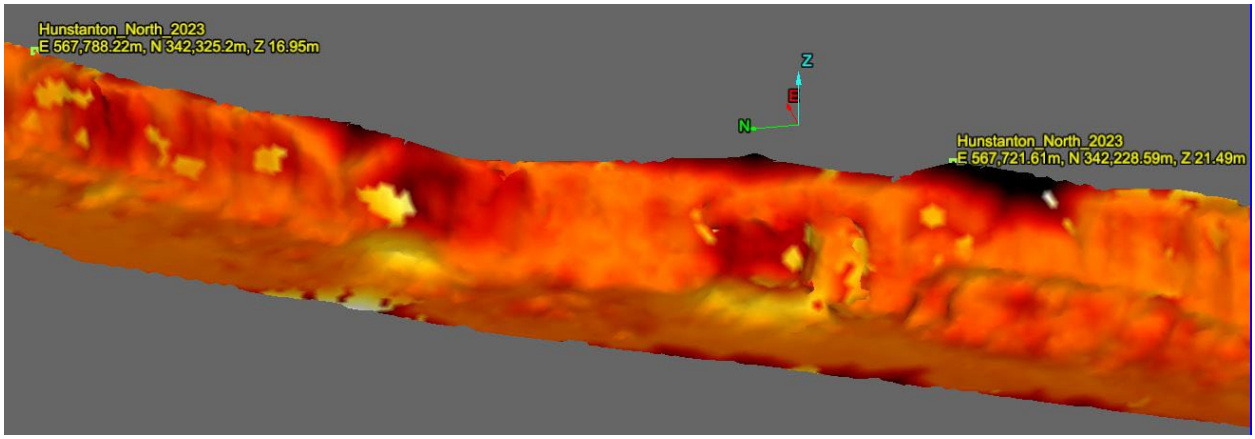


Figure 15 – 2010 to 2023 change model of 342229 m North to 342325 m North (for legend see Figure 15. Height range = 6.3 m to 15.7 m)

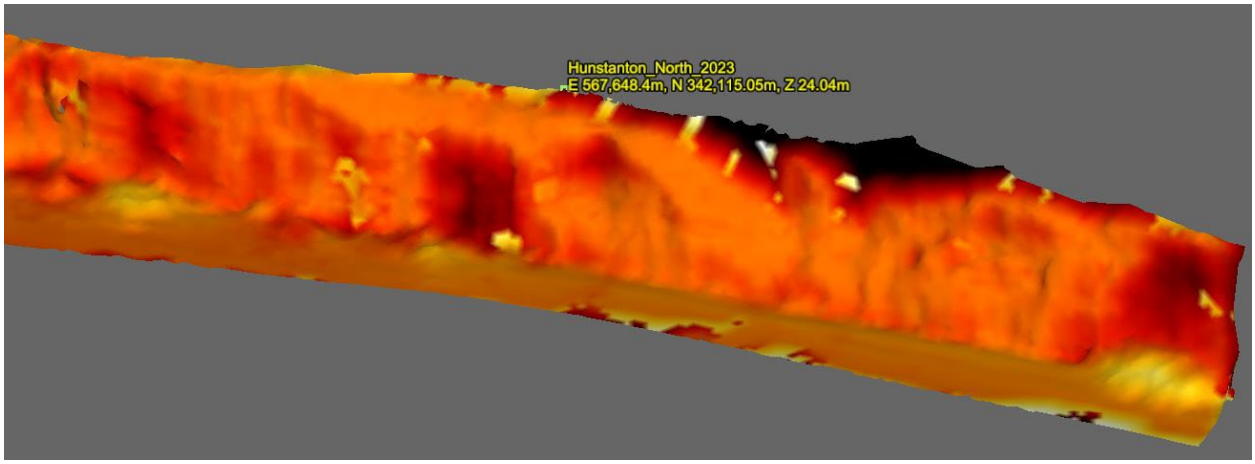


Figure 16 – 2010 to 2023 change model of 342115 m North (for legend see Figure 15. Height range = 6.3 m to 15.7 m)

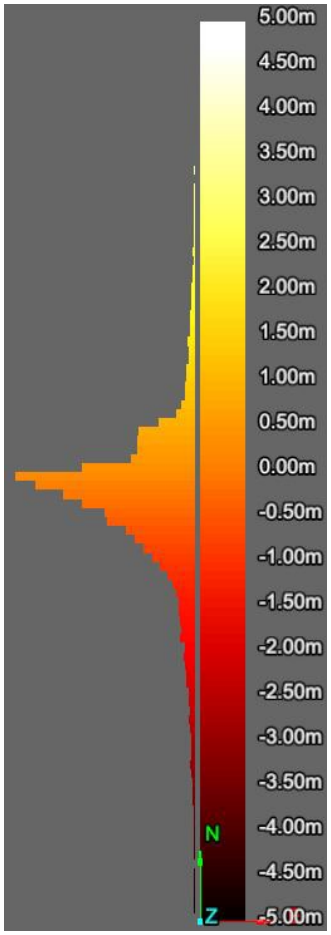


Figure 17 – North section legend (-5 m to 5 m) for 2010 to 2023 change model

Figure 18 shows the change between the 2022 and 2023 surveys, for the entire North section follows the trend of previous years. It shows that the major change occurs between 342300 m North and 342048 m North, with the greatest loss (~2 m) occurring at 342090 m North, 342150 m North, and 342222 m North (Figure 19). The legend for Figures 18 and 19 can be seen in Figure 20, which shows a histogram of the +/- 2 m loss/gain distribution.

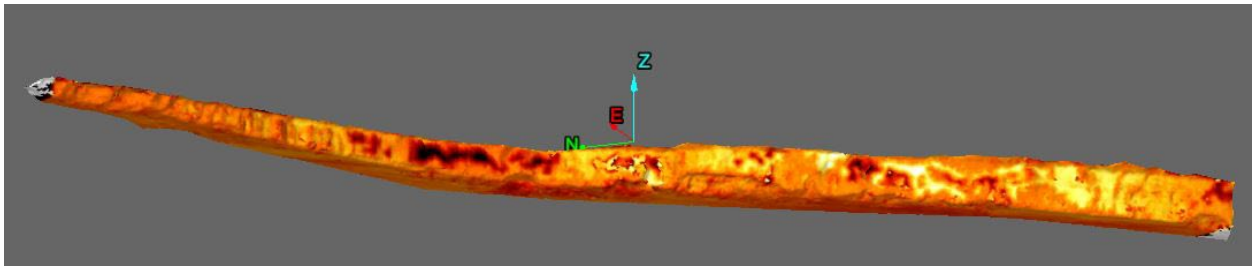


Figure 18 – 2022 to 2023 change model of entire north section (for legend see Figure 17. Height range = 6.3 m to 15.7 m)

Figure 19 - 2022 to 2023 change model of 342318 m North (for legend see Figure 20. Height range = 6.3 m to 15.7 m)

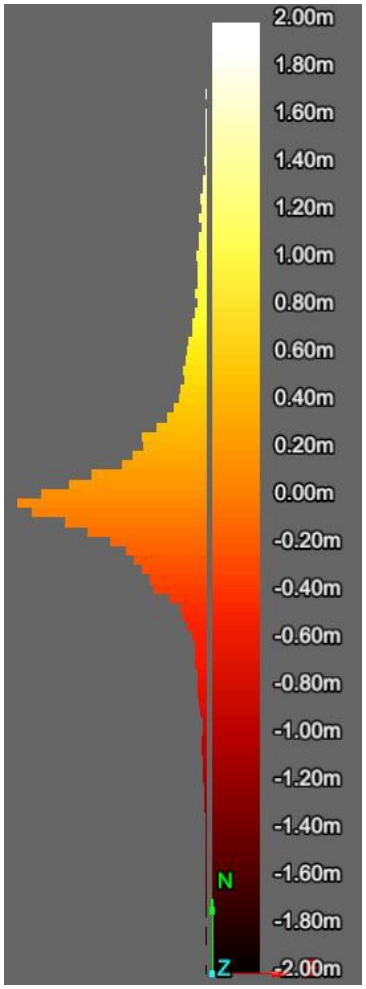


Figure 20 – North section legend (-2 m to 2 m) for 2022 to 2023 change model

5.2 MIDDLE SECTION

Figures 21 & 22 show the Middle section, where at 341955 m North (Figure 23) there remains a significant amount (~6 m) of accretion on the foreshore. This has come from the adjacent cliff face, which shows a loss of ~6 m. However, further areas of loss (~3 m) can be seen south of this point. From 341655 m North to 341811 m North (Figure 24) there are large areas of the cliff

face with losses of up to 5 m. Again, this area shows much smaller (~3.5 m) amounts of accretion in the foreshore. The legend for these figures can be seen in Figure 25.

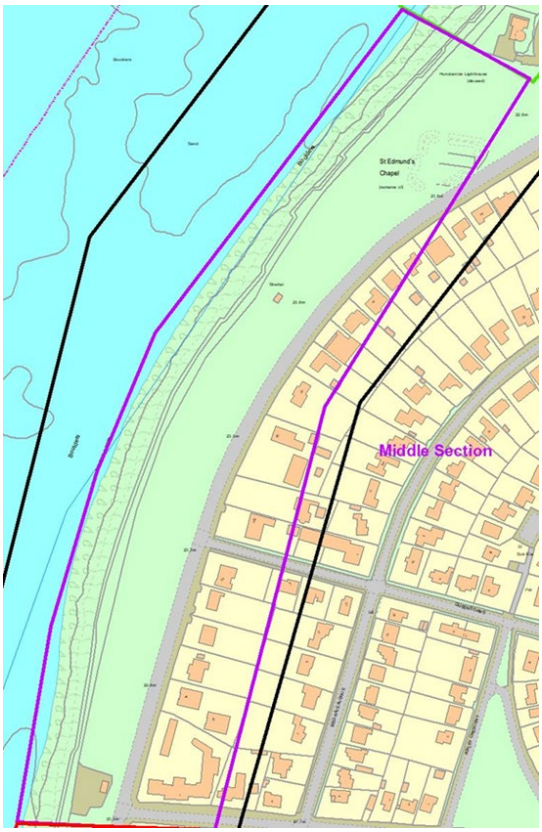


Figure 21 – Plan view of Middle section

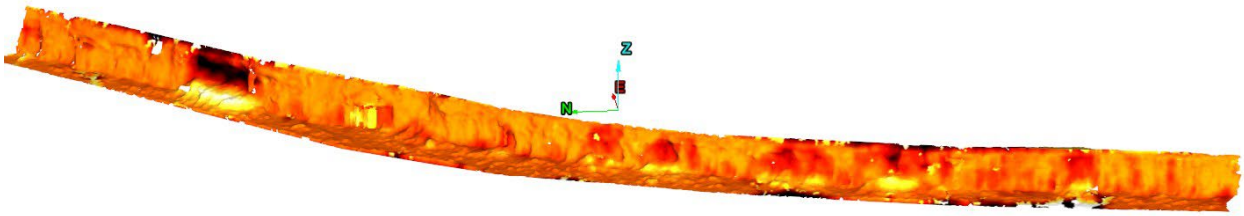


Figure 22 – 3D change model of view of the entire Middle section

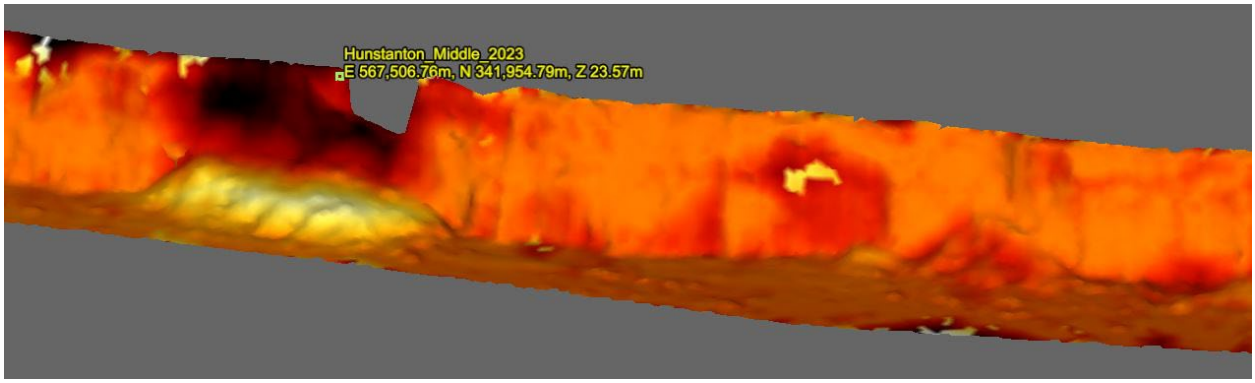


Figure 23 – 2010 to 2023 change model of the area around 341955 m North (for legend see Figure 22. Height range = 16.5 m to 18.8 m)

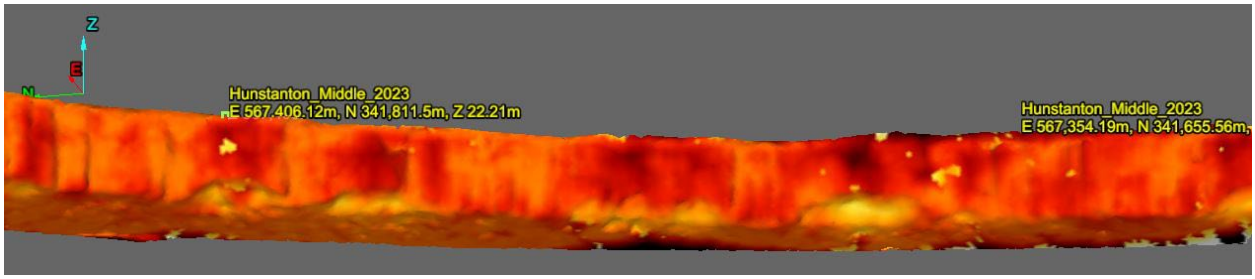


Figure 24 – 2010 to 2023 change model of 341666 m North to 341812 m North (for legend see Figure 22. Height range = 16.5 m to 18.8 m)

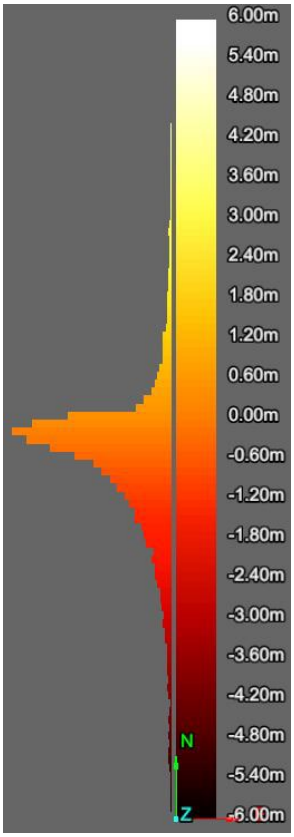


Figure 25 – Middle section legend (-6 m to 6 m) for 2010 to 2023 change model

Figure 26 shows the change between the 2022 and 2023 surveys, for the entire Middle section. It shows minor change across the full section from 341550 m North to 342050 m North, with significant areas of loss (~2 m) occurring at 341970 m North, 341846 m North and 341649 m North (Figure 27). The legend for Figures 26 and 27 can be seen in Figure 28, which shows a histogram of the +/- 2 m loss/gain distribution.

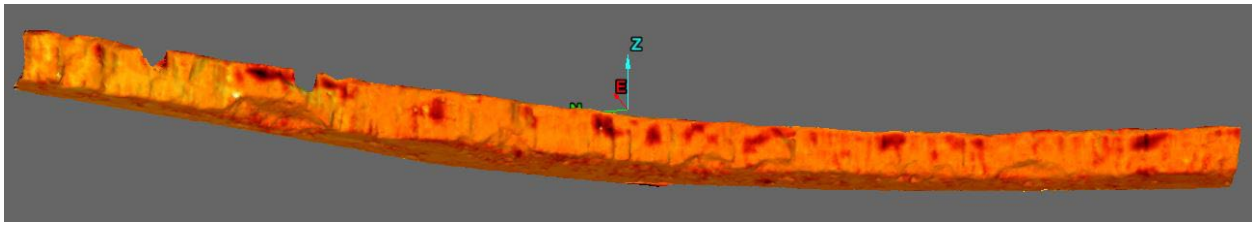


Figure 26 – 2022 to 2023 change model of entire middle section (for legend see Figure 24. Height range = 16.5 m to 18.8 m)

Figure 27 – 2022 to 2023 change model of 341469 m North to 341970 m North (for legend see Figure 28. Height range = 16.5 m to 18.8 m)

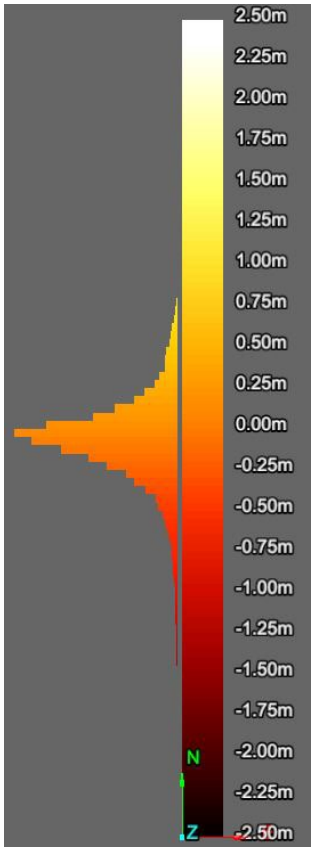


Figure 28 – Middle section legend (-2.5 m to 2.5 m) for 2022 to 2023 change model

5.3 SOUTH SECTION

The south section (Figures 27 & 28) is the shortest section of the survey area, covering a length of the cliffs of approximately 185 m. Within this section the cliff face from 341428 m North to 341474 m North (Figure 28) shows a significant amount of erosion of up to 4 m, again with similar levels of accretion on the foreshore of approximately 3.5 m. The legend for this figure can be seen in Figure 29.

Figure 29 – Plan view of South section

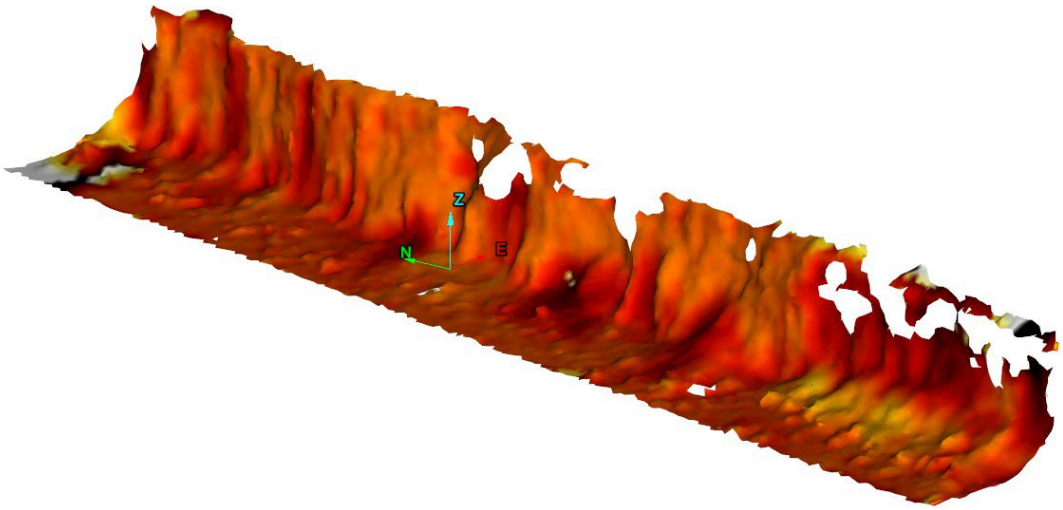


Figure 30 – 3D view of entire South section

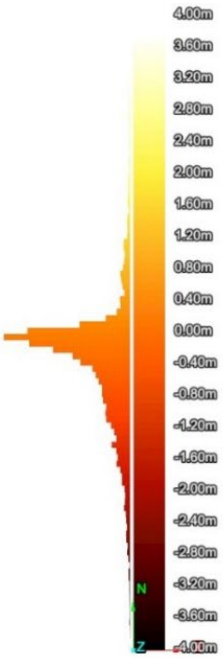


Figure 31 – South section legend (-4 m to 4 m) for 2010 to 2022 change model

Figure 30 shows the change between the 2010 and 2023 surveys, for the entire South section. It shows that there are areas of significant change (~2 m) at 341437 m North, 341449 m North and 341515 m North. It also shows that there is an area of accretion on the foreshore (~1.5 m) at 341370 m North. The legend for Figure 30 can be seen in Figure 31, which shows a histogram of the +/- 2 m loss/gain distribution.

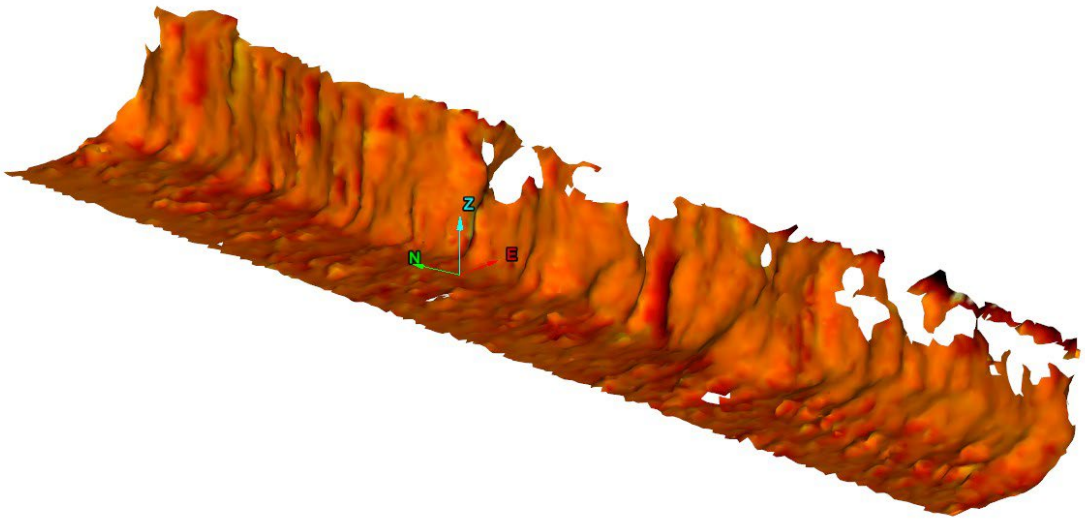


Figure 32 – 2021 to 2022 change model of entire south section (for legend see Figure 31. Height range = 14.0 m to 17.0 m)

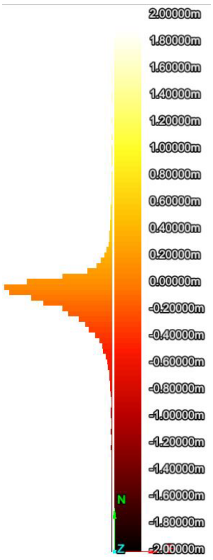


Figure 33 – South section legend (-2 m to 2 m) for 2021 to 2022 change model

Figure 32 shows the change between the 2022 and 2023 surveys, for the entire South section. It shows that there are areas of significant change (~2 m) at 341540 m North, 341501 m North and 341454 m North. The legend for Figure 32 can be seen in Figure 31, which shows a histogram of the +/- 2 m loss/gain distribution.

Table 4 shows the BNG Easting and Northing positions of the areas of change described in Chapter 5.

Section	Period	Figure	Northing	Easting
North	**2010-2023**	15	342229	567722
			342325	567788
		16	342115	567648
North	**2022-2023**	18	342318	567776
Middle	**2010-2023**	23	341955	567507
		24	341666	567354
			341812	567406
Middle	**2022-2023**	27	341649	567354
			341846	567423
			341670	567520
South	**2010-2023**	30	341437	567308
			341449	567312
			341515	567327
South	**2022-2023**	32	341454	567313
			341501	567322
			341540	567334

Table 4 – BNG Eastings and Northings for areas of change.

6 Beach Levels

The fusion surface models created previously, in Maptek I-Site Studio, were used for calculating the changes in beach level between the base year (2010) and the current year (2023) and from each intermediate year to the subsequent year, as follows:

- North – 2010 to 2023, 2022 to 2023 (2)
- Middle – 2010 to 2023, 2022 to 2023 (2)
- South – 2010 to 2023, 2022 to 2023 (2)

Change models were created using the *Colour Distance from Objects* tool. The resulting model is coloured by the distance between the objects according to the colour versus distance relationship specified. Beach models for all sections, from last year's report, can be found in Appendix 2.

Figure 34 shows the height change model for the North section from 2010 to 2023. Figure 35 shows the same section from 2022 to 2023. Figure 36 shows the legend for *both* sections of the cliff line.

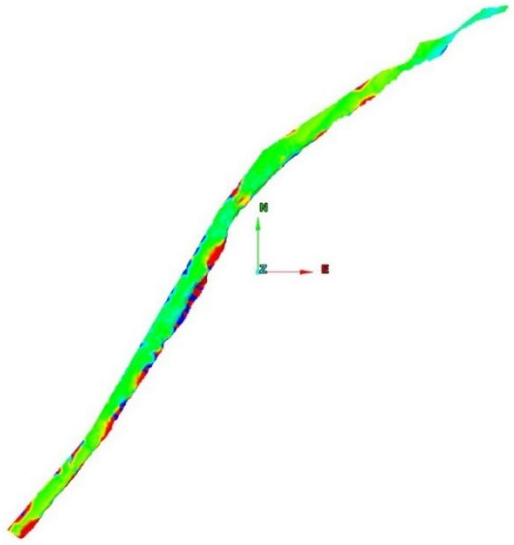


Figure 34 – 3D Beach height change model for North section from 2010 to 2023 (For legend see Figure 36)

Figure 34 shows that the beach has lowered by ~2.5 m in the northern-most section and has been raised by ~2.5 m in the southern-most section, during the period 2010 to 2023.

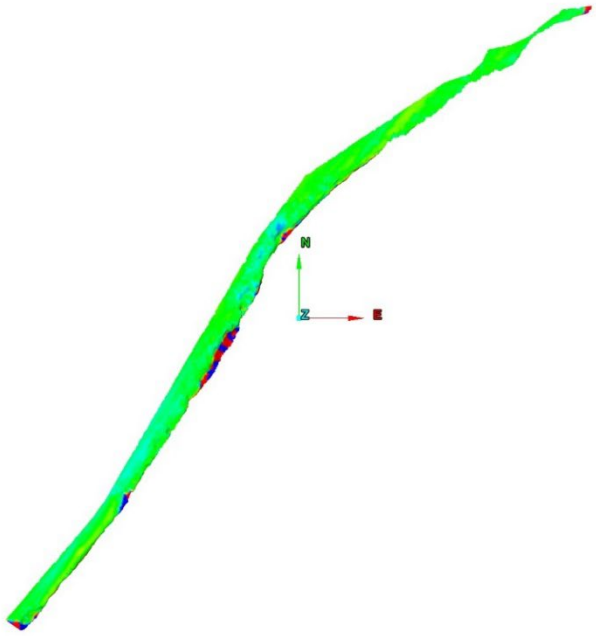


Figure 35 – 3D Beach height change model for North section from 2022 to 2023 (For legend see Figure 36)

Figure 35 shows that the beach has lowered by ~1 m in the central section but otherwise has remained constant, during the period 2022 to 2023.

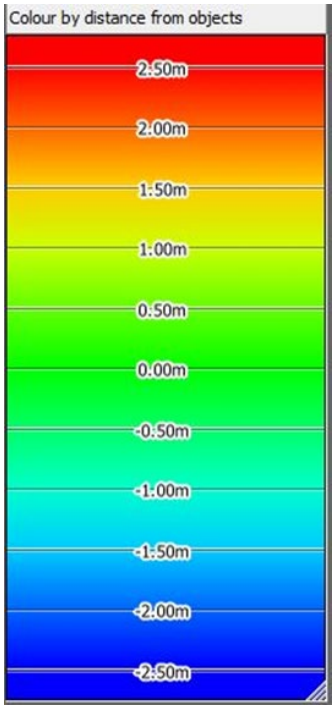


Figure 36 – Legends for *all* 2.5 m change sections (Figures 34 & 35)

Figure 37 shows the height change model for the Middle section from 2010 to 2023. Figure 38 shows the same section from 2022 to 2023.

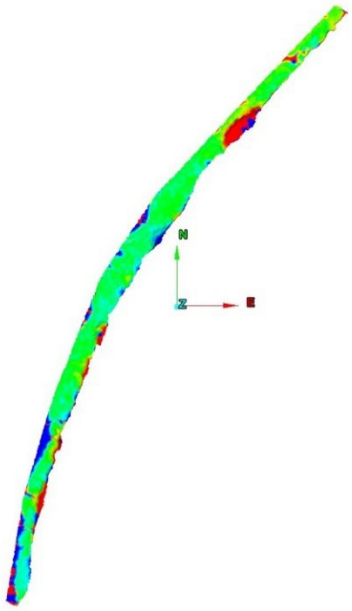


Figure 37 – 3D Beach height change model for Middle section from 2010 to 2023 (For legend see Figure 39)

Figure 37 shows that the beach has lowered by ~2.5 m in the southern-most and central sections and has been raised by ~2.5 m in the northern-most section, during the period 2010 to 2023.

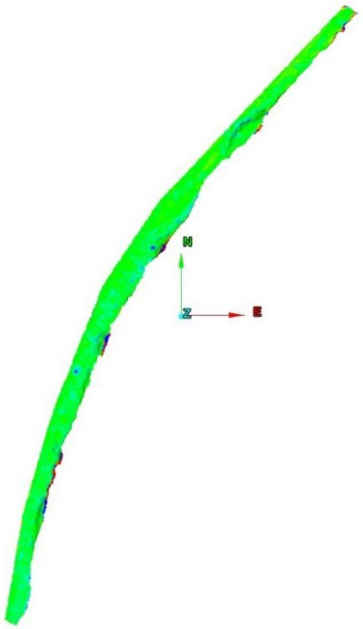


Figure 38 – 3D Beach height change model for Middle section from 2022 to 2023 (For legend see Figure 39)

Figure 38 shows that the beach has remained fairly constant, during the period 2022 to 2023.

All in all, the beach across the North and Middle sections of the cliffs has remained constant, with some (~2m) changes over the 2010 to 2023 period.

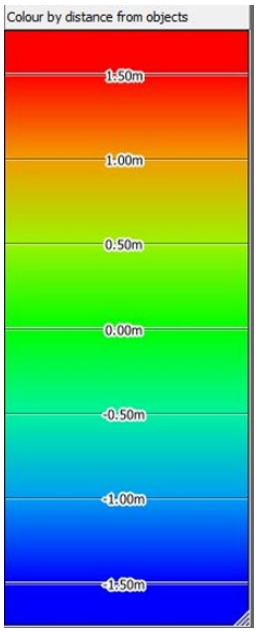


Figure 39 – Legends for *all* 1.5 m change sections (Figures 37 & 38)

Figure 40 shows the height change model for the South section from 2010 to 2023. Figure 41 shows the same section from 2022 to 2023.

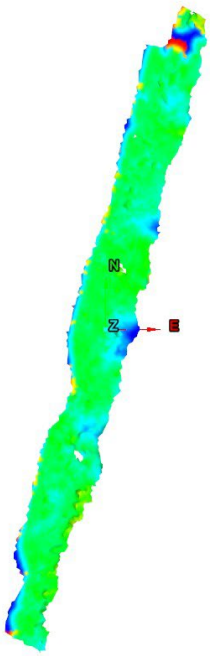


Figure 40 – 3D Beach height change model for South section from 2010 to 2023 (For legend see Figure 42)

Figure 41 shows that the beach has lowered by ~2.5 m in the northern-most section, during the period 2010 to 2023.

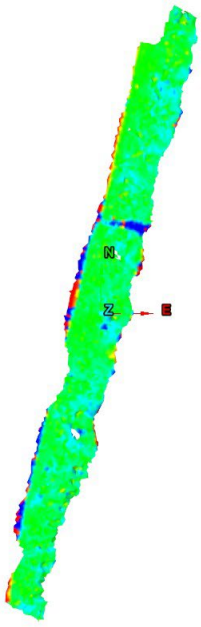


Figure 41 – 3D Beach height change model for Middle section from 2022 to 2023 (For legend see Figure 42)

Figure 42 shows that the beach has remained fairly constant, during the period 2022 to 2023.

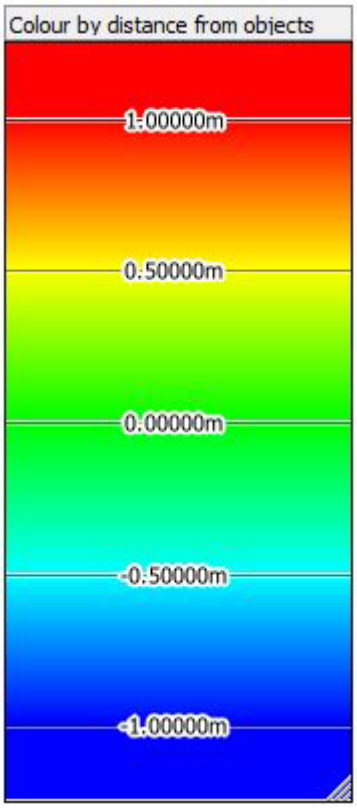


Figure 42 – Legends for *all* 1.5 m change sections (Figures 40 & 41)

7 Estimation of Erosion

In the Interim Baseline Report, compiled as part of the **H**unstanton **C**oastal **M**anagement **P**lan (**HCMP**), four properties were identified as being at risk of erosion, in the next 100 years. These properties are in Figure 43 and consist of three shelters and the Lighthouse. Four additional properties were added for the 2020-2021 annual survey, along with three positions of the B1161 (Cliff Parade Road) where it intersects with the junctions of King's Road, Clarence Road and Lincoln Square South. These properties are included again in this survey. The properties are shown in Figure 44 and consist of the Lighthouse Café, the Coastguard Cottages, the Coastguard Lookout and the ruins of St. Edmund's Chapel. Their approximate position and distance to the nearest cliff edge are shown in Figure 45. By combining these with the recession rates given in Table 3, it is possible to generate an Erosion Risk Rating (Table 5).

Figure 7-5: Map showing properties in Unit A at risk of erosion in the next 100 years

Figure 43 – Plan of area with initial 'at risk' properties shown

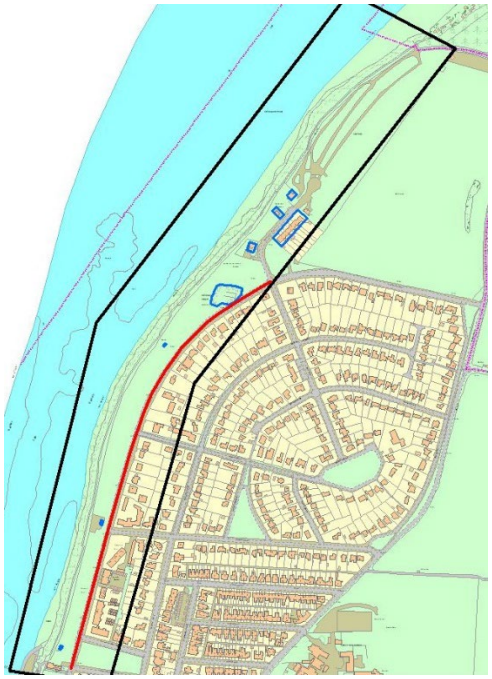


Figure 44 – Plan of section under investigation, showing initial and added 'at risk' properties and road section

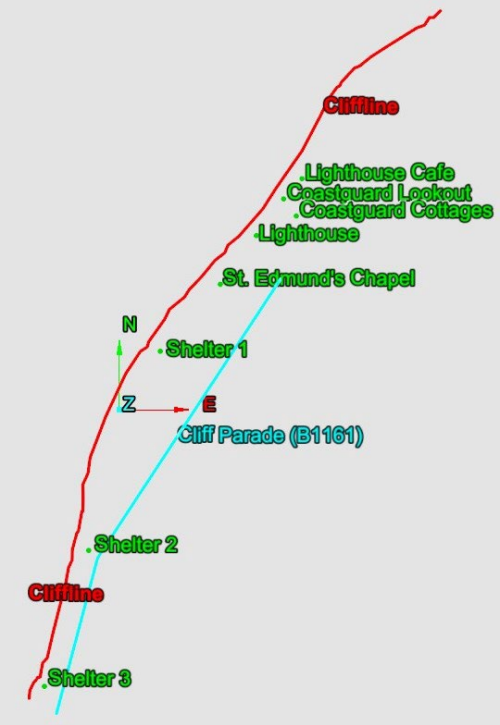


Figure 45 – Position of 'at risk' properties relevant to cliff edge

Table 5– Property Erosion Risk Rating

Property Name	Approx. Easting (m)	Approx. Northing (m)	Closest cliff edge (m)	Horizontal Change (m)	Loss at Property (m)	Risk Rating (2023)	Risk Rating (2022)	Rating Change
Lighthouse	567625	342058	19	4	5.5	*11.6*	*11.6*	*0.0*
Shelter 1	567473	341875	22	3	1	*1.4*	*0.9*	*0.5*
Shelter 2	567360	341560	25	3	2.5	*3.0*	*3.0*	*0.0*
Shelter 3	567290	341345	16	3	2	*3.8*	*3.8*	*0.0*
St. Edmund's Chapel	567568	341981	31	3	2.5	*2.4*	*1.6*	*0.8*
Coastguard Lookout	567668	342116	19	4	3	*6.3*	*4.7*	*1.6*
Coastguard Cottages	567688	342089	48	4	5	*4.2*	*1.8*	*2.4*
Lighthouse Café	567697	342148	25	3	2.5	*3.0*	*2.0*	*1.0*
Cliff Parade (King's Road)	567663	341989	94	5	5.5	*2.9*	*1.9*	*1.0*
Cliff Parade (Clarence Road)	567374	341548	38	4	2.5	*2.9*	*1.9*	*1.0*
Cliff Parade (Lincoln Square South)	567309	341302	49	3	2	*1.2*	*1.2*	*0.0*

In order to calculate the Erosion Risk Rating, the following equation was applied to each 'at risk' property as follows:

$$R = \frac{(M \; x \; L) x \; 10}{C}$$

Where: R = Erosion Risk Rating

M = *Horizontal Change (m)

L = ^Loss at Property (m)

C = Closest cliff edge to the property (m)

The properties that remain most at risk (Table 5) are the Lighthouse with an R value of 11.6, the Coastguard Lookout with an R value of 6.3, an increase of 1.6, and the Coastguard Cottages with an R value of 4.2, an increase of 2.4. The only other property to change is Cliff Parade (at King's Road) with an R value of 2.9, an increase of 1.0.

Shelter 3 remains the closest property to the cliff at 16 m, whilst the Lighthouse and the Coastguard Lookout are both 19 m from the cliff.

Note:*Horizontal Change relates to the amount of loss at any point on the cliff below the property (i.e., depth of a block-fall etc.) from 2010 to 2023, in metres.

^Loss at Property relates to the amount of loss at the cliff-line itself from 2010 to 2023, in metres.

8 Trigger Levels

A pilot study of Trigger Levels was discussed in a meeting with BCKLWN on July 8, 2022, and as a result this addendum was added to the 2022 report. They are now a section in all following reports. The Trigger Levels were prepared for the section of cliff between the Lighthouse and the Shelter 3 (North, Middle and South sections), for the years 2010 to 2100.

To work out the possible loss and change to the cliffs at Hunstanton in the area of the North & Middle sections, the average loss per year needed to be calculated. Table 6 shows the cliff recession values for the sections from October 2012 to August 2023 and the average loss per year value calculated from these (North = 1201 m^3/year & 2537 t/year, Middle = 1027 m^3/year & 2362 t/year). From these values a forecasted projection was made for the years 2025, 2030, 2040, 2050, 2070, 2090 & 2100; these can be seen in Figures 46 and 47.

Table 6 – Estimated cliff recession projections (loss in m^3 and tonnes)

Period		Elaspsed Time	Cumulative Time	North Section			Middle Section			South Section		
Start	End	(days)	(days)	Material Loss (m3)	Cumulative Loss (m3)	Cumulative Loss/m (m3)	Material Loss (m3)	Cumulative Loss (m3)	Cumulative Loss/m (m3)	Material Loss (m3)	Cumulative Loss (m3)	Cumulative Loss/m (m3)
Aug-10	Oct-12	785	785							200	200	1
Oct-12	Oct-17	1829	2614	1850	1850	4	5500	5500	10	2000	2200	12
Oct-17	Mar-19	522	3136	1200	3050	6	1250	6750	12	150	2350	13
Mar-19	Aug-20	510	3646	2000	5050	10	3500	10250	18	950	3300	18
Aug-20	Mar-21	239	3885	2700	7750	15	500	10750	19	100	3400	18
Mar-21	Apr-22	370	4255	5100	12850	25	150	10900	19	150	3550	19
Apr-22	Apr-23	365	4620	2340	15190	29	2092	12992	23	420	3970	21
Loss/Year					***1201***			***1027***			**314**	
Apr-23	Aug-25	853	5473		17992	35		15388	27		4702	8
Aug-25	Aug-30	1826	7299		23996	47		20524	36		6272	11
Aug-30	Aug-40	3653	10952		36005	70		30795	54		9410	16
Aug-40	Aug-50	3652	14604		48014	93		41066	71		12549	22
Aug-50	Aug-70	7305	21909		72032	140		61609	107		18826	33
Aug-70	Aug-90	7305	29214		96050	187		82152	143		25103	44
Aug-90	Aug-00	3652	32866		108059	210		92423	161		28242	49

Period		Elaspsed Time (days)	Cumulative Time (days)	North Section			Middle Section			South Section		
Start	End			Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)
Aug-10	Oct-12	785	785							460	460	2
Oct-12	Oct-17	1829	2614	4255	4255	8	12650	12650	22	4600	5060	27
Oct-17	Mar-19	522	3136	2760	7015	14	2875	15525	27	345	5405	29
Mar-19	Aug-20	510	3646	4600	11615	23	8050	23575	41	2185	7590	41
Aug-20	Mar-21	239	3885	6210	17825	35	1150	24725	43	230	7820	42
Mar-21	Apr-22	370	4255	11730	29555	57	345	25070	44	345	8165	44
Apr-22	Apr-23	365	4620	5382	34937	68	4812	29882	52	966	9131	49
Loss/Year					***2762***			***2362***			***722***	
Apr-23	Aug-25	853	5473		41381	80		35393	69		10815	21
Aug-25	Aug-30	1826	7299		55191	107		47205	92		14425	28
Aug-30	Aug-40	3653	10952		82812	161		70829	138		21643	42
Aug-40	Aug-50	3652	14604		110433	214		94453	183		28862	56
Aug-50	Aug-70	7305	21909		165674	322		141701	275		43300	84
Aug-70	Aug-90	7305	29214		220915	429		188949	367		57738	112
Aug-90	Aug-00	3652	32866		248536	483		212573	413		64956	126

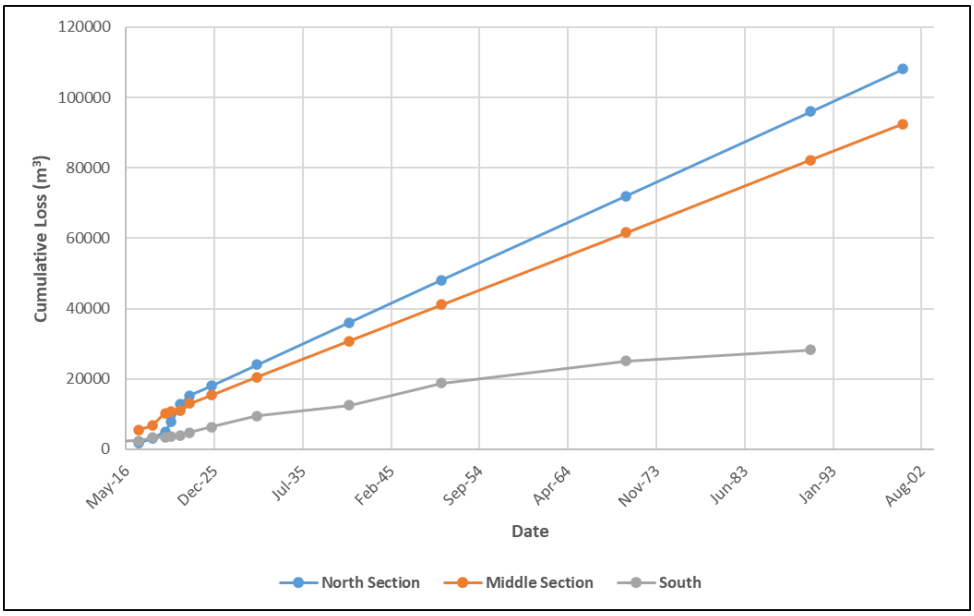


Figure 46 – Projected Cumulative Loss (m3) v Time

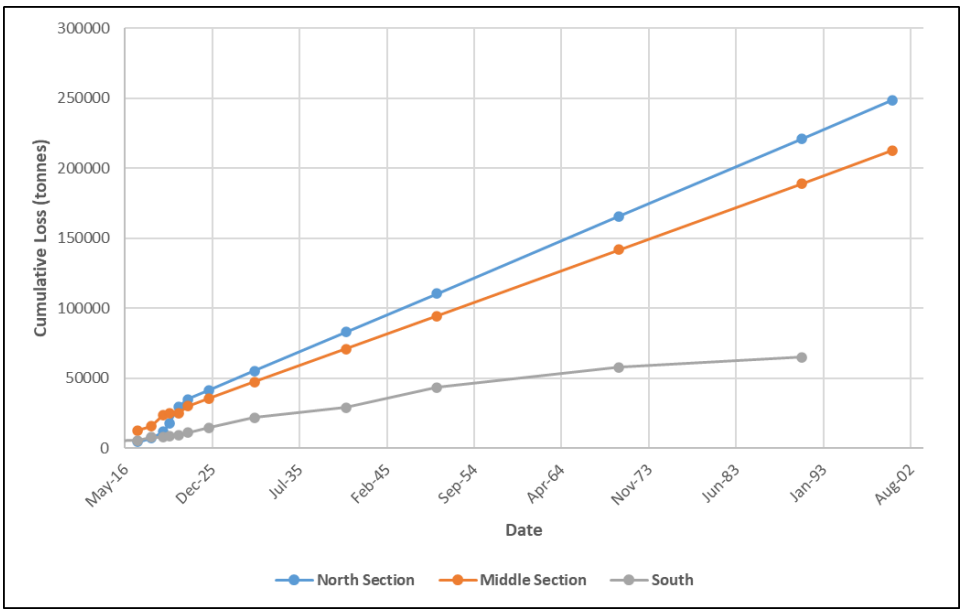


Figure 47 – Projected Cumulative Loss (tonnes) v Time

An alternative way of showing this is to forecast the Risk rating values for the Lighthouse, Coastguard Lookout, Coastguard Cottages, Lighthouse Café, St. Edmund's Chapel, Shelter 1 and Cliff Parade (King's Road). Table 8 shows the increased Risk rating values for these properties. These values were calculated by taking the average Horizontal Change, Loss at Property and Closest Cliff Edge values and projecting them to the years 2025, 2030, 2040, 2050, 2070, 2090 and 2100.

The Trigger Levels can be assumed where the Closest Cliff Edge has reduced to less than the preferred minimum value of *10 m (Lighthouse – 2070, Coastguard Lookout – 2070, Lighthouse Café & Shelter 1 – 2090), or where the Loss at the Property exceeds 10 m (Lighthouse, Coastguard Cottages & Cliff Parade – 2040 onwards; Coastguard Lookout, Lighthouse Café & St. Edmund's Chapel – 2070 onwards). Table 7 shows these calculated changes.

Table 7 – Projected Cliff edge distance & Loss

Property Name	Edge at 2023	Change/ yr (m)	Loss/yr (m)	Edge 25	Change 25	Loss 25	Edge 30	Change 30	Loss 30	Edge 40	Change 40	Loss 40	Edge 50	Change 50	Loss 50	Edge 70	Change 70	Loss 70	Edge 90	Change 90	Loss 90	Edge 2100	Change 210	Loss 2100
Lighthouse	19	0.3	0.4	18.4	4.7	6.5	16.8	6.3	8.7	13.6	9.5	13.0	10.5	12.6	17.4	4.1	19.0	26.1	-2.2	25.3	34.8	-8.5	28.5	39.1
Coastguard Lookout	19	0.3	0.2	18.4	4.7	3.6	16.8	6.3	4.7	13.6	9.5	7.1	10.5	12.6	9.5	4.1	19.0	14.2	-2.2	25.3	19.0	-8.5	28.5	21.3
Coastguard Cottages	50	0.3	0.4	49.4	4.7	5.9	47.8	6.3	7.9	44.6	9.5	11.9	41.5	12.6	15.8	35.1	19.0	23.7	28.8	25.3	31.6	22.5	28.5	35.6
Lighthouse Café	25	0.2	0.2	24.5	3.6	3.0	23.3	4.7	3.9	21.0	7.1	5.9	18.6	9.5	7.9	13.9	14.2	11.9	9.1	19.0	15.8	4.4	21.3	17.8
St. Edmund's Chapel	31	0.2	0.2	30.5	3.6	3.0	29.3	4.7	3.9	27.0	7.1	5.9	24.6	9.5	7.9	19.9	14.2	11.9	15.1	19.0	15.8	10.4	21.3	17.8
Shelter 1	22	0.2	0.1	21.5	3.6	1.2	20.3	4.7	1.6	18.0	7.1	2.4	15.6	9.5	3.2	10.9	14.2	4.7	6.3	19.0	6.3	1.4	21.3	7.1
Cliff Parade (King's Road)	94	0.4	0.4	93.2	5.9	6.5	91.2	7.9	8.7	87.3	11.9	13.0	83.3	15.8	17.4	75.4	23.7	26.1	67.5	31.6	34.8	59.6	35.6	39.1

Table 8 – Projected Risk Rating (2025 to 2100)

Property Name	Approx. Easting (m)	Approx. Northing (m)	Closest cliff edge (m)	Horizontal Change (m)	Loss at Property (m)	Cumulative Time (days)	Risk Rating (2023)	Risk Rating (2025)	Risk Rating (2030)	Risk Rating (2040)	Risk Rating (2050)	Risk Rating (2070)	Risk Rating (2090)	Risk Rating (2100)
Lighthouse	567625	342058	19	4	5.5	4620	11.6	16.8	32.7	90.7	210.1	1195.9	-4021.1	-1307.9
Coastguard Lookout	567668	342116	19	4	3.0	4620	6.3	9.2	17.8	49.5	114.6	652.3	-2193.3	-713.4
Coastguard Cottages	567688	342089	48	4	5.0	4620	4.2	5.7	10.4	25.2	48.2	128.0	277.6	450.1
Lighthouse Café	567697	342148	25	3	2.5	4620	3.0	4.3	8.0	20.1	40.3	121.8	329.2	869.4
St. Edmund's Chapel	567568	341981	31	3	2.5	4620	2.4	3.4	6.4	15.6	30.5	85.0	198.5	366.2
Shelter 1	567473	341875	22	3	1.0	4620	1.4	2.0	3.7	9.4	19.2	62.2	196.4	1111.6
Cliff Parade (King's Road)	567663	341989	94	5	5.5	4620	2.9	4.1	7.5	17.7	33.0	82.0	162.9	233.5

Table 8 shows where the Risk Rating value exceeds 50 (Orange), 100 (Red) or has failed and therefore is negative (Purple).

The Horizontal Change and Loss at Property values were determined by dividing the 2023 value by the cumulative change to give a yearly value e.g., 0.3 m (Change) and 0.5 m (Loss) for the Lighthouse, and multiplying it by the additional years, then subtracting them from the 2023 values. The Risk Rating was then calculated using the same formula as in Section 7.

Note: *10 m is the preferred minimum distance agreed with the BCKLWN.

9 Fence Lines

At a meeting with BCKLWN on August 29, 2023 it was agreed that in addition to the Trigger Levels, BGS would provide information on Fence Line positions and their potential life span for the 2023 report.

However, the data provided, although massive (>3 Billion points) does not show enough of the cliff top, above the beach (probably because the scan has only been acquired from the beach), and there are no discernible fence lines apparent in the data. Figure 48 shows a Nadir image of all 3 scans and Figure 49 shows a close-up of the cliff line. Both images show ***NO*** fence lines.

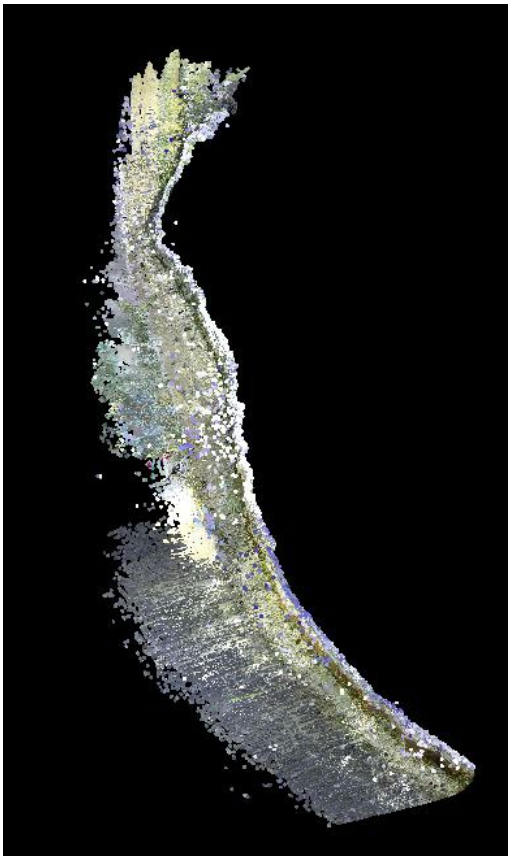


Figure 48 – Nadir image of scans, showing *No* fence lines

Figure 49 – Close-up image of cliff line, showing *No* fence lines

After consultation with BCKLWN it was agreed to look at the previous (2022) year's survey data to see if they had captured the fence lines. Unfortunately, they had not.

It was also agreed to look at alternate data, such as the Anglian Coastal Monitoring Programme's aerial photography data for the Hunstanton area, which does show the fence lines. This data will be used in the 2024 report to indicate Fence Line positions and calculate their potential life spans.

10 Standards & Methodologies

All BGS ground-based geomatics surveys follow the methodology set out in Jones (2017) and the specification in Jones (2019). The latter is split into three specific protocols:

- Specification for Collection of TLS Data – this includes pre-survey scanner choice and preparation of equipment; health and safety; use of survey equipment in the field; undertaking the survey; naming convention.
- Specification for Registering of TLS Data – this includes geo-referencing scans to OSGB36, or other national, grid co-ordinates; aligning and combining point clouds; cleaning and validating point clouds; exporting scans.
- Specification for Delivery and Archiving of TLS Data – this includes project deliverables; location of both raw and registered point clouds; file naming; metadata.

11 Technical Summary

This report was produced by the British Geological Survey, for the Borough Council of King's Lynn & West Norfolk. The purpose of this report is to act as an annual record of cliff surveys at Hunstanton, Norfolk, using a LiDAR scan provided to the client by the Anglian Coastal Monitoring Programme, covering the year 2023, and consists of the following:

- A review of the data provided and the extents of the survey.
- Volume calculations (Table 3) of loss, including a series of cross-sections and graphs to illustrate these changes.
- An analysis of the change in the cliff, portrayed as 3D Change models of the full section, split into three parts: North, Middle and South.
- An estimation of the degree of erosion by determining an Erosion Risk Rating (Table 4).
- An analysis of the Beach Level changes from 2010 to 2023.
- Trigger Levels for management implementation for the north and middle cliff sections up to 2100.
- Fence Line positions and potential lifespan were not able to be calculated due to lack of visibility in provide scans.
- Appendices containing a suite of Surface and Change models.

In summary, the report found the following:

- The data from the 2023 LiDAR scan covers the North, Middle and South sections of the cliffs. They have been analysed using these same sections of cliff.
- The Volume Calculation data (Table 3) show a total loss of 32152 m^3 across the full 1.275 km section, which is 2542 m^3/year or 5846 tonnes/year (estimated). This is an increase across the three sections of 199 m^3/year or 456 tonnes/year (estimated). The North section is still the most active, with an average loss of 1201 m^3/year (up from 1103 m^3), followed by the Middle section, with an average loss of 1027 m^3/year (up from 936 m^3). The South section is the least active, with an average loss of 314 m^3/year.

- The North and Middle sections show similar horizontal movement of parts of their cliff line of ~5 m. The South section shows a lower rate of erosion. Each section of the cliff was analysed separately:
    - North – The greatest amount of loss since survey establishment in 2010 (>4 m) occurs between BNG 342229 m to 342325 m North (Figure 13) and in the area directly in front of the Lighthouse and Coastguard Lookout around BNG 342115 m North (Figure 14). The largest change between 2022 and 2023 surveys (~2 m) can be seen at BNG 342090 m North, 342150 m North, and 342222 m North (Figure 16).
    - Middle – At BNG 341955 m North (Figure 20) there is a significant amount of accretion (~6 m) on the foreshore and loss (~6 m) from the cliff face, since survey establishment in 2010. Between BNG 341655 m and 341811 m North (Figure 21) large areas of erosion (~5 m) can be seen. The largest change between 2022 and 2023 surveys (~2 m) can be seen at BNG 342037 m and 341647 m North (Figure 23).
    - South – From BNG 341428 m North to 341474 m North (Figure 28) there is a large amount of accretion (~4 m) on the foreshore and loss (~3.5 m) from the cliff face, since survey establishment in 2010. The largest change between 2022 and 2023, at BNG 341437 m North, 341449 m North and 341515 m North is 2 m.
- By combining the results obtained from the Volume Calculations (Section 4) and from the Change Analysis (Section 5) we are able to generate an Erosion Risk Rating for the 'at risk' properties (Table 4). This rating shows that the properties most at risk are the Lighthouse (R = 11.6), the Coastguard Lookout (R = 6.3) and the Coastguard Cottages (R = 4.2) The only other property to change is Cliff Parade (King's Road) (R = 2.9, +1.0).
- Beach levels were modelled and calculated for each section separately:
    - North – The beach has lowered by ~2.5 m in the northern-most section and has been raised by ~2.5 m in the southern-most section, during the period 2010 to 2023 (Figure 34). The beach has lowered by ~1 m in the central section but otherwise has remained constant, during the period 2022 to 2023 (Figure 35).
    - Middle – The beach has lowered by ~2.5 m in the southern-most and central sections and has been raised by ~2.5 m in the northern-most section, during the period 2010 to 2023 (Figure 37). The beach has remained constant, during the period 2022 to 2023 (Figure 38).
    - South – The beach has lowered by ~2.5 m in the northern-most section, during the period 2010 to 2023 (Figure 40). The beach has remained constant, during the period 2022 to 2023 (Figure 41).

12 Conclusions

The following conclusions can be made from the analysis of the 2023 LiDAR data:

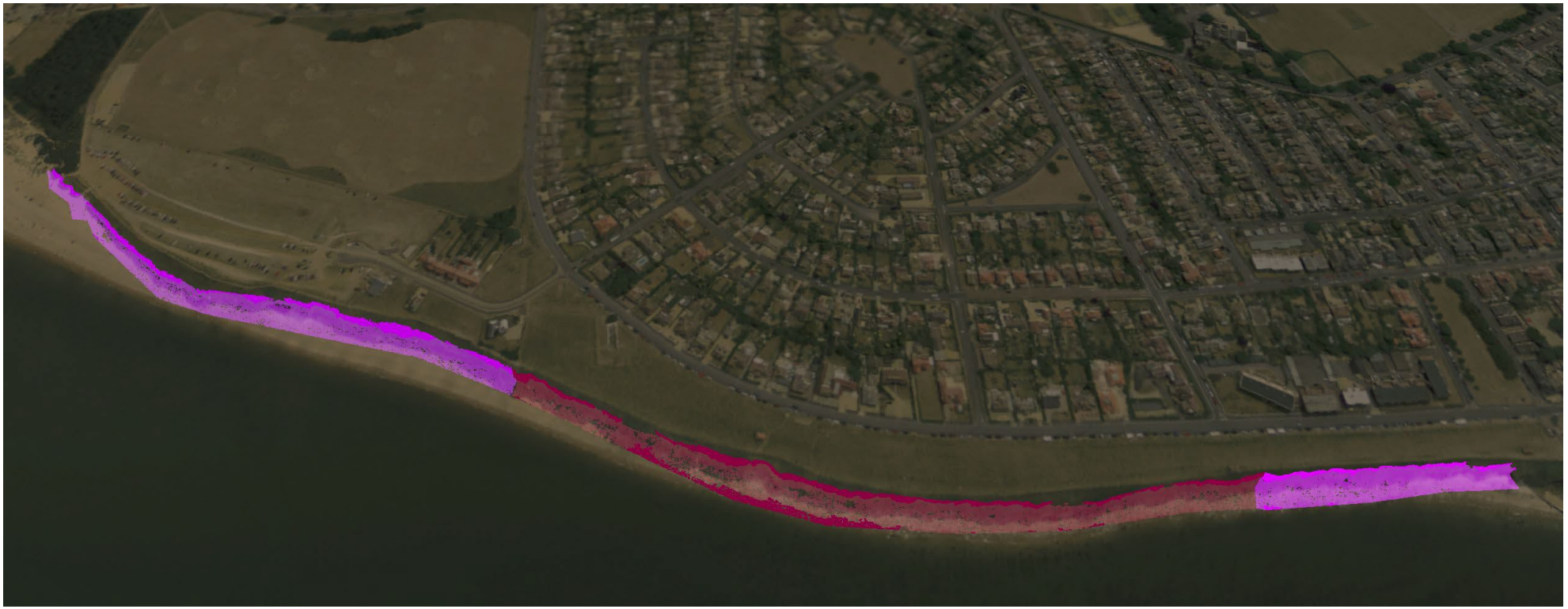
- Some accelerated erosion has been observed over the 2022-2023 survey period, especially in the Middle section.
- The cliff erosion rates remain mostly in-line with the previous reports, with a slight increase for the period 2022-2023 of 0.01 m/year.
- The current cliff erosion follows the predictions noted in the Hunstanton Coastal Management Plan (HCMP), Interim Baseline Report (HCMP, 2018).
- The annual monitoring and cliff regression analysis and reporting should continue until at least 2025.
- The most active area of cliff erosion is still the northern section of the cliffs, in front of the Lighthouse and the Coastguard Lookout.

- Beach levels have lowered consistently across both sections over the 2010-2023 survey period.
- Updated Trigger Levels project that by 2050 the Lighthouse and the Coastguard Lookout ***will*** be at risk, by 2070 the Coastguard Cottages and the Lighthouse Café ***will*** be at risk, and by 2090 S. Edmund's Chappel, Selter 1 and Cliff Parade ***will*** be at risk. This is because the preferred trigger level of the cliff edge being within 10 meters of the property is projected to have been reached.
- These levels show a useful insight into future risk and should be considered keeping in future reports.
- Some changes may be required to the active HCMP*.
- Better resolution data, with fewer points and more visibility above the cliff line, is required to calculate the Fence Lines, from the supplied LiDAR data.

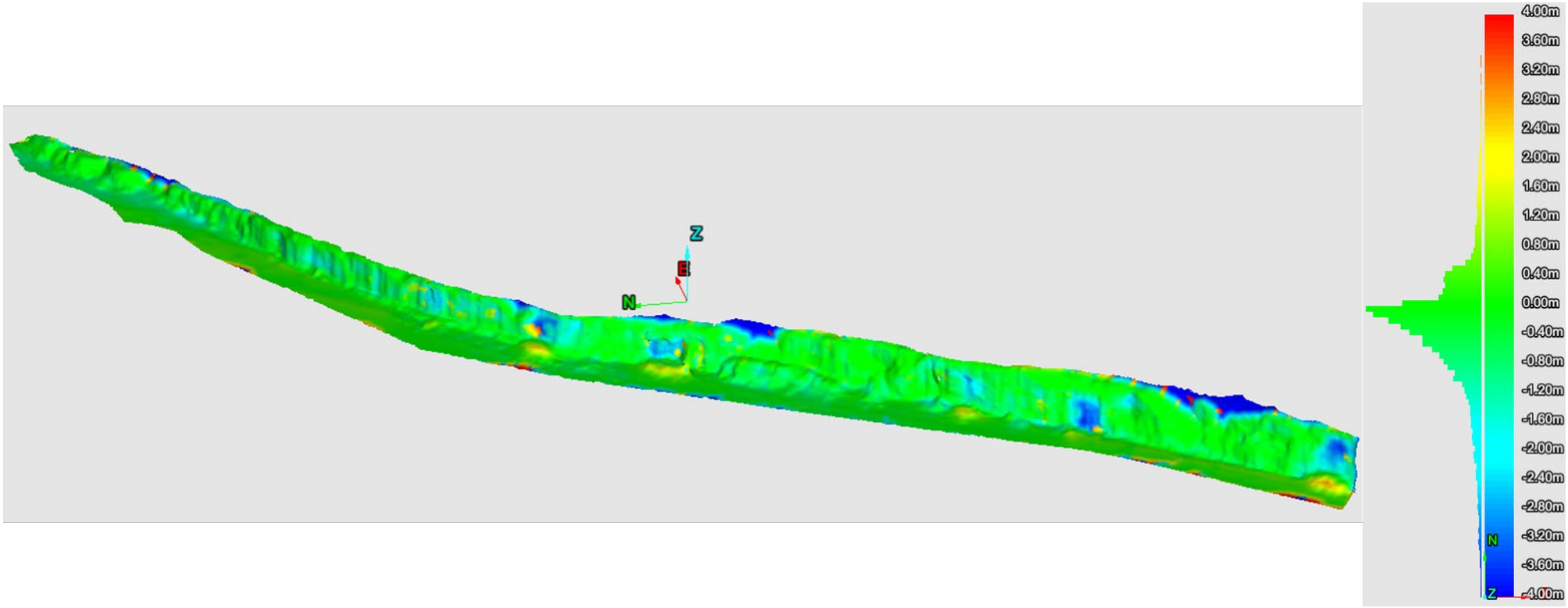
Note: *The HCMP stated preferred management options may be required in year 50, 55 or 60 of the 100-year Plan (relating to 2068, 2072 and 2078 respectively). Based on the trigger point predictions from this report, the preferred management option could be required in some locations from 2050 onwards (relating to year 32 of the HCMP). The updated and higher resolution data which has been collected from this monitoring programme is further clarifying when future management may be required. Thus, this is validating the usefulness of this annual data collection and report.

Appendix 1 Change Models

Aerial view of entire section

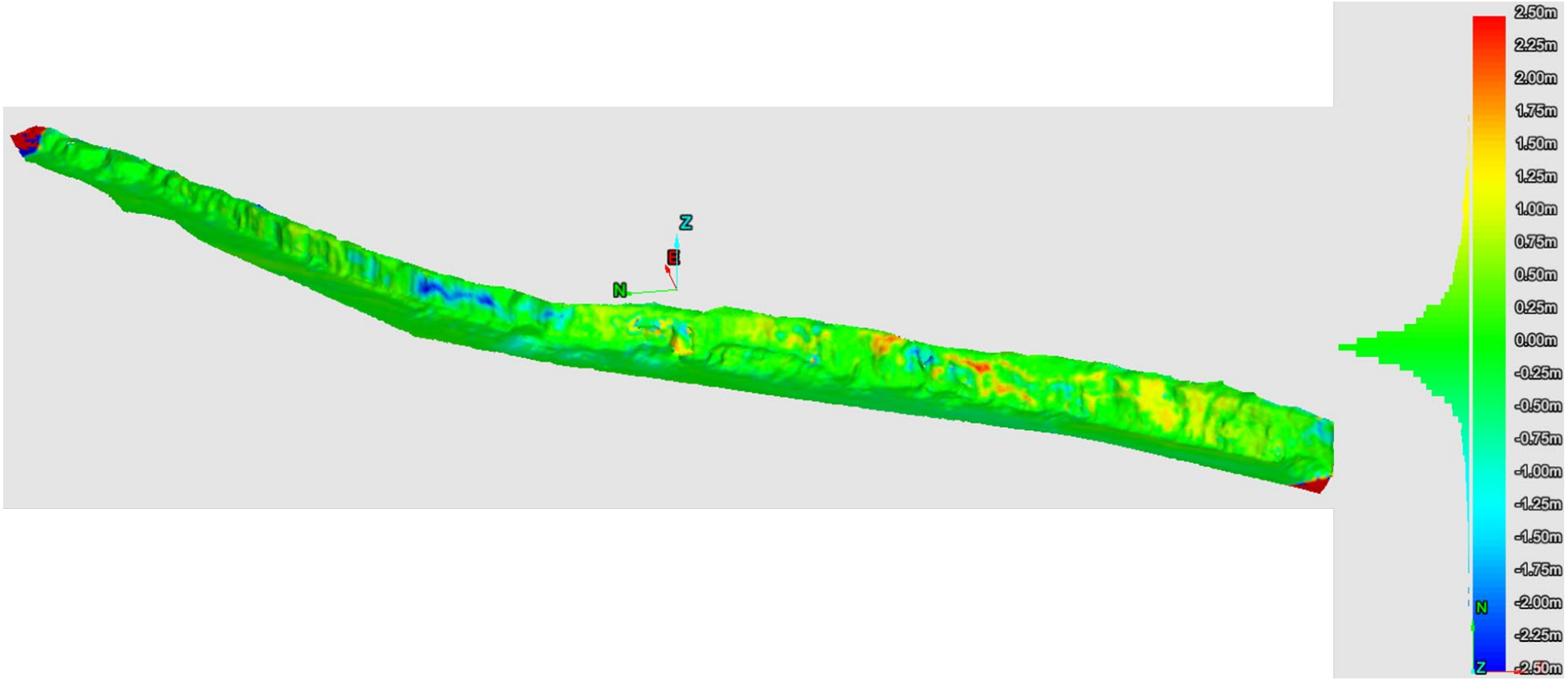


North Section, 2010 to 2023 (Extents: E 567934 m, N 342430 m to E 567586 m, N 342048 m)



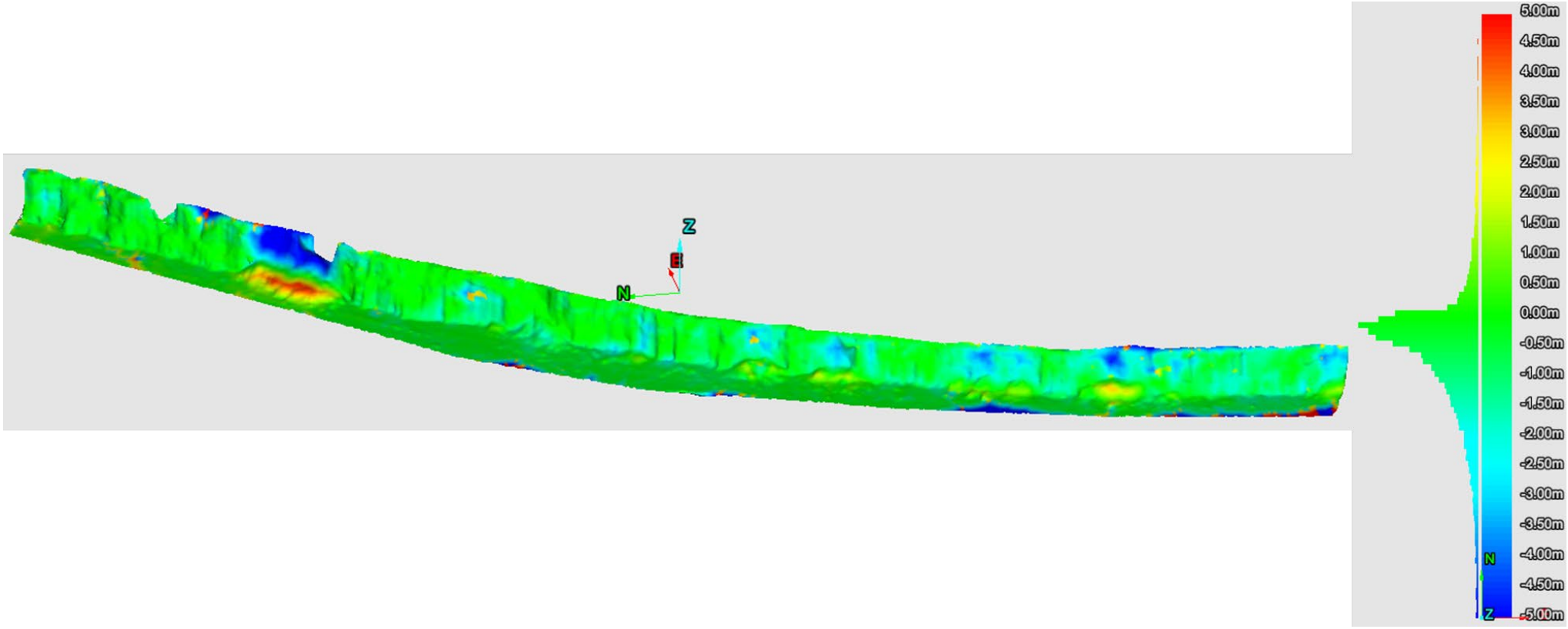
Note: Change = -4.0 m (Blue) to +4.0 m (Red)

North Section, 2022 to 2023 (Extents: E 567934 m, N 342430 m to E 567586 m, N 342048 m)



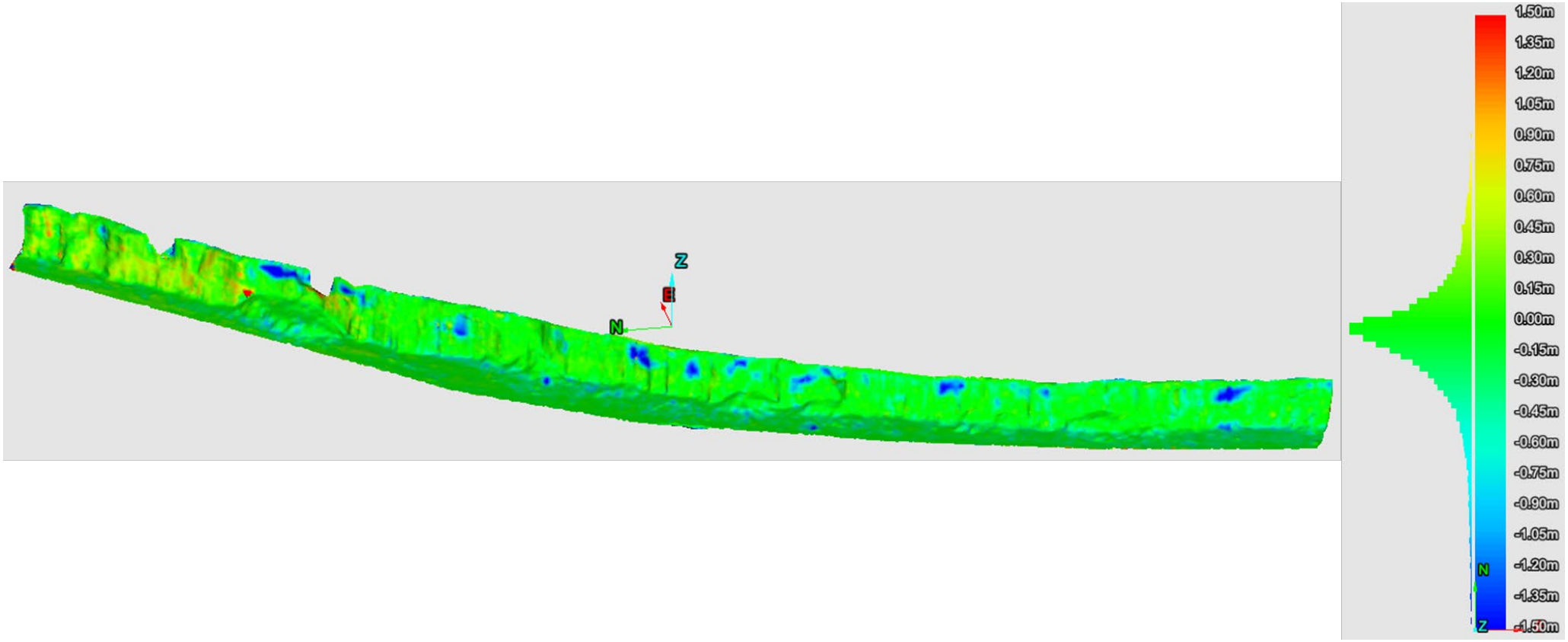
Note: Change = -2.5 m (Blue) to +2.5 m (Red)

Middle Section, 2010 to 2023 (Extents: E 567574 m, N 342053 m to E 567348 m, N 341604 m)



Note: Change = -5.0 m (Blue) to +5.0 m (Red)

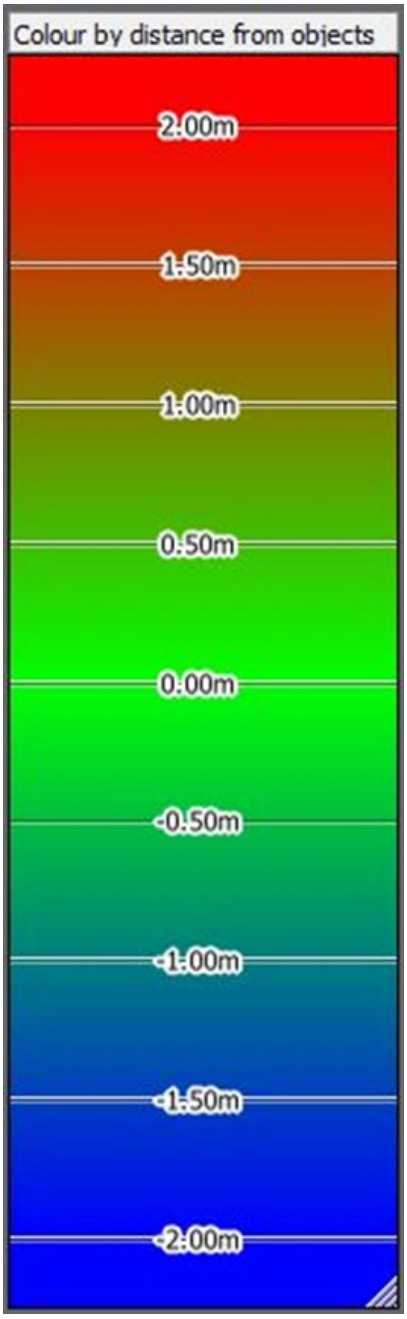
Middle Section, 2022 to 2023 (Extents: E 567574 m, N 342053 m to E 567348 m, N 341604 m)



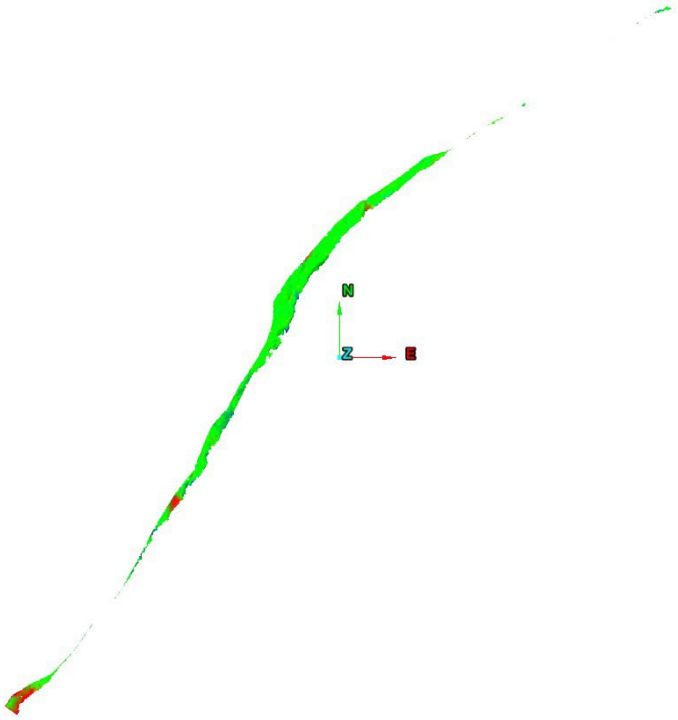
Note: Change = -1.5 m (Blue) to +1.5 m (Red)

Appendix 2 Beach Level Models

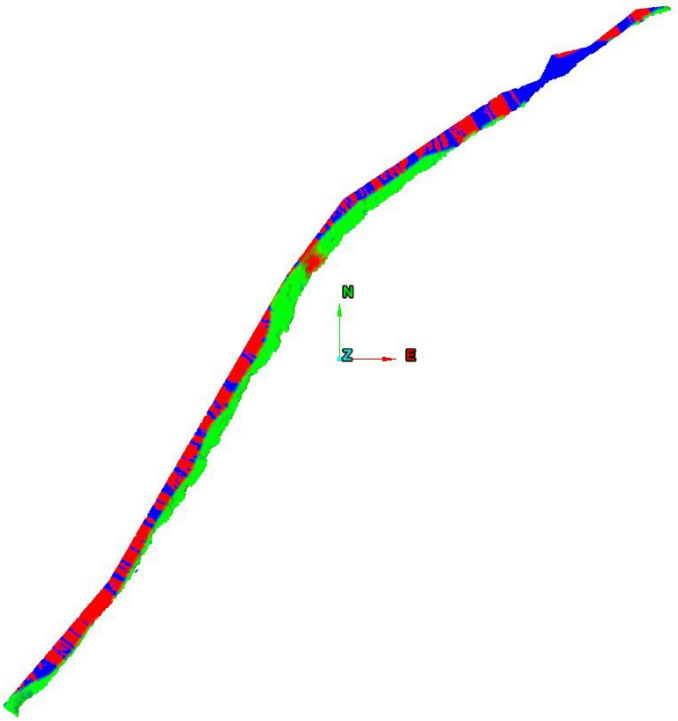
Legend for *all* Appendix 2 Sections



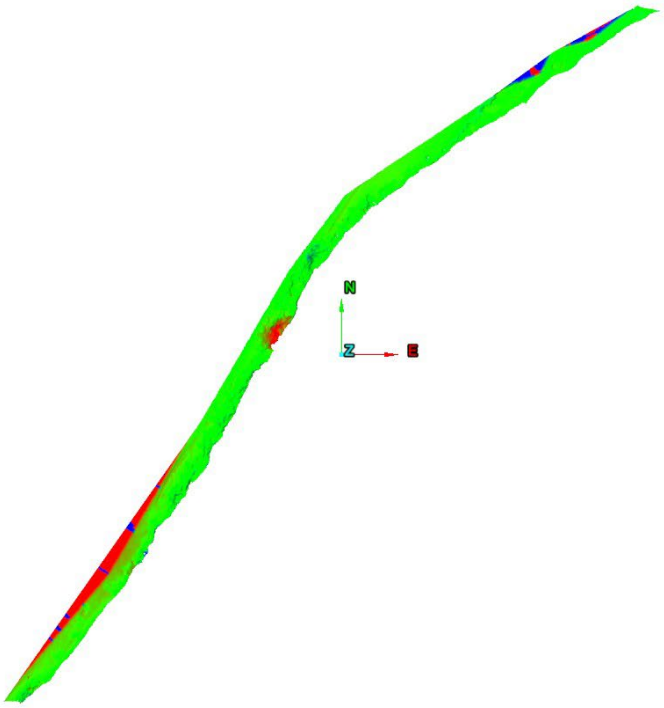
North Section, 2010 to 2017



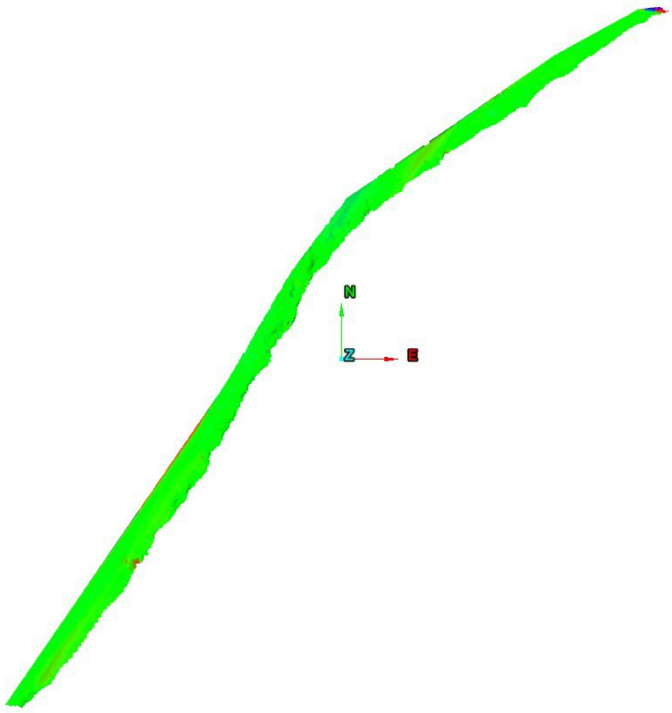
North Section, 2017 to 2019



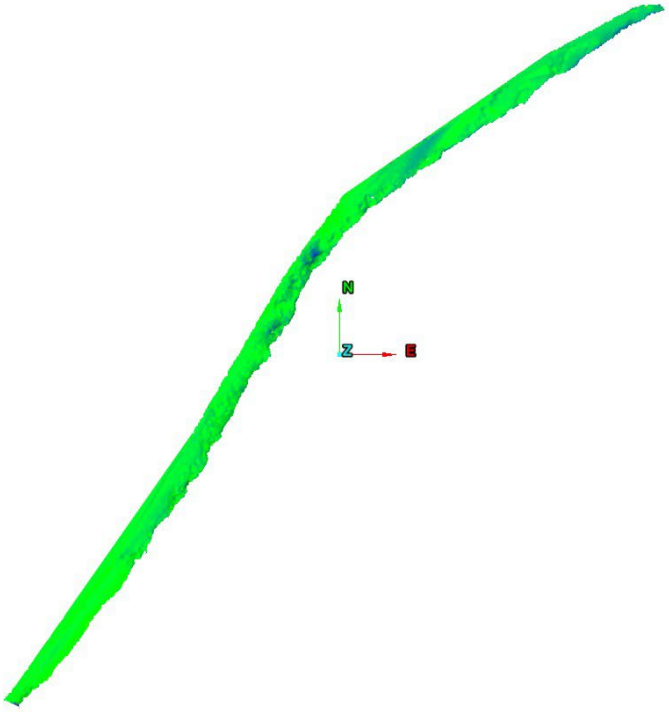
North Section, 2019 to 2020



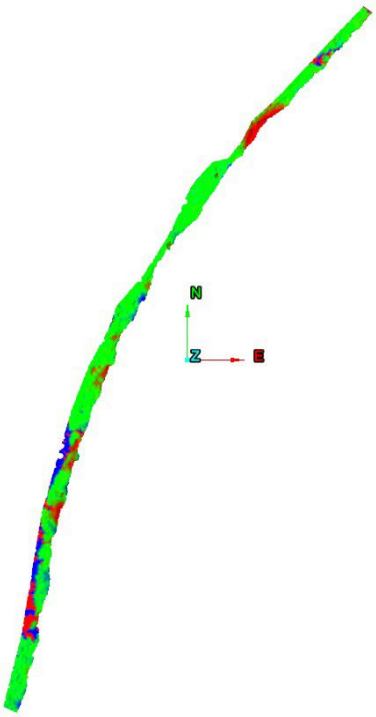
North Section, 2020 to 2021



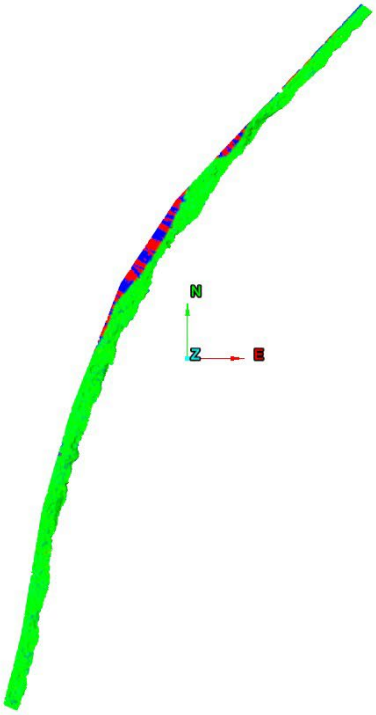
North Section, 2021 to 2022



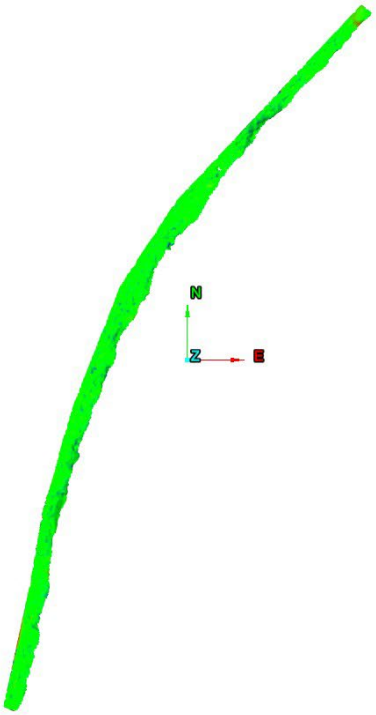
Middle Section, 2010 to 2017



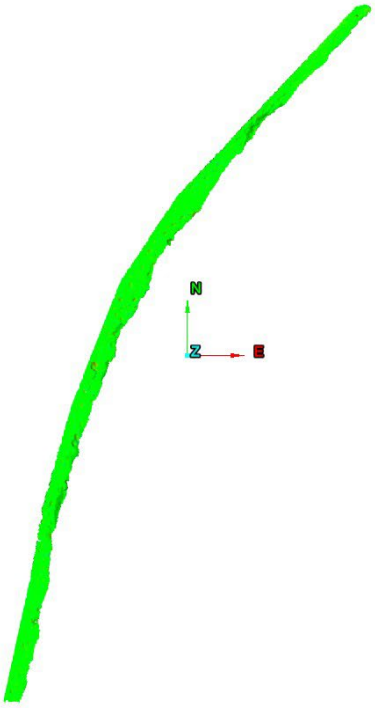
Middle Section, 2017 to 2019



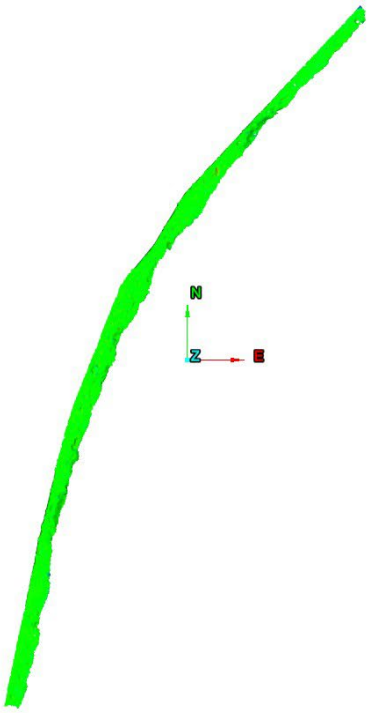
Middle Section, 2019 to 2020



Middle Section, 2020 to 2021



Middle Section, 2021 to 2022



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