Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2021:2022)

Multi-Hazards & Resilience Programme

Commercial Report CR/22/111

BRITISH GEOLOGICAL SURVEY

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Hunstanton Cliffs: Annual Terrestrial LiDAR Survey (2021:2022)

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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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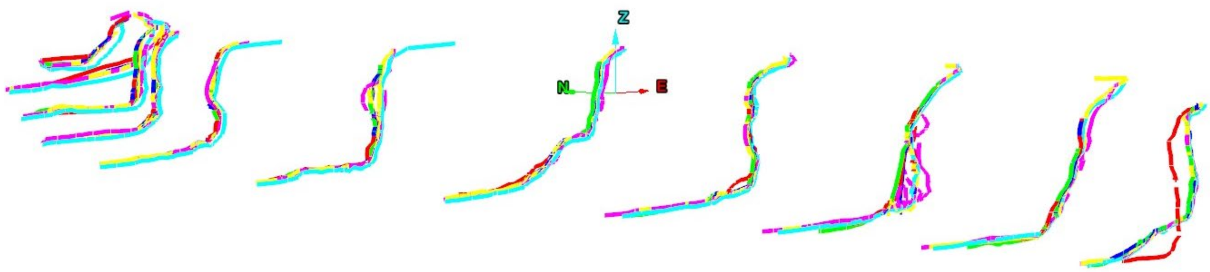


TABLES

Summary

This report is the published product of the **B**ritish **G**eological **S**urvey (**BGS**) and describes the results of the Annual 2022 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 2022.

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 (2021) scan. A table detailing the amount of erosion, the volume loss and the metres lost over the section surveyed is also included, as is an addendum containing 'Trigger' levels.

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 an e-mail dated July 1, 2022, the Council asked the BGS to supply them with an annual report, based on data acquired from the 2022 survey, to include the following (Project Code NEE7028R):

- *Change models identifying areas of loss and/or accretion from 'base' year (2010) to 'current' year (2020, 2021)*
- *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 2022*
- **Trigger Levels for management implementation*

Note*: *Additional content added in meeting with BCKLWN on July 8, 2022.*

2 Data & Extents

The Borough Council of King's Lynn & West Norfolk supplied the BGS with georeferenced point cloud data (in .las format) from 2022. The area under review is shown in Figure 1 and the data 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	+/- 3.5	RGB	16908245	840143	1009386	369921

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

The survey of 2022 was the same size as the previous (2019-2021) surveys and was again divided into three smaller sections in order to provide a better accuracy for the volume calculations, and to take into account that the 2012 survey covered a smaller southern section of the cliff-line. The sections were split where the 2012 data was situated (south) and at a gap in the data on the 2010 survey. 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.

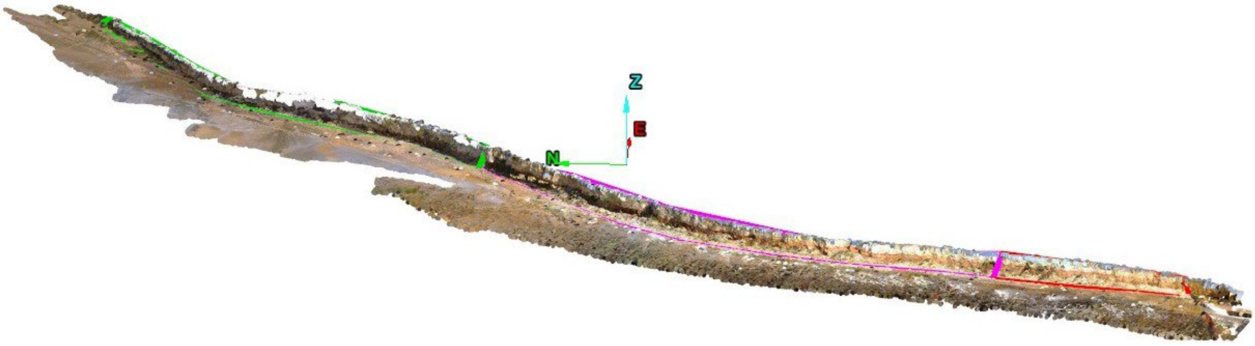


Figure 2 – RGB coloured point cloud of 2021 survey showing sections: Green = North, Magenta = Middle, Red = South (Extents: E 567954 m, N 342450 m to E 567268 m, N 341332 m. Height range = 6.3 m to 18.8 m)

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

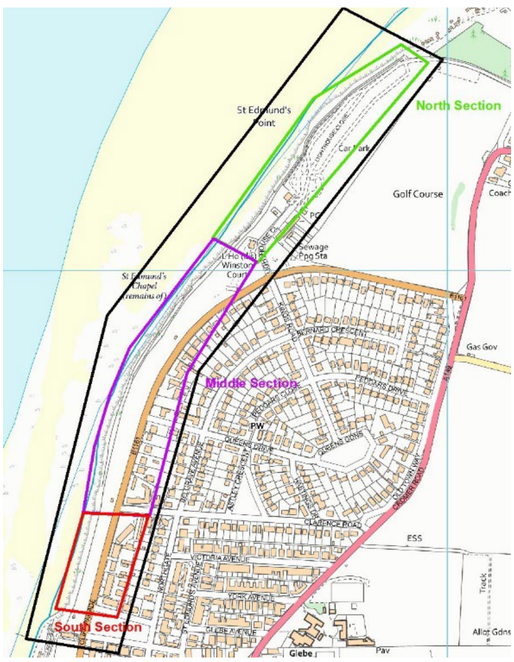


Figure 3 – Plan view of scan area sections: Green = North, Magenta = Middle, Red = South

Figure 4 shows the coverage and extents of the scans from the latest (2022) survey. They are displayed as RGB colour values.

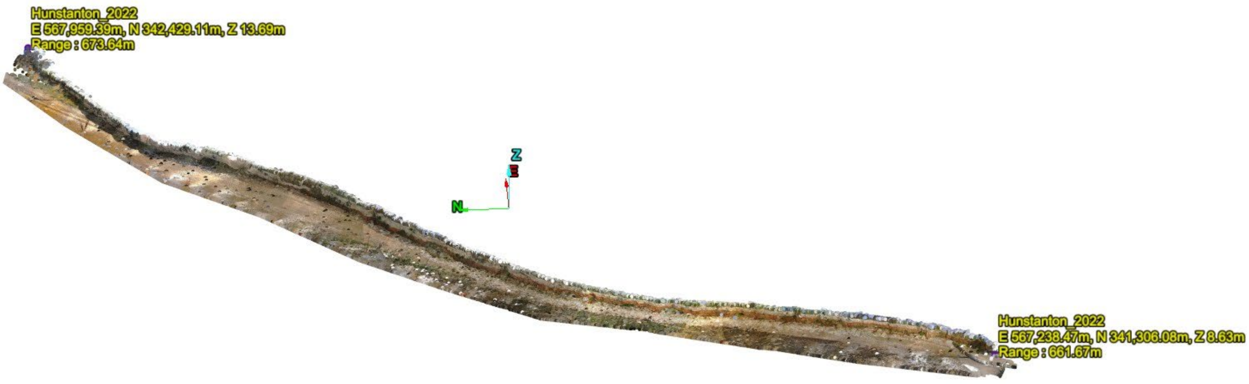


Figure 4 – 2022 point cloud data displayed using the RGB colour values (Extents: E 567959 m, N 342429 m to E 567238 m, N 341306 m. Height range = 6.3 m to 18.8 m)

The point cloud data provided, in .las format, for the survey, was imported by BGS into 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

In order 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

In order 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 – 2022 (Figure 5)
- Middle – 2022 (Figure 6)
- South – 2022 (Figure 7)

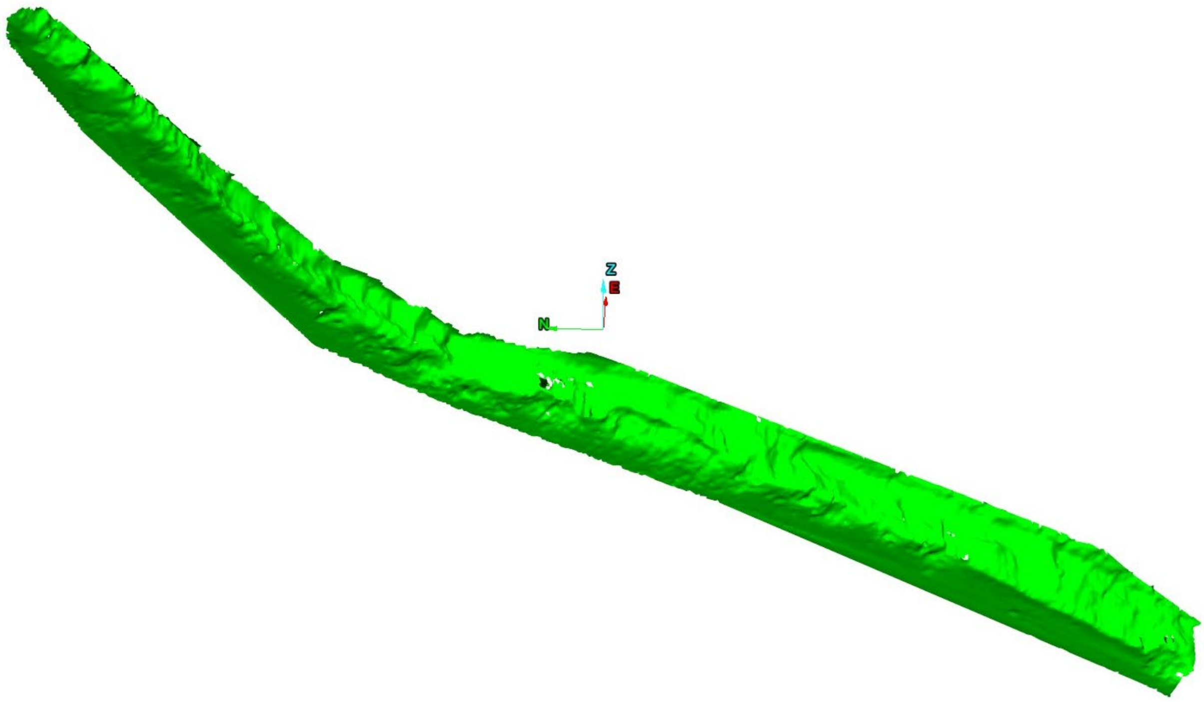


Figure 5 – North Section, 2022 (Extents: E 567929 m, N 342429 m to E 567586 m, N 342048 m)

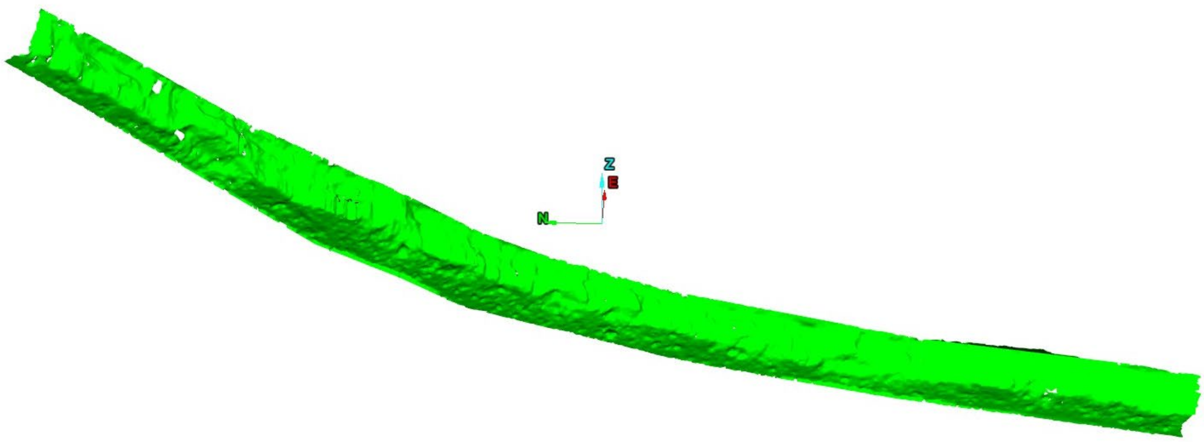


Figure 6 – Middle Section, 2022 (Extents: E 567578 m, N 342042 m to E 567332 m, N 341542 m)

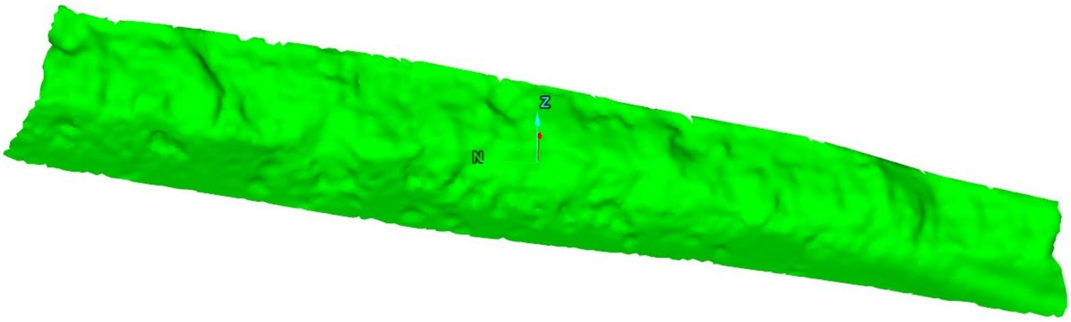


Figure 7 – South Section, 2022 (Extents: E 567329 m, N 341540 m to E 567272 m, N 341359 m)

3.2 CHANGE MODELS

Maptek I-Site Studio was used to create change models between the base year (2010) and the current year (2022) and from the previous year (2021) to the current year (2022), as follows:

- North – 2010 to 2022, 2021 to 2022 (2)
- Middle – 2010 to 2022, 2021 to 2022 (2)
- South – 2010 to 2022, 2021 to 2022 (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 2022 (Table 3). The data shown have been extracted from the three sections previously outlined in Figure 2 and Table 2. In order 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), 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, in order to make sure all lines are visible.

Table 3 – Cliff recession, derived from TLS

Period		Elaspsed	Cumulative	North Section			Middle Section			South Section		
		Time	Time	Material	Cumulative	Cumulative	Material	Cumulative	Cumulative	Material	Cumulative	Cumulative
Start	End	(days)	(days)	Loss (m^3)	Loss (m^3)	Loss/m (m^3)	Loss (m^3)	Loss (m^3)	Loss/m (m^3)	Loss (m^3)	Loss (m^3)	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
Aug-10	Apr-22		*4255*		12850	25		10900	19		3550	19
Loss/Year					1103			936			305	

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*
	29555	57	*4*		25070	44	*3*		8165	44	*3*
	2537				2152				701		

The data show a *new* total loss of 27300 m^3 across the 1.275 km combined sections, relating to an estimated mass of approximately 62790 tonnes* of material. These values work out to 2343 m^3/year (up from the previous value of 2059 m^3/year), which is an estimated 5390 tonnes/year (up from the previous value of 4736 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 slight rise from 2021 to 2022, a continued increase in the amount of loss from the North section over the period 2020 to 2022, and a slight rise in the amount of loss from the South section over the period 2012 to 2022.

Cliff height has not been taken into account in the calculations (above) as it varies considerably, from ~6.3 m to ~15.7 m in the north section, from ~16.5 to ~18.8 m in the middle section and from ~14.0 m to ~17.0 m in the south 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 taking into account the yearly loss (2343 m^3), the cliff length (1275 m) and the cliff height (16 m) giving a total value of 0.11 m/year (up from the previous value of 0.1 m/year).

These results show an increasing rate of recession, albeit a small one, across the time period 2021 to 2022 of 0.01 m/year.

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.

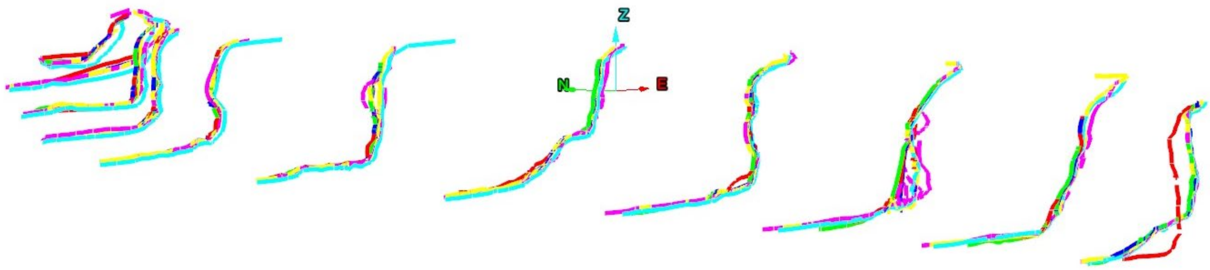


Figure 8 – Cross-sections, at 50 m spacing, for North section: Red = 2010, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021, Cyan = 2022 (Extents: E 567929 m, N 342429 m to E 567586 m, N 342048 m)

Figure 9 – Cross-sections, at 50 m spacing, for Middle section: Red = 2010, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021, Cyan = 2022 Extents: E 567578 m, N 342042 m to E 567332 m, N 341542 m)

Figure 10 – Cross-sections, at 50 m spacing, for South section: Red = 2010, Black = 2012, Blue = 2017, Green = 2019, Yellow = 2020, Fuchsia = 2021, Cyan = 2022 (Extents: E 567329 m, N 341540 m to E 567272 m, N 341359 m)

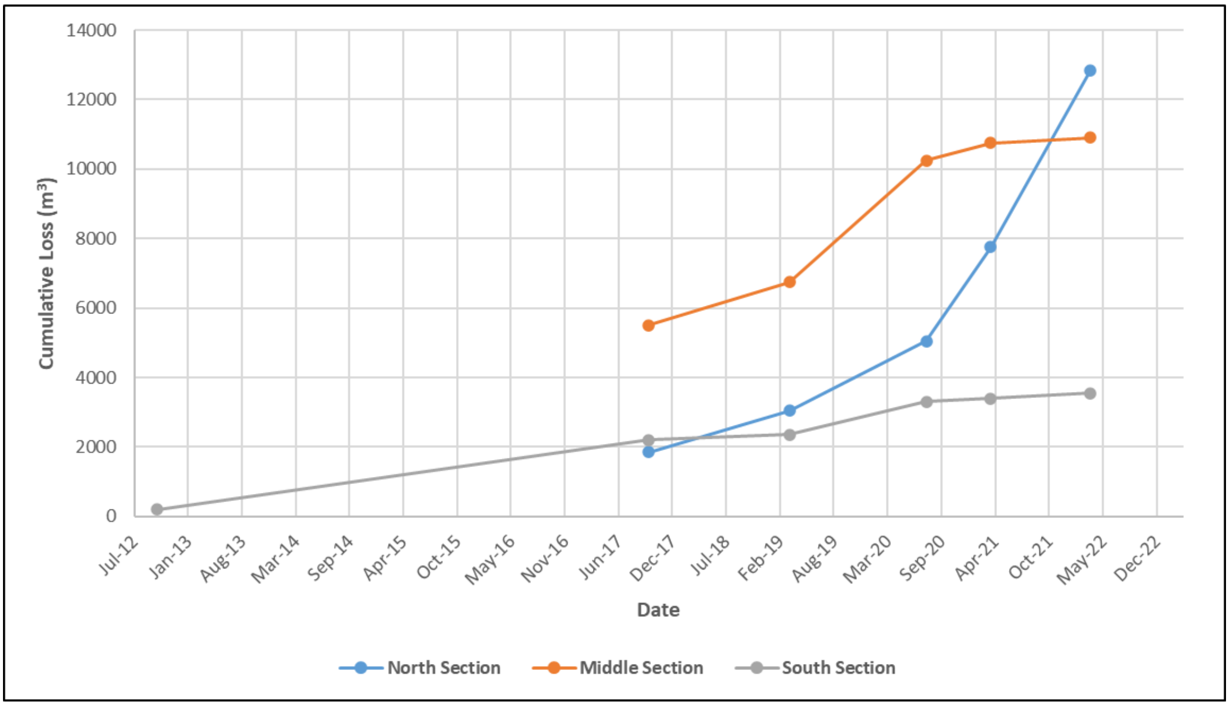


Figure 11 – Cumulative Loss (m^3) v Time

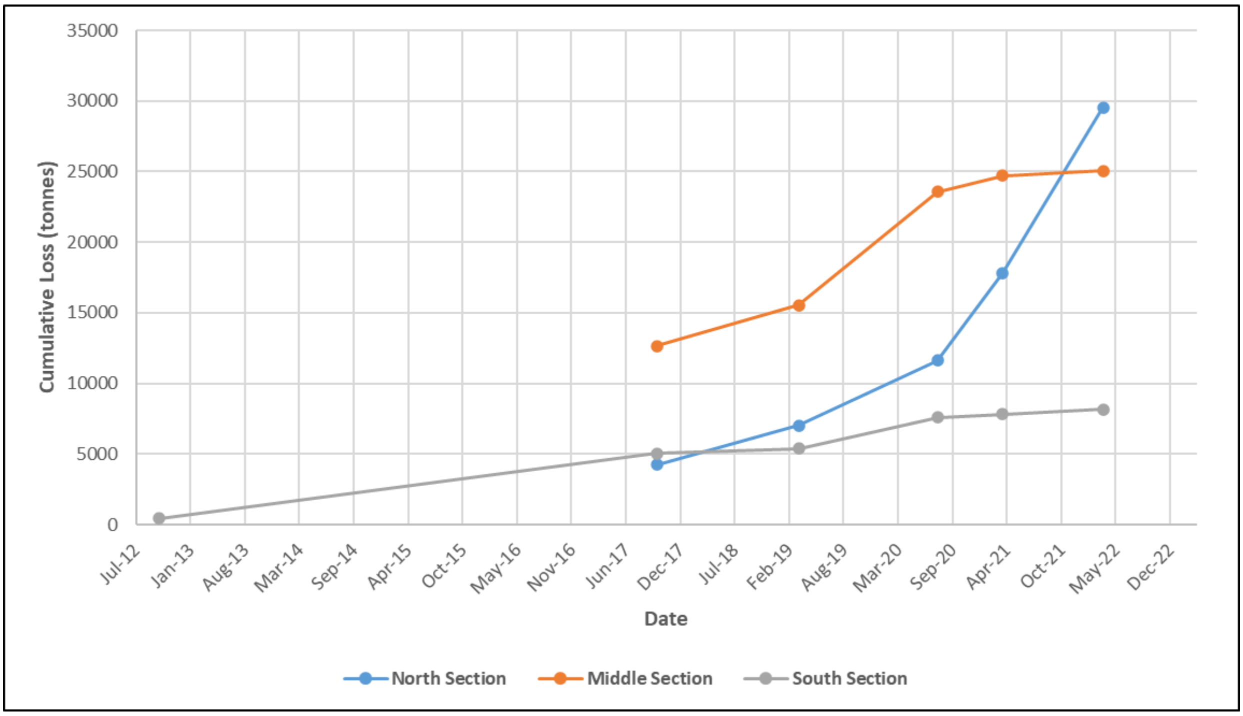


Figure 12 – Cumulative Loss (tonnes) v Time

5 Analysis of Change

This is an annual report, based on the data obtained from the 2022 survey. This discussion of results will refer to the change between the 2010 and 2022 surveys. This discussion will also look at the change between the 2021 and 2022 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; in order 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) 342201 m North to 342290 m North (Figure 15) which show that ~4 m of loss has occurred in the cliff face and accretion has followed on the foreshore. At the southernmost part of the section, at 342070 m North to 342174 m North (Figure 16), there is a large area of erosion in the cliff face of >4 m, with a similar amount of accretion on the foreshore. This area sits directly in front of the Lighthouse. 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

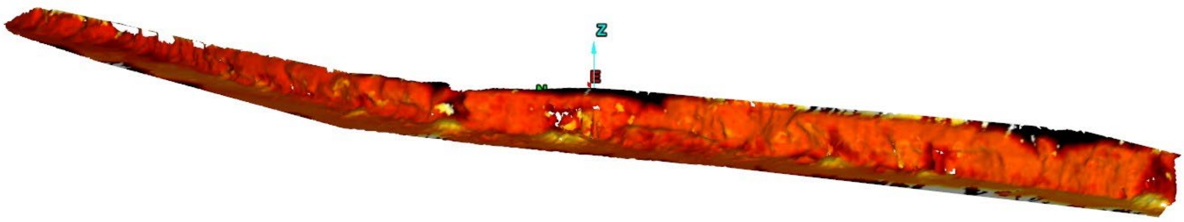


Figure 14 – 3D view of the entire North section

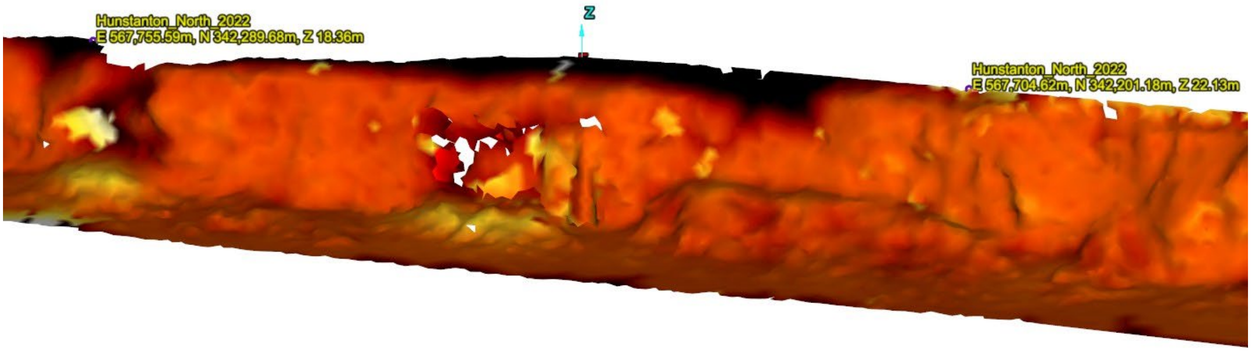


Figure 15 – 2010 to 2022 change model of 342201 m North to 342290 m North (for legend see Figure 17. Height range = 6.3 m to 15.7 m)

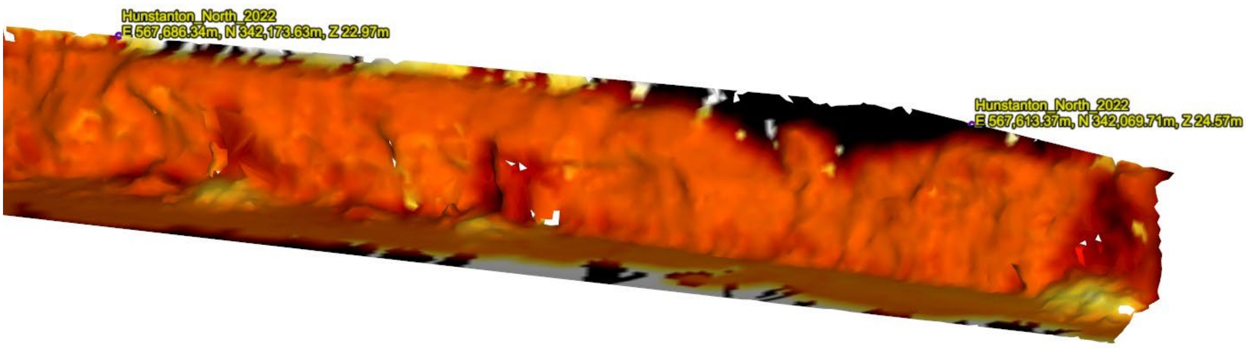


Figure 16 – 2010 to 2022 change model of 342070 m North to 342174 m North (for legend see Figure 17. Height range = 6.3 m to 15.7 m)

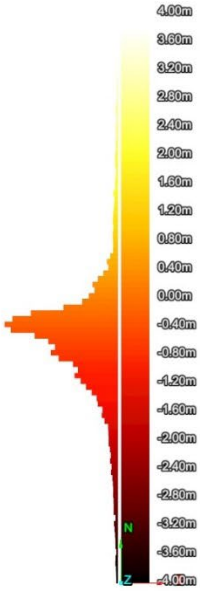


Figure 17 – North section legend (-4 m to 4 m) for 2010 to 2022 change model

Figure 18 shows the change between the 2021 and 2022 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. The legend for Figure 18 can be seen in Figure 19, which shows a histogram of the +/- 2 m loss/gain distribution.

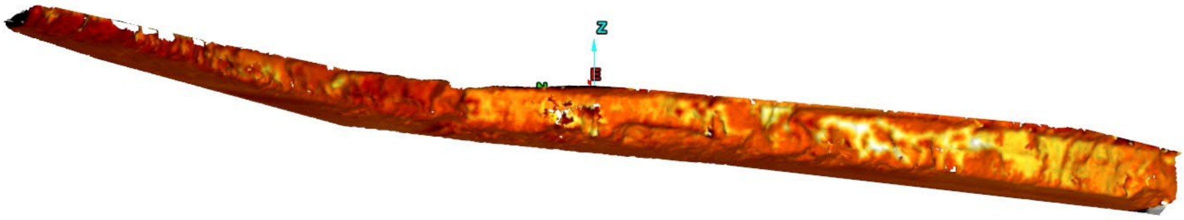


Figure 18 – 2021 to 2022 change model of entire north section (for legend see Figure 19. Height range = 6.3 m to 15.7 m)

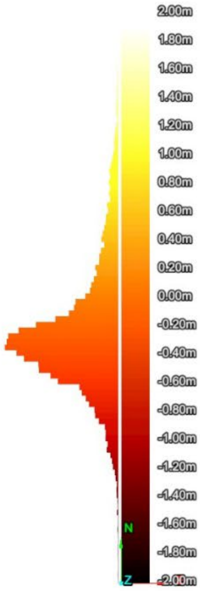


Figure 19 – North section legend (-2 m to 2 m) for 2021 to 2022 change model

5.2 MIDDLE SECTION

Figures 20 & 21 show the Middle section, where at 341953 m North (Figure 22) there remains a significant amount (>5 m) of accretion on the foreshore. This has come from the adjacent cliff face, which shows a loss of ~5 m. However, further areas of loss (~3 m) can be seen south of this point. From 341593 m North to 341809 m North (Figure 23) 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 24.

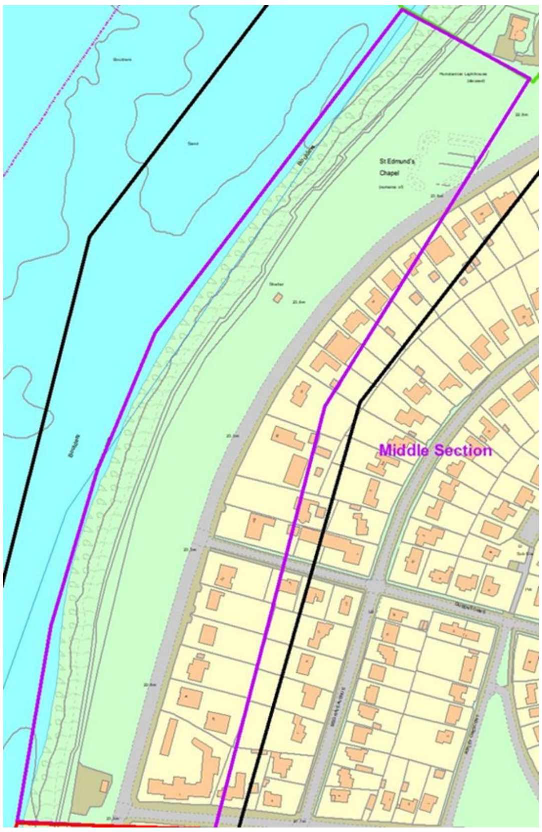


Figure 20 – Plan view of Middle section

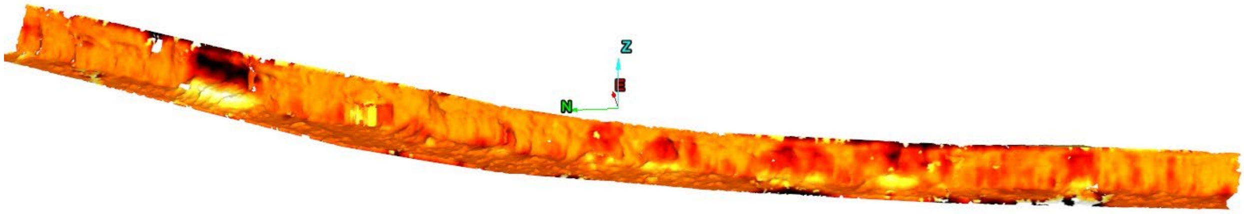


Figure 21 – Plan view of Middle section

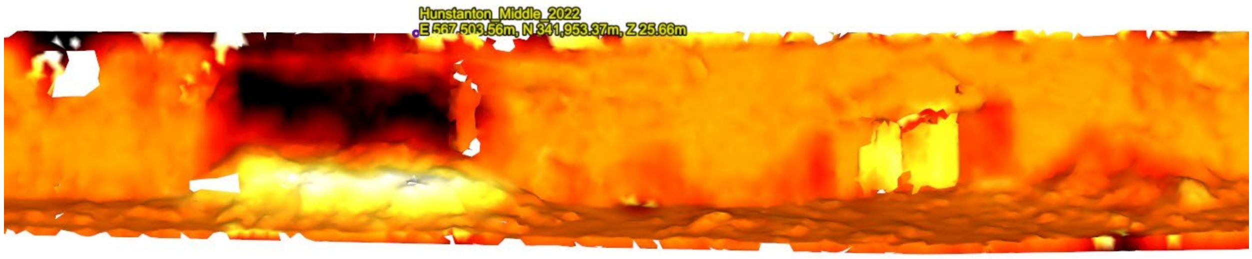


Figure 22 – 2010 to 2022 change model of the area around 341953 m North (for legend see Figure 24. Height range = 16.5 m to 18.8 m)

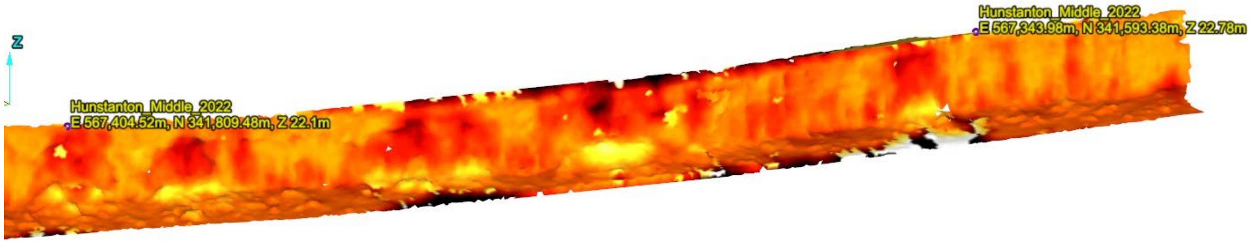


Figure 23 – 2010 to 2021 change model of 341593 m North to 341809 m North (for legend see Figure 24. Height range = 16.5 m to 18.8 m)

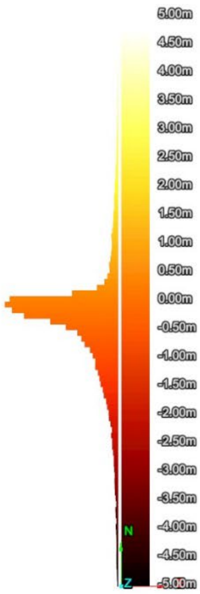


Figure 24 – Middle section legend (-5 m to 5 m) for 2010 to 2022 change model

Figure 25 shows the change between the 2021 and 2022 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 342037 m North and 341647 m North. The legend for Figure 25 can be seen in Figure 26, which shows a histogram of the +/- 2 m loss/gain distribution.

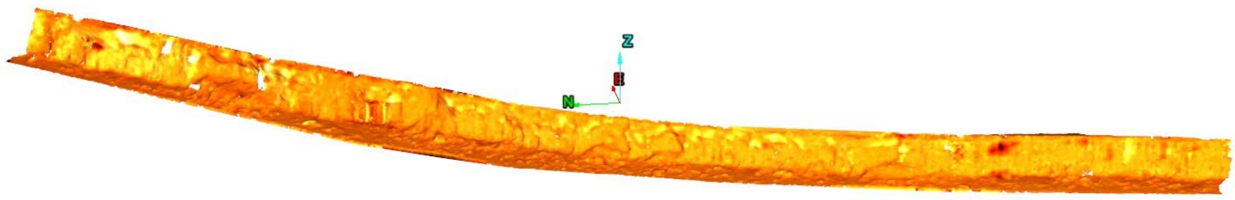


Figure 25 – 2021 to 2022 change model of entire middle section (for legend see Figure 26. Height range = 16.5 m to 18.8 m)

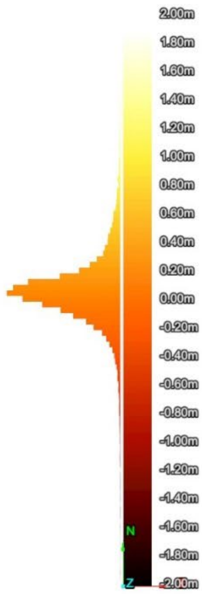


Figure 26 – Middle section legend (-2 m to 2 m) for 2021 to 2022 change model

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 lesser levels of accretion on the foreshore of approximately 2.5 m. As could be seen in the southernmost part of the middle section this section shows erosion levels reached 1.5 m in the foreshore. The legend for this figure can be seen in Figure 29.

Figure 27 – Plan view of South section

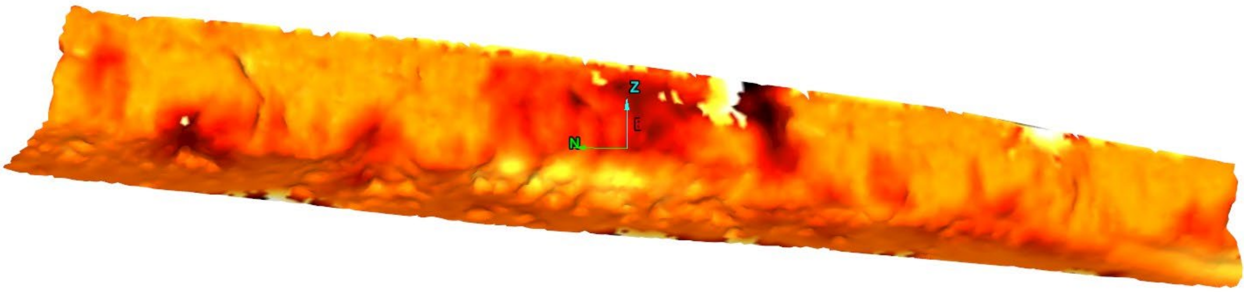


Figure 28 – 3D view of entire South section

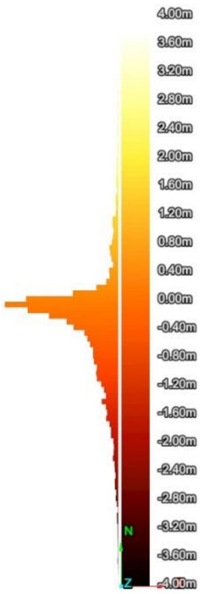


Figure 29 – South section legend (-4 m to 4 m) for 2010 to 2022 change model

Figure 30 shows the change between the 2021 and 2022 surveys, for the entire South section. It shows that there are areas of significant change (~1 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 m) at 341370 m North. The legend for Figure 30 can be seen in Figure 31, which shows a histogram of the +/- 1 m loss/gain distribution.

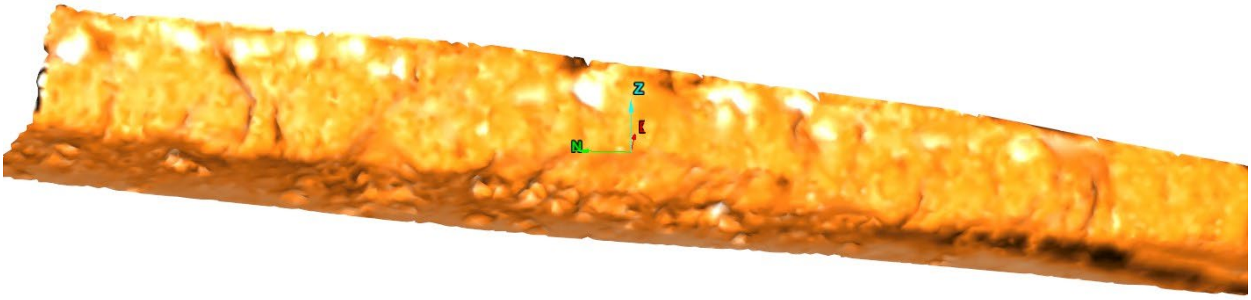


Figure 30 – 2021 to 2022 change model of entire south section (for legend see Figure 31. Height range = 14.0 m to 17.0 m)

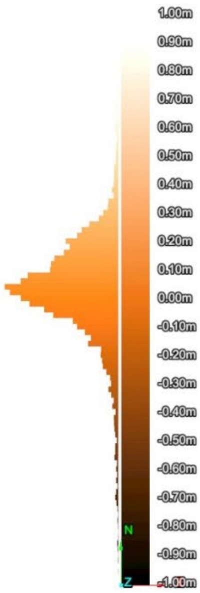


Figure 31 – South section legend (-1 m to 1 m) for 2021 to 2022 change model

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 (2022) and from each intermediate year to the subsequent year, as follows:

- North – 2010 to 2022, 2010 to 2017, 2017 to 2019, 2019 to 2020, 2020 to 2021, 2021 to 2022 (6)
- Middle – 2010 to 2022, 2010 to 2017, 2017 to 2019, 2019 to 2020, 2020 to 2021, 2021 to 2022 (6)
- South – 2010 to 2022, 2010 to 2012, 2012 to 2017, 2017 to 2019, 2019 to 2020, 2020 to 2021, 2021 to 2022 (7)

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, of all years, can be found in Appendix 2.

Figure 32 shows the height change model for the North section from 2010 to 2022. Figure 33 shows the same section from 2021 to 2022. Figure 34 shows the legend for *all* three sections of the cliff line.

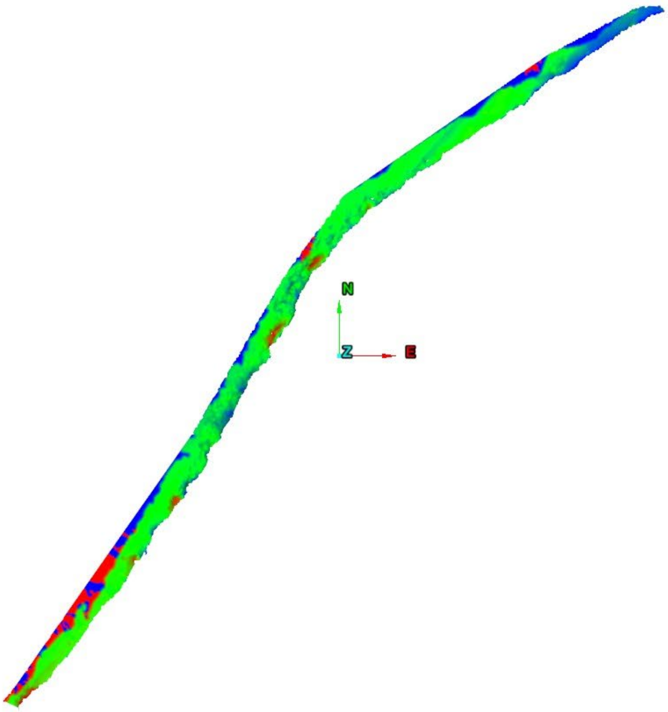


Figure 32 – Beach height change model for North section from 2010 to 2022

Figure 32 shows that the beach has lowered by ~2 m in the northern-most section and has been raised by ~2 m in the southern-most section, during the period 2010 to 2022.

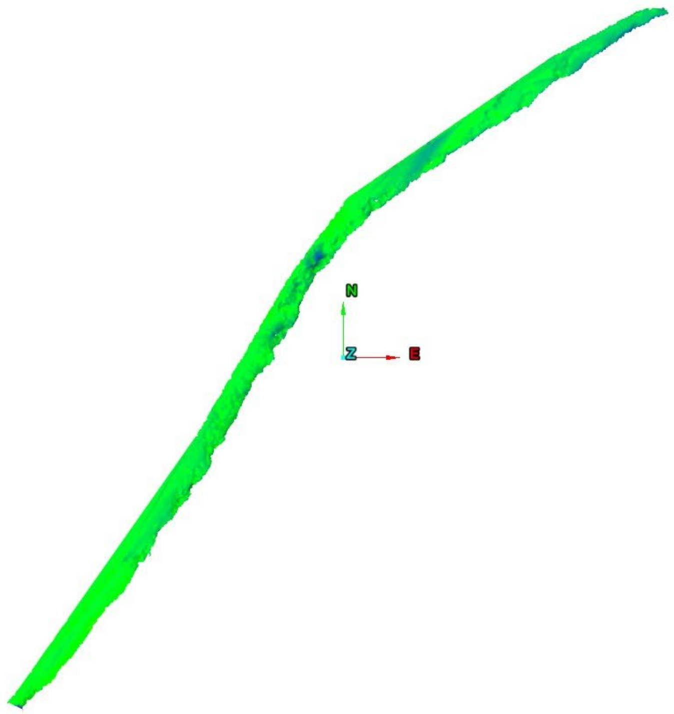


Figure 33 – Beach height change model for North section from 2021 to 2022

Figure 33 shows that the beach has lowered by ~2 m in the central section but otherwise has remained fairly constant, during the period 2021 to 2022.

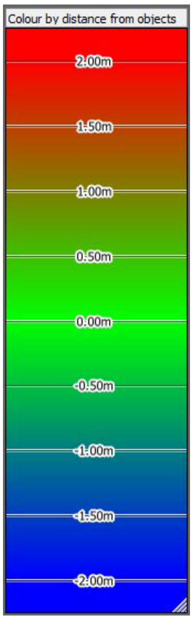


Figure 34 – Legend for *all* sections

Figure 35 shows the height change model for the Middle section from 2010 to 2022. Figure 36 shows the same section from 2021 to 2022.

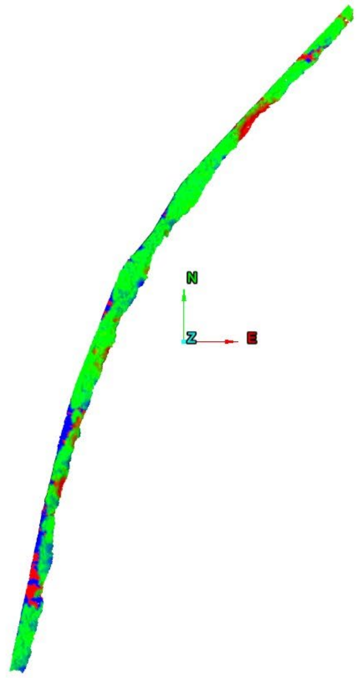


Figure 35 – Beach height change model for Middle section from 2010 to 2022

Figure 35 shows that the beach has lowered by ~2 m in the southern-most and central sections and has been raised by ~2 m in the northern-most section, during the period 2010 to 2022.

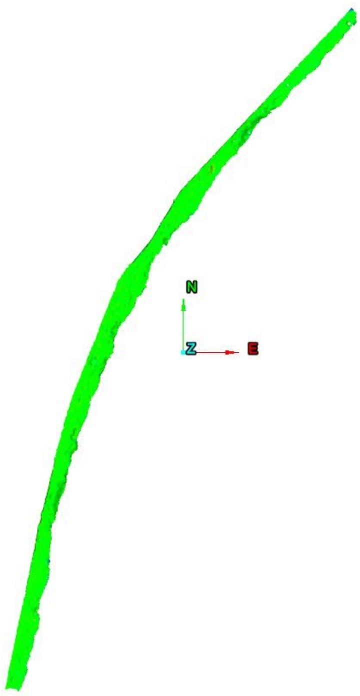


Figure 36 – Beach height change model for Middle section from 2021 to 2022

Figure 36 shows that the beach has remained fairly constant, during the period 2021 to 2022.

Figure 37 shows the height change model for the South section from 2010 to 2022. Figure 38 shows the same section from 2021 to 2022.

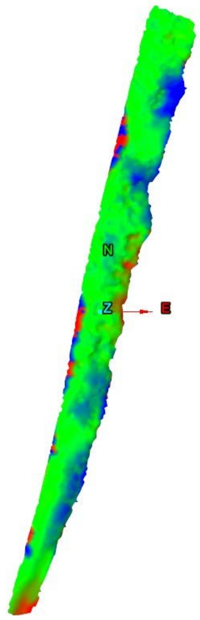


Figure 37 – Beach height change model for South section from 2010 to 2022

Figure 37 shows that the beach has lowered by ~2 m in most parts of the section, during the period 2010 to 2022.

Figure 38 – Beach height change model for South section from 2021 to 2022

Figure 38 shows that the beach has remained fairly constant, during the period 2021 to 2022.

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 located in Figure 40 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 41 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 42. By combining these with the recession rates given in Table 3, it is possible to generate an Erosion Risk Rating (Table 4).

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

Figure 39 – Plan of area with initial 'at risk' properties shown

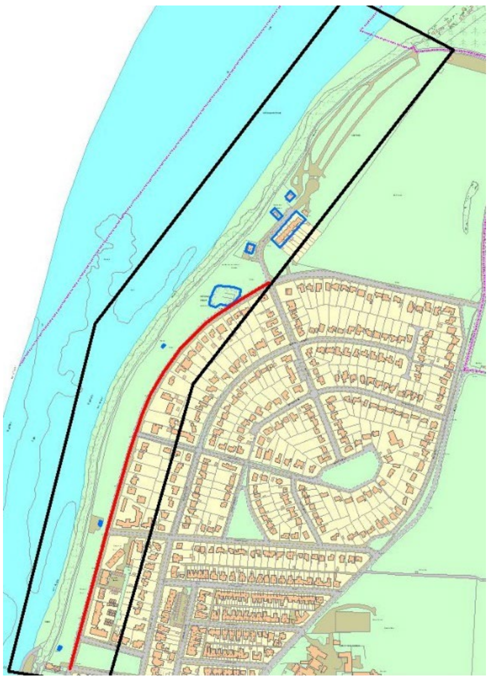


Figure 40 – Plan of section under investigation, showing initial and added 'at risk' properties and road section

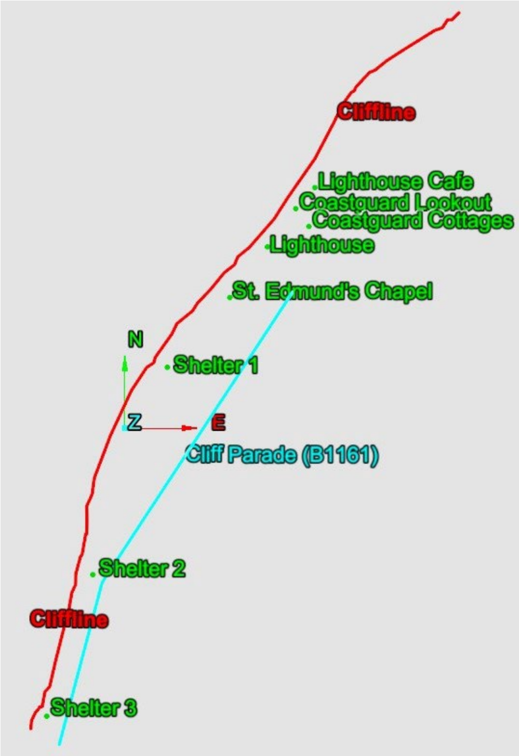


Figure 41 – Position of 'at risk' properties relevant to cliff edge

Table 4– 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 (2022)	Risk Rating (2021)	Rating Change
Lighthouse	567625	342058	19	4	5.5	*11.6*	*3.3*	*8.2*
Shelter 1	567473	341875	22	2	1	*0.9*	*0.9*	*0.0*
Shelter 2	567360	341560	25	3	2.5	*3.0*	*1.2*	*1.8*
Shelter 3	567290	341345	16	3	2	*3.8*	*3.8*	*0.0*
St. Edmund's Chapel	567568	341981	31	2	2.5	*1.6*	*1.6*	*0.0*
Coastguard Lookout	567668	342116	19	3	3	*4.7*	*2.0*	*2.7*
Coastguard Cottages	567688	342089	50	3	3	*1.8*	*0.8*	*1.0*
Lighthouse Café	567697	342148	25	2	2.5	*2.0*	*2.0*	*0.0*
Cliff Parade (King's Road)	567663	341989	95	4	4.5	*1.9*	*0.5*	*1.4*
Cliff Parade (Clarence Road)	567374	341548	39	3	2.5	*1.9*	*0.8*	*1.2*
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:

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

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 4) are the Lighthouse with an R value of 11.6, an increase of 8.2 due to the increased loss of 2m at the cliff edge, the Coastguard Lookout with an R value of 4.7, an increase of 2.7 due to the increased loss of 1m. Shelter 3, although remaining unchanged has an R value of 3.8. Shelter 2 has an R value of 3.0, up by 1.8, whilst Cliff Parade (at King's Road and Clarence Road) both have a R value of 1.9, up by 1.4 and 1.2 respectively. All other properties R values have remained the same.

Shelter 3 remains the closest property to the cliff at 16 m, whilst the Lighthouse and the Coastguard Lookout are now 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 2022, in metres.

^Loss at Property relates to the amount of loss at the cliff-line itself from 2010 to 2022, in metres.

8 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.

9 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 2022, 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, South
- An estimation of the degree of erosion by determining an Erosion Risk Rating (Table 4)
- An addendum containing 'Trigger' points was added to this report, following discussions with BCKLWN
- Appendices containing a suite of Surface and Change models

In summary, the report found the following:

- The data from the 2022 LiDAR scan covers the same section of cliff as those covered by the previous 2010, 2017, 2019, 2020 and 2021 LiDAR scans. They have been analysed using the same three (smaller) sections of cliff.
- The Volume Calculation data (Table 3) show a total loss of 27300 m^3 across the full 1.275 km section, which is 2343 m^3/year or 5390 tonnes/year (estimated). This is an increase across the entire section of 5400 tonnes/year or 654 tonnes/year (estimated). The North section is now the most active, with an average loss of 1103 m^3/year (up from 729 m^3), followed by the Middle section, with an average loss of 936 m^3/year (down from 1011 m^3) and finally the South section, with an average loss of 305 m^3/year (down from 320 m^3).
- The North section shows the greatest horizontal movement of the cliff line of 4 m, followed by both the Middle and South sections at 3 m. However, the Middle section is considerably larger than the South section, so the actual amount of material loss is far greater. Each section of the cliff was analysed separately:
    - North – The greatest amount of loss (>4 m) occurs between BNG 342070 m to 342174 m North (Figure 16) directly in front of the Lighthouse. Further large-scale changes in this section (~4 m) can be seen between BNG 342201 m to 342290 m North (Figure 15). The largest change between 2021 and 2022 (~2 m) can be seen at BNG 342090 m North, 342150 m North, and 342222 m (Figure 18).
    - Middle – At BNG 341953 m North (Figure 22) there is a significant amount of accretion (>5 m) on the foreshore and loss (~5 m) from the cliff face. Between BNG 341593 m and 341809 m North (Figure 23) large areas of erosion (~5 m) can be seen. The largest change between 2021 and 2022 (~2 m) can be seen between BNG 341647 m and 342037 m North (Figure 25).
    - South – The greatest amount of loss (~4 m) can be seen between BNG 341428 m to 341474 m North (Figure 28). The largest change between 2021 and 2022 (~1 m) can be seen at BNG 341437 m, 341449 m and 341515 m North (Figure 30), with an area of accretion on the foreshore (~1 m) at BNG 341370 m North.
- 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 = 8.2), the Coastguard Lookout (R = 4.7) and Shelter 3 (R = 3.8).

- Beach levels were modelled and calculated for each section separately:
    - North – The beach has lowered by ~2 m in the northern-most section and has been raised by ~2 m in the southern-most section, during the period 2010 to 2022 (Figure 32). The beach has lowered by ~2 m in the central section but otherwise has remained fairly constant, during the period 2021 to 2022 (Figure 33).
    - Middle – The beach has lowered by ~2 m in the southern-most and central sections and has been raised by ~2 m in the northern-most section, during the period 2010 to 2022 (Figure 35). The beach has remained fairly constant, during the period 2021 to 2022 (Figure 36).
    - South – The beach has lowered by ~2 m in most parts of the section, during the period 2010 to 2022 (Figure 37). The beach has remained fairly constant, during the period 2021 to 2022 (Figure 38).

10 Conclusions

The following conclusions can be made from the analysis of the 2022 LiDAR data:

- Some accelerated erosion has been observed over the 2021-2022 survey period, especially in the North section
- The cliff erosion rates remain mostly in-line with the previous reports, with the North section continuing to increase
- 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 2024
- The most active area of cliff erosion is now in the northern section of the cliffs, in front of the Lighthouse
- Beach levels have lowered consistently across all sections over the 2010-2022 survey period
- Trigger Levels calculated show that by 2040 the Lighthouse may be 'at risk' and by 2050 so might the Coastguard Lookout. These levels show a useful insight into future risk and should be considered keeping and extending to all properties, for future reports
- Some changes may be required to the active HCMP*

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.

Addendum 1 – 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 this (2022) report. The Trigger Levels were prepared for the section of cliff between the Lighthouse and the Coastguard Lookout (North section), for the years 2010 to 2050.

In order to work out the possible loss and change to the cliffs at Hunstanton in the area of the North section, the average loss per year needed to be calculated. Table 5 shows the cliff recession values for the North section from October 2012 to April 2022 and the average loss per year value calculated from these (1103 m^3/year, 2537 t/year). From these values a forecasted projection was made for the years 2025, 2030, 2040 and 2050; these can be seen in Figures 42 and 43.

Table 5 – Estimated cliff recession projections (loss in m^3 and tonnes)

Period		Elaspsed Time (days)	Cumulative Time (days)	North Section			North Section		
Start	End			Material Loss (m3)	Cumulative Loss (m3)	Cumulative Loss/m (m3)	Material Loss (t)	Cumulative Loss (t)	Cumulative Loss/m (t)
Aug-10	Oct-12	785	785						
Oct-12	Oct-17	1829	2614	1850	1850	4	4255	4255	8
Oct-17	Mar-19	522	3136	1200	3050	6	2760	7015	14
Mar-19	Aug-20	510	3646	2000	5050	10	4600	11615	23
Aug-20	Mar-21	239	3885	2700	7750	15	6210	17825	35
Mar-21	Apr-22	370	4255	5100	12850	25	11730	29555	57
Loss/Year					*1103*			*2537*	
Apr-22	Aug-25	1218	5473		15423	30		35474	69
Aug-25	Aug-30	1826	7299		20939	41		48159	94
Aug-30	Aug-40	3653	10952		31969	62		73529	143
Aug-40	Mar-50	3529	14481		42631	83		98052	190

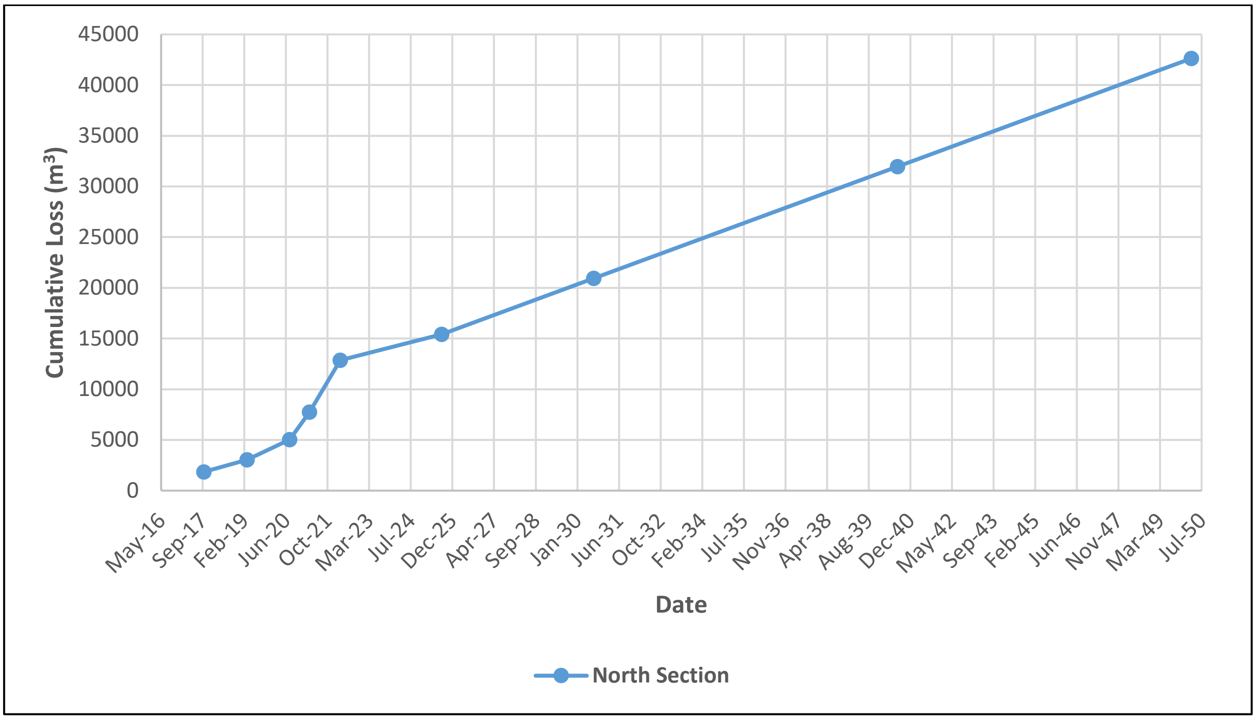


Figure 42 – Projected Cumulative Loss (m3) v Time

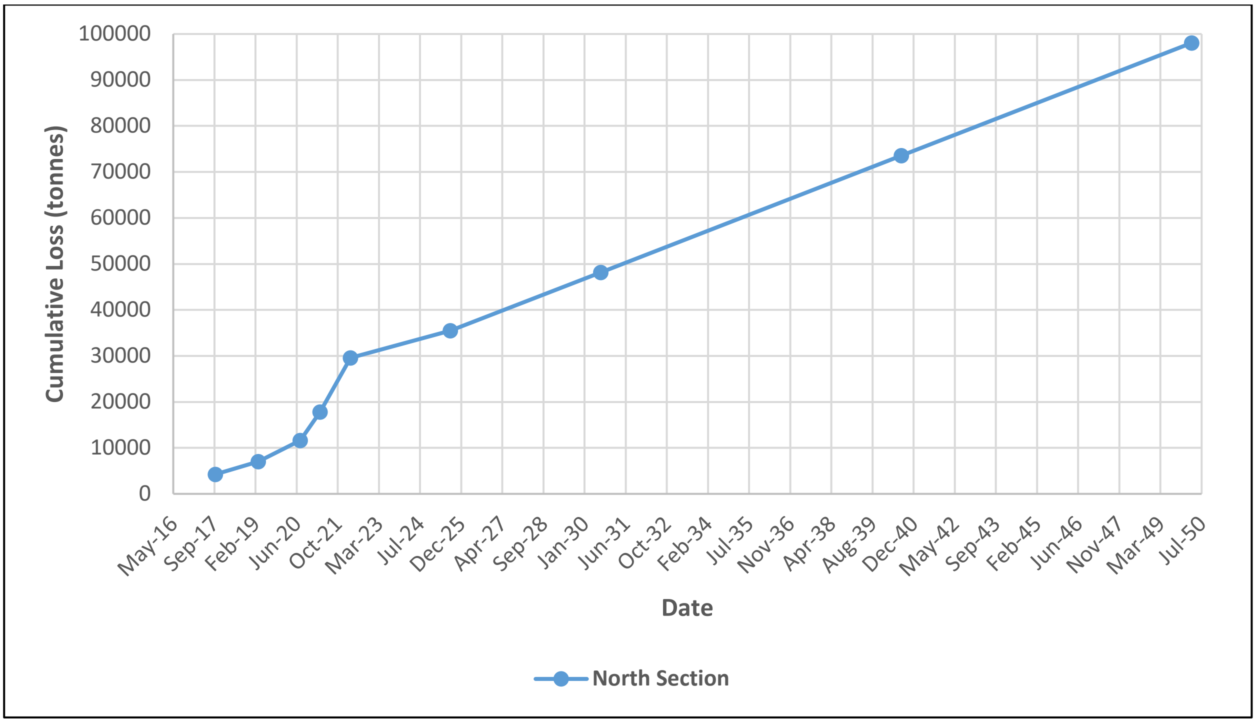


Figure 43 – Projected Cumulative Loss (tonnes) v Time

An alternative way of showing this is to forecast the Risk rating values for the Lighthouse, Coastguard Lookout, Coastguard Cottages, and Lighthouse Café. Table 6 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 and 2050.

The Trigger Levels can be assumed where the Closest Cliff Edge has reduced to less than the preferred minimum value of *10 m (Lighthouse – 2050), or where the Loss at the Property exceeds 10 m (Lighthouse – 2040 and 2050, Coastguard Lookout – 2050). The Risk Rating value also exceeds 50.

Table 6 – Projected Risk Rating (2025 to 2050)

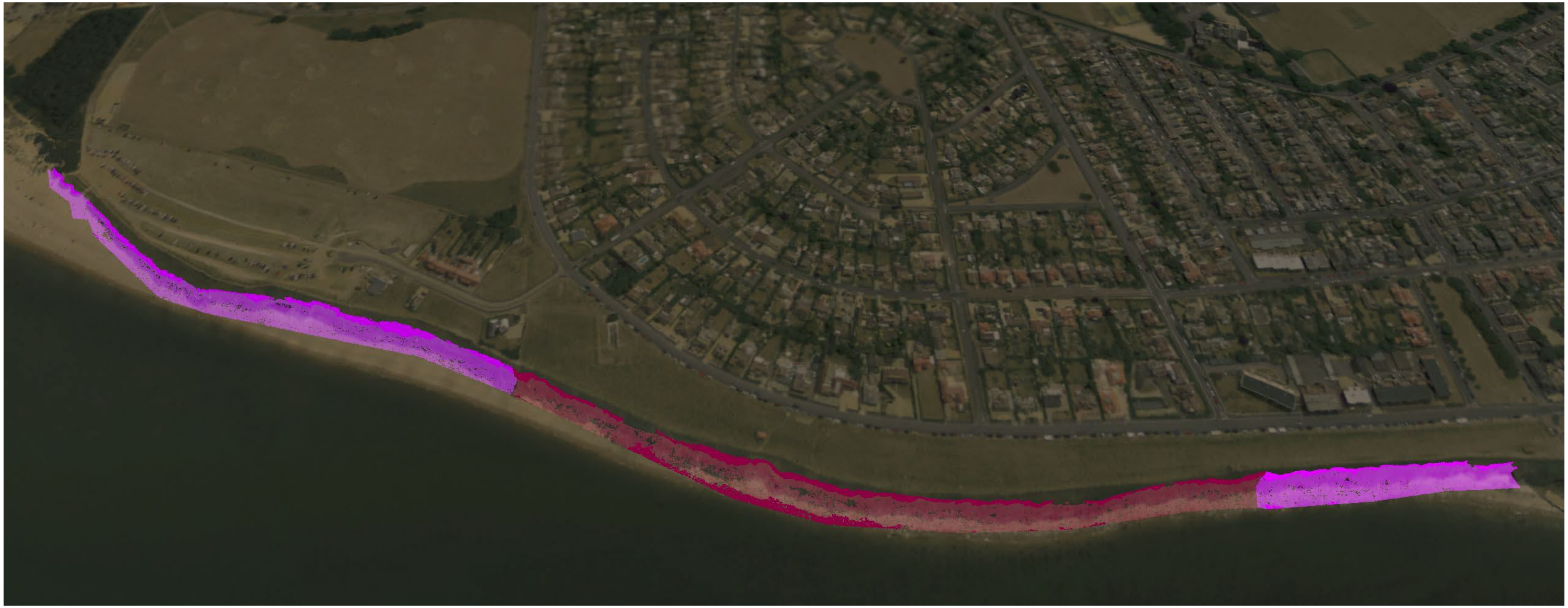
Property Name	Approx. Easting (m)	Approx. Northing (m)	Closest cliff edge (m)	Horizontal Change (m)	Loss at Property (m)	Cumulative Time (days)	Risk Rating (2022)	Risk Rating (2025)	Risk Rating (2030)	Risk Rating (2040)	Risk Rating (2050)
Lighthouse	567625	342058	19	4	5.5	4255	11.6	20.3	39.8	113.7	271.5
Coastguard Lookout	567668	342116	19	3	3.0	4255	4.7	8.2	15.6	41.5	88.4
Coastguard Cottages	567688	342089	50	3	3.0	4255	1.8	3.0	5.5	13.1	24.4
Lighthouse Café	567697	342148	25	2	2.5	4255	2.0	3.4	6.2	15.1	28.7

The Horizontal Change and Loss at Property values were determined by dividing the 2022 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 2022 values. The Risk Rating was then calculated using the same formula as in Section 7.

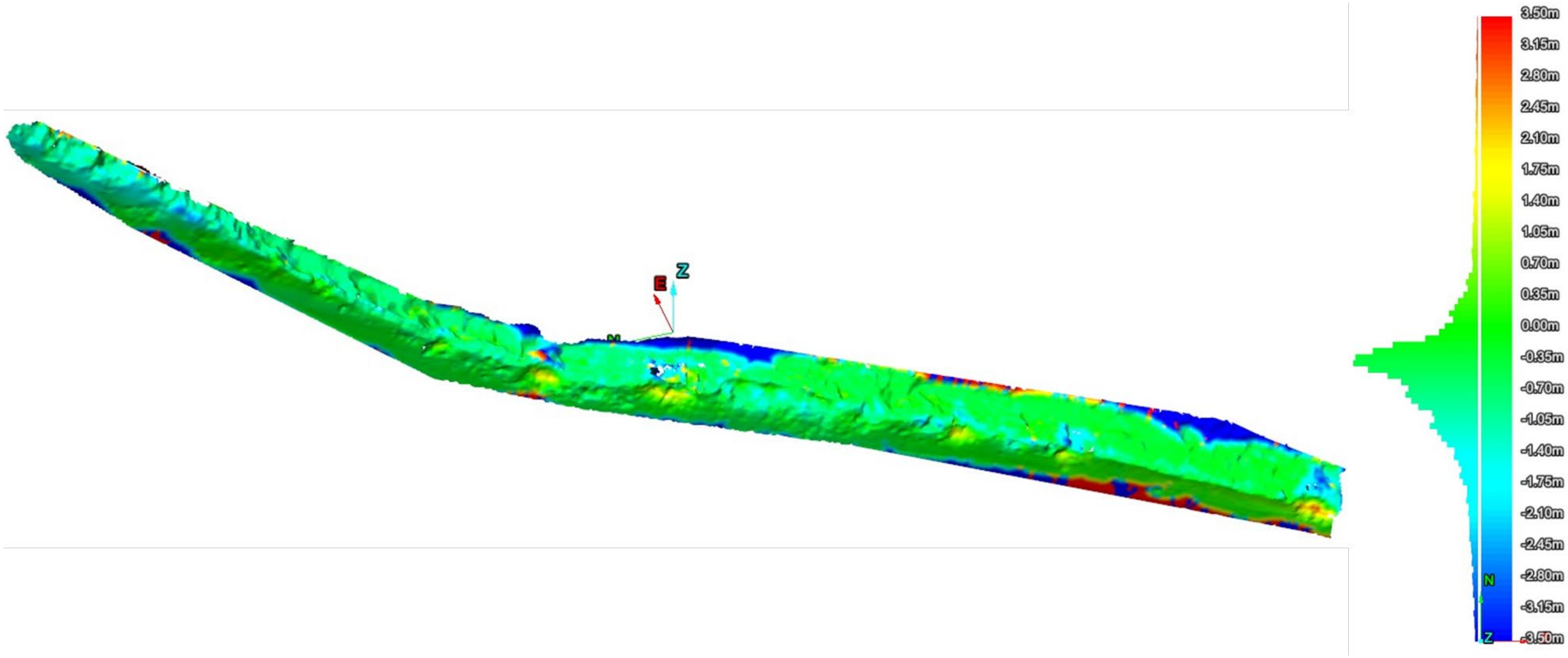
Note: *10 m is the preferred minimum distance agreed with the BCKLWN.

Appendix 1 Change Models

Aerial view of entire section

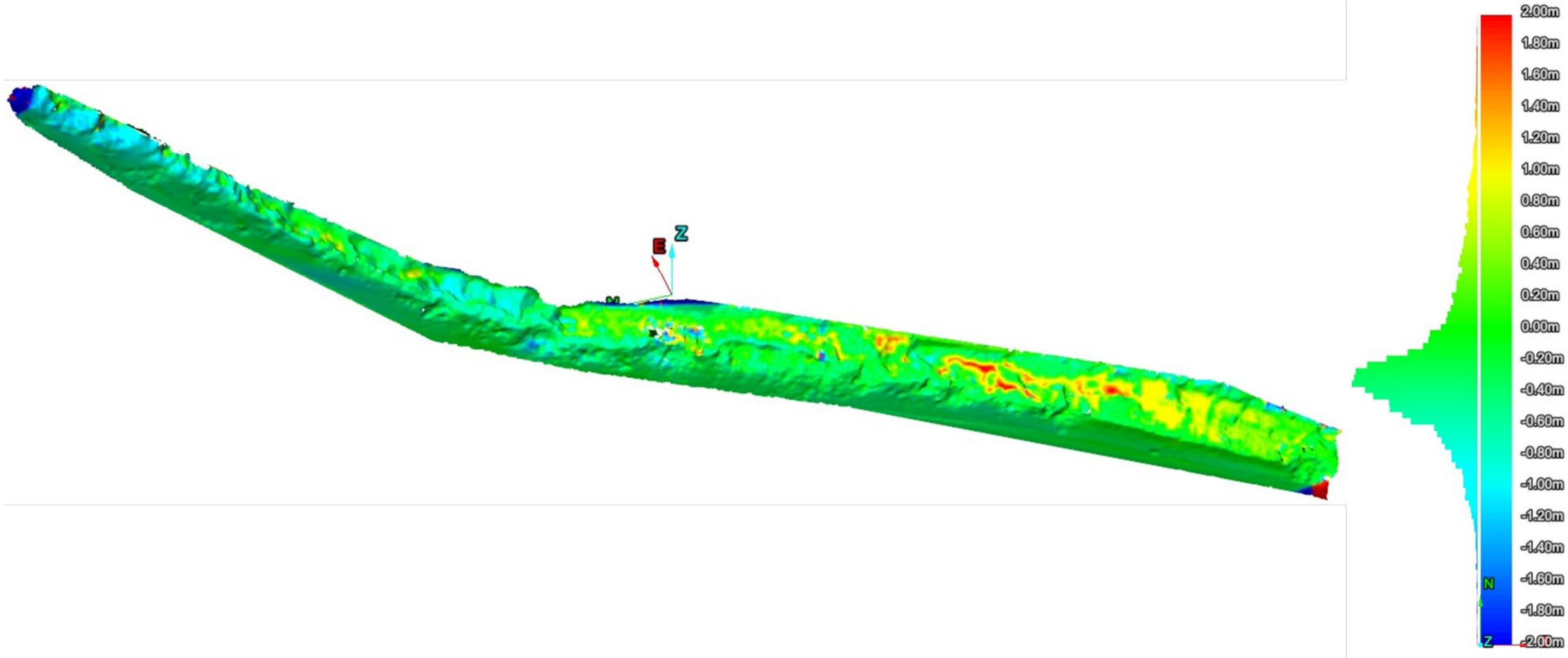


North Section, 2010 to 2022 (Extents: E 567929 m, N 342429 m to E 567586 m, N 342048 m)



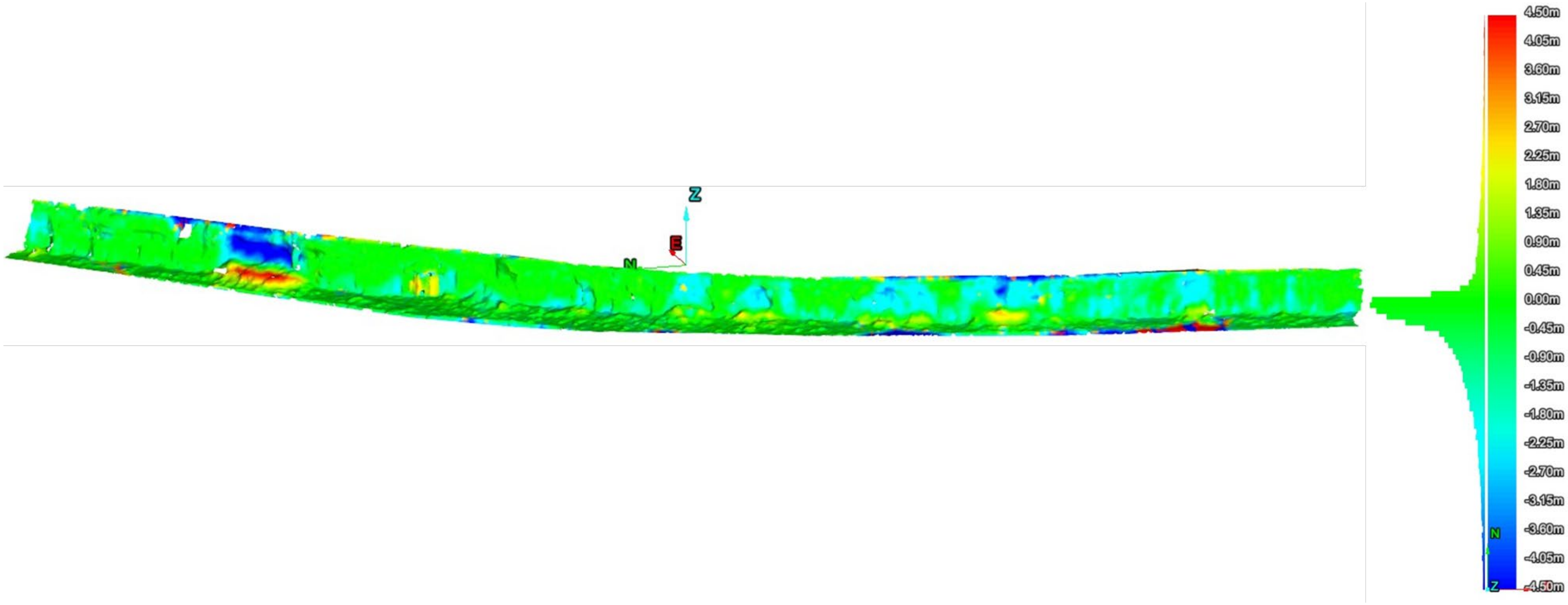
Note: Change = -3.5 m (Blue) to +3.5 m (Red)

North Section, 2021 to 2022 (Extents: E 567929 m, N 342429 m to E 567586 m, N 342048 m)



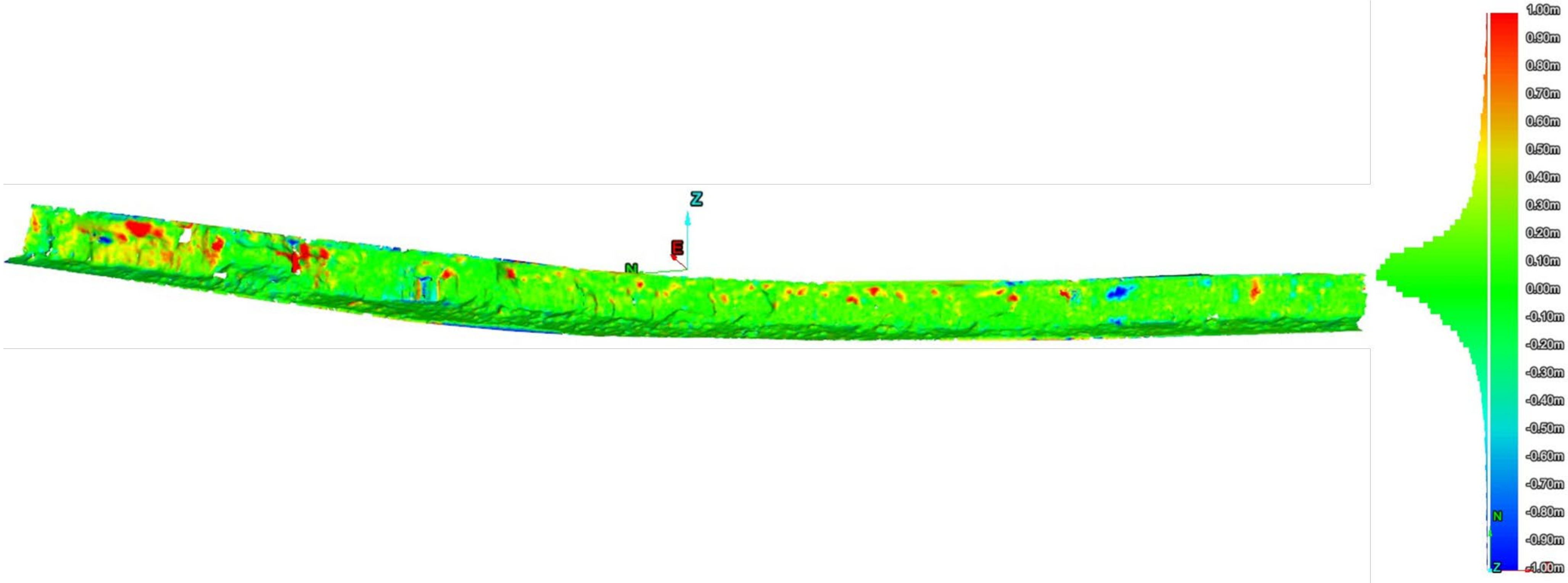
Note: Change = -2 m (Blue) to +2 m (Red)

Middle Section, 2010 to 2022 (Extents: E 567578 m, N 342042 m to E 567332 m, N 341542 m)



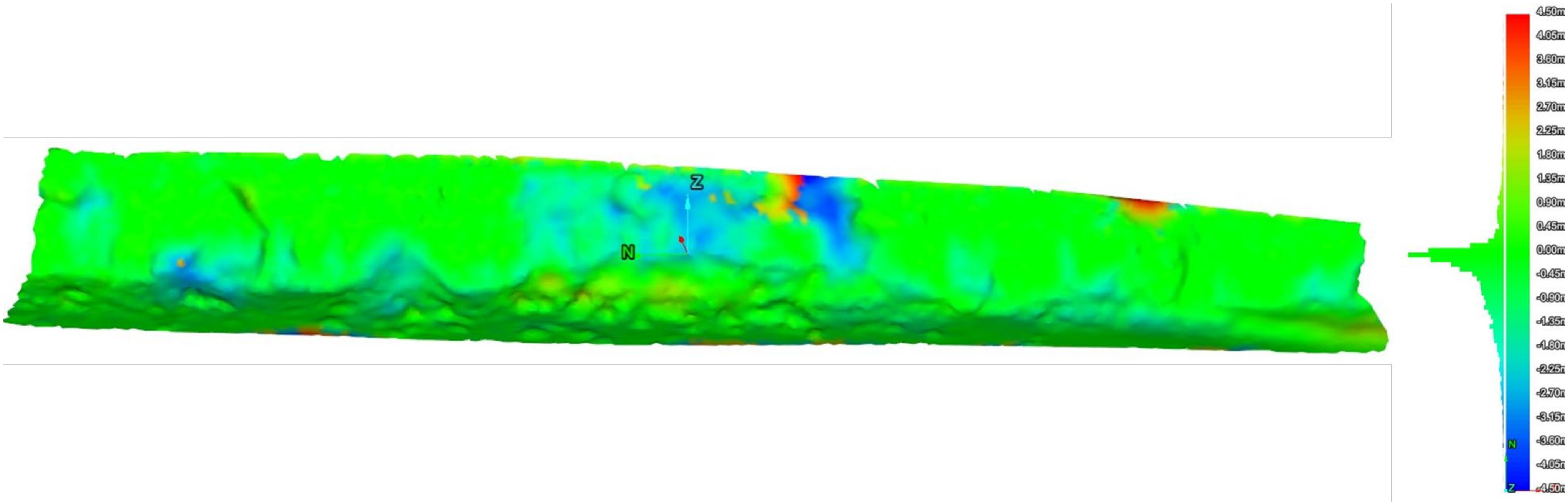
Note: Change = -4.5 m (Blue) to +4.5 m (Red)

Middle Section, 2021 to 2022 (Extents: E 567578 m, N 342042 m to E 567332 m, N 341542 m)



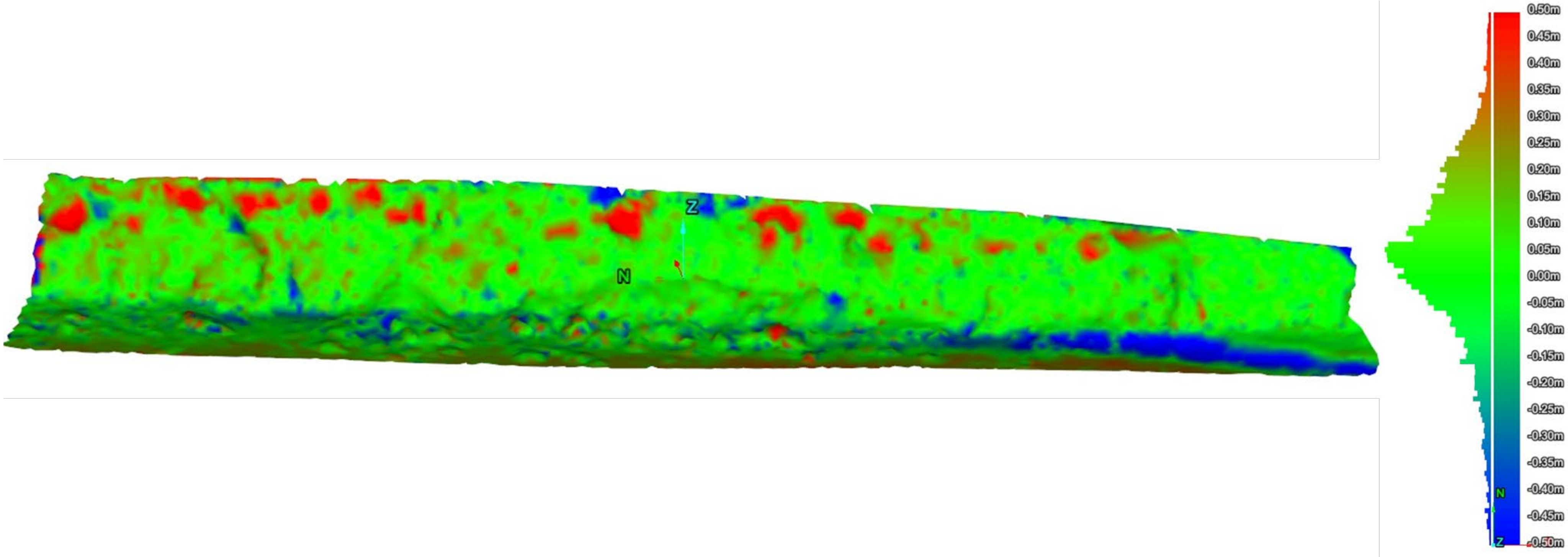
Note: Change = -1 m (Blue) to +1 m (Red)

South Section, 2010 to 2022 (Extents: E 567329 m, N 341540 m to E 567272 m, N 341359 m)



Note: Change = -4.5 m (Blue) to +4.5 m (Red)

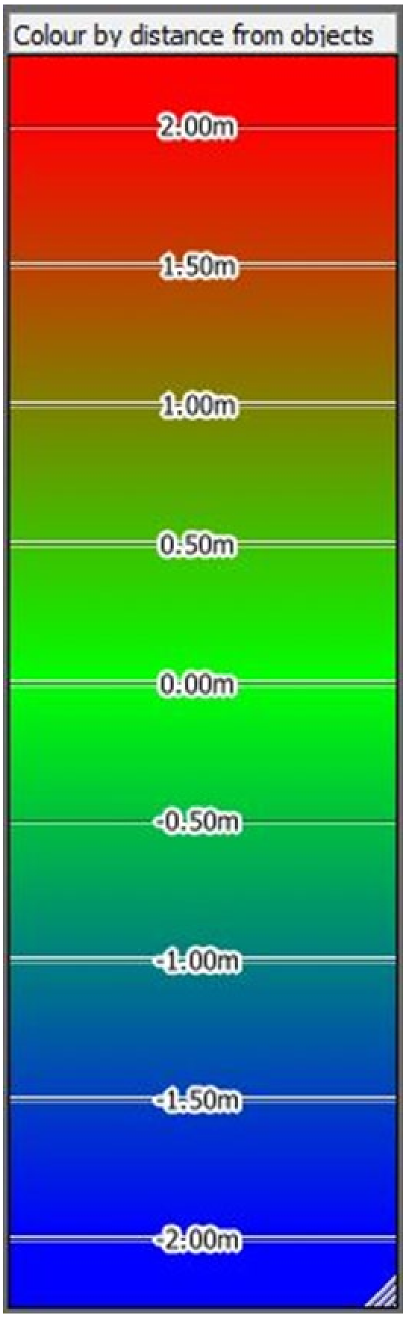
South Section, 2021 to 2022 (Extents: E 567329 m, N 341540 m to E 567272 m, N 341359 m)



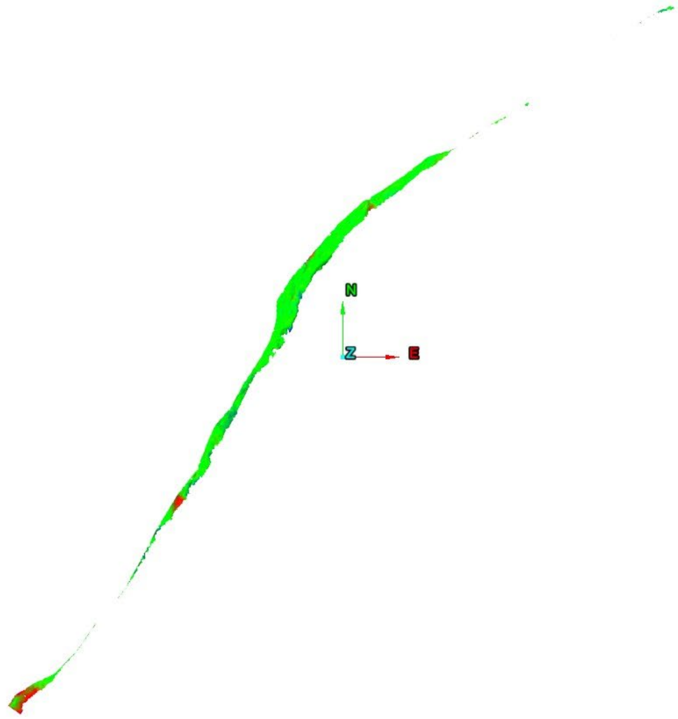
Note: Change = -0.5 m (Blue) to +0.5 m (Red

Appendix 2 Beach Level Models

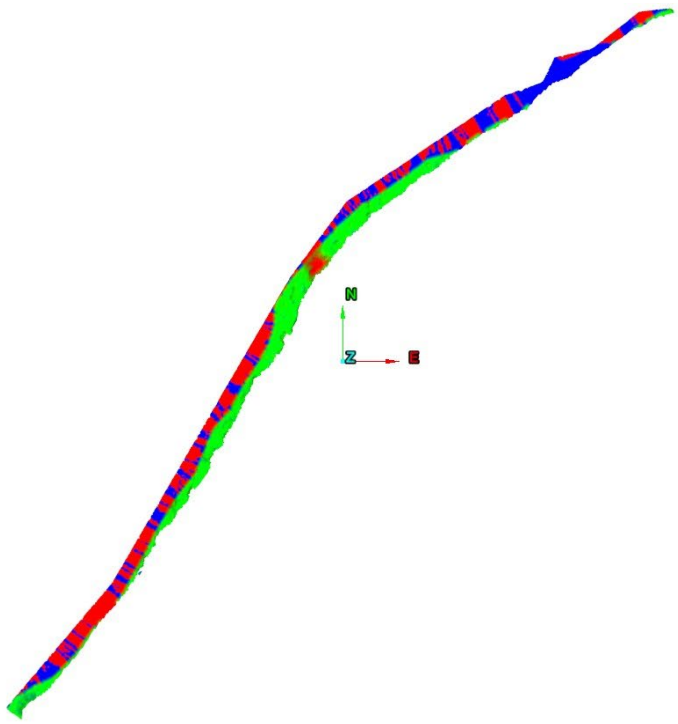
Legend for all Sections



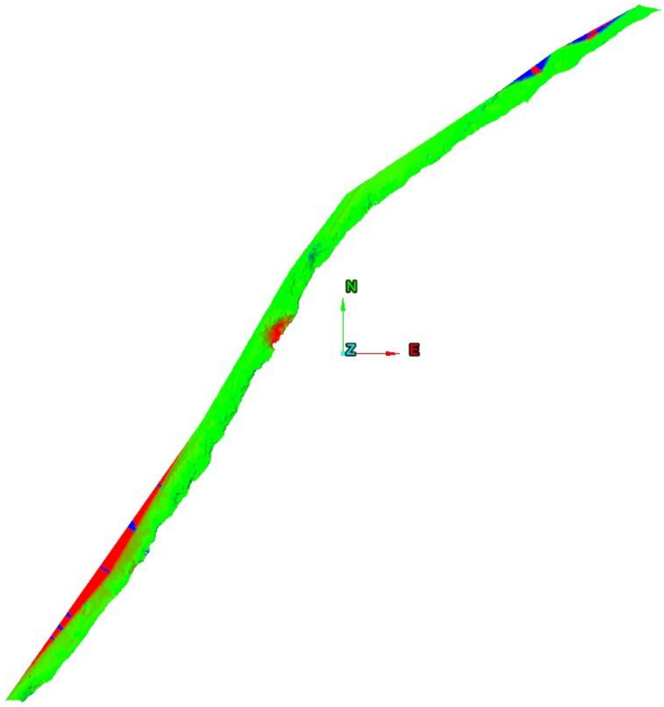
North Section, 2010 to 2017



North Section, 2017 to 2019



North Section, 2019 to 2020



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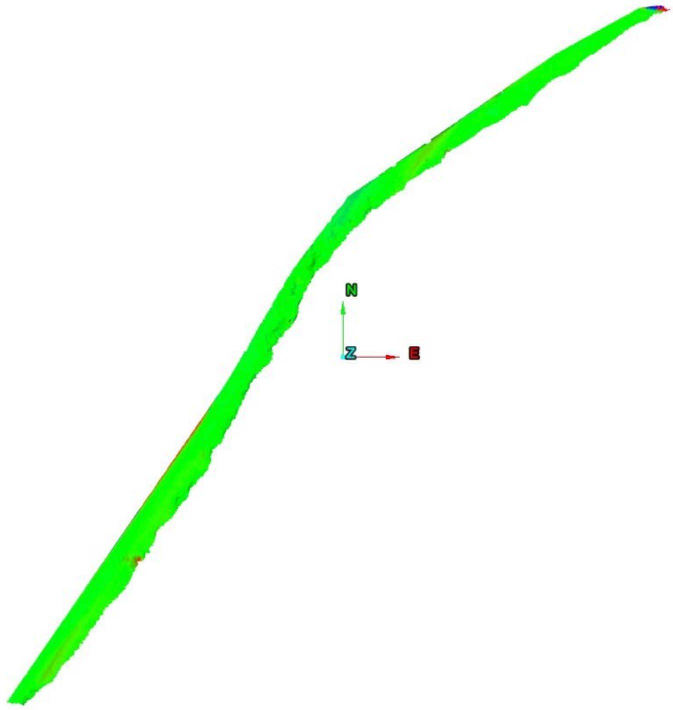
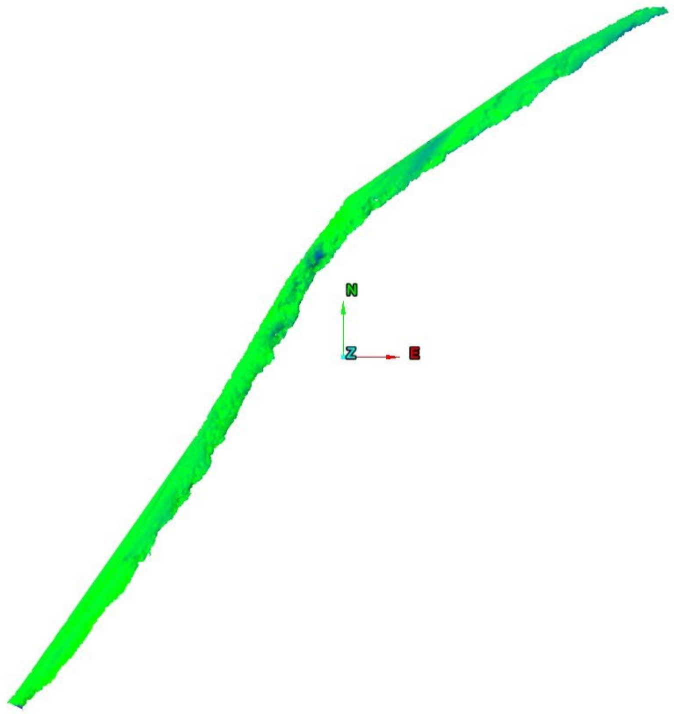
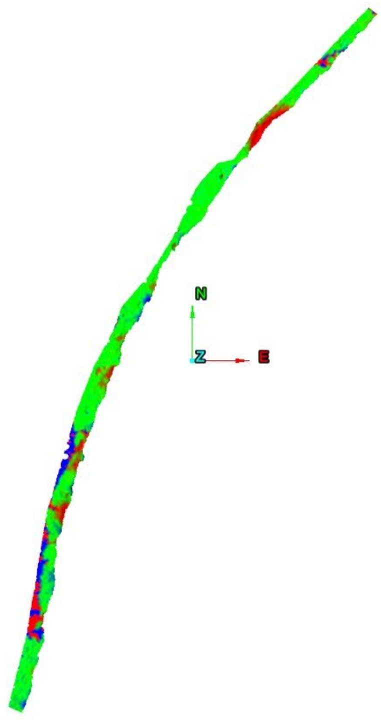


North Section, 2021 to 2022



Middle Section, 2010 to 2017



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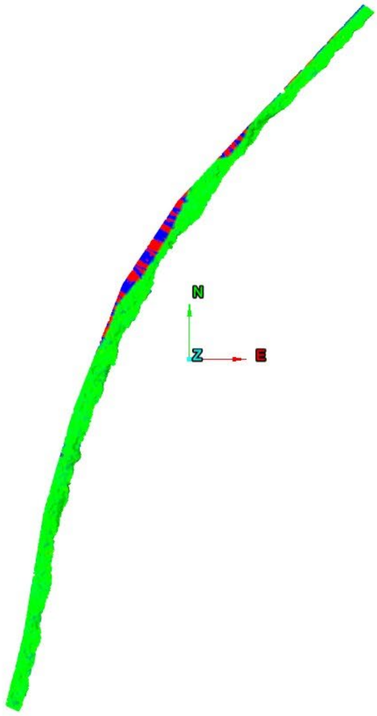

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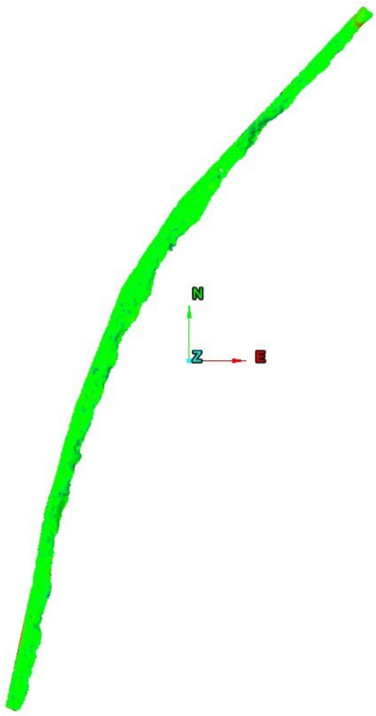

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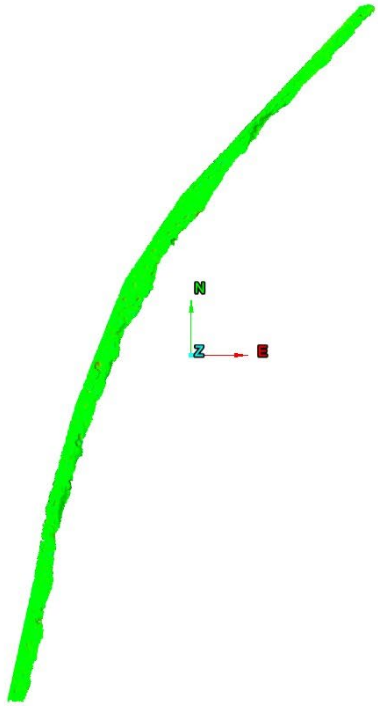

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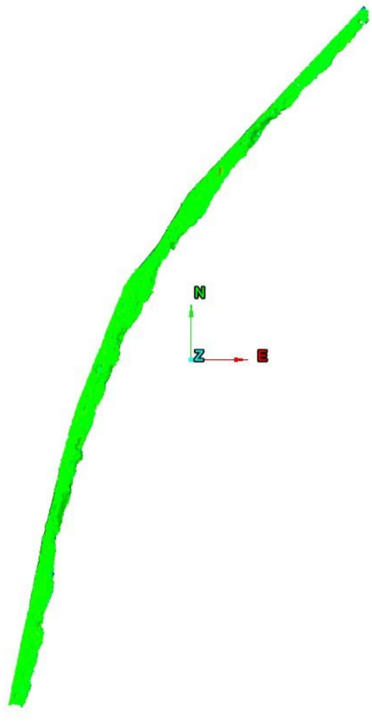
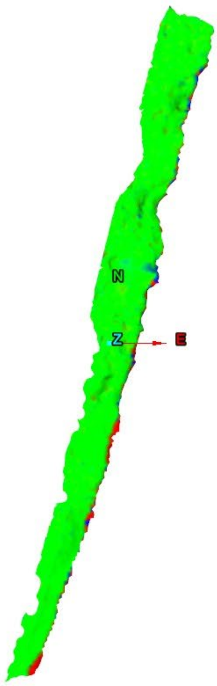
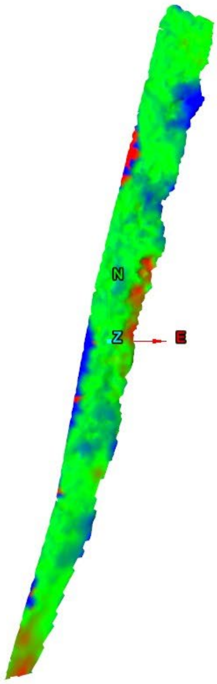


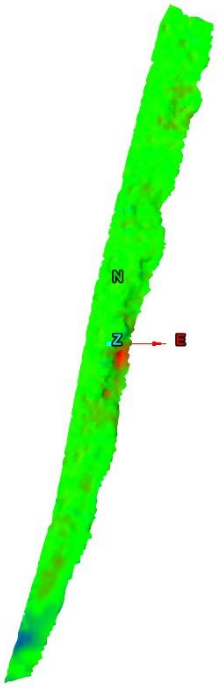
South Section, 2010 to 2012



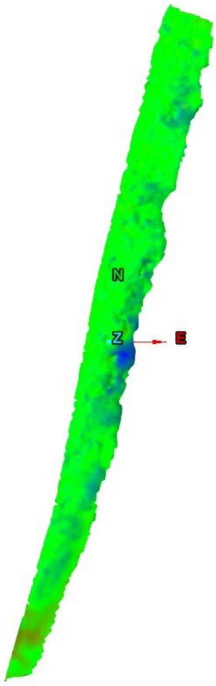
North Section, 2012 to 2017



North Section, 2017 to 2019



North Section, 2019 to 2020



North Section, 2020 to 2021

North Section, 2021 to 2022

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://of-ukrinerc.olib.oclc.org/folio/.

HCMP 2018. Hunstanton Coastal Management Plan Interim Baseline Report 6055215, Borough Council of King's Lynn & West Norfolk. April 2018.

JONES, L D. 2019. Ground-Based Geomatic Surveys: Specification for Terrestrial and Mobile LiDAR Scanning. British Geological Survey Open Report, OR/19/33, 33pp.

JONES, L D. 2017. Ground-Based Geomatic Surveys at the BGS - A Manual for Specialist Data Collection and Processing. British Geological Survey Open Report, OR/17/40, 43pp.

M3C2 2020. Cloud Compare Online. Available at: https://www.cloudcompare.org/doc/wiki/index.php?title=M3C2_(plugin)