SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Fistral Beach Report

Topographic and LiDAR Data Analysis

SWCM | TBR25 | 12/04/2024

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Summary

This report utilises Light Detection and Ranging (LiDAR), topography and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Fistral. The aim is to highlight coastal change at Fistral using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Fistral Beach is a west north-westerly facing sandy beach over 700 m wide, is detailed as the study site. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change of the intertidal beach area over time. LiDAR data is compared from each available flight to show difference models of the intertidal area, to compare volumetric data over time and to show change in Mean Seal Level and Dune Toe contours over time.

Since 2007, 42 topographic surveys were conducted at Fistral, including 4 baselines and 35 interim surveys. Topographic analysis indicates the survey unit has overall been accreting (Fig.5). However, various erosional episodes have taken place as a result of the energetic winter periods in 2014, 2016, 2018 and 2020. Despite these impacts, the beach suggests recovery during the summer period.

Beach volume was extracted from the Beach and Mobile Zones from 9 LiDAR flights between 2008 and 2022. The Mobile Zone has experienced continual erosion, losing 10% in volume between 2008 and 2022. Considerable erosive events were recorded between the 2012 and 2014 surveys and 2017 and 2019 surveys. The Beach Zone has shown the opposite, accreting by 17% in volume between 2008 and 2022, suggesting that material made available from the erosion of the Mobile Zone is feeding the lower beach. The Dune Toe contours have eroded by up to 4-5 m along the length of beach, seeing up to 13 m of dune recession to the south.

Overall, the dune system of Fistral has experienced a loss in volume, suffering several erosional periods, resulting in a heavily impacted dune system but an accreting beach.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Fistral Beach using data collected as part of the South West Coastal Monitoring (SWCM) Programme since 2007. Four zones have been identified to define the beach/dune area and are defined as:

- **Beach Zone** – The wet beach area has been defined using Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS) contours extracted from all LiDAR data captured by SWCM. The Beach Zone will therefore encompass the area between the MHWS and MLWS contours, with volumes for this area extracted from each LiDAR surface.
- **Mobile Zone** – This area is defined as the active dune face and embryo dune[1] from MHWS +1 m to the back of the mobile area, often distinguished by vegetation depth or urban development. The Mobile Zone has been defined using aerial imagery from 2007 to 2021 and historic OS maps and has been verified through site visits.
- **Fixed Zone** – This area is defined by permanent dune vegetation that may also include scrub or invasive species, effectively denoting vegetation atop sandy soil.
- **Developed Zone** – This is defined as urban development areas (i.e., car parks, unnatural grassy areas, roads, houses etc.) which have been built atop previously present dune systems.

1.1 Study Site

Fistral Beach is a west north-westerly facing sandy beach over 700 m wide and 250 m long, backed by an eroding dune system (Fig.1). The dune system leads onto a golf course, preventing the dune to naturally rollback. There's a car park, lifeguard station and building complex to the north of the beach, protected by sheet piling rip-rap sea defence. To the north, a rock platform is present with a small sandy cove situated in the northern corner. Following this, a hard rock headland protrudes out seawards in the north and to the south. The beach has a semi-diurnal tide type and an average spring tidal range of 6.4 m.



Figure 1 - Location Map of Fistral Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[1] An embryo dune, or yellow dune, is the earliest stage of dune growth, usually found along the seaward extent of a dune system or newly formed dune.

2.0 Methods

Data utilised in this report was collected by SWCM between 2007 and 2024. Information on topographic and LiDAR data collection and specifications can be found on the Website for the National Network of Coastal Monitoring Programmes.

2.1 Topographic Data

SWCM have undertaken routine topographic beach surveys at 34 of the 40 MS4S sites since 2006. All surveys are conducted from the MLWS contour to the backshore. On average, each surveyed beach receives two interim surveys a year and one full coverage survey every 5 years:

- Interim - Conducted twice a year in the spring (conducted between January and April), and autumn (conducted between September and December). An interim survey consists of collecting data points at 5m intervals along pre-defined profiles; these are outlined in Figure 1.
- Full coverage – Conducted once per phase (6 years), or annually at more vulnerable sites (conducted between May and September). Full coverage surveys include a full profile survey at 50 m intervals and continuous spot height data collected across a 5 m grid covering the whole beach.

Analysis of the Cross-Sectional Area (CSA) change is conducted for each individual profile between each separate survey. Changes in CSA are measured relative to the fixed master profile which is defined by a pre-determined stable landward position and the MLWS level in reference to Ordnance Datum.

2.1.1 Topographic Data Analysis

Topographic data is presented as the following, where applicable:

Trend Analysis Plot - The combined profile trend in CSA is presented for each survey unit (example shown in Fig.2). The sum of all interim profile CSA is combined for each survey conducted to date to provide a survey unit with a single 'beach area' value, known hence-forth as the Combined Profile Area (CPA). CPA is compared using linear trend analysis over a temporal scale (Fig.2).

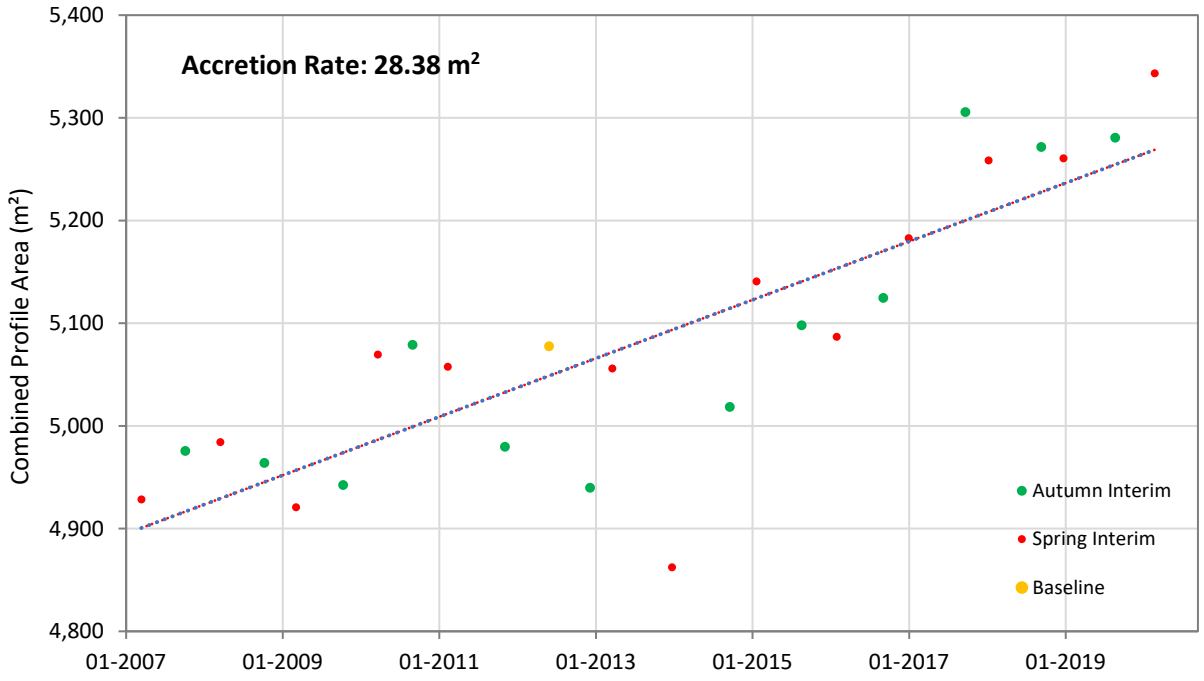


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

If a profile has been omitted from a particular survey, for reasons of obstruction or similar, the average CSA of that profile from all available surveys is taken to ensure a consistent 'beach area'; if fewer than 75% of surveys have been conducted for a particular profile, the profile is omitted.

Profile Extremes Analysis - This plot displays the range of CSA values recorded throughout the duration of data collection (2006-2024) for each individual interim profile; the most recent survey is represented as a green dot. An example is given in figure 3. This plot provides the reader with information on how the CSA for each interim profile from the most recent survey corresponds to the entire dataset range.

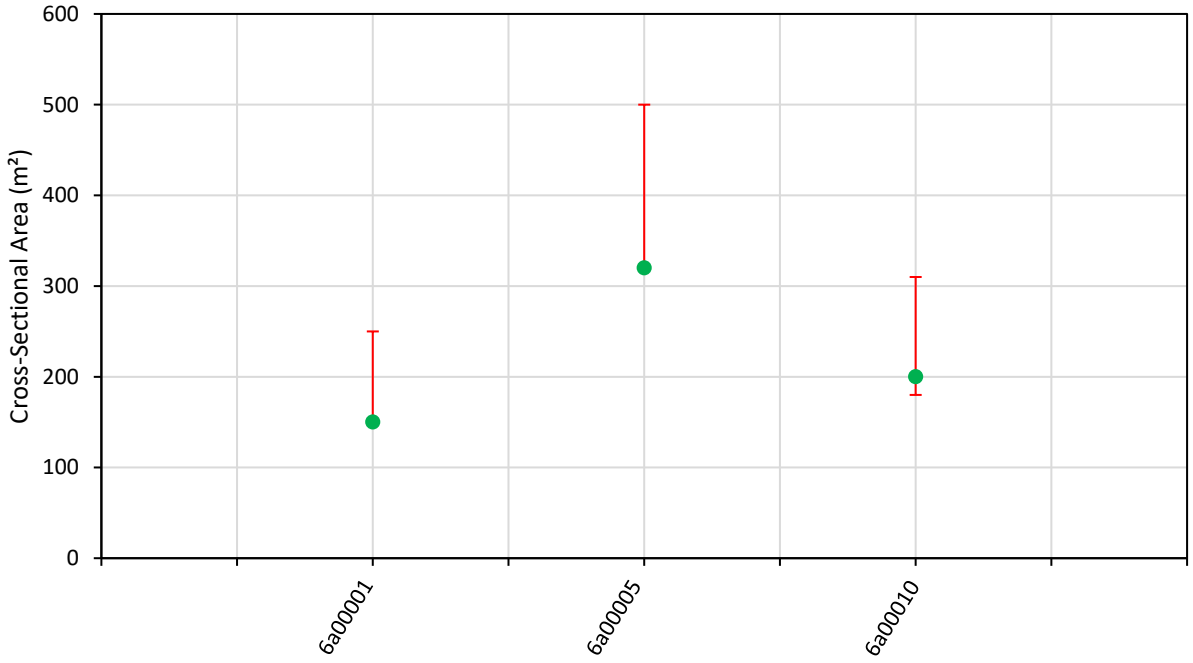


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

CSA Time Series Plot - CSA measurements for each interim profile are displayed on a separate plot representing values from each interim and full coverage survey conducted to date (example shown in Fig.4). This provides the reader with information on each interim profile's CSA evolution through time.

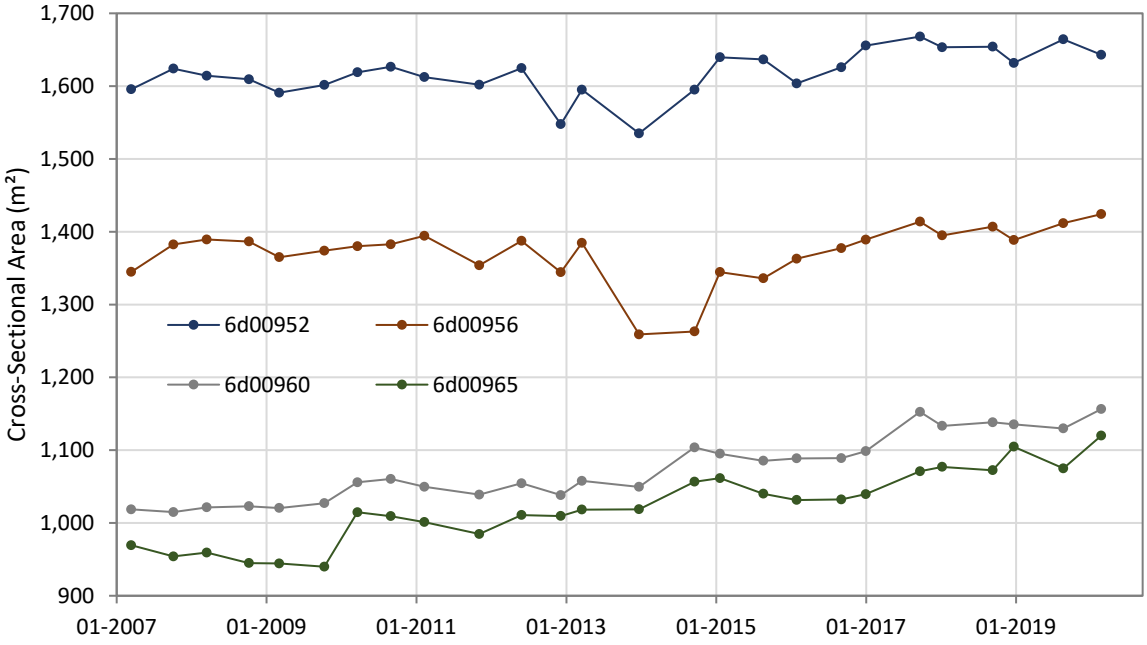


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

Individual Profile Charts - Each interim profile is portrayed as a cross-sectional profile comparing the most recent spring interim (blue), the previous spring interim (green) and the original full coverage survey (red). Profiles are displayed against the master profile (dotted red line) and are presented in the Appendices.

The 2013/2014 Storms – The winter period between September 2013 and April 2014 was, for many beaches in Cornwall, the most destructive period since SWCM records began in 2007. An abnormal number of significant storms, occurring in quick succession, heavily impacted many beaches, causing the loss of sediment from the intertidal area and dune face. This period is extensively discussed throughout this report and will hereinafter be referred to as the 2013/2014 winter period.

2.2 LiDAR Data

Airborne Light Detection and Ranging (LiDAR) data have been captured as part of the SWCM since 2007. Products include a point clouds, from which filtered and unfiltered 1 m^2 gridded surface models are derived:

- Unfiltered (Digital Elevation Model) representing the earth's surface including natural and artificial features such as trees and buildings.
- Filtered (Digital Terrain Model) representing the bare earth surface, with trees, buildings, cars etc. removed.

LiDAR is captured between September and March to minimise vegetation capture. Data is captured between MLWS and up to approximately 500 m inland. This report utilises "filtered" LiDAR data.

2.2.1 LiDAR Data Analysis

LiDAR data analysis is presented as the following:

Difference Modelling – Separate LiDAR surfaces are compared to produce a difference model of change based on gridded spot height elevations. The raw spot height data is processed into a gridded digital terrain model (DTM) and successive models are subtracted from one another to produce a difference model for the survey unit. Change in elevation is shown for values +/- 0.25 m and is represented by a colour scale bar.

Volume Extraction - Net sediment volume (m^3) is extracted for each LiDAR surface from the Beach Zone above MLWS and Mobile Zone above MHWS for trend comparison over time.

Contour Analysis – Contours are mapped from four LiDAR epochs spanning from 2007 to 2023, representing Mean Sea Level (MSL) and dune toe (calculated using the Stockdon equation by UoP, 2023[2]).

2.3 Accuracy Statement

Topographic Data – All survey points recorded along profiles have a measurement accuracy of +/- 0.03 m RMSE[3] in the horizontal and +/-0.03 m RMSE in the vertical.

LiDAR Data – Each LiDAR point cloud dataset has an average point density of 1.5 points per square metre. The digital terrain surfaces provide a minimum accuracy in elevation data of +/- 0.10 m RMSE with a minimum horizontal standard deviation as < 0.05 m. Please note that while every endeavour has been made to capture LiDAR as far seaward as MLWS, tidal and weather restrictions may in some instances have precluded this and coverage may be slightly reduced

[2] Please refer to the following for Dune Toe elevation calculation: UoP, 2023. MS4S: Contemporary Dune Evolution and Future Predictions, Report, University of Plymouth, 33 pp.

[3] RMSE – Root-Mean-Square Error

3.0 Results

3.1 Topographic Data Analysis

There has been a total of 42 topographic surveys at Fistral Beach since 2007, 4 of which are baseline surveys, 35 are interim surveys and 3 are post-storm surveys. Exact dates of each survey for Fistral Beach are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting at 10.4 m^2 y^{-1} equating to 0.13% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2018 spring interim (7,288 m^2); however, the beach has seen a couple of erosive periods in 2014, 2016, 2018 and 2020. The highest recorded combined area was during the autumn interim of 2023 (8,449 m^2).

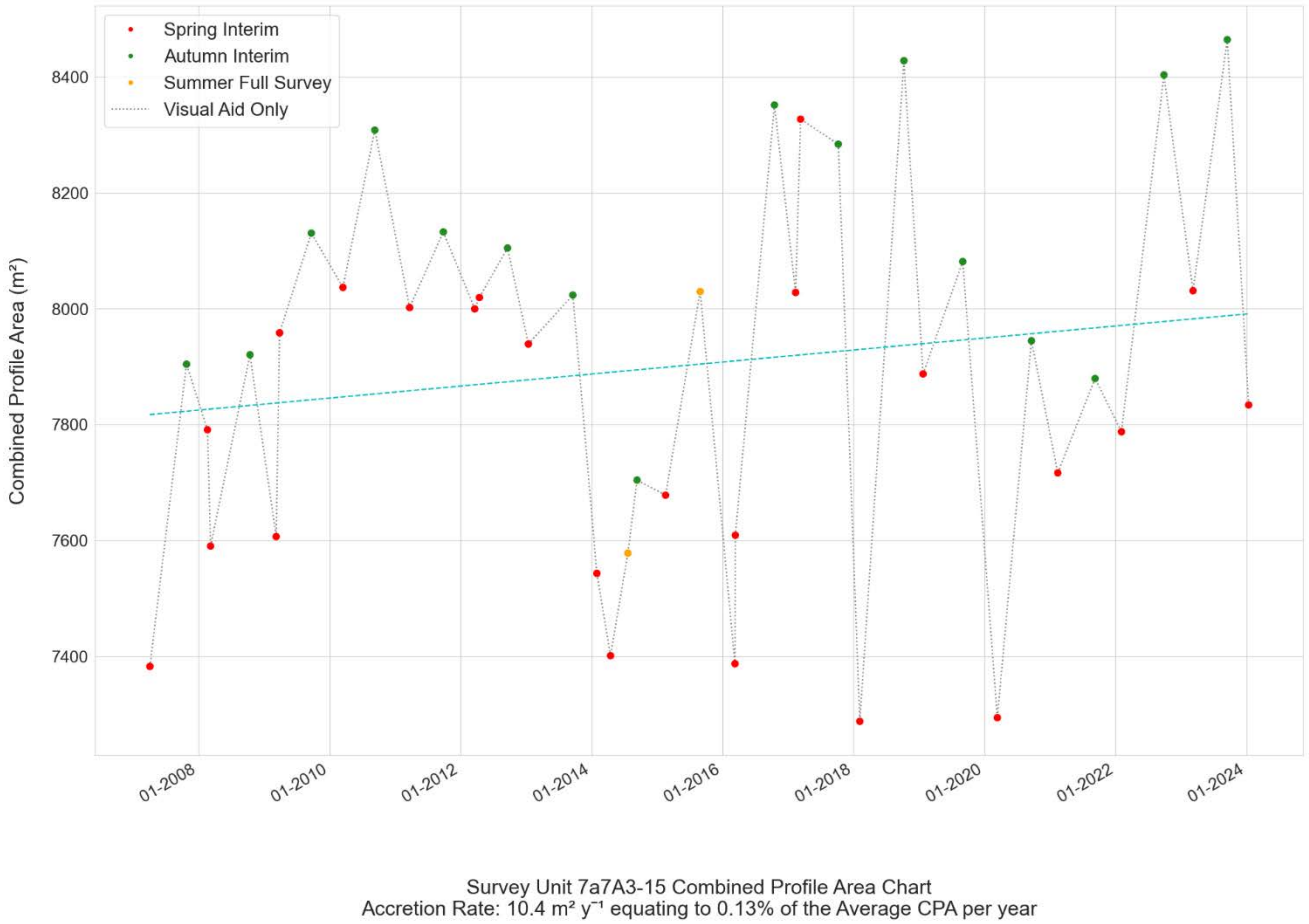


Figure 5 - The Combined Profile Area (CPA) for Fistral Beach, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When comparing to the entire dataset (Fig.6), during the 2024 spring interim all Fistral Beach profiles remained relatively stable with only profile 7a01690 displaying a below average value.

When comparing profile cross-sectional areas to the entire time series (Fig.7), all profiles again have displayed continual accretion since 2007 with minimal seasonal variation apparent in any profile. All profiles shown a seasonal variability, as well as displaying an impact from the 2013/14 winter season.

Profile Charts for Fistral Beach can be found in Appendix 1, these display the cross-sections of each profile for the initial baseline survey conducted in 2007 along with the two most recent interim surveys. Generally, all profiles have seen a loss of material along the upper beach and dune face but seen an increase in beach elevation across the lower half of the beach by up to 1 m.

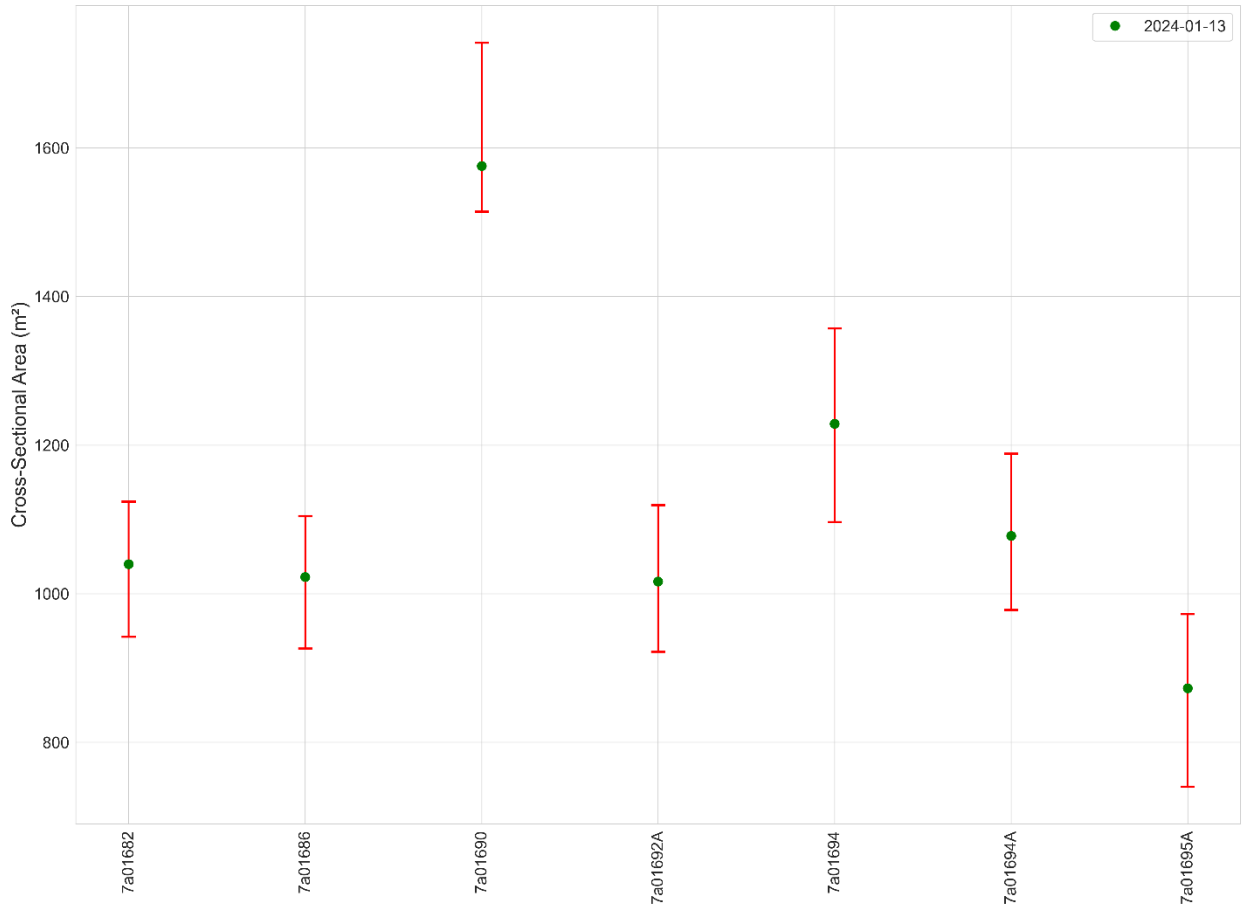


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2024.

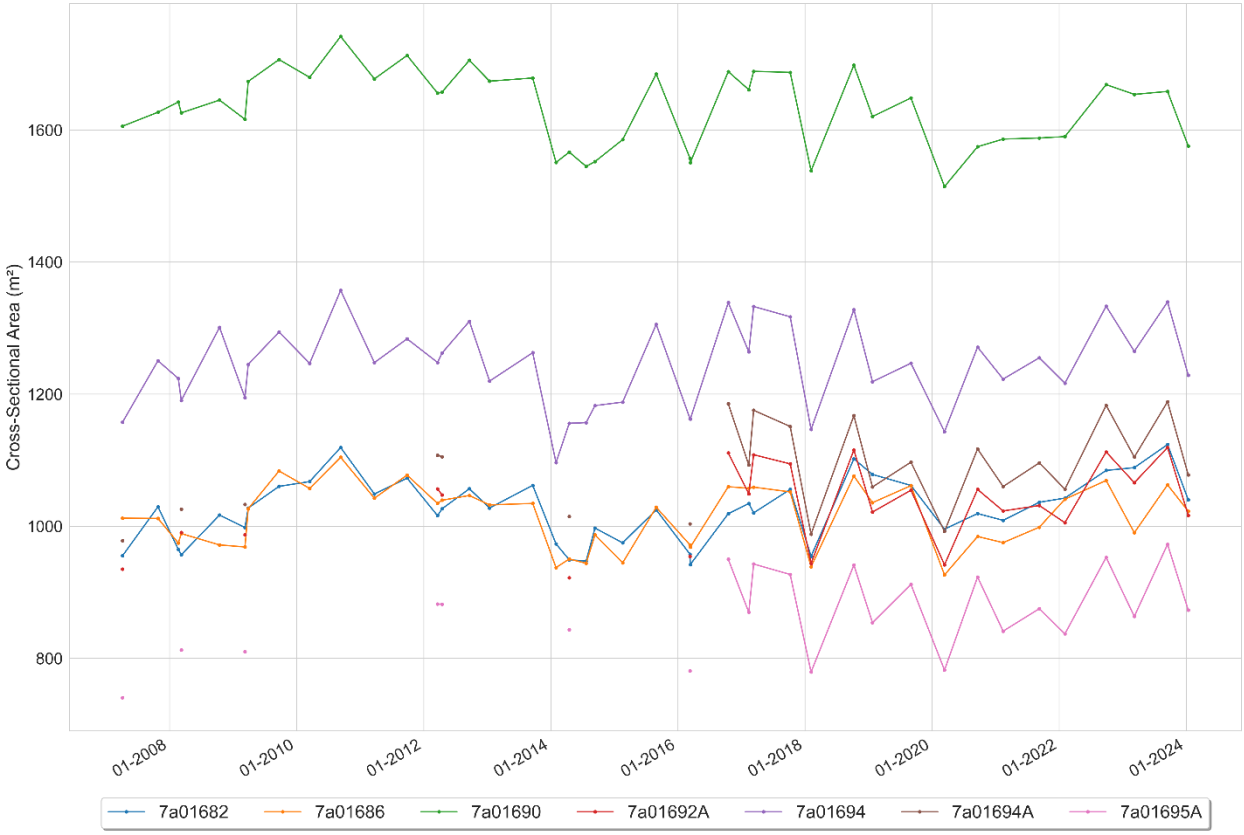


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

There has been a total of 10 LiDAR flights captured at Fistral Beach since 2007 through the SWCM Programme.

Difference Models

Difference models between each epoch of LiDAR data are presented here. Accretion and erosion values observed behind the dune system can be attributable to noise in the filtered LiDAR data or man-made changes in elevation and should be dismissed as such.

Figure 8 shows the difference in elevation between the first filtered LiDAR data from March 2008 compared to the most recent, captured in October 2022. There is widespread accretion, of up to 1.5 m observed along the intertidal zone up to the MSL contour, whereas the mobile dune face has experienced acute erosion of >3 m. The dune and beach face followed, eroding by up to 1.5 m.

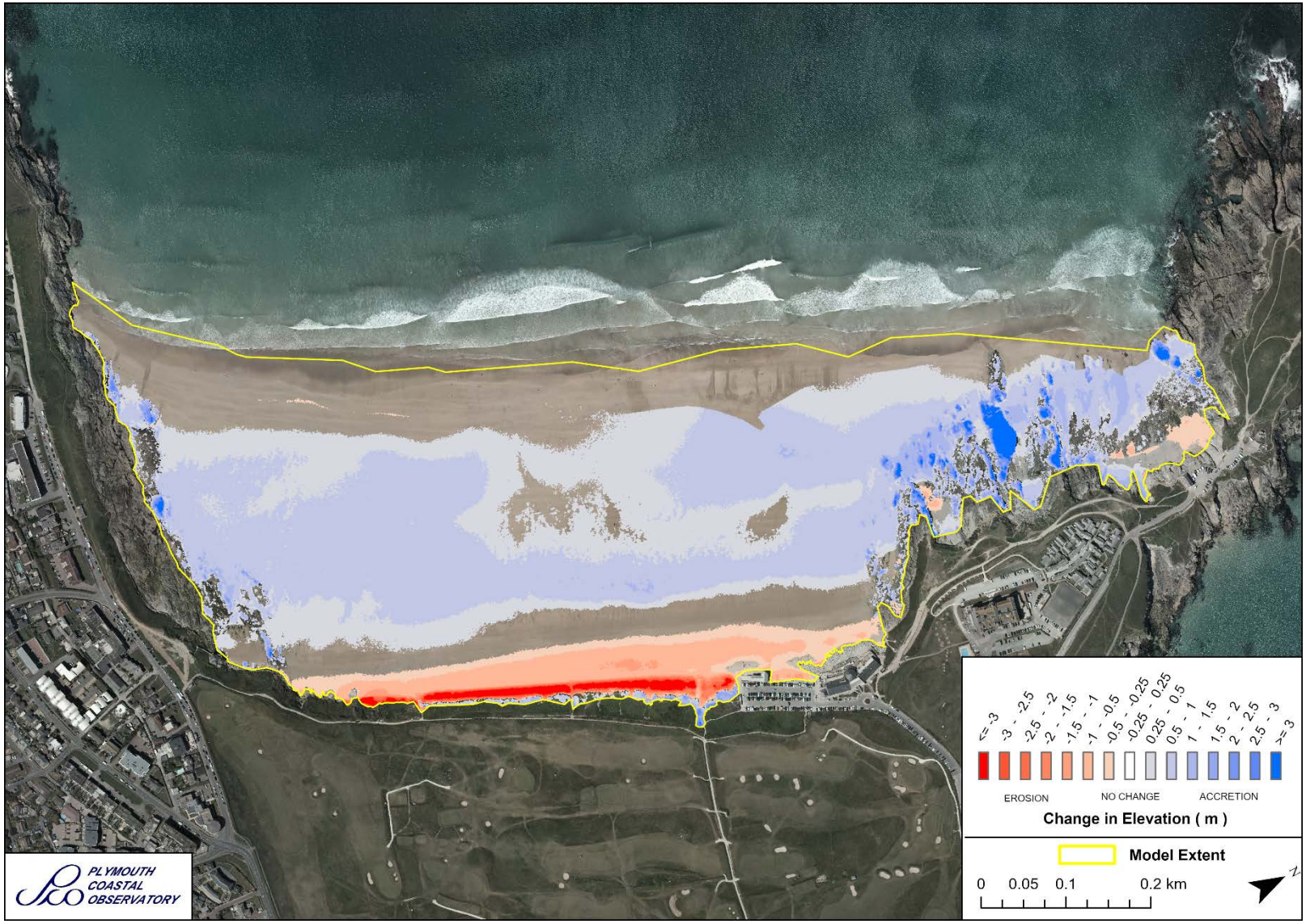


Figure 8 – Difference model indicating the changes in elevation observed between the March 2008 and October 2022 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from March 2008 compared to March 2009. Unlike Figure 8, minimal change has occurred across the unit, seeing low-level erosion along the dune face. Acute accretion can be observed to the north, seeing a build-up of material around the rocky reef.

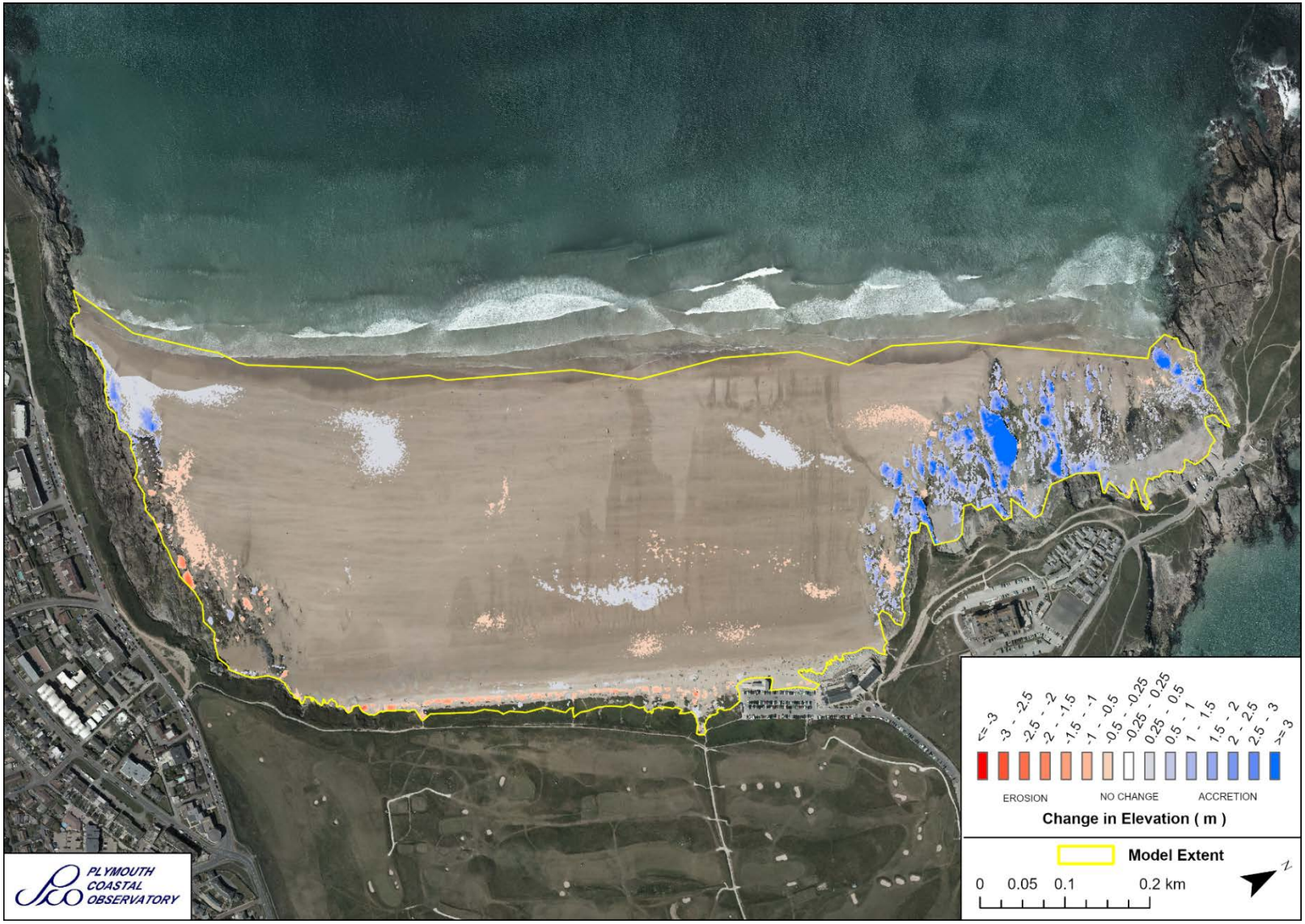


Figure 9 - Difference model indicating the changes in elevation observed between the March 2008 and March 2009 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from March 2009 compared to October 2010. Oppositely to that observed in Figure 9, there is widespread accretion along the MSL mark for the entire beach, accreting by up to 1 m in places. The dune crest has seen some accretion whilst the beach face has seen a removal of material along the entire frontage, losing up to 1.5 m towards the middle.

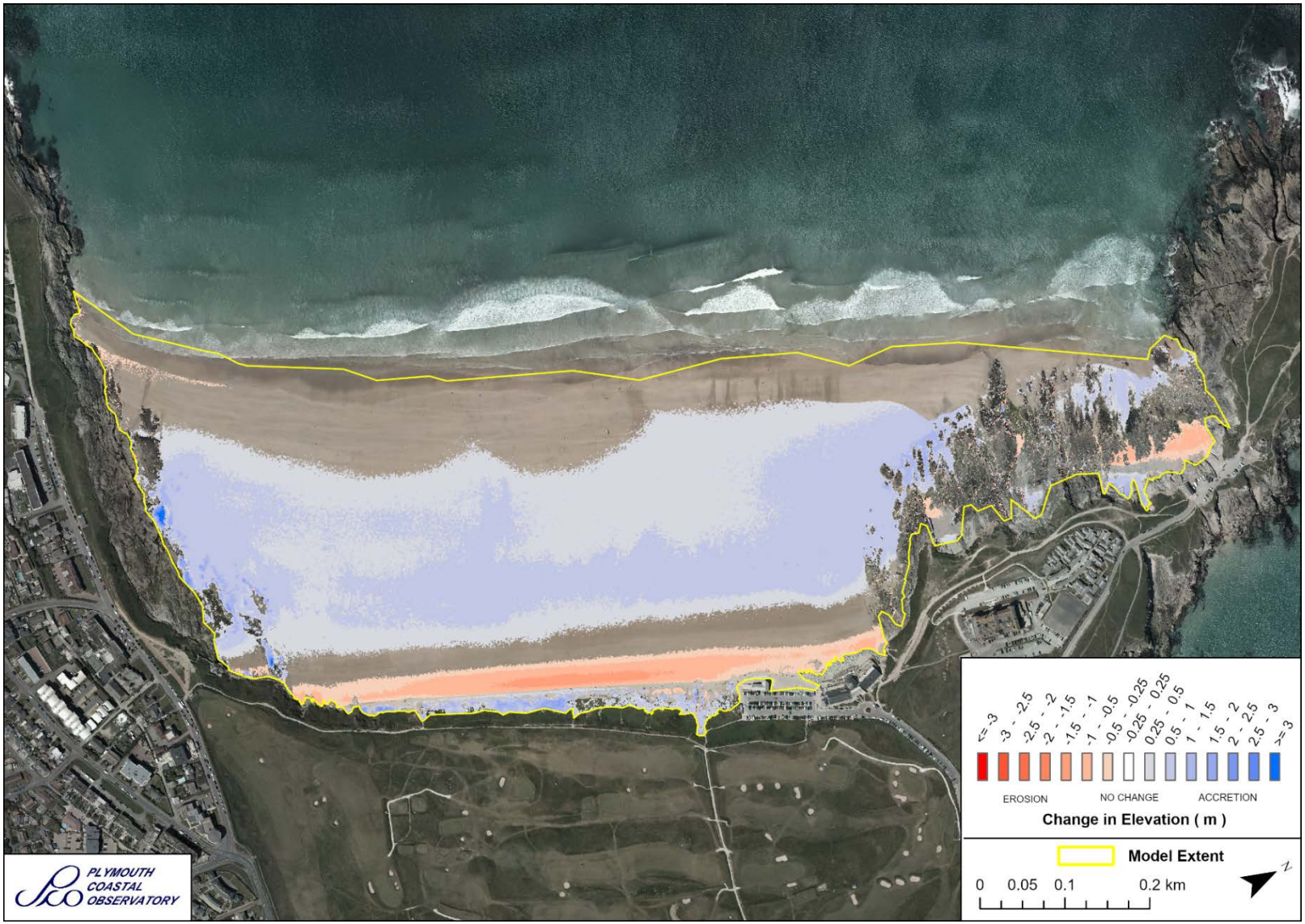


Figure 10 – Difference model indicating the changes in elevation observed between the March 2009 and October 2010 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from October 2010 compared to April 2012. This epoch shows areas of erosion to the south and just below the MSL mark, losing up to 1 m in elevation. Similarly, up to 2.5 m of erosion has occurred in the middle of the dune frontage, whilst the high-water mark has also seen a loss of material. Patches of low-level accretion can be seen along the high-water mark to the south.

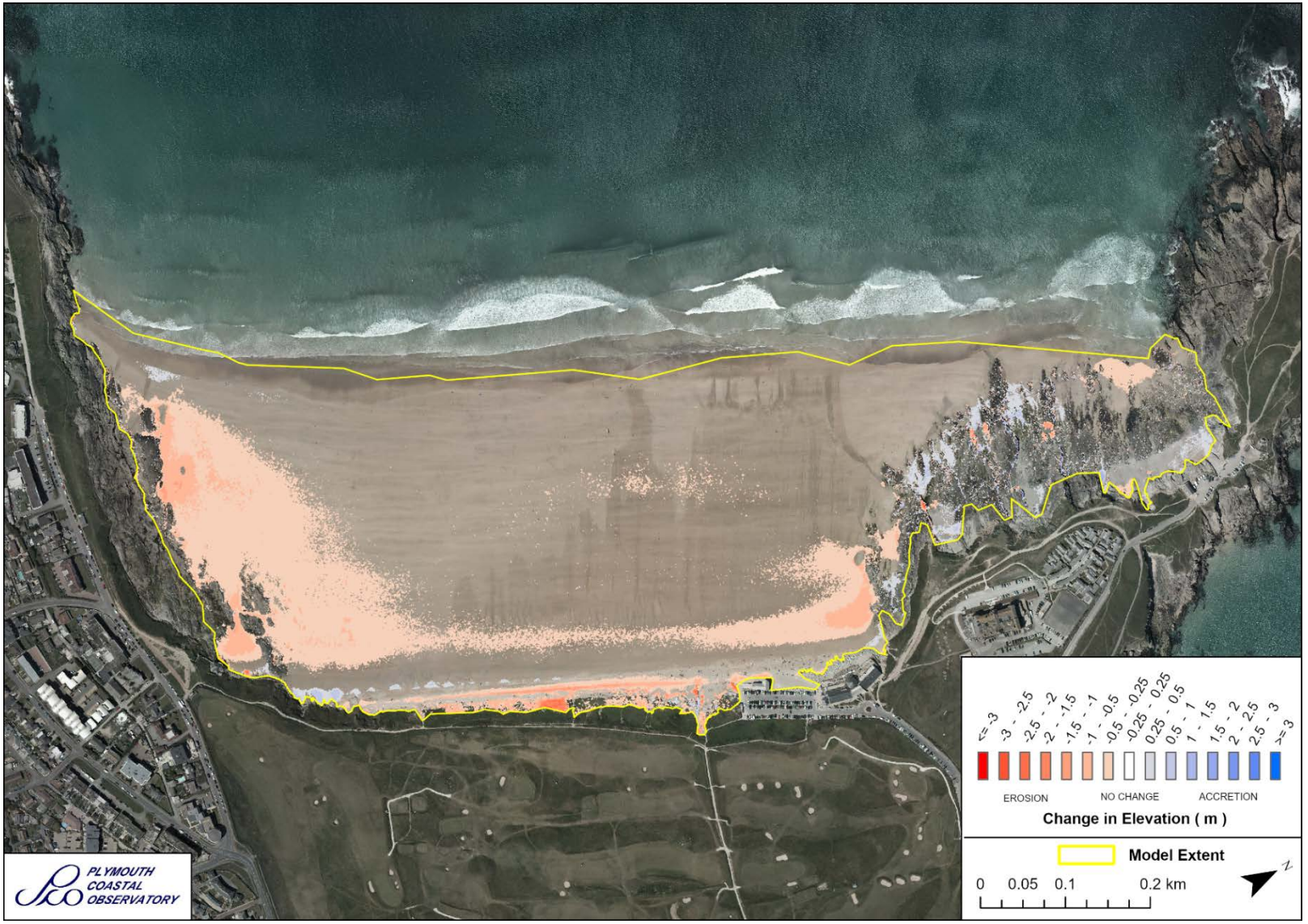


Figure 11 - Difference model indicating the changes in elevation observed between the October 2010 and April 2012 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from April 2012 compared to March 2014. Widespread erosion is observed across the intertidal zone, seeing a loss of 1.5 m in some areas. The dune face has seen acute erosion along the entire frontage losing >3 m in elevation. Erosion continued along the beach face, to the north, experiencing a loss of 1 m.

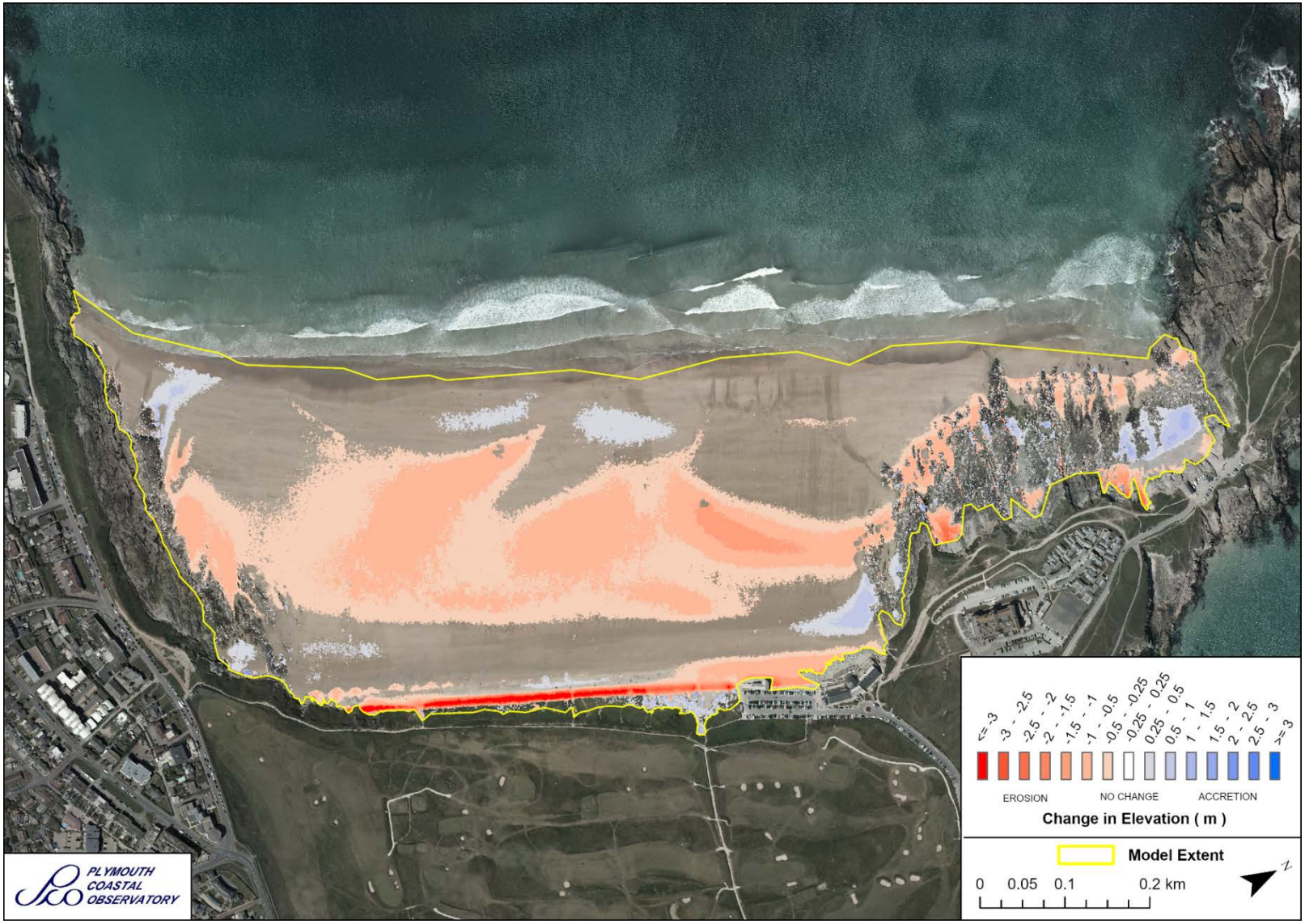


Figure 12 - Difference model indicating the changes in elevation observed between the April 2012 and March 2014 filtered LiDAR datasets within the yellow model extent.

Figure 13 shows differences in elevation between filtered LiDAR data from March 2014 compared to March 2016. A mixture of erosion and accretion had been observed along the dune face, losing up to 3 m towards the north of the dune system. The beach face, however, has seen a build-up of material, indicating material from the dune has been redistributed into the beach. Patches of erosion and accretion can be observed across the intertidal zone.

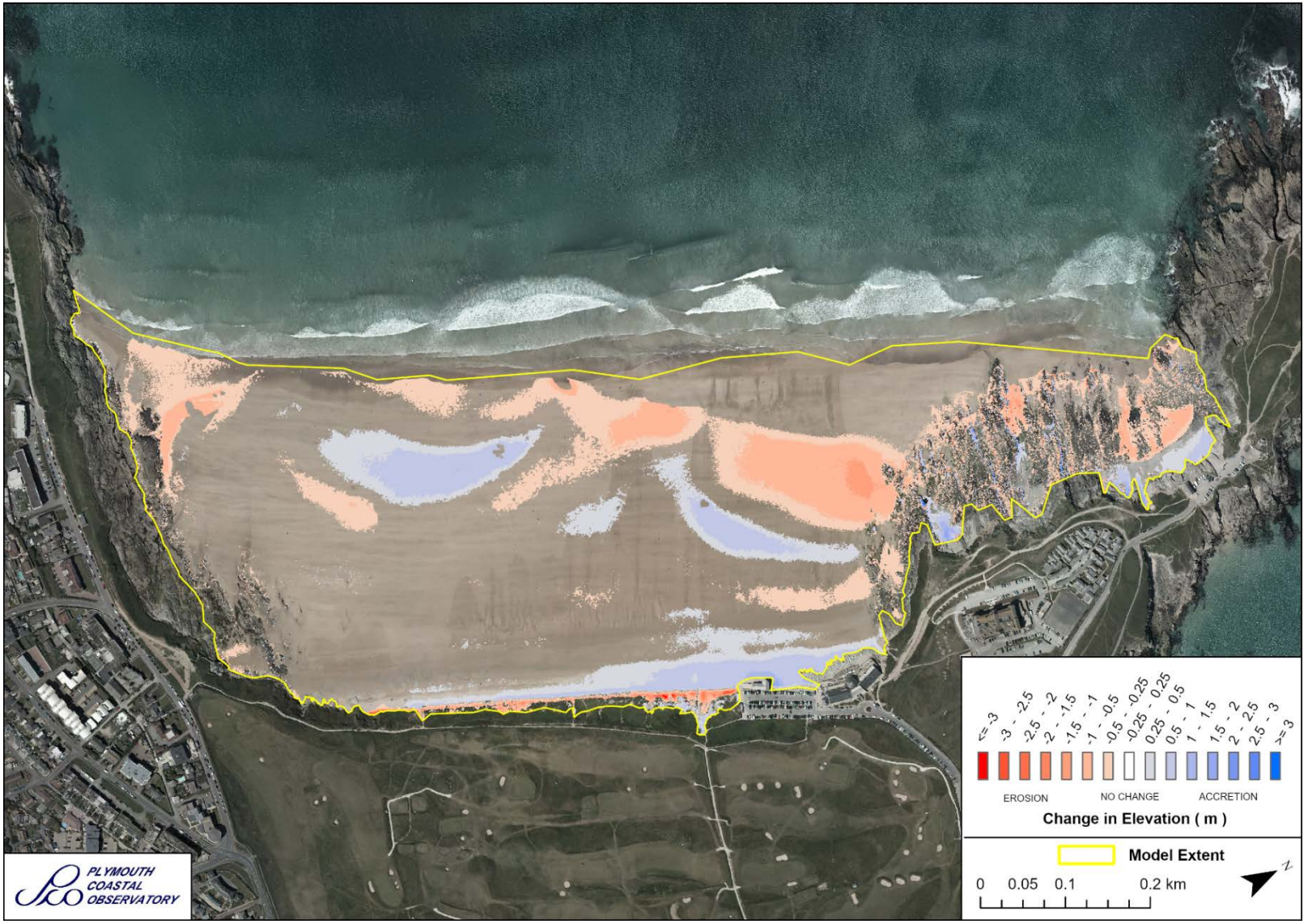


Figure 13 - Difference model indicating the changes in elevation observed between the March 2014 and March 2016 filtered LiDAR datasets within the yellow model extent.

Figure 14 shows differences in elevation between filtered LiDAR data from March 2016 compared to March 2017. Unlike Figure 13, this epoch has experienced widespread accretion across the intertidal zone, losing up 1 m in elevation. Similarly, accretion can be seen along beach face, whilst a thin band of erosion can be seen along the dune crest.

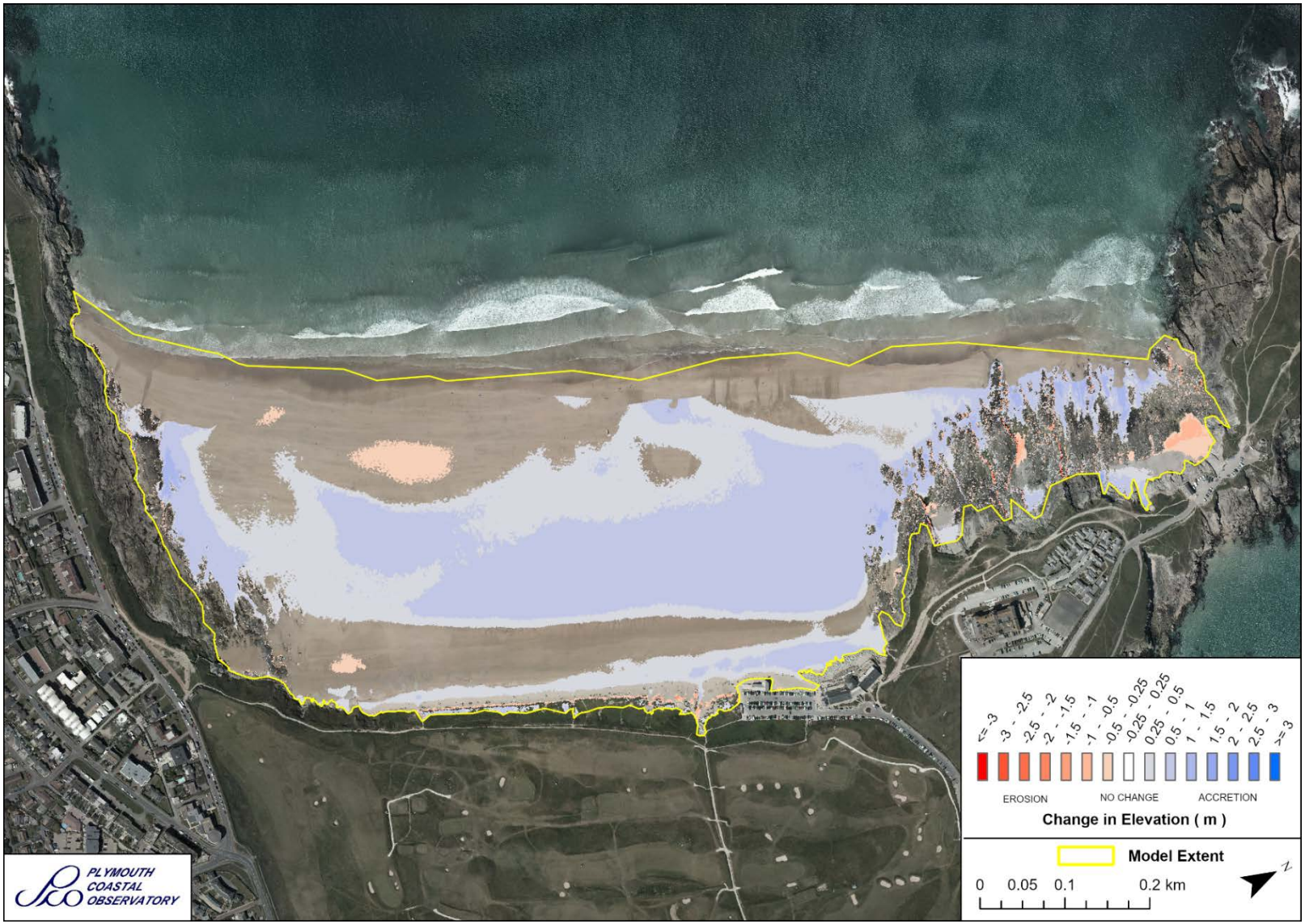


Figure 14 - Difference model indicating the changes in elevation observed between the March 2016 and March 2017 filtered LiDAR datasets within the yellow model extent.

Figure 15 shows differences in elevation between filtered LiDAR data from March 2017 compared to April 2019. This epoch has seen erosion along the upper beach seeing up to a 1.5 m loss along the high-water mark. Patches of erosion can also be seen to the north of the dune system creating various dune blowouts, likely caused by wind, storm events and human trampling.

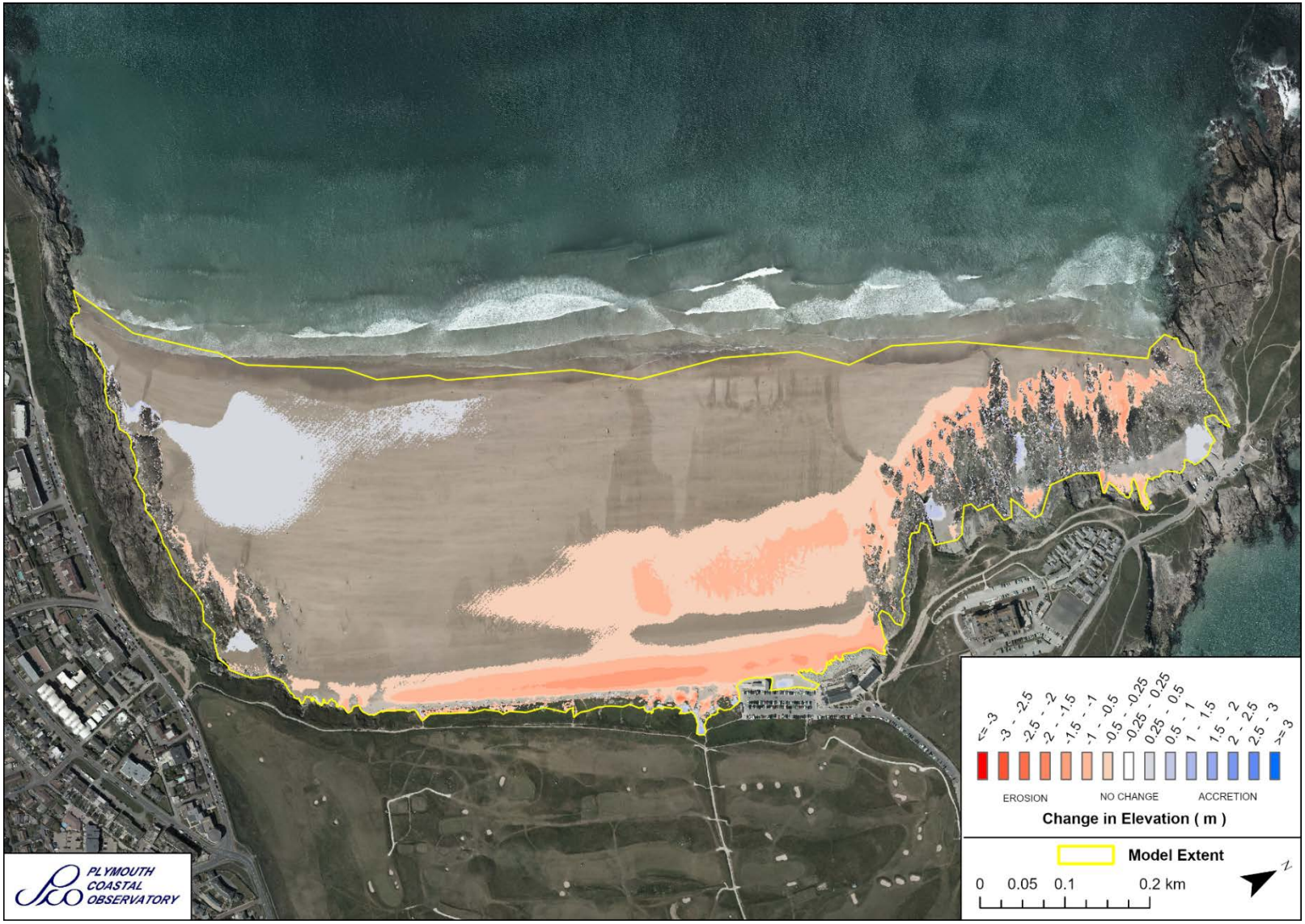


Figure 15 - Difference model indicating the changes in elevation observed between the March 2017 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 16 shows differences in elevation between filtered LiDAR data from April 2019 compared to November 2020. The dune crest has experienced accretion whilst the dune face has seen a loss of material seeing a lowering of 1.5 m. Below the high-water mark up to 2 m of accretion has built-up along the northern half of the beach. Areas of low-level erosion and accretion can be observed across the unit.

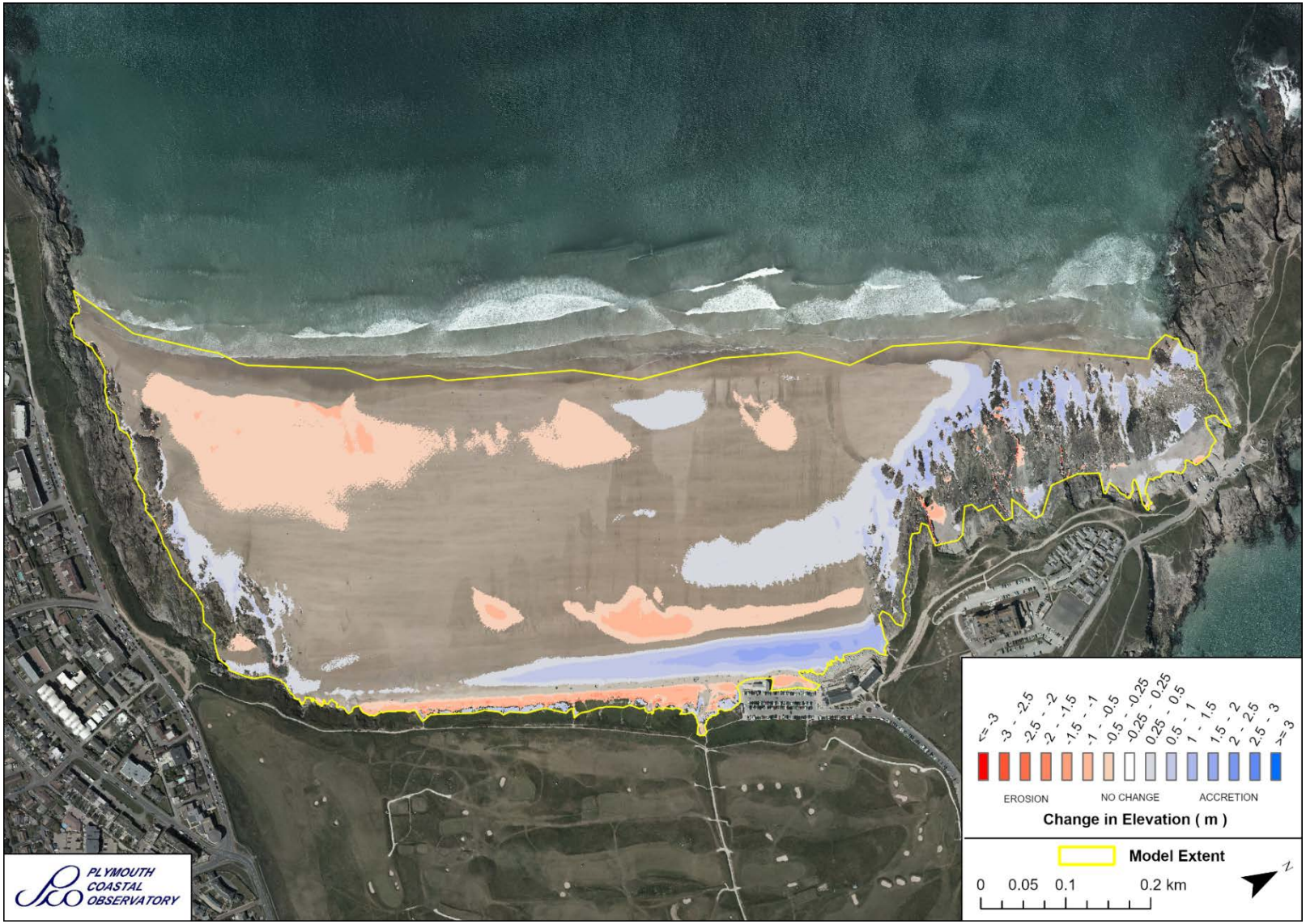


Figure 16 - Difference model indicating the changes in elevation observed between the April 2019 and November 2020 filtered LiDAR datasets within the yellow model extent.

Figure 17 shows differences in elevation between filtered LiDAR data from November 2020 compared to October 2022. The intertidal zone has seen widespread accretion, whilst a band of up to 2 m of erosion was experienced along the high-water mark. The beach face saw low-level accretion along the width of the beach, whilst the crest of the dune experienced ~1.5 m of erosion.

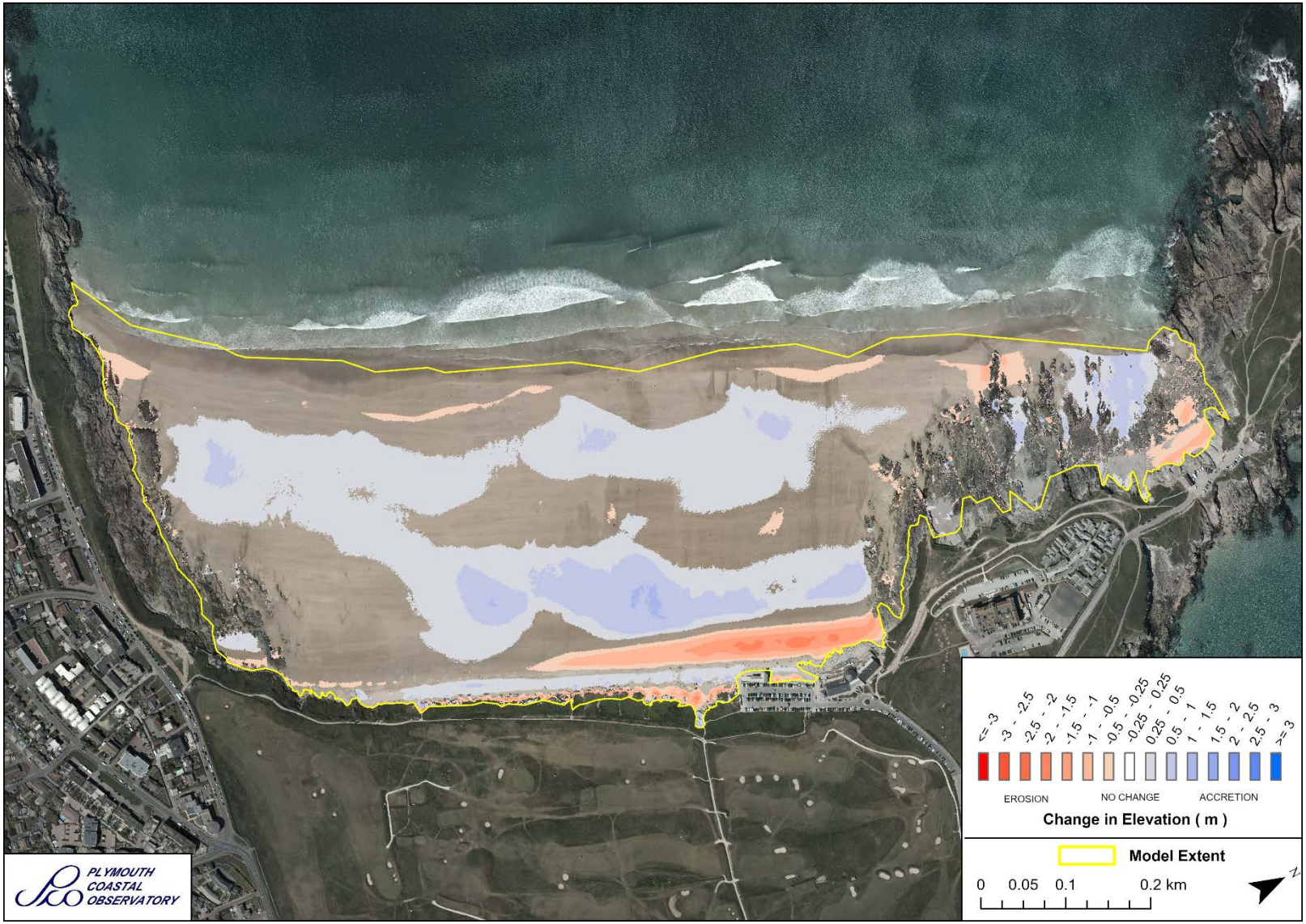


Figure 17 - Difference model indicating the changes in elevation observed between the November 2020 and October 2022 filtered LiDAR datasets within the yellow model extent.

3.2.1 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.40 m OD) are shown in Table 1 and Figure 18. The Mobile Zone has shown continual erosion between 2008 and 2022, with considerable losses in volume observed between the 2012 and 2014 surveys and between the 2017 and 2019 surveys losing 6% in volume on both occasions (Fig.18). The lowest recorded volume in the Mobile Zone was during the 2019 survey at 187,510 m^3 (Table 1).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-3.00 m OD) are shown in Table 1 and Figure 19. Unlike the Mobile Zone, Beach Zone volume has shown a gradual increase between 2008 and 2022, accreting by 17% in material between 2008 and 2022 (Fig.19). Potentially suggesting that the erosion of the Mobile Zone is subsequently accreting the Beach Zone, with the highest observed volume recorded during the latest 2022 survey at 1,141,641 m^3 (Table 1).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.40 m OD) and for the Beach Zone above MLWS (-3.00 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
03/2008	209,877	971,762
03/2009	208,862	1,020,845
10/2010	210,490	1,126,640
04/2012	202,599	1,084,659
04/2014	189,684	1,020,248
03/2016	193,602	1,006,509
03/2017	200,483	1,104,182
04/2019	187,510	1,085,563
11/2020	192,938	1,096,536
10/2022	189,842	1,141,641

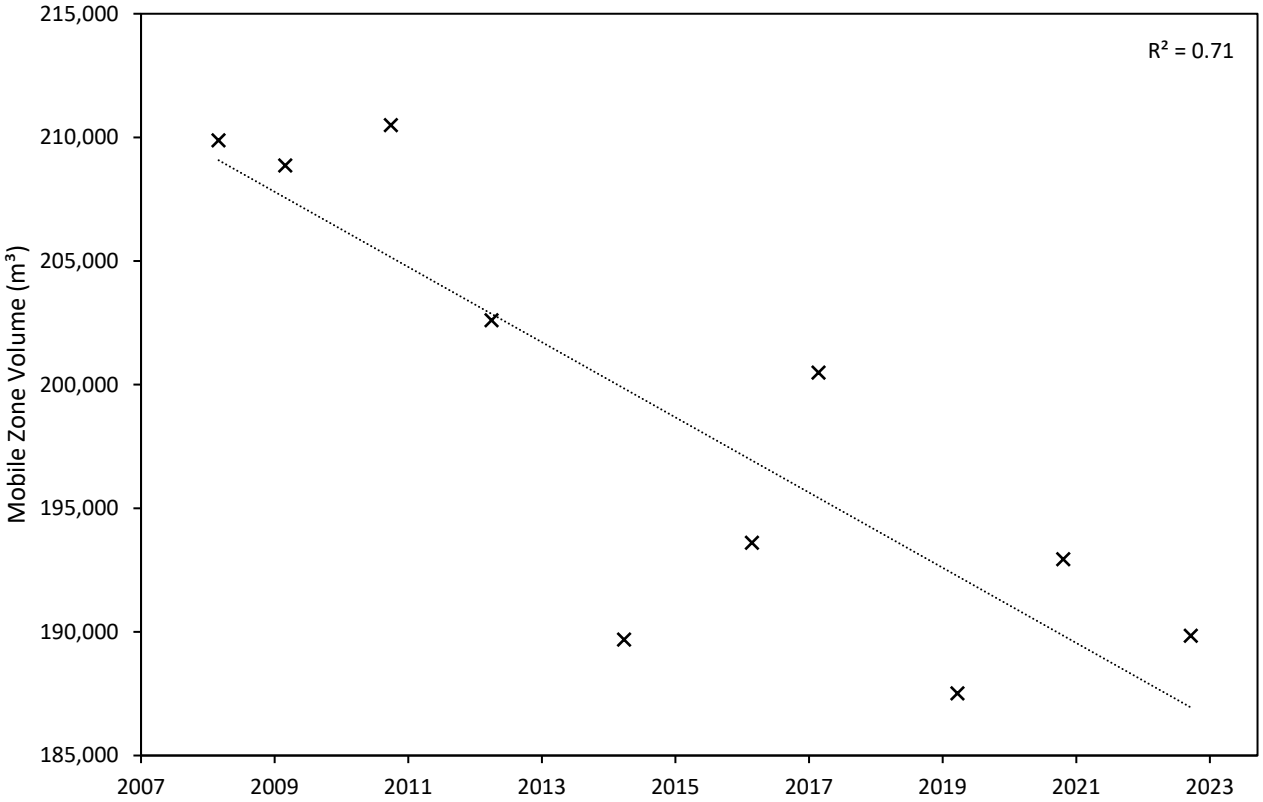


Figure 18 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.40 m OD) for each filtered LiDAR datasets between 2008 and 2020.

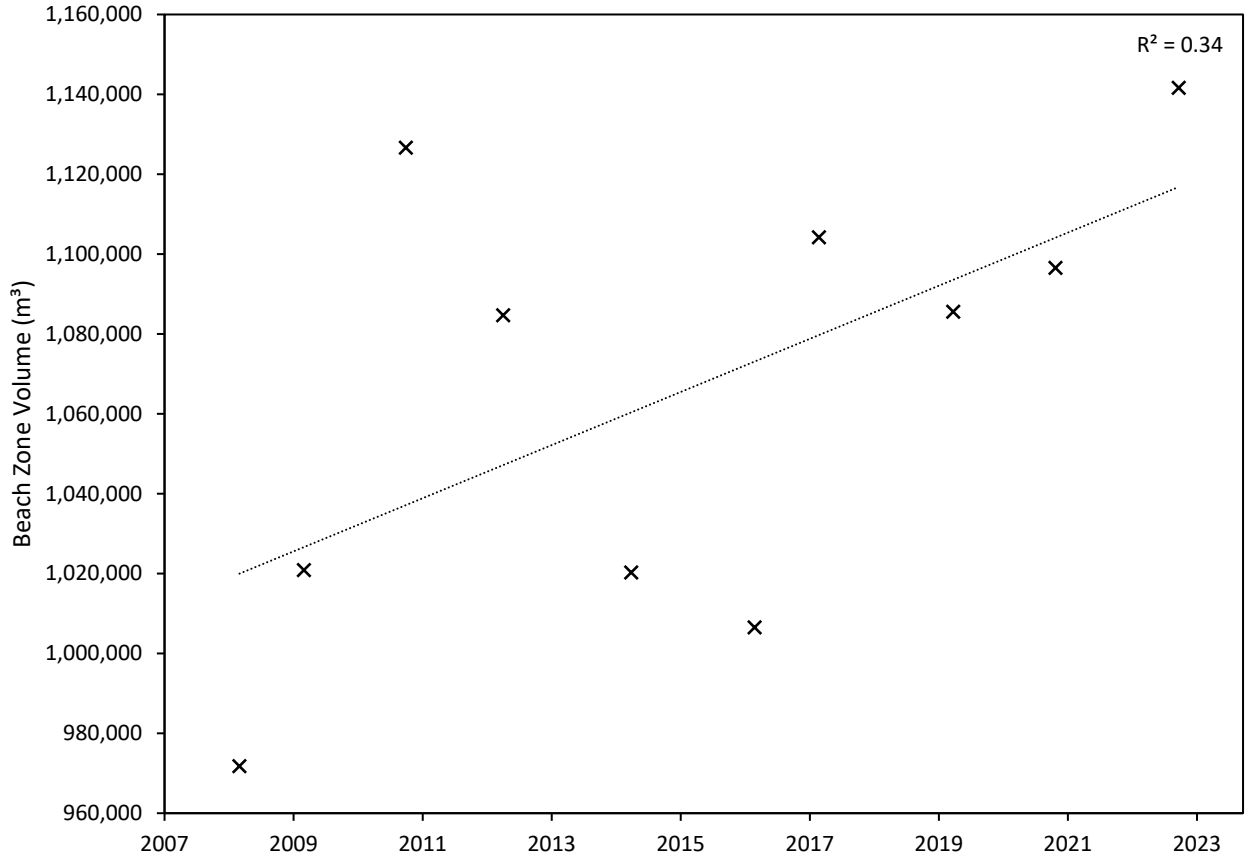


Figure 19 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2008 and 2020.

3.2.2 Contour Comparison

Figure 20 shows the Mean Sea Level (MSL) and Dune Toe contours from the 2008, 2014, 2019 and 2022 LiDAR datasets. MSL contours indicate a widening of the beach from 2008 to 2022 by approximately 40 m. The Dune Toe contours have eroded by up to 4-5 m along the length of beach, seeing up to 13 m of dune recession to the south.

3.3 Historic Aerial Maps

Historic aerial photography captured in 2001 by the Environment Agency (Fig. 21) and from 2007 onwards by the SWCM (Figs. 22-25) are presented here.

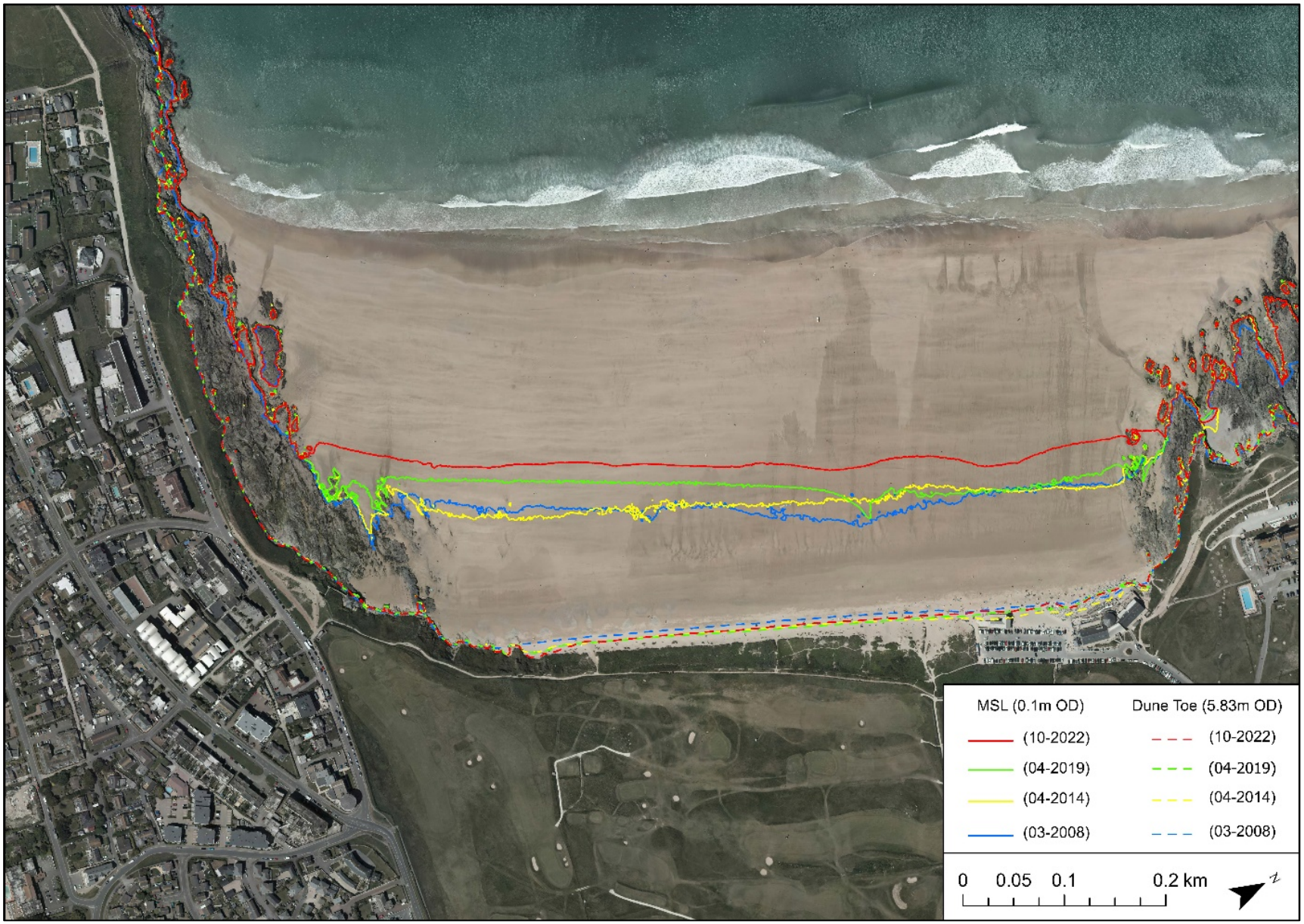


Figure 20 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022 LiDAR datasets.



Figure 21 – Aerial imagery from 2001.



Figure 22 – Aerial imagery from 2008.



Figure 23 – Aerial imagery from 2010.



Figure 24 – Aerial imagery from 2014.



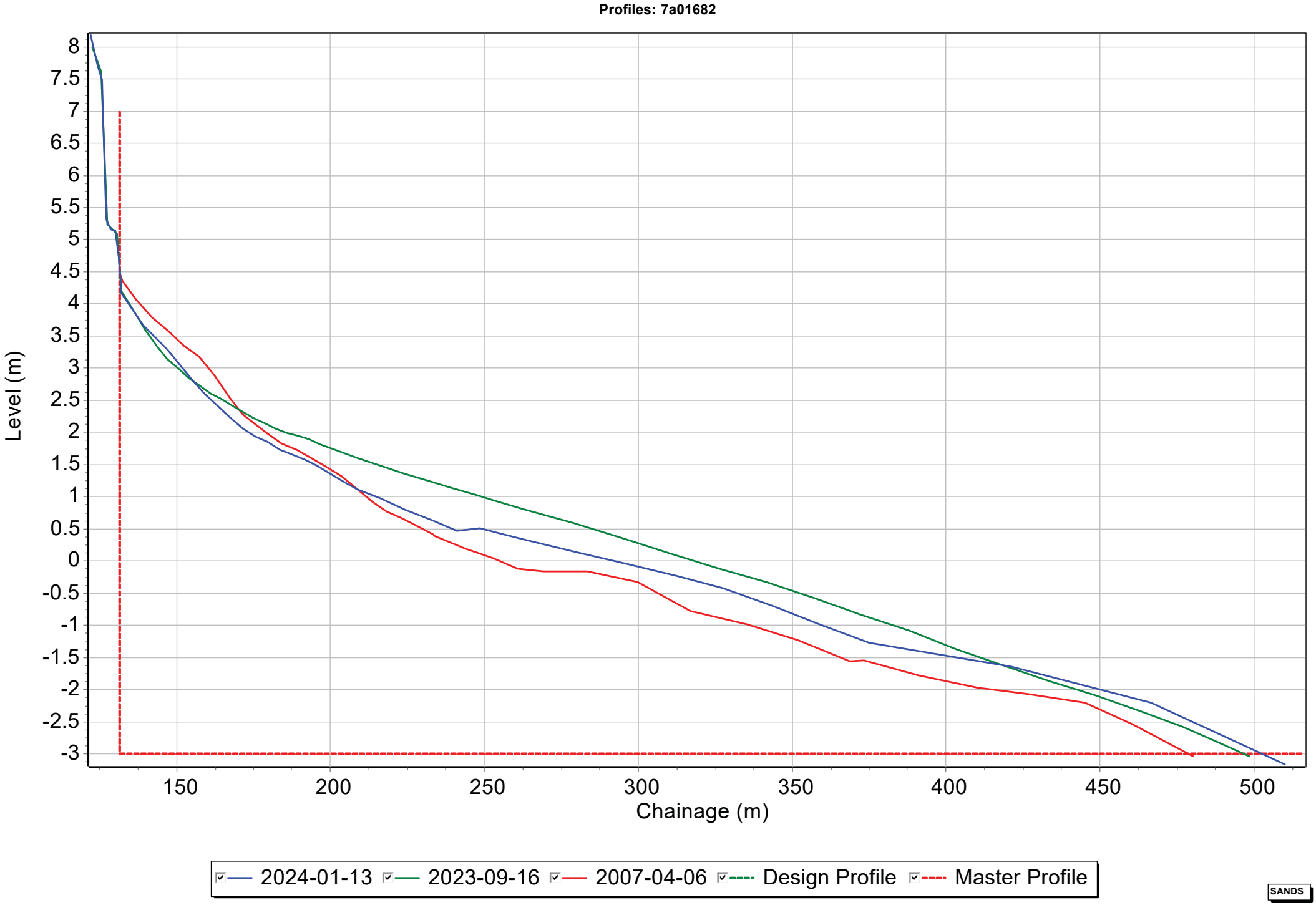
Figure 25 – Aerial imagery from 2017.

Glossary

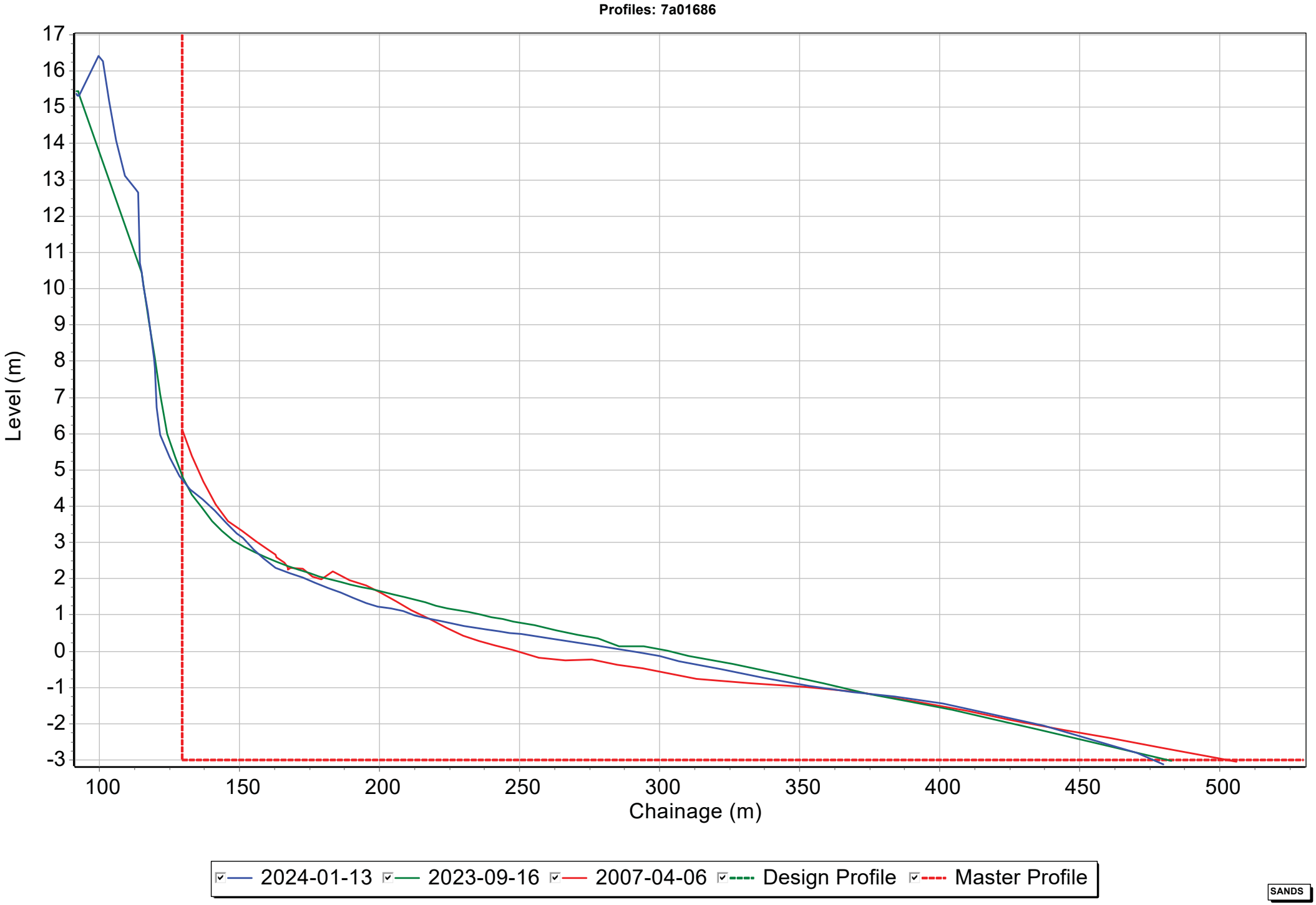
1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
4. Cross-Sectional Area (CSA): The area of a two-dimensional cross-section of a cross-shore beach profile, running between Mean Low Water Spring and the back of the beach.
5. Developed Zone: Areas of urban development built atop previously present dune systems.
6. Difference Modelling: Comparison of separate LiDAR surfaces to produce a difference model of change based on gridded spot height elevations.
7. Digital Elevation Model (DEM) and Digital Terrain Model (DTM): DEM represents the Earth's surface with all features, while DTM represents the bare earth surface, excluding vegetation and structures.
8. Embryo Dune: The earliest stage of dune growth, typically found along the seaward extent of a dune system or newly formed dune.
9. Erosion: The process by which local sea level rise, strong wave action, and coastal flooding wear down or carry away rocks, soils, and sands along the coast.
10. Fixed Zone: Area defined by permanent dune vegetation, including scrub or invasive species, denoting vegetation atop sandy soil.
11. Intertidal Bar: A ridge or mound of sand, gravel, or other sediment deposited in the intertidal zone along a shoreline.
12. LiDAR: Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth.
13. Mean High Water Spring (MHWS): The height of mean high-water springs is the average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.
14. Mean Low Water Spring (MLWS): The height of the mean low-water springs is the average height obtained by the two successive low waters during the same period.
15. Mobile Zone: The area including the active dune face and embryo dune that is in motion due to wind action or other factors.
16. Root-Mean-Square Error (RMSE): A measure of the differences between values predicted by a model and the observed values.
17. Tidal Range: The vertical difference between high tide and low tide during a tidal cycle.

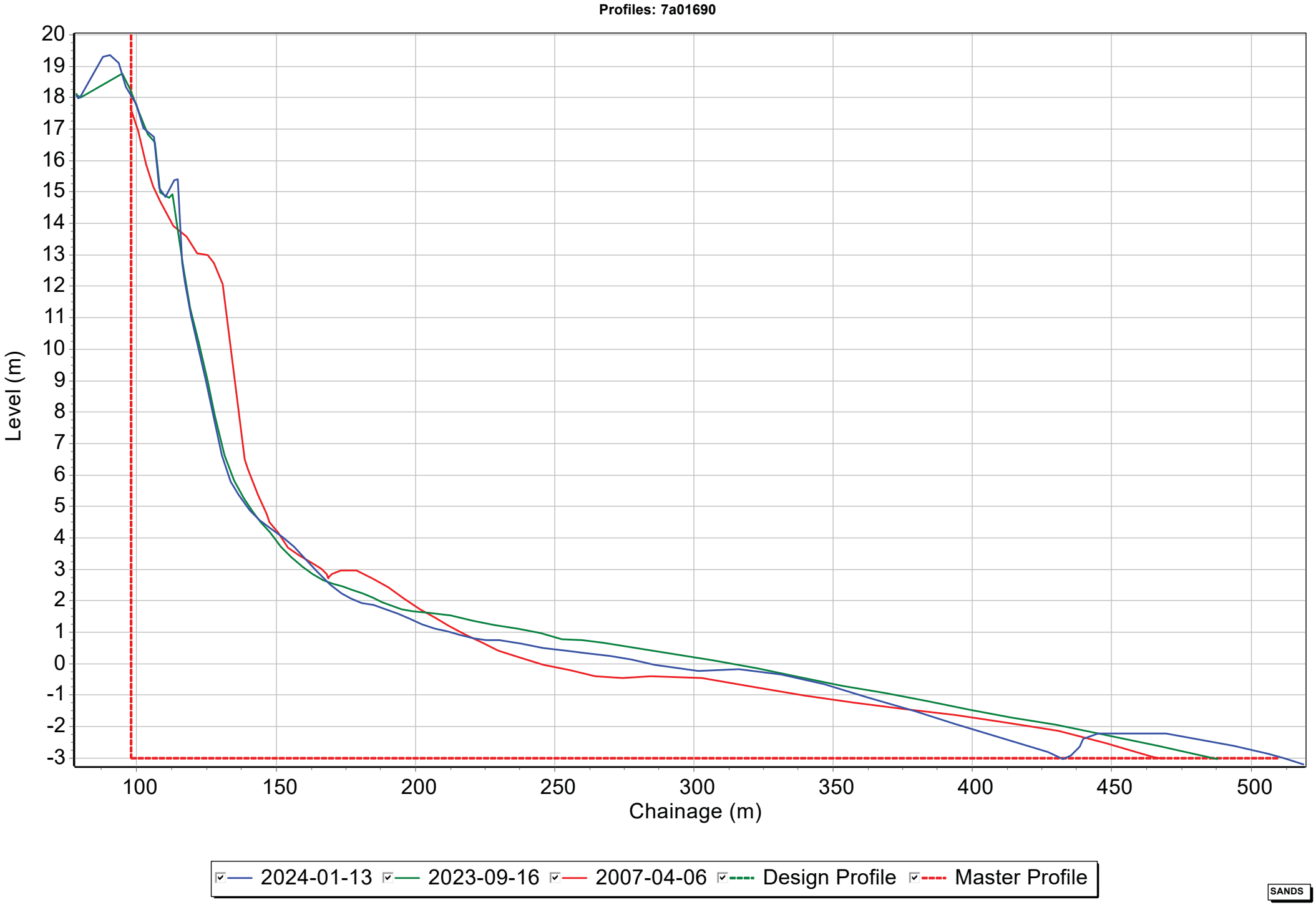
Appendices

Appendix 1 – Profile charts showing the cross-shore area of each interim profile from the most recent survey (blue), second most recent survey (green) and first survey, also known as the baseline (red) at Fistral Beach are presented below.

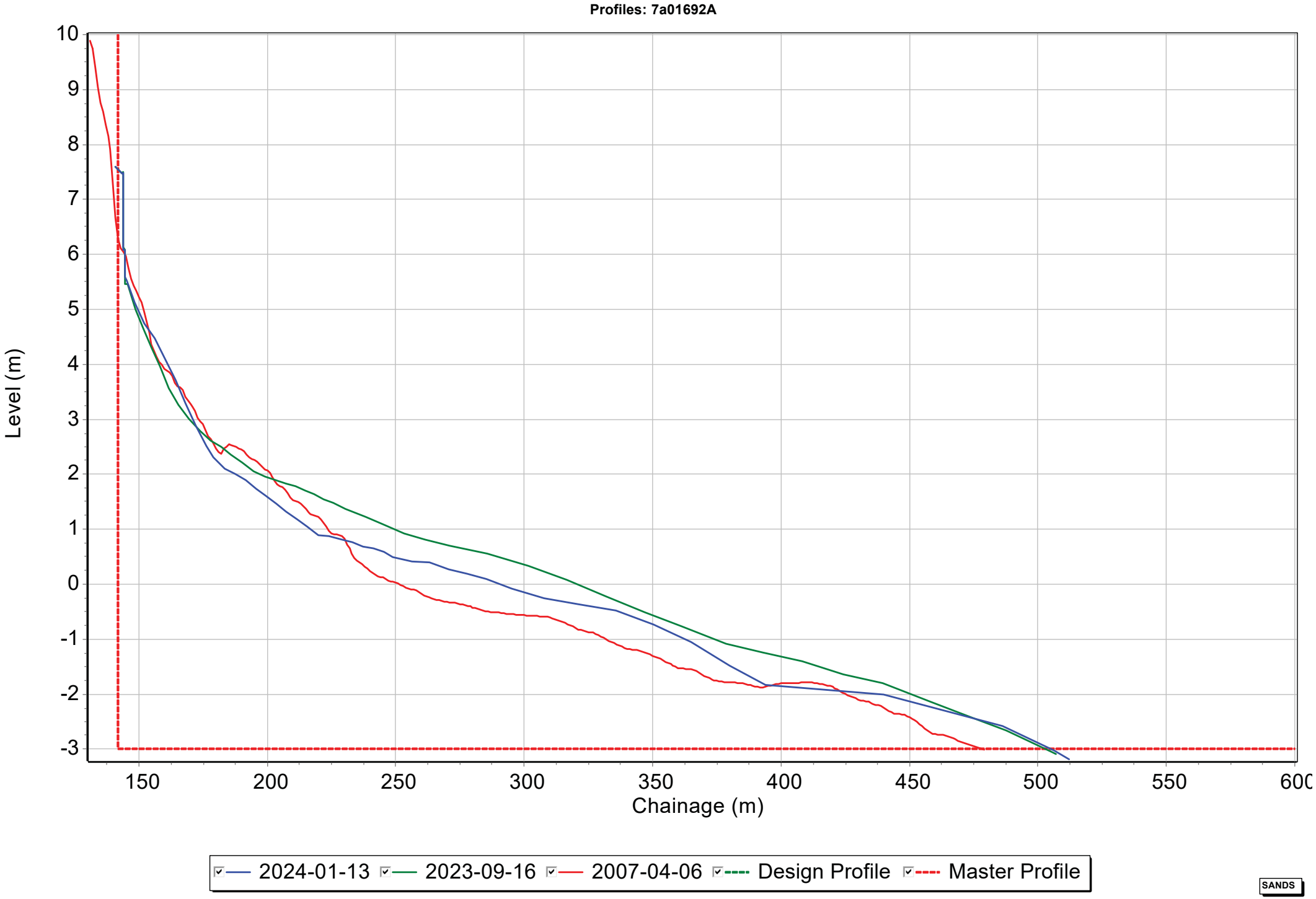

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7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
150
200
250
300
350
400
450
500
Chainage (m)
2024-01-13
2023-09-16
2007-04-06
Design Profile
Master Profile

SANDS

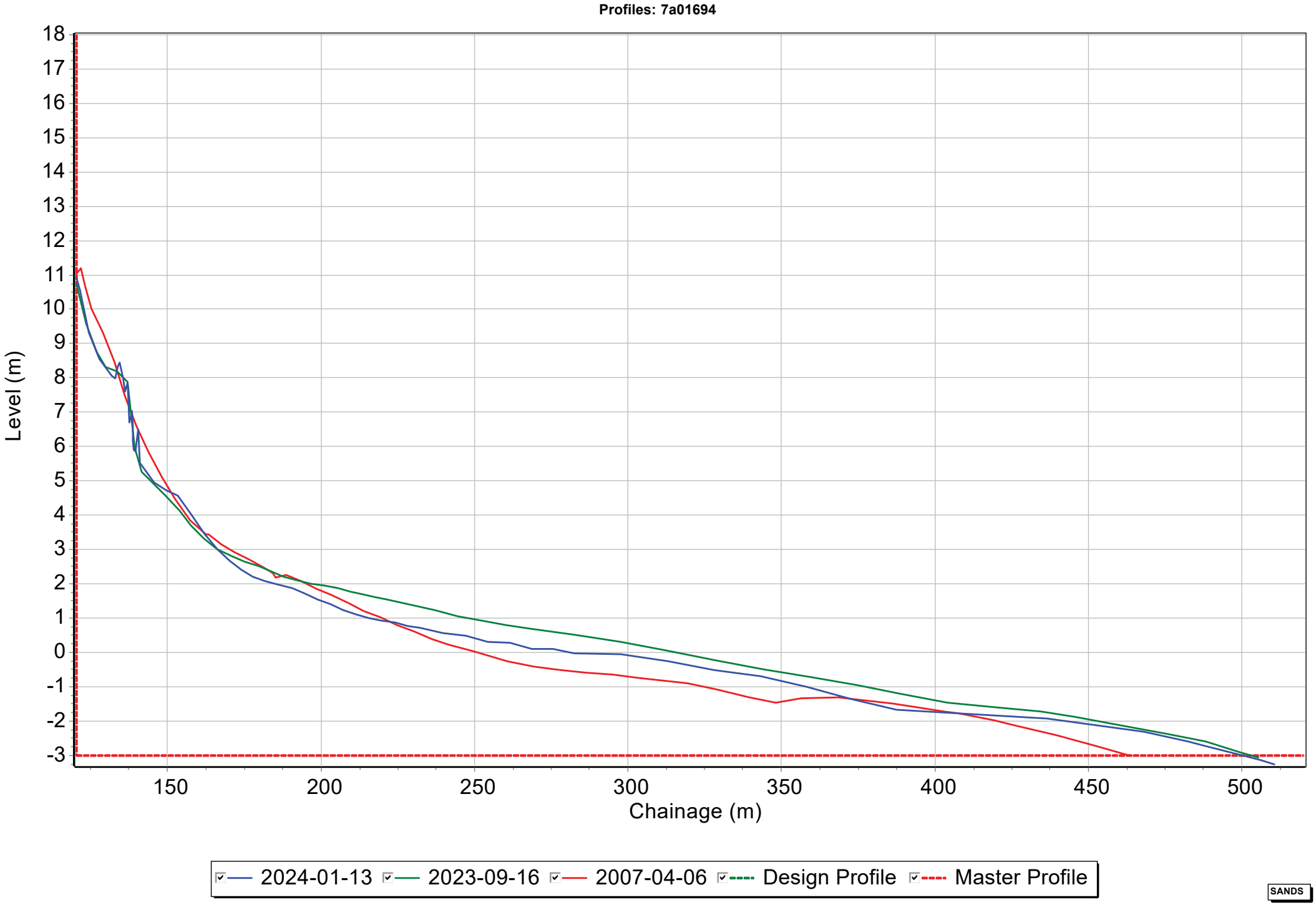

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1
0
-1
-2
-3
100
150
200
250
300
350
400
450
500
Chainage (m)
2024-01-13
2023-09-16
2007-04-06
Design Profile
Master Profile


Profiles: 7a01690
Level (m)
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Chainage (m)
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2023-09-16
2007-04-06
Design Profile
Master Profile

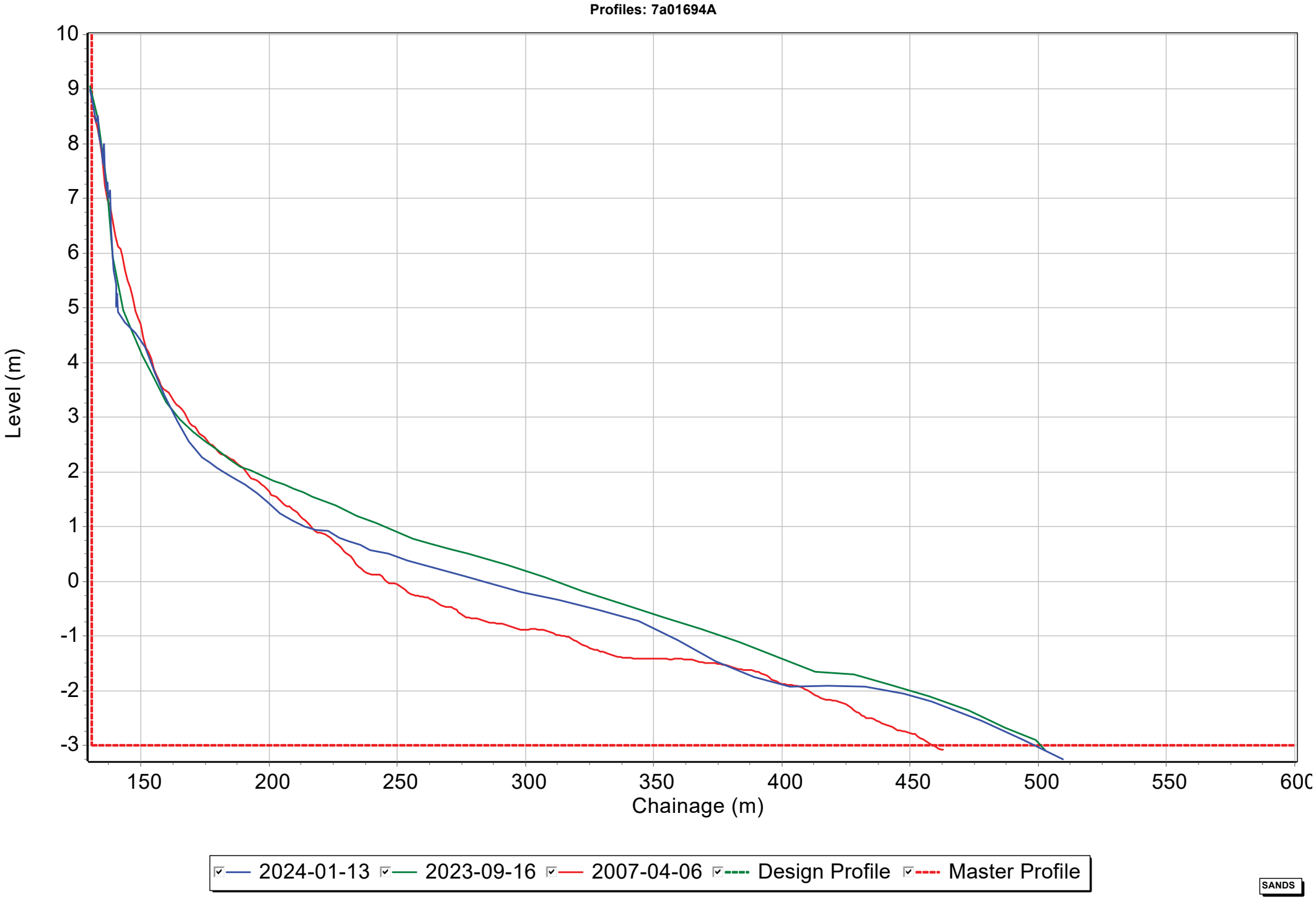
SANDS


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Chainage (m)
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2023-09-16
2007-04-06
Design Profile
Master Profile

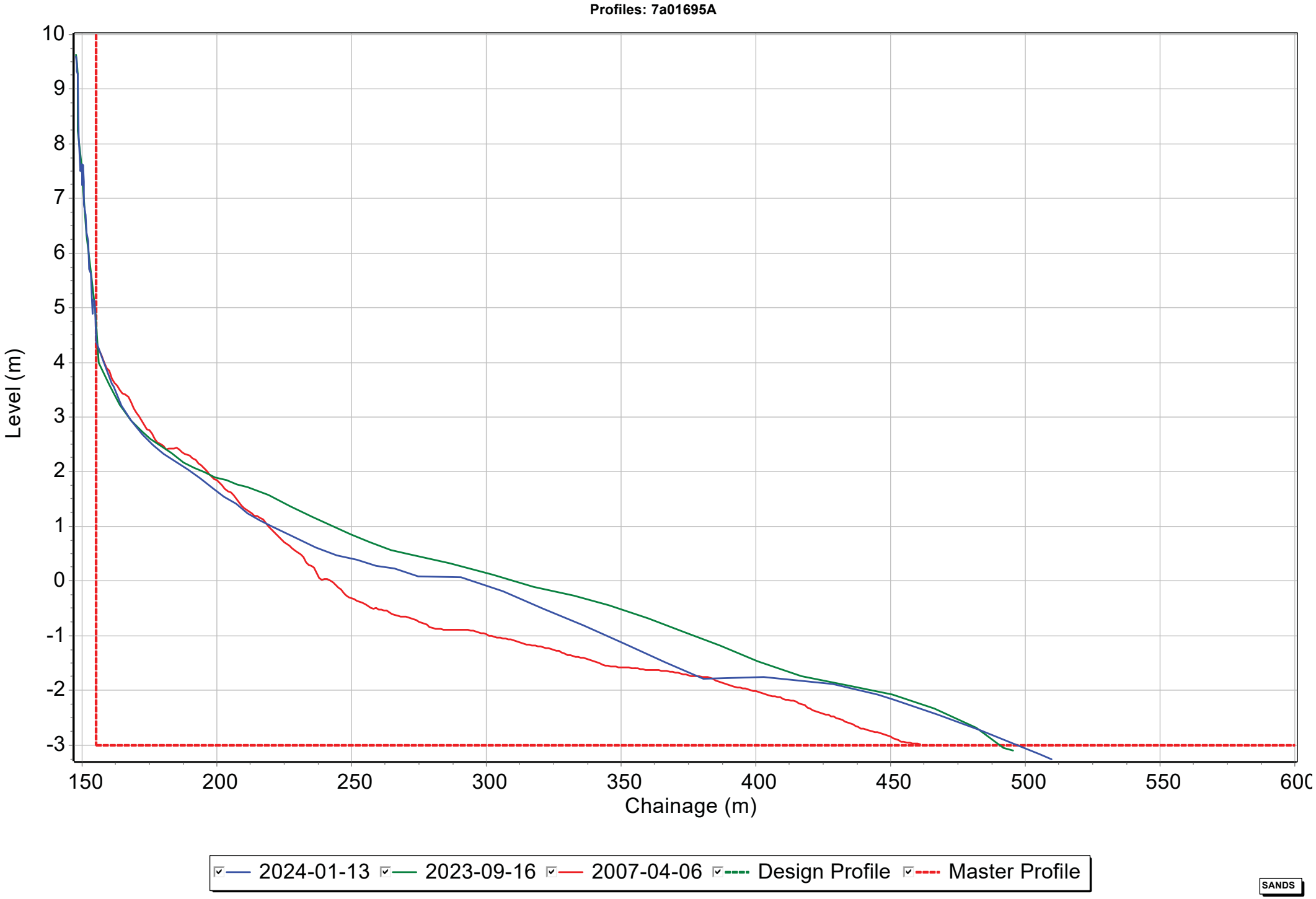
SANDS


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Chainage (m)
2024-01-13
2023-09-16
2007-04-06
Design Profile
Master Profile

SANDS


Profiles: 7a01694A
Level (m)
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Chainage (m)
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2023-09-16
2007-04-06
Design Profile
Master Profile

SANDS


Profiles: 7a01695A
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Chainage (m)
2024-01-13
2023-09-16
2007-04-06
Design Profile
Master Profile

SANDS