SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand - Seaton Beach Report

Topographic and LiDAR Data Analysis

SWCM TBR01 18/12/2023

South West Coastal Monitoring
University of Plymouth
Drake Circus
Plymouth
PL4 8AA
+44 (0)1752 586 155
coastal.observatory@plymouth.ac.uk
www.southwest.coastalmonitoring.org

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Author	**J Saunders**
Approved By	**E Siggery**

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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 change at Seaton. The aim is to highlight coastal change at Seaton using SWCM data collected since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Seaton, a southwest-facing gravel sand beach approximately 300 m wide, with no active dune system is detailed as the study site. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change to the intertidal beach area over time. LiDAR data from each available flight is compared to create difference models of the intertidal area, compare volumetric data over time and to show change in Mean Seal Level (MSL) and dune toe contours over time.

Since 2007, 24 topographic surveys were conducted at Seaton, including 4 baselines and 20 interim surveys. Analysis of topographic data suggests the survey unit has remained stable between 2007 and 2023. Despite this, notable fluctuations were observed, with the lowest combined area recorded in 2016 and the highest in 2013. In 2023, most profiles showed below-average cross-sectional area values. Despite seasonal variation, profiles generally remained stable, with a loss in cross-sectional area after the 2013/14 winter.

Beach volume extracted from 9 LiDAR flights between 2007 and 2022 within the Mobile Zone showed no significant trend but showed a similar impact to the topographic data following the 2013/14 winter storms, which saw a loss of 33% of beach material from above Mean High Water Spring between the 2012 and 2014 surveys. The lowest volume in the Mobile Zone was recorded in February 2016 but as of 2022 has since returned to pre-2014 levels. The Beach Zone equally showed no trend in volumetric data change since 2007, with the lowest volume observed in 2016 but returning to pre-2013/14 levels by 2019. The beach is also highly dominated by fluvial forces to the west caused by the River Seaton, which influences erosion and accretion cycles depending on conditions.

Overall Seaton beach has remained relatively stable between 2007 and 2023 despite large fluctuations in material from the 2013/14 and 2016 winters.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Seaton 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

Seaton consists of a gravel upper beach and sandy low tide terrace with a cross shore distance of ~150 m and longshore distance of ~300 m, with the Seaton River exiting to the westerly extent (Fig.1). The beach is orientated to the southwest, with a predominant south-westerly wave climate and mean spring tidal range of 4.8 m. Seaton Beach currently has no active dune system in place, the mobile and fixed zones are therefore defined using theory of previous dune coverage at the site. The four beach and dune zones are represented in Figure 1.

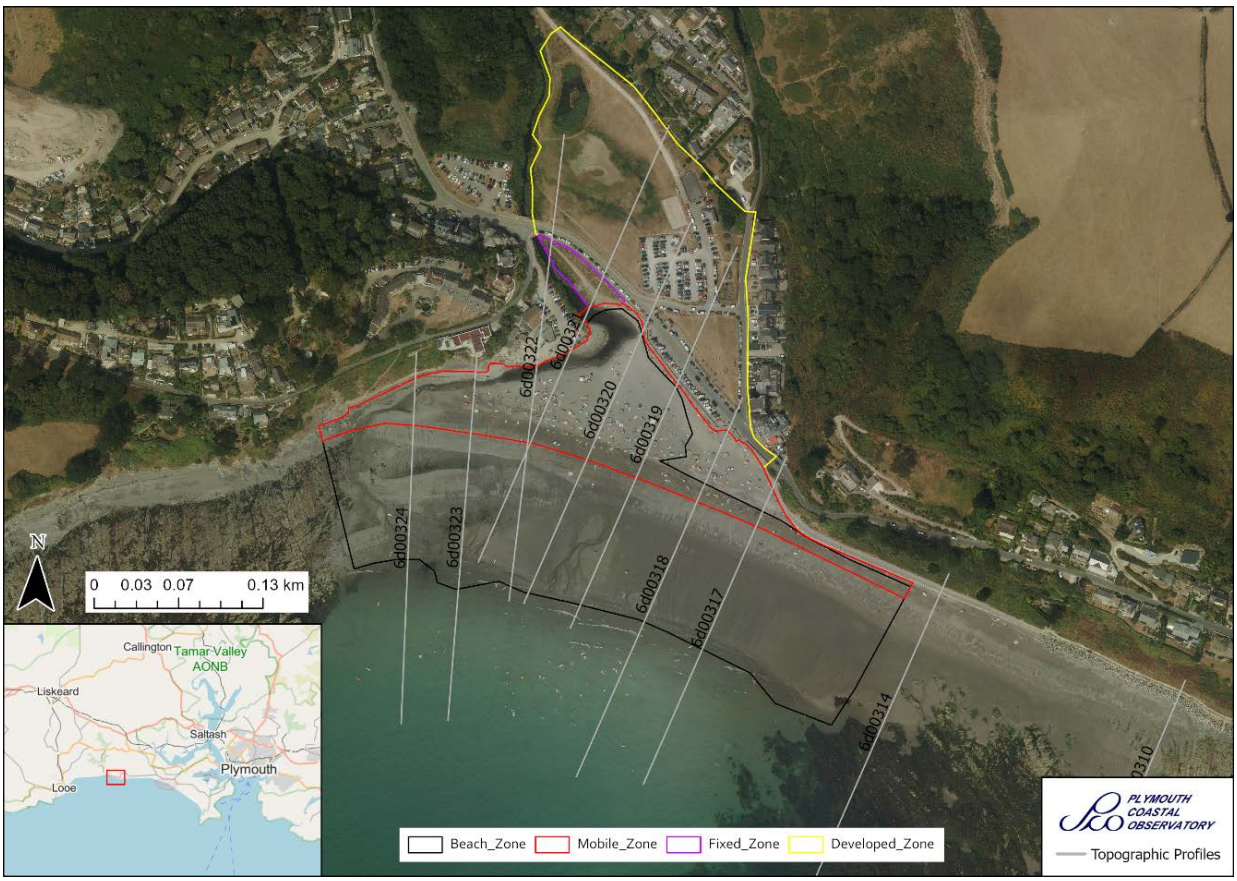


Figure 1 - Location Map of Seaton Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[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).

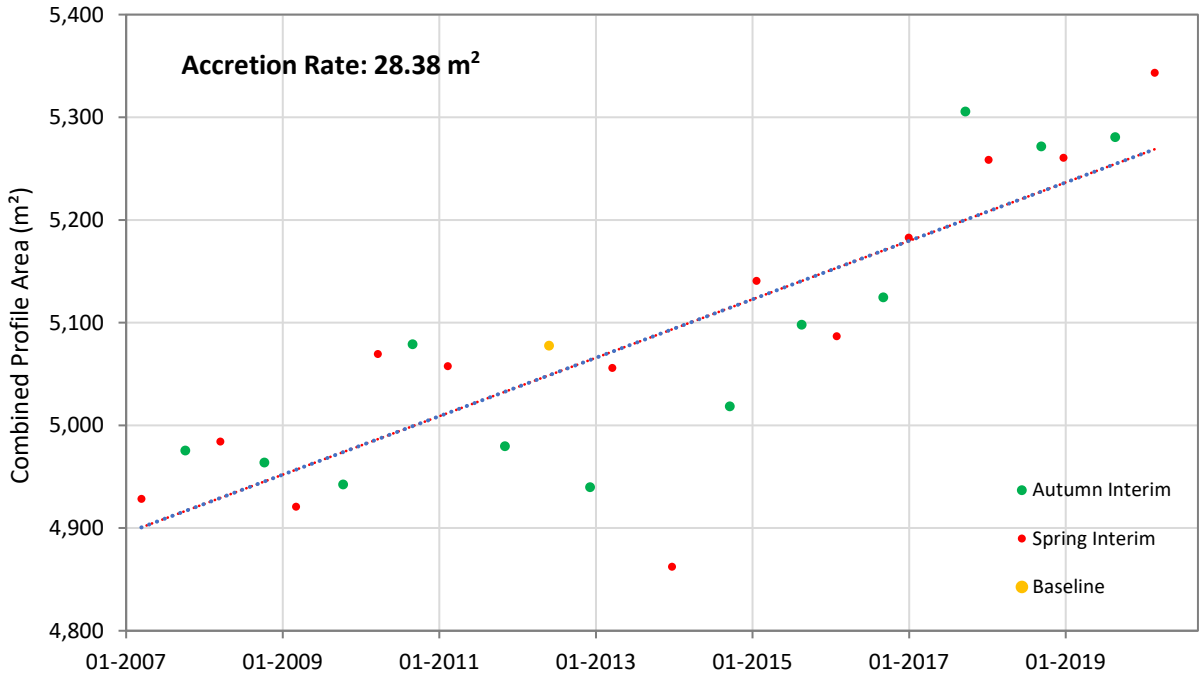


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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 (2006-2022) 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.

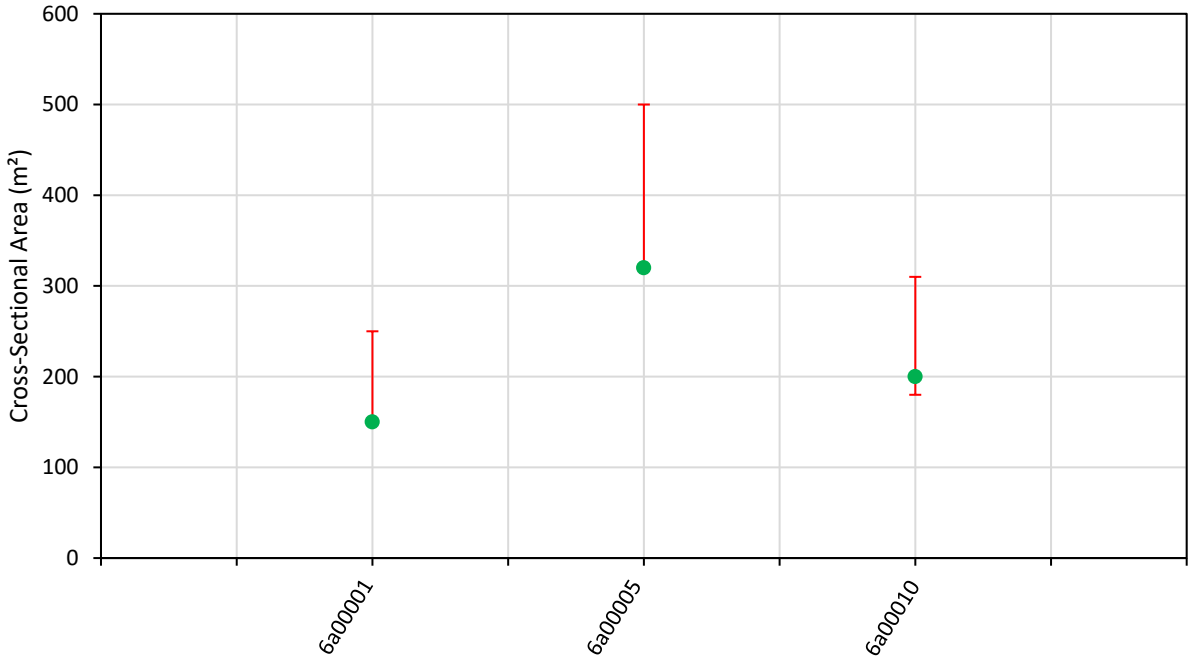


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

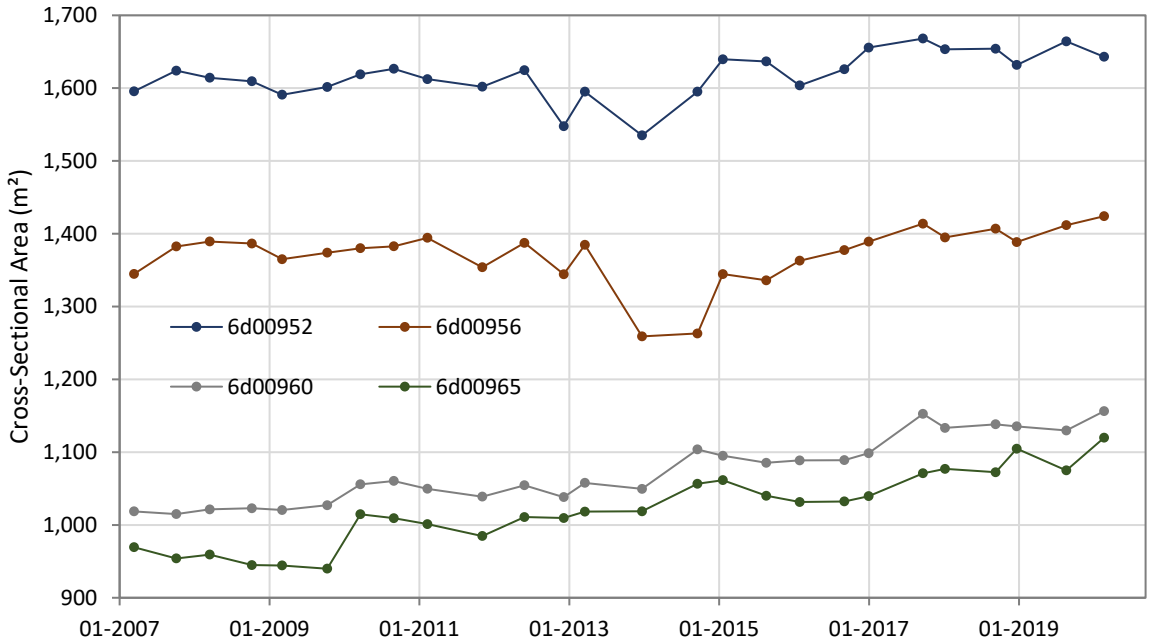


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 24 topographic surveys at Seaton since 2007, 4 of which are baseline surveys and 20 are interim surveys. Exact dates of each survey for Seaton are available to view on our survey record. Analysis of the CPA indicates the beach has been accreting at 0.4 m^2 y^{-1} equating to 0.01% of the average beach area per year (Fig.5). The lowest recorded combined area was during the 2016 spring interim (4,580 m^2), the following years up to 2020 saw a recovery of the beach material to pre-2014 levels. The highest recorded combined area was during the 2013 spring interim (4,996 m^2).

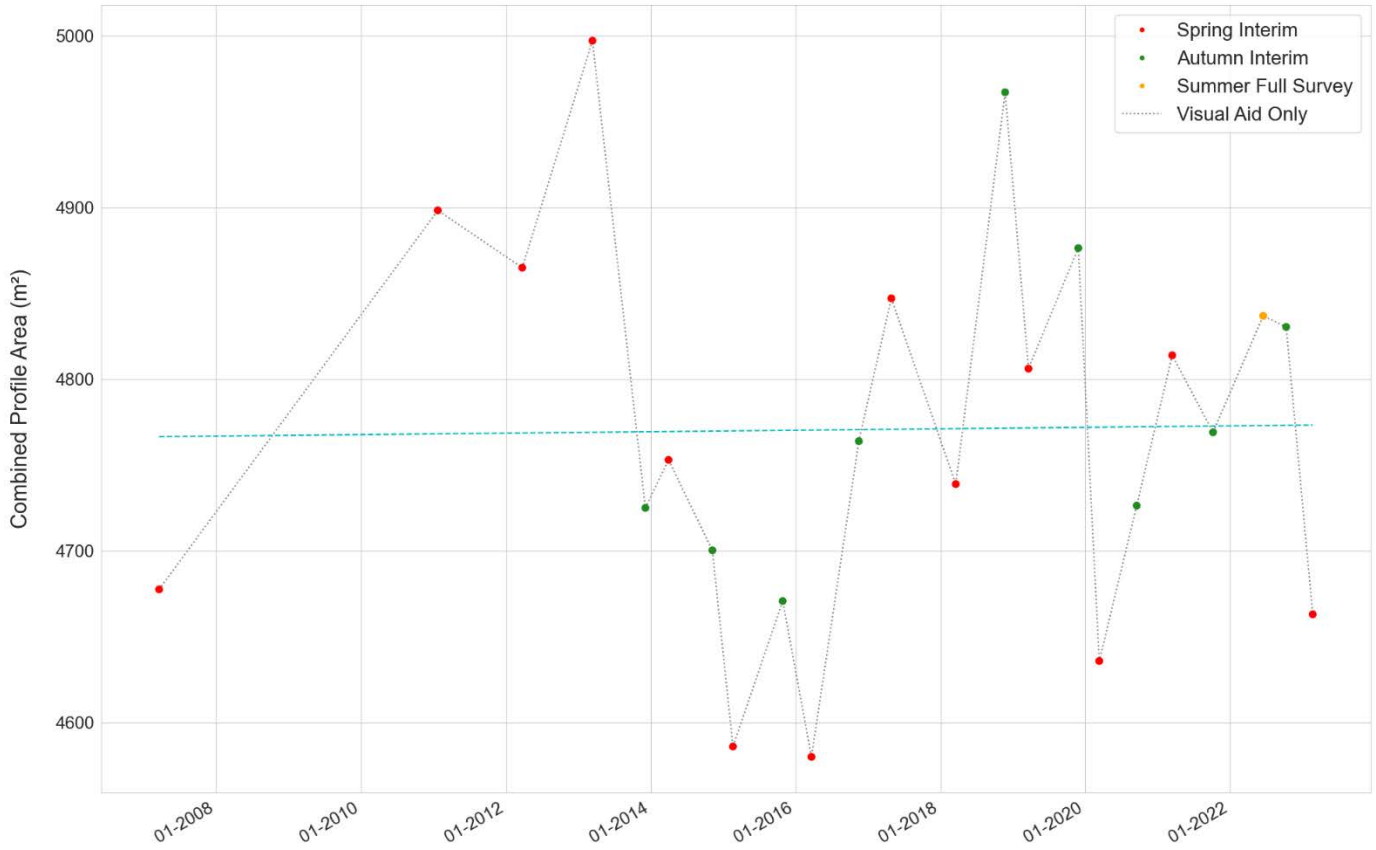


Figure 5 - The Combined Profile Area (CPA) for Seaton, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing the 2023 autumn interim survey to the entire dataset (Fig.6), most profiles at Seaton showed below average CSA values, with 6d00321 and 6d00322 showing their lowest on record.

When comparing profile cross-sectional areas to the entire time series (Fig.7a+b) the majority have remained relatively stable, showing high seasonal variation (accreted in the autumn and eroded in the spring). Most profiles indicated a loss in CPA following the 2013/14 winter, which was preceded by the highest period of accretion throughout the survey unit between the Spring of 2012 and Autumn of 2013 (Fig.7a+b).

Profile Charts for Seaton 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.

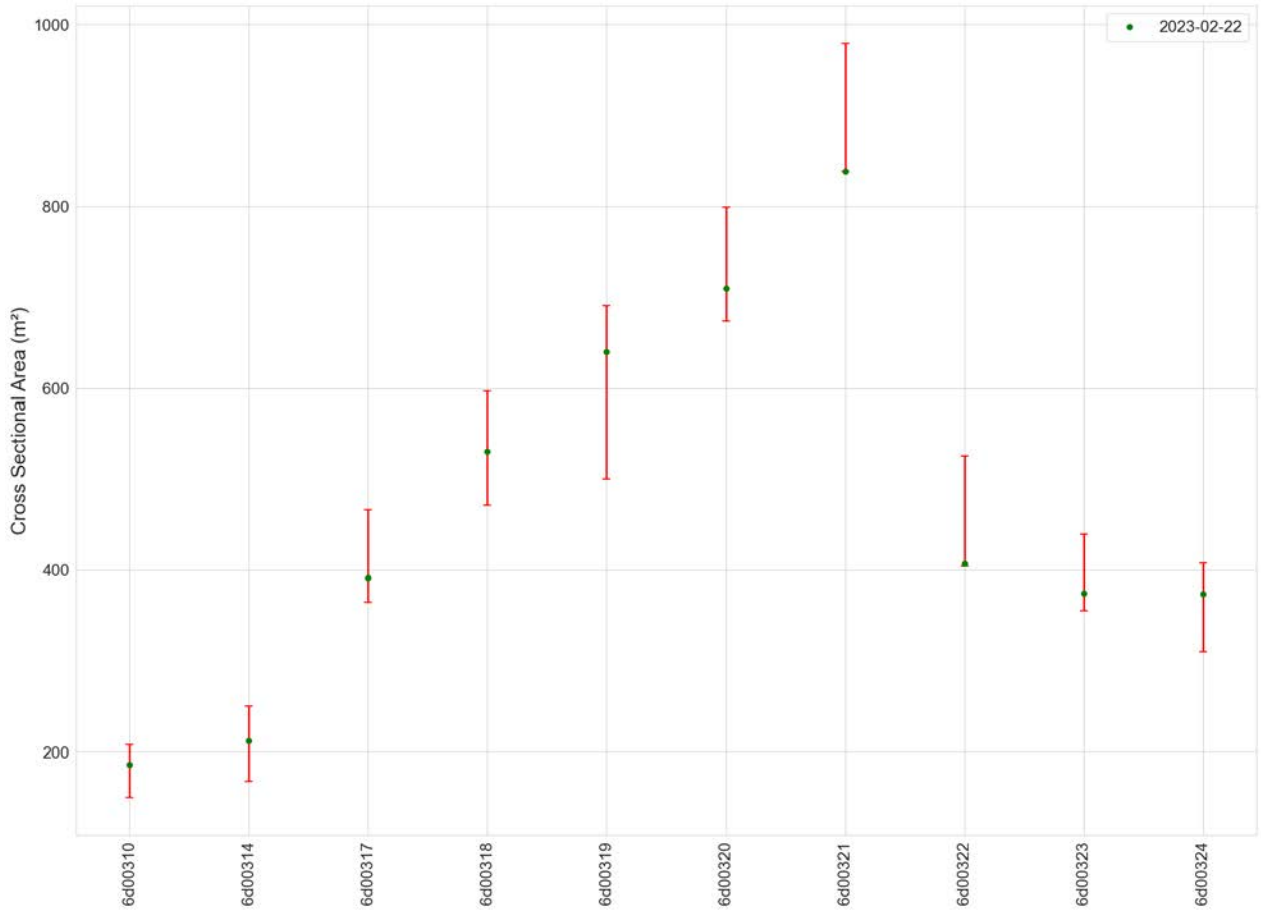


Figure 6 - Cross-sectional area values of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2023.

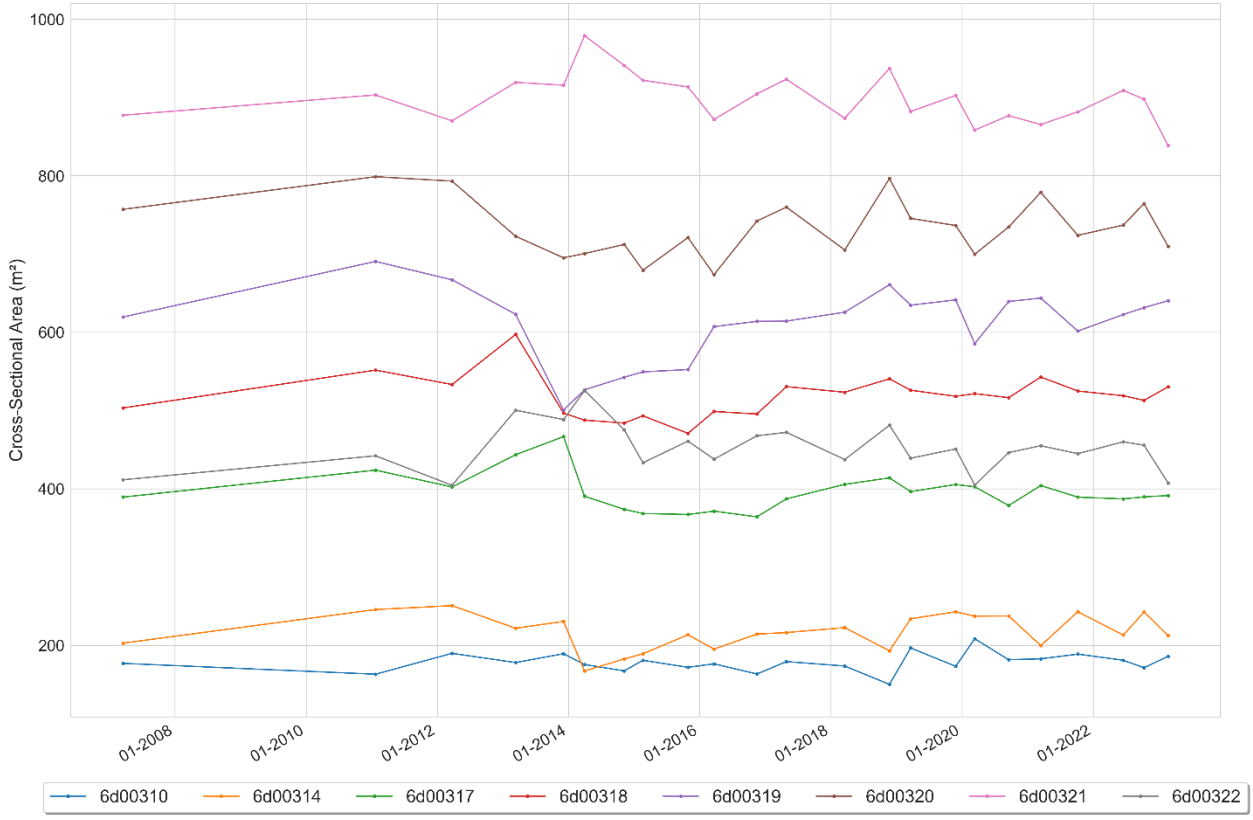


Figure 7a - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

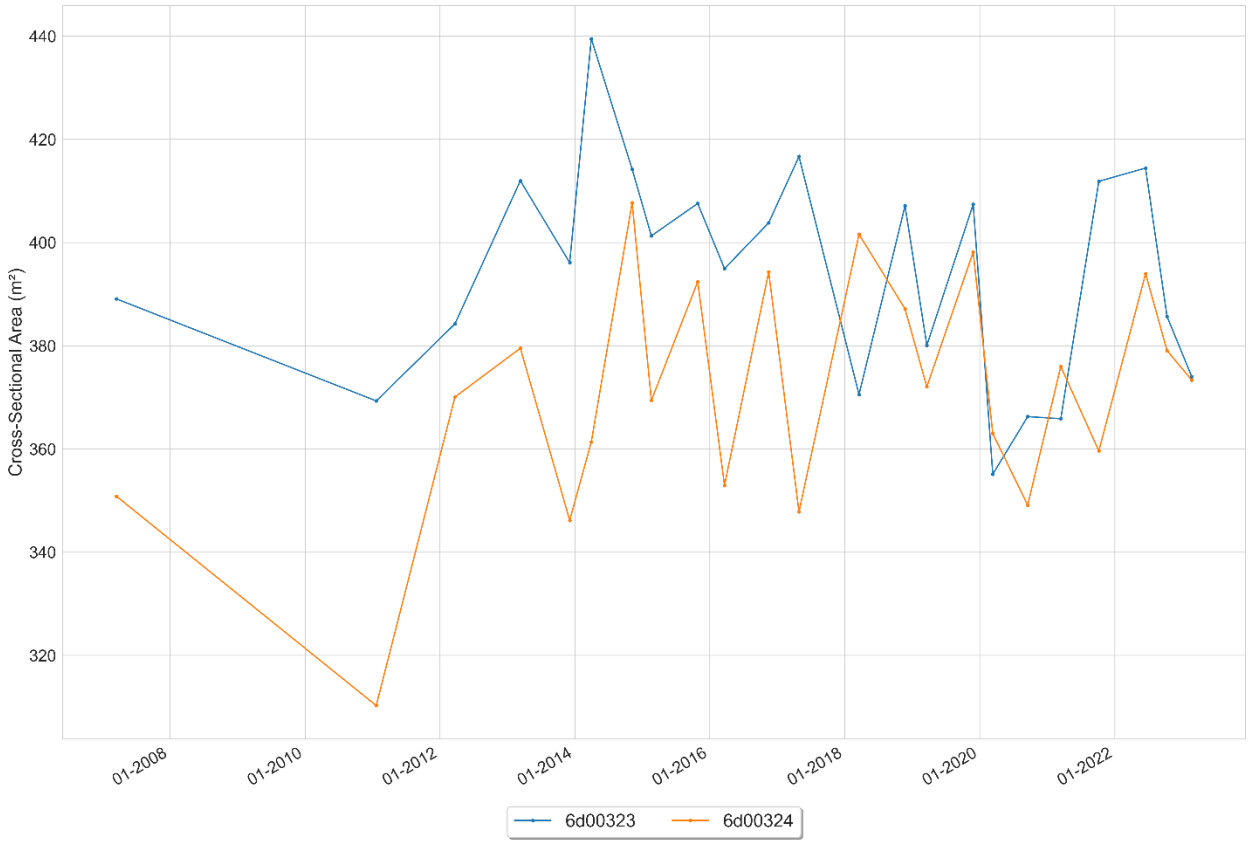


Figure 7b - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

3.2 LiDAR Data Analysis

There has been a total of 9 LiDAR flights captured at Seaton since 2007 through the SWCM.

3.2.1 Difference Models

Difference models between each epoch of LiDAR data are presented below. 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 2008 compared to the most recent, captured in 2022. The plot shows considerable erosion (>1 m elevation change) along the upper beach face and across the berm in front of the beach road. There is also large-scale accretion observed to the south west of the beach, however this, along with the erosion observed along the river channel can be attributed to fluvial influences (Fig.8).

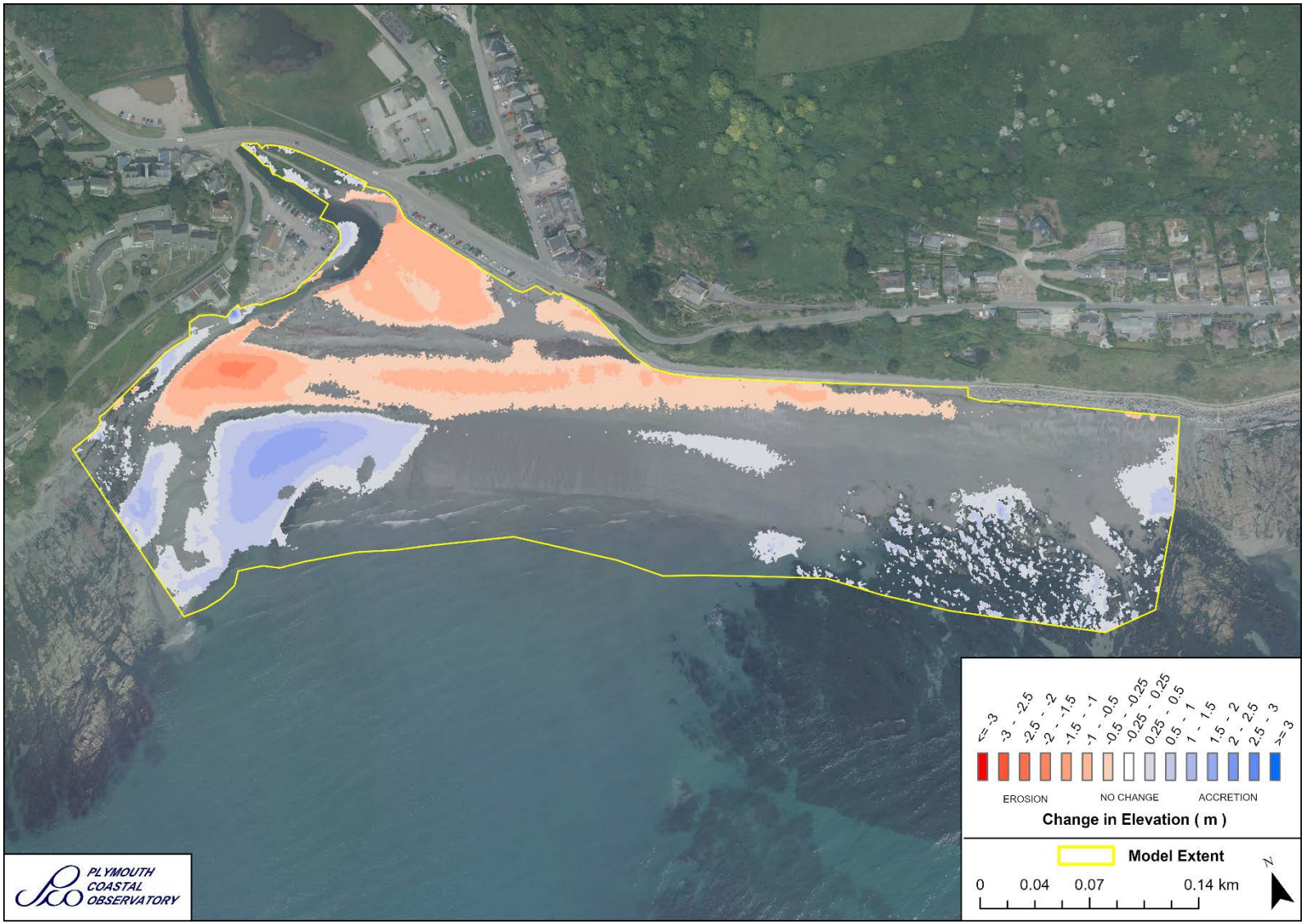


Figure 6 – Difference model indicating the changes in elevation observed between the March 2008 and March 2022 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from February 2008 compared to January 2009. Accretion can be observed along the low-tide terrace, predominantely to the west of the beach with subsequent erosion of up to 1.5 m in elevation observed along the upper beach face and along the river mouth to the west (Fig.9).

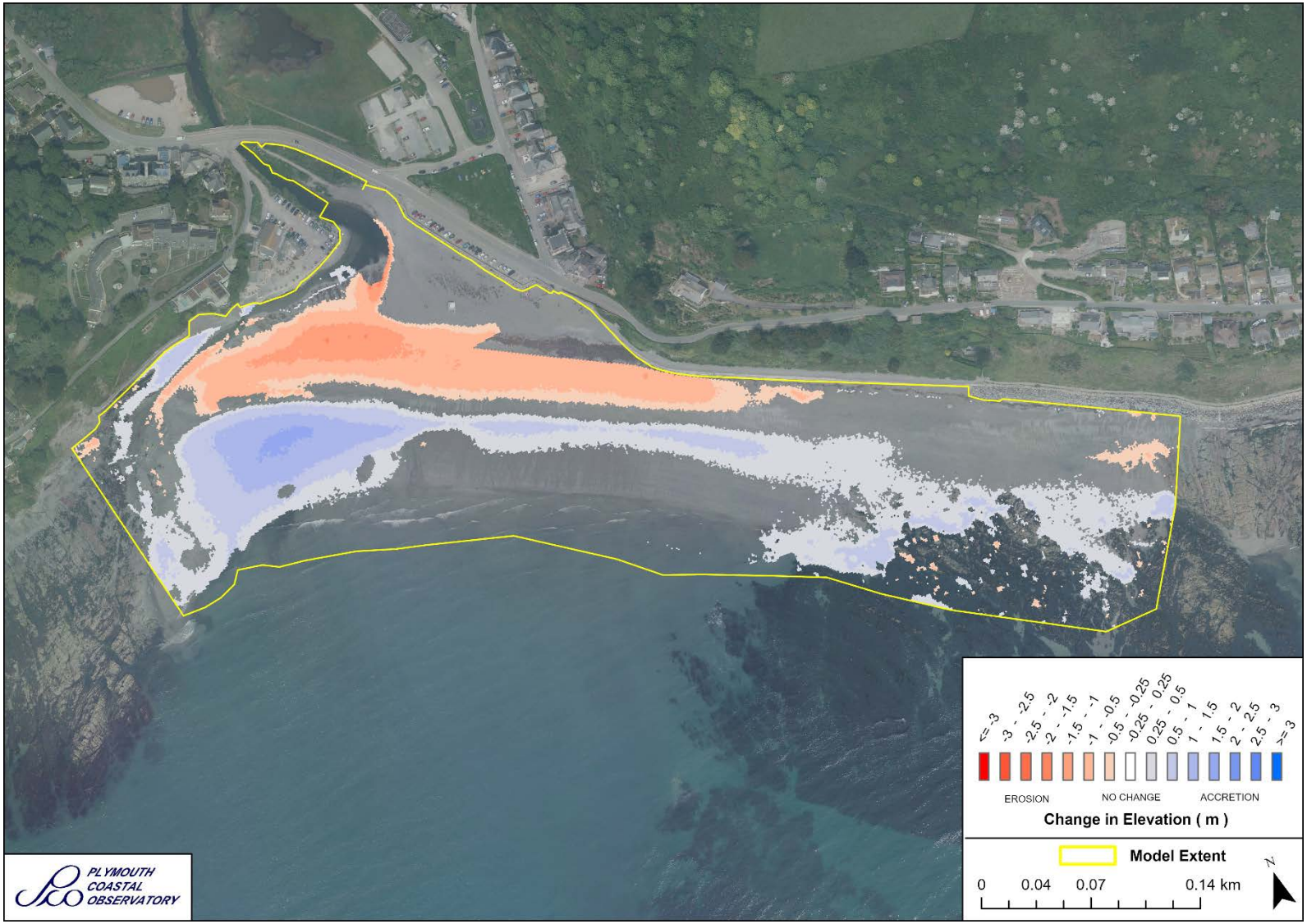


Figure 7 - Difference model indicating the changes in elevation observed between the February 2008 and January 2009 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from January 2009 compared to January 2010. Here, the opposite is observed to figure 9, with accretion by up to 1.5 m in elevation along the upper beach face, predominantly to the west of the beach with subsequent erosion observed along the low-tide terrace (Fig.10).

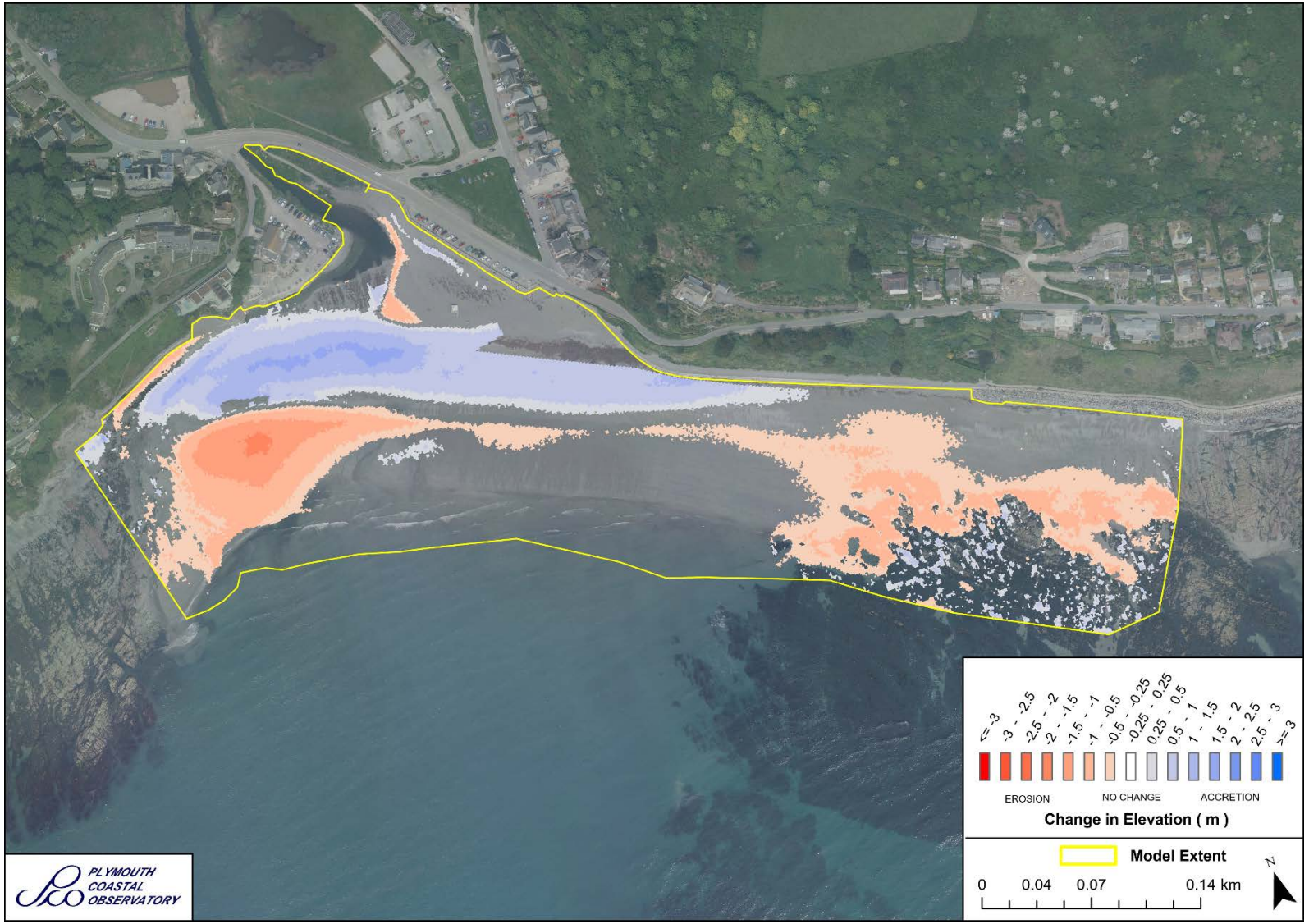


Figure 8 - Difference model indicating the changes in elevation observed between the January 2009 and January 2010 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from January 2010 and January 2011. This epoch indicates minor areas of change, with accretion and erosion observed primarily along the course of the river channel. Areas of erosion are also observed along the toe of the sea defence to the east of the beach (Fig.11).

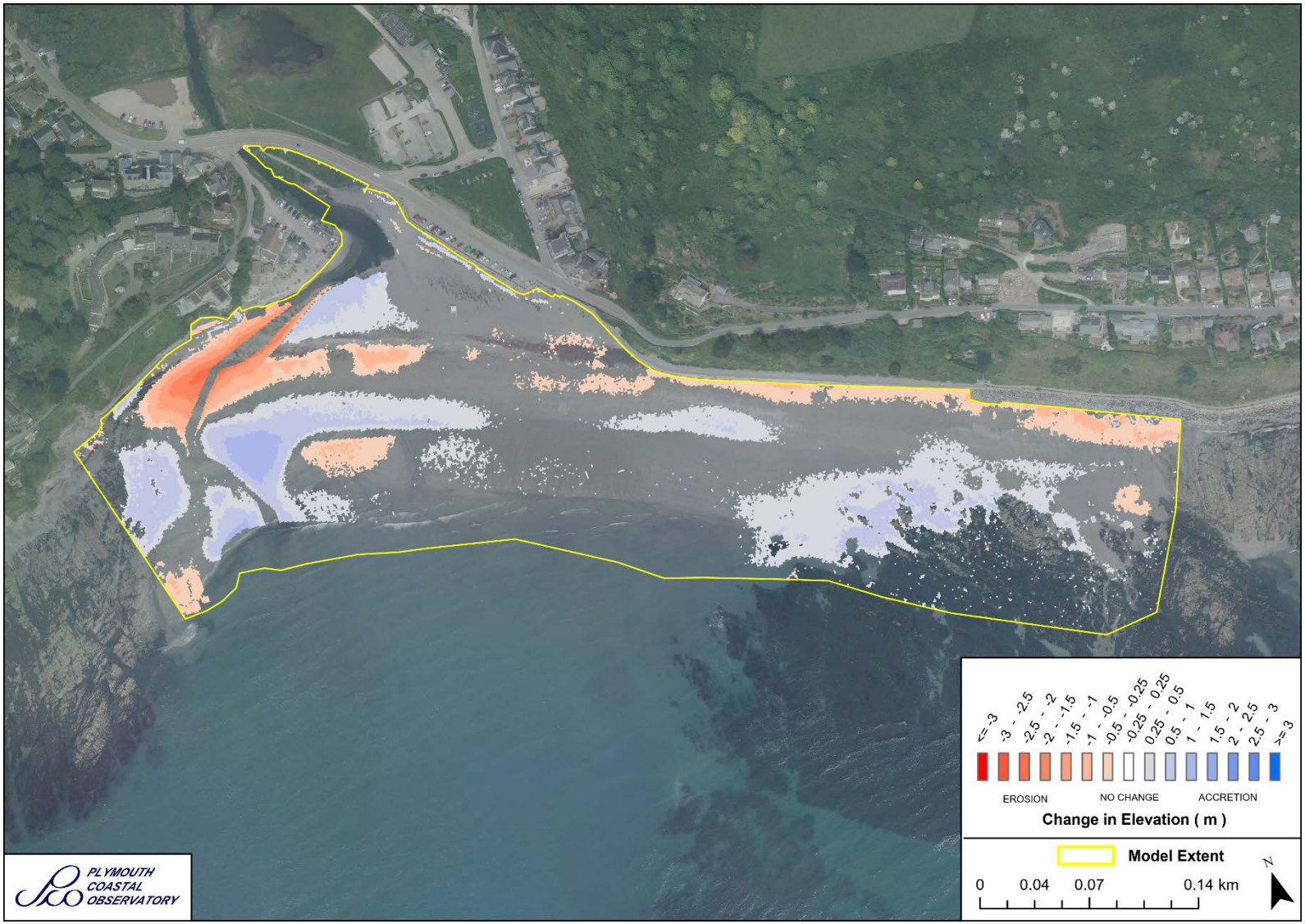


Figure 9 – Difference model indicating the changes in elevation observed between the January 2010 and January 2011 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from January 2011 and March 2012. The majority of the beach underwent erosion of the low-tide terrace and upper beach face during this epoch with a loss of elevation by up to 2 m in places, localised accretion can be observed around the river channel (Fig.12).

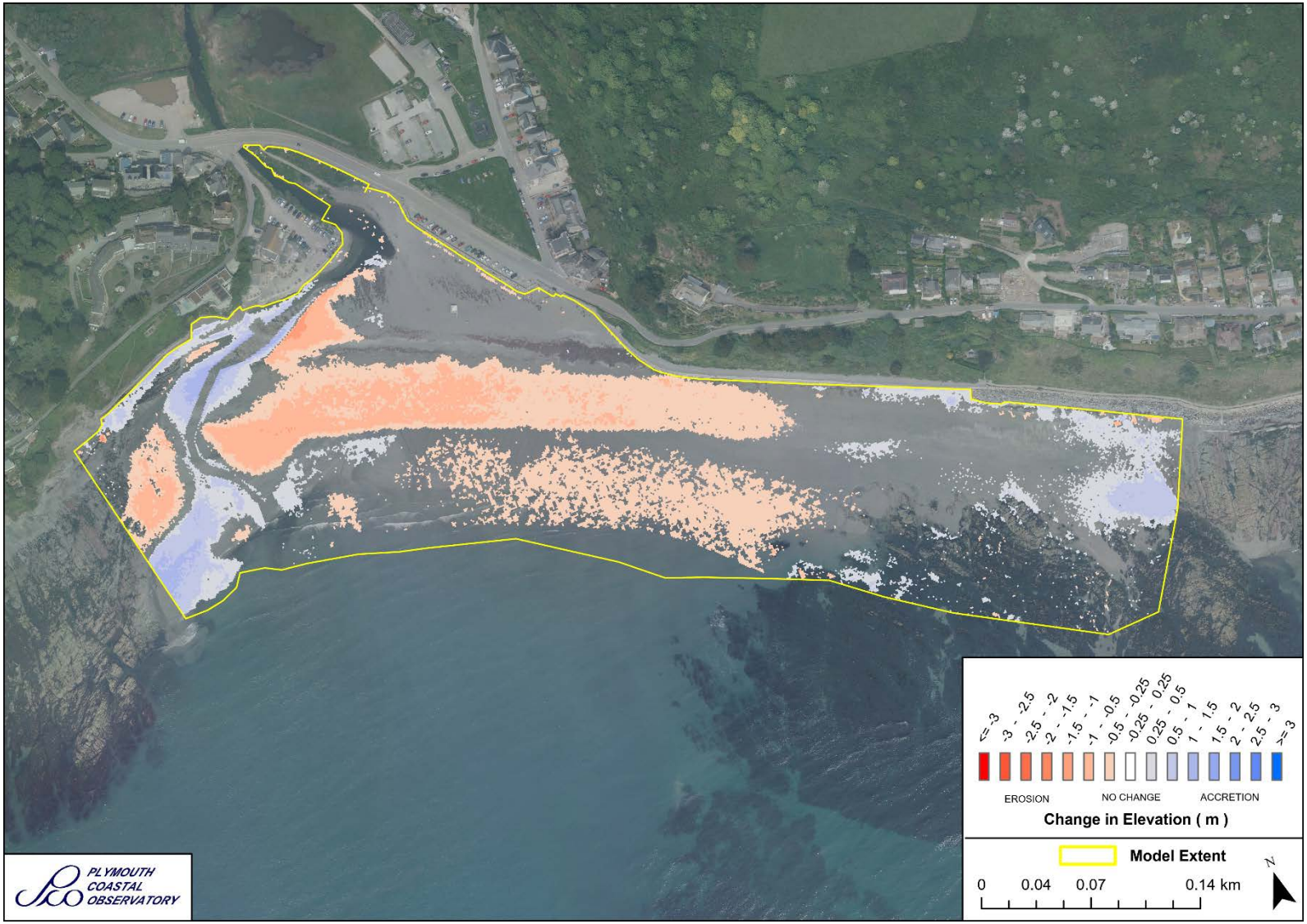


Figure 10 - Difference model indicating the changes in elevation observed between the January 2011 and March 2012 filtered LiDAR datasets within the yellow model extent.

Figure 13 shows differences in elevation between filtered LiDAR data from March 2012 and May 2014. There are substantial changes observed during this epoch due to the impact of the 2013/14 winter storms, with severe erosion observed along the entire upper beach berm to the west of the beach, with elevation changing by over 3 m in places, there is also erosion along the low-tide terrace to the east (Fig.13). Substantial accretion is also observed to the extreme west of the beach, reflecting the movement of the river channel from its usual position hugging the west of the beach to a more central position (Fig.13).

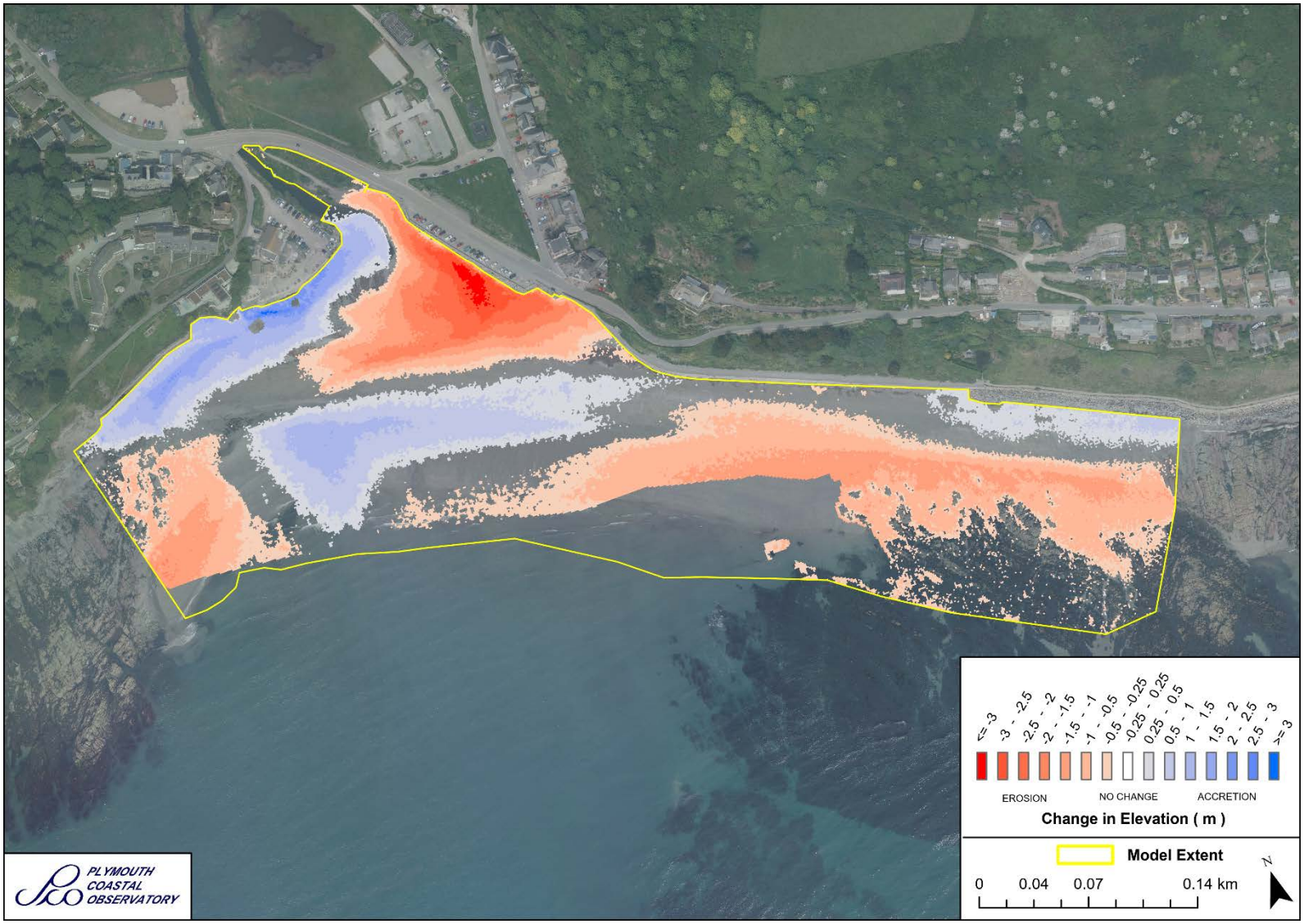


Figure 11 - Difference model indicating the changes in elevation observed between the March 2012 and May 2014 filtered LiDAR datasets within the yellow model extent.

Figure 14 shows differences in elevation between filtered LiDAR data from May 2014 and February 2016. The opposite to the 2012-2014 epoch can be witnessed here as the beach recovers from the impact of the 2013/14 winter storms, with severe erosion observed along the river channel, and considerable accretion observed along the upper beach berm and in front of the beach road with up to a 2.5 m gain in elevation (Fig.14).

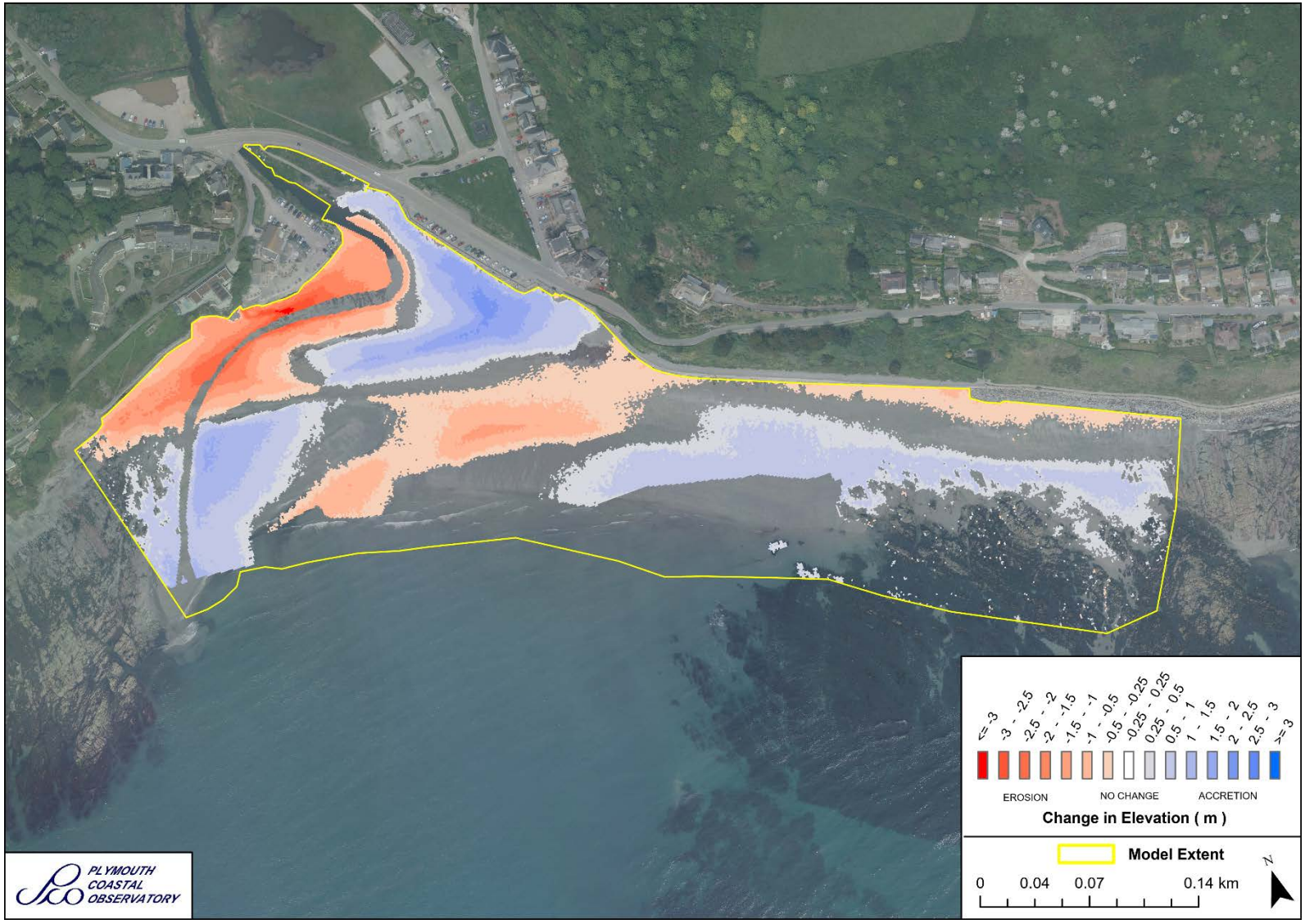


Figure 12 - Difference model indicating the changes in elevation observed between the May 2014 and February 2016 filtered LiDAR datasets within the yellow model extent.

Figure 15 shows differences in elevation between filtered LiDAR data from February 2016 and April 2019. This epoch is dominated by accretion along the upper beach berm and either side of the river channel as the beach continues to recover from the 2013/14 winter, corresponding erosion is also observed along the low-tide terrace to the west of the beach (Fig.15).

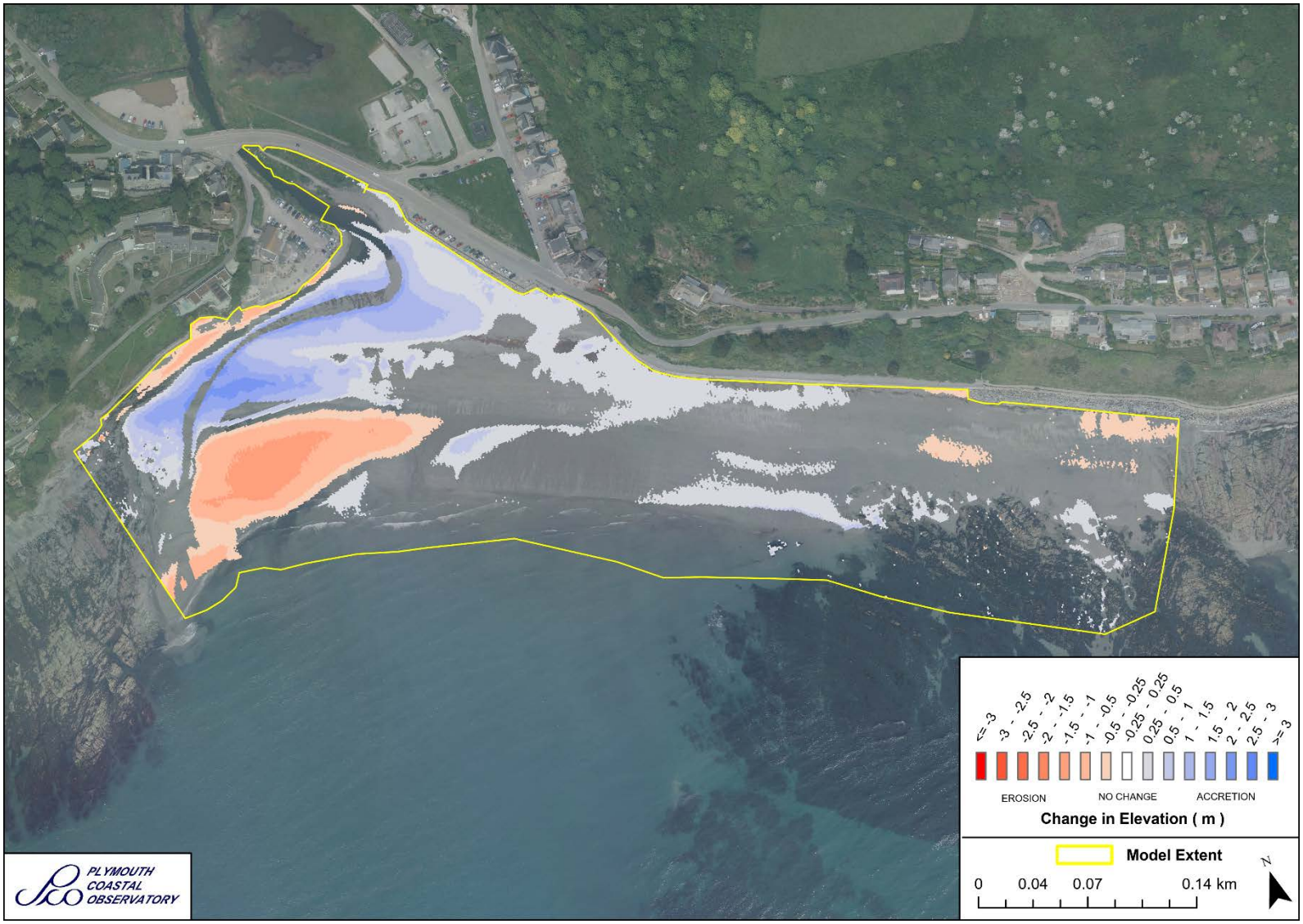


Figure 13 - Difference model indicating the changes in elevation observed between the February 2016 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 16 shows differences in elevation between filtered LiDAR data from April 2019 and September 2020. Again, the epoch is dominated by accretion along the upper berm and river channel seeing increases in elevation by up to 3 m in places, erosion is also observed along the low tide terrace adjacent to the river mouth (Fig.16).

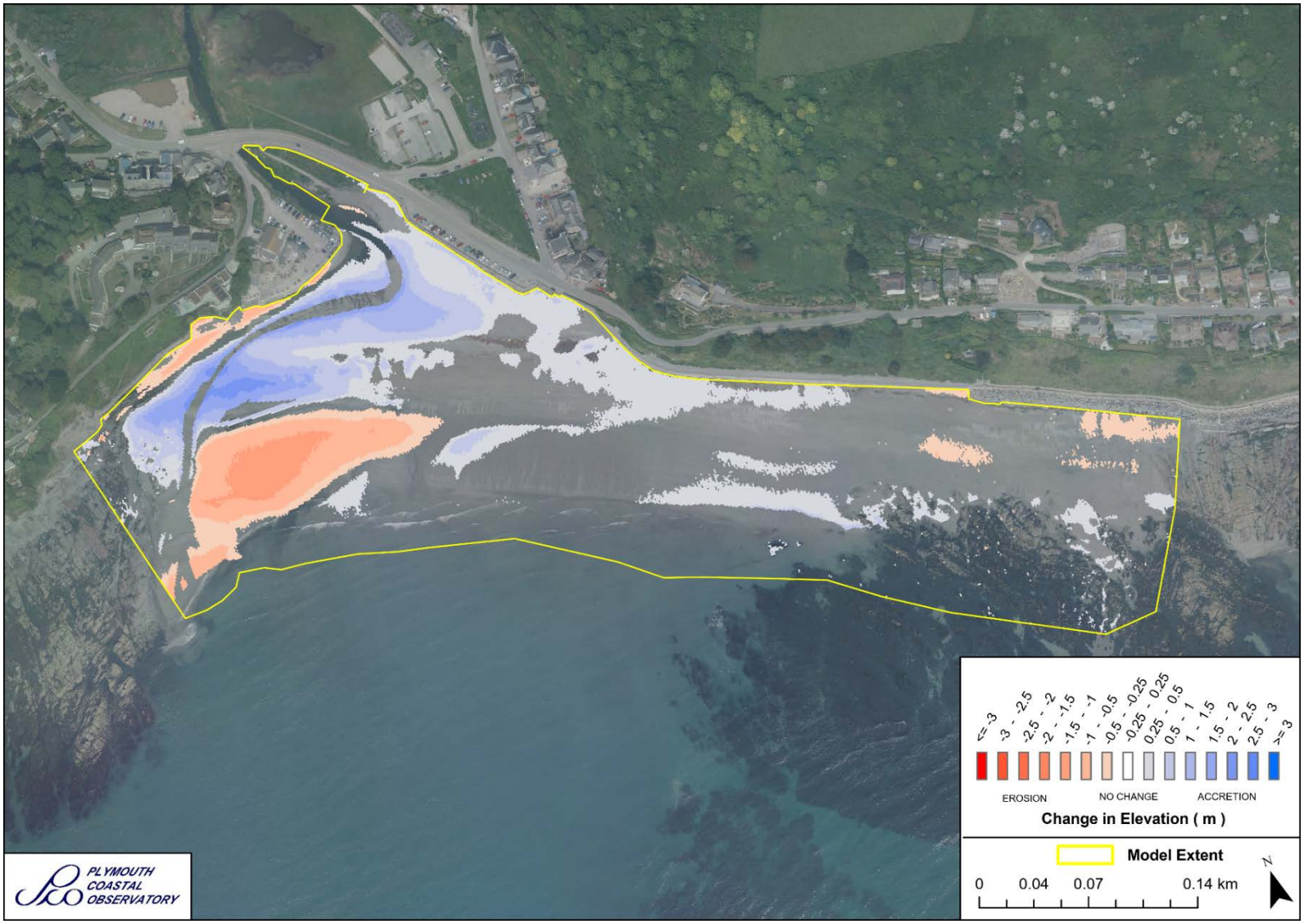


Figure 14 - Difference model indicating the changes in elevation observed between the April 2019 and September 2020 filtered LiDAR datasets within the yellow model extent.

Figure 17 shows differences in elevation between filtered LiDAR data from September 2020 and March 2022. This epoch is dominated by erosion of the lower beach face to the west of the survey unit, adjacent to the river channel, with reduced accretion observed along the low-tide terrace to the southwest of the survey unit (Fig.17).

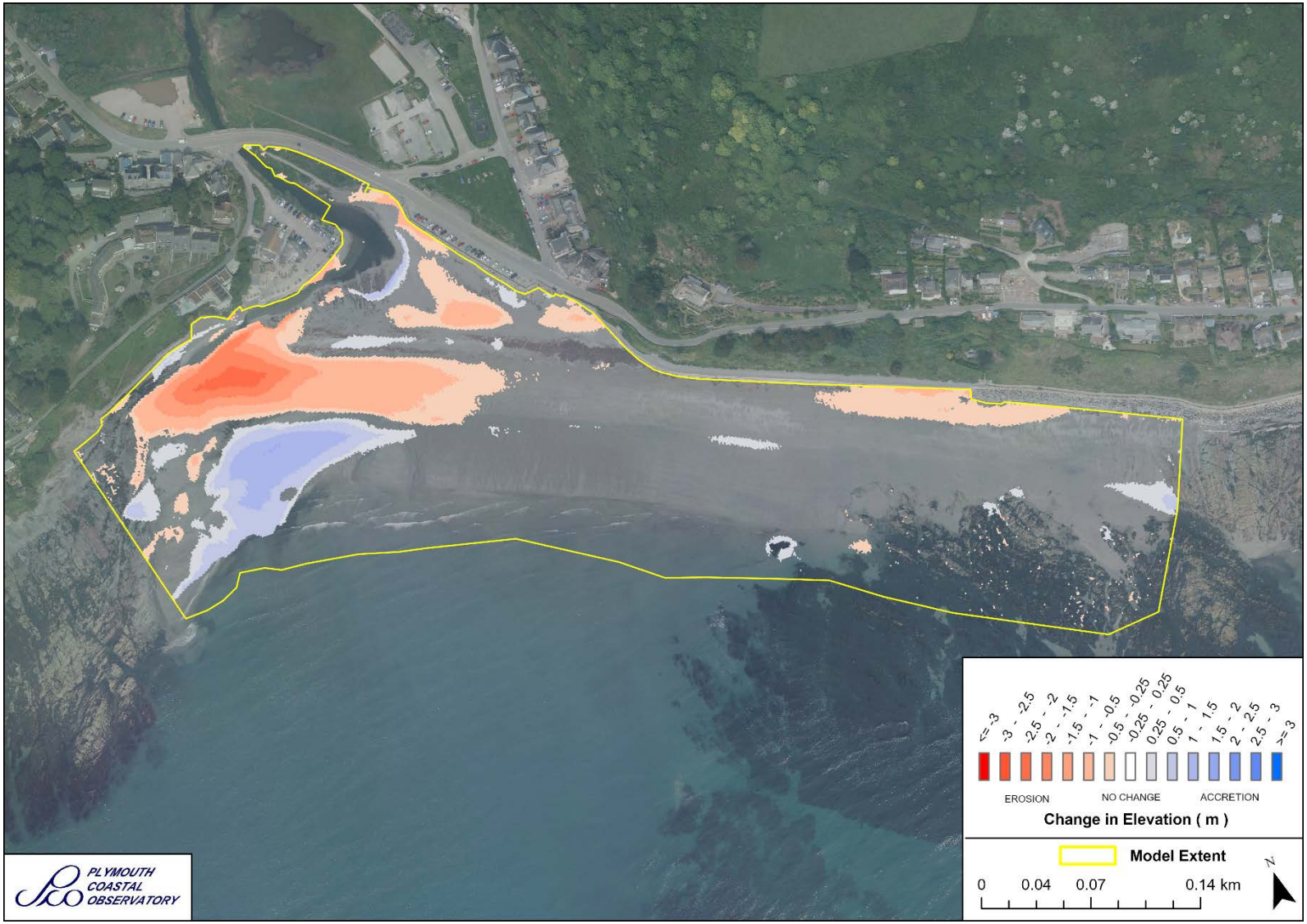


Figure 17 - Difference model indicating the changes in elevation observed between the September 2020 and March 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.35 m OD) are shown in Table 1 and figure 18. The volumetric data in the Mobile Zone is comparable to that recorded in the topographic dataset, showing no significant trend for accretion or erosion. The impact of the 2013/14 winter storms is significant on the Mobile Zone, which loses 7268 m^3 (equating to 33%) of beach material above MHWS between the 2012 and 2014 surveys (Table 1). Similarly to the topographic data, the lowest volume recorded in the Mobile Zone was during the February 2016 survey (14,522 m^3) since which, Mobile Zone volumes have returned to pre-2014 levels (Fig.18).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.45 m OD) are also shown in Table 1. The volumetric data trend in the Beach Zone is comparable to that of the Mobile Zone, with the lowest volume recorded during the 2016 survey (199,405 m^3) however by 2019, the volume had returned to pre-2013/14 levels (Fig.19).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (2.35 m OD) and for the Beach Zone above MLWS (-2.45 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
02/2008	22,790	206,917
01/2009	17,603	210,914
01/2010	24,366	210,520
01/2011	22,637	218,863
03/2012	21,790	222,473
05/2014	14,522	202,997
02/2016	13,393	199,405
04/2019	21,603	222,714
09/2020	20,935	210,008
03/2022	17,439	207,389

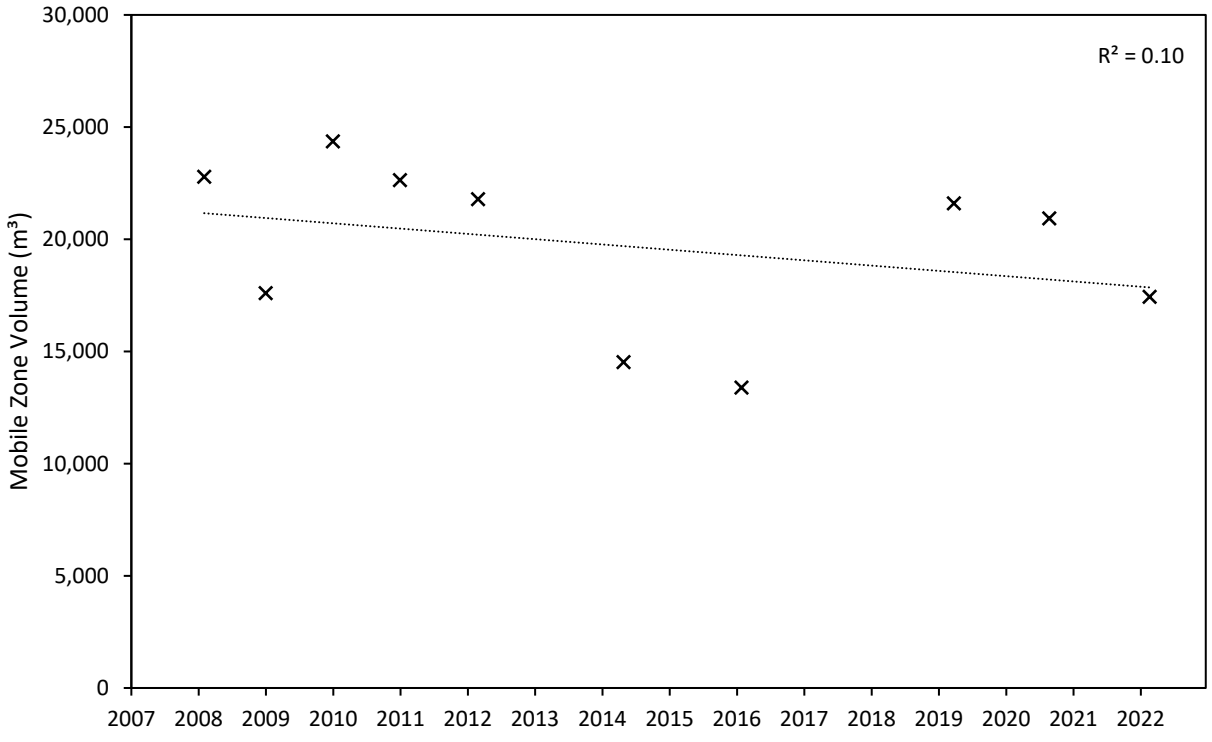


Figure 15 - Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.35 m OD) for each filtered LiDAR datasets between 2008 and 2022.

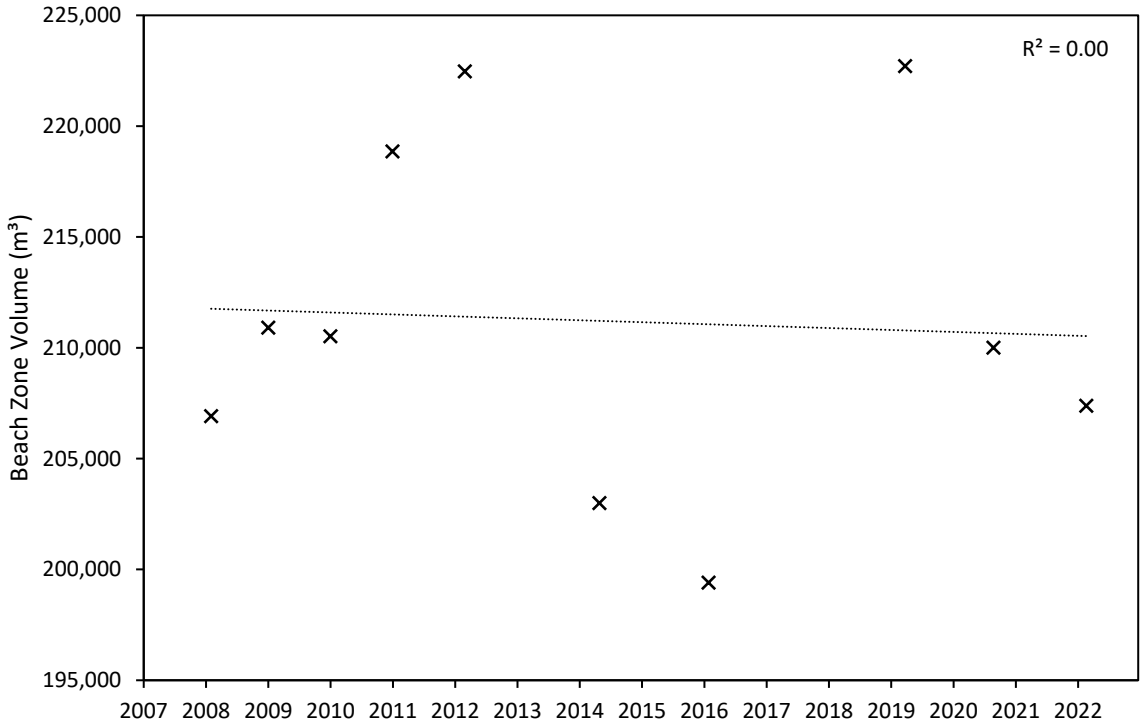


Figure 16 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-2.45 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.2.3 Contour Comparison

Figure 20 indicates the Mean Sea Level (MSL) and Dune Toe contours from 2008, 2014, 2019 and 2022 LiDAR datasets, projected onto aerial imagery captured in 2022. Dune Toe contours are influenced by the course of the Seaton River to the West, and generally do not change between datasets. This is with the exception of 2014 where the upper beach was heavily eroded, and its material subsequently deposited to the lower beach and to the West with the moving of the river channel following the high energy winter period. This is also identified in the MSL contour, which shows a progradation of the lower beach seawards for the 2014 LiDAR contour, other displayed contours show minimal change and are primarily influenced by the course of the Seaton River to the west.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency and from 2007 onwards by the SWCM 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 2007.



Figure 23 – Aerial imagery from 2009.



Figure 24 – Aerial imagery from 2014.



Figure 25 – Aerial imagery from 2018.



Figure 26 – Aerial imagery from 2022.

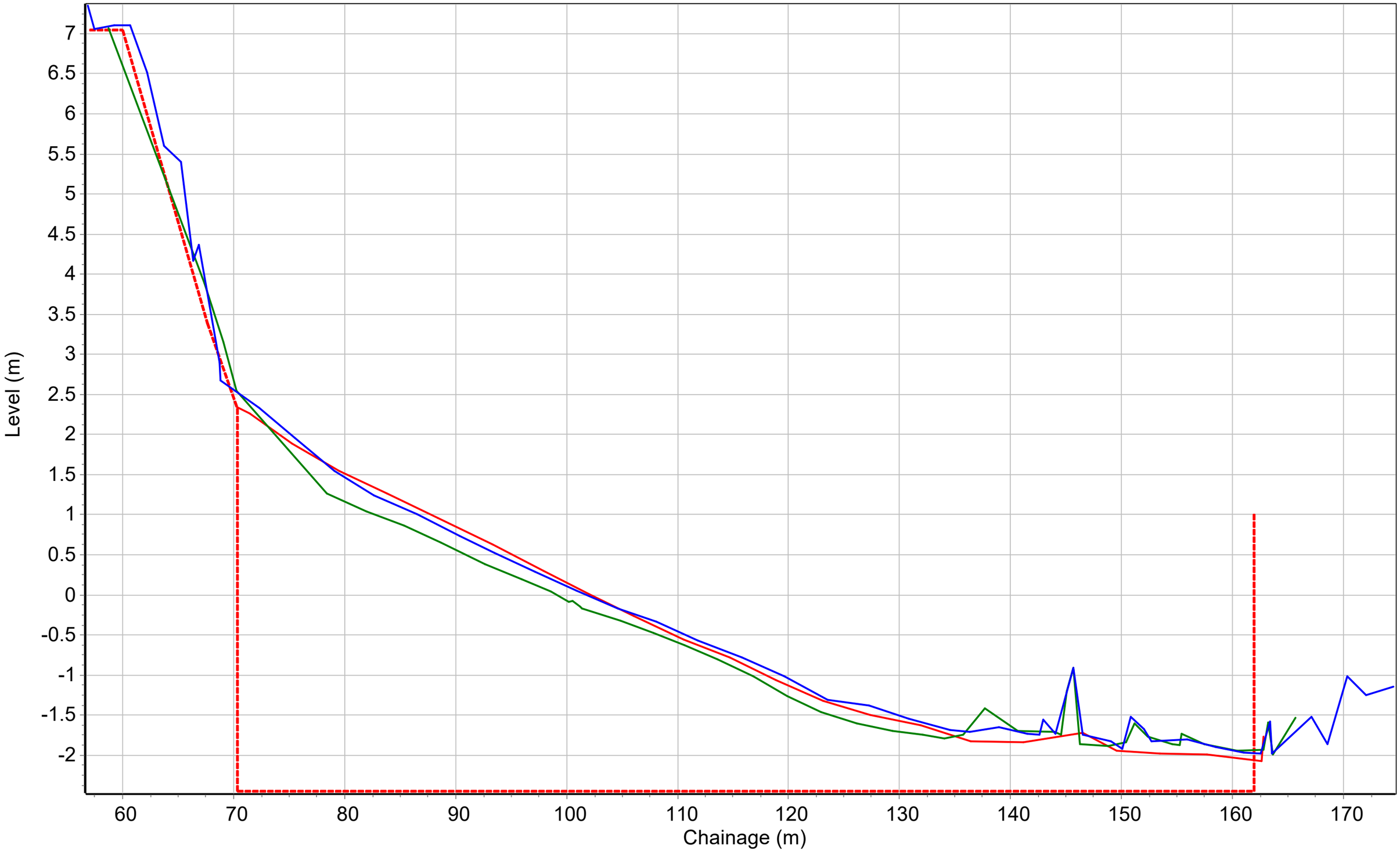
Glossary

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

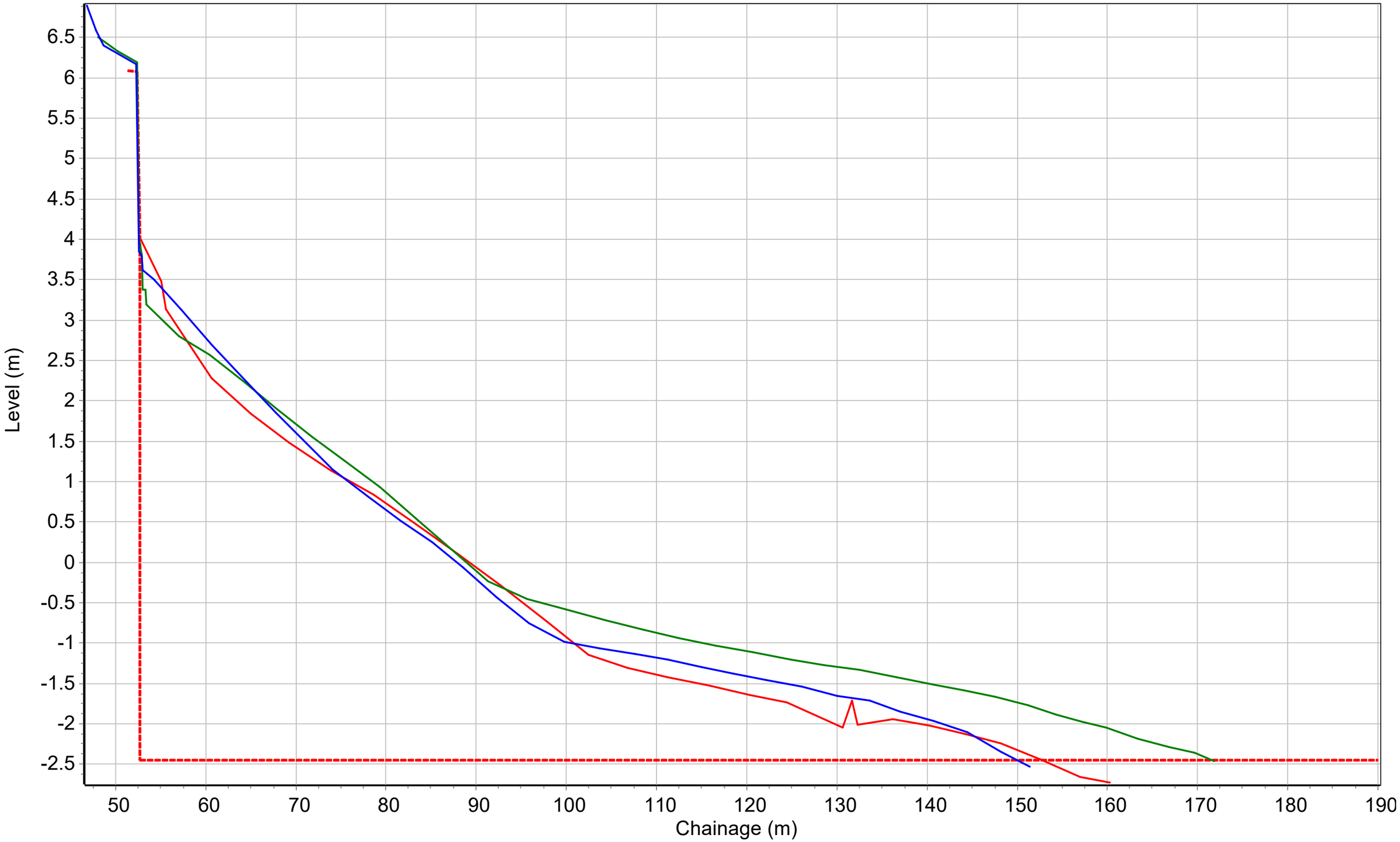
Appendix 1 – Profile charts showing the cross-shore area of each interim profile from the most recent survey (blue), second most recent survey (green) and first survey, also known as the baseline (red) at Crooklets are presented below.

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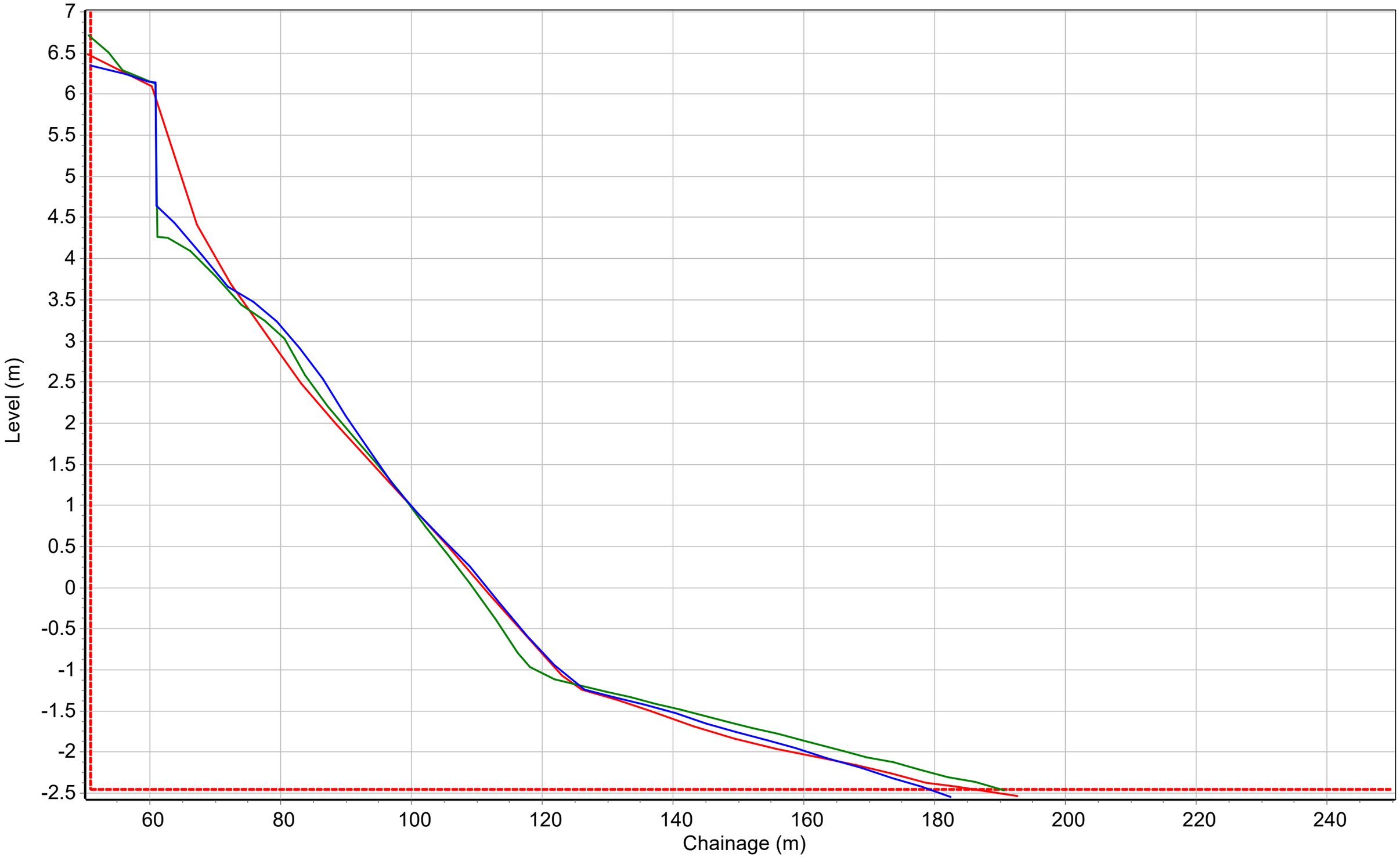
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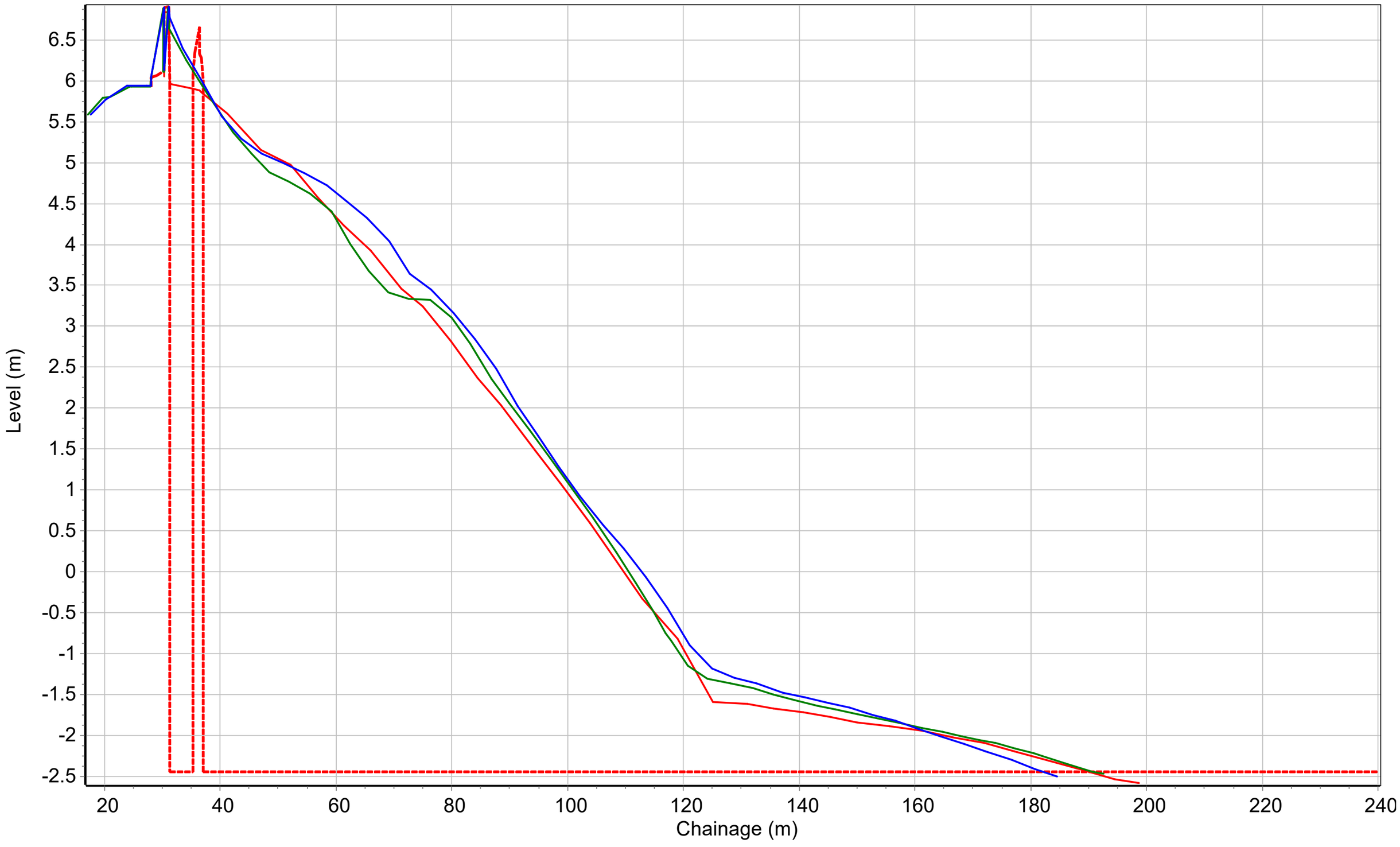
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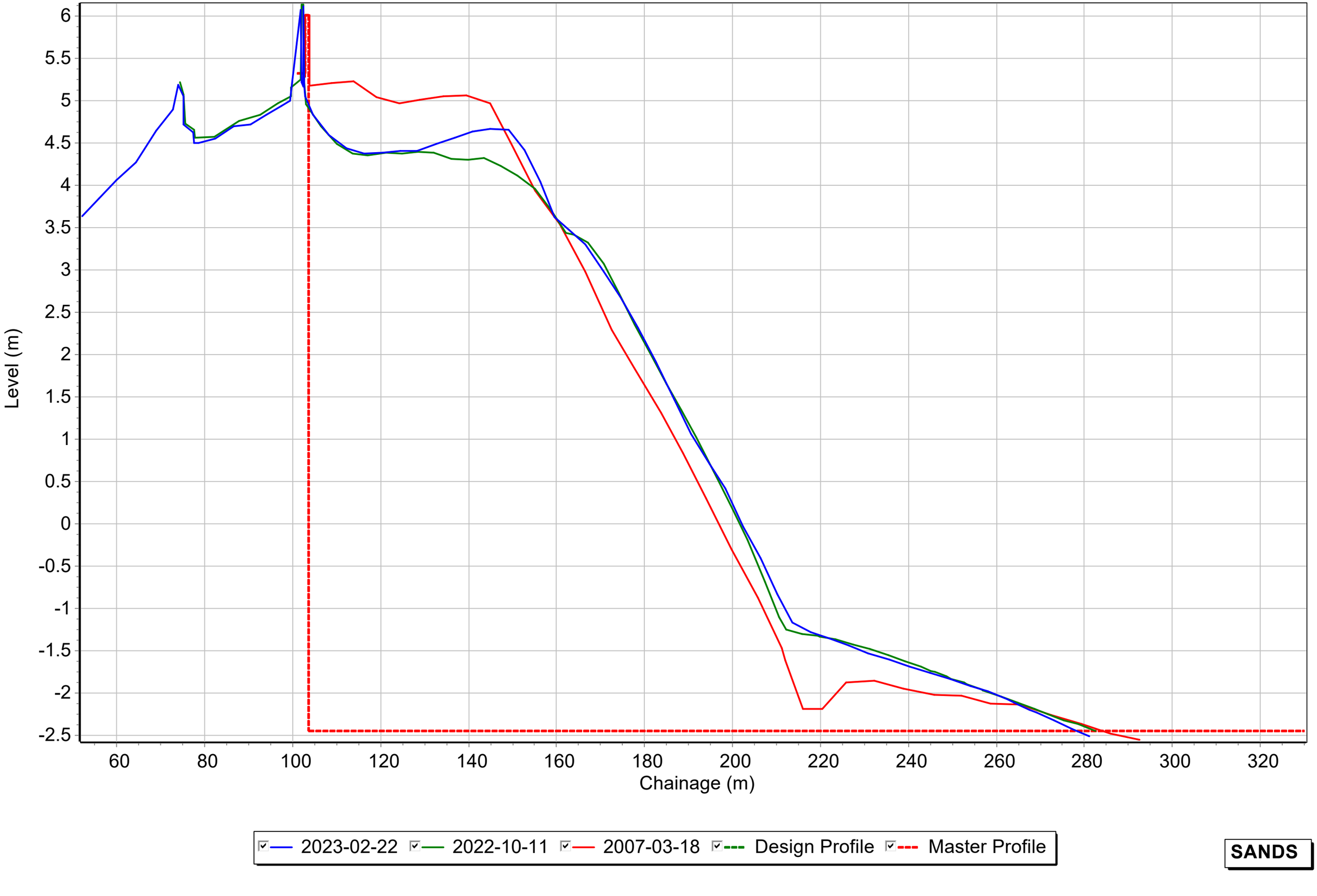
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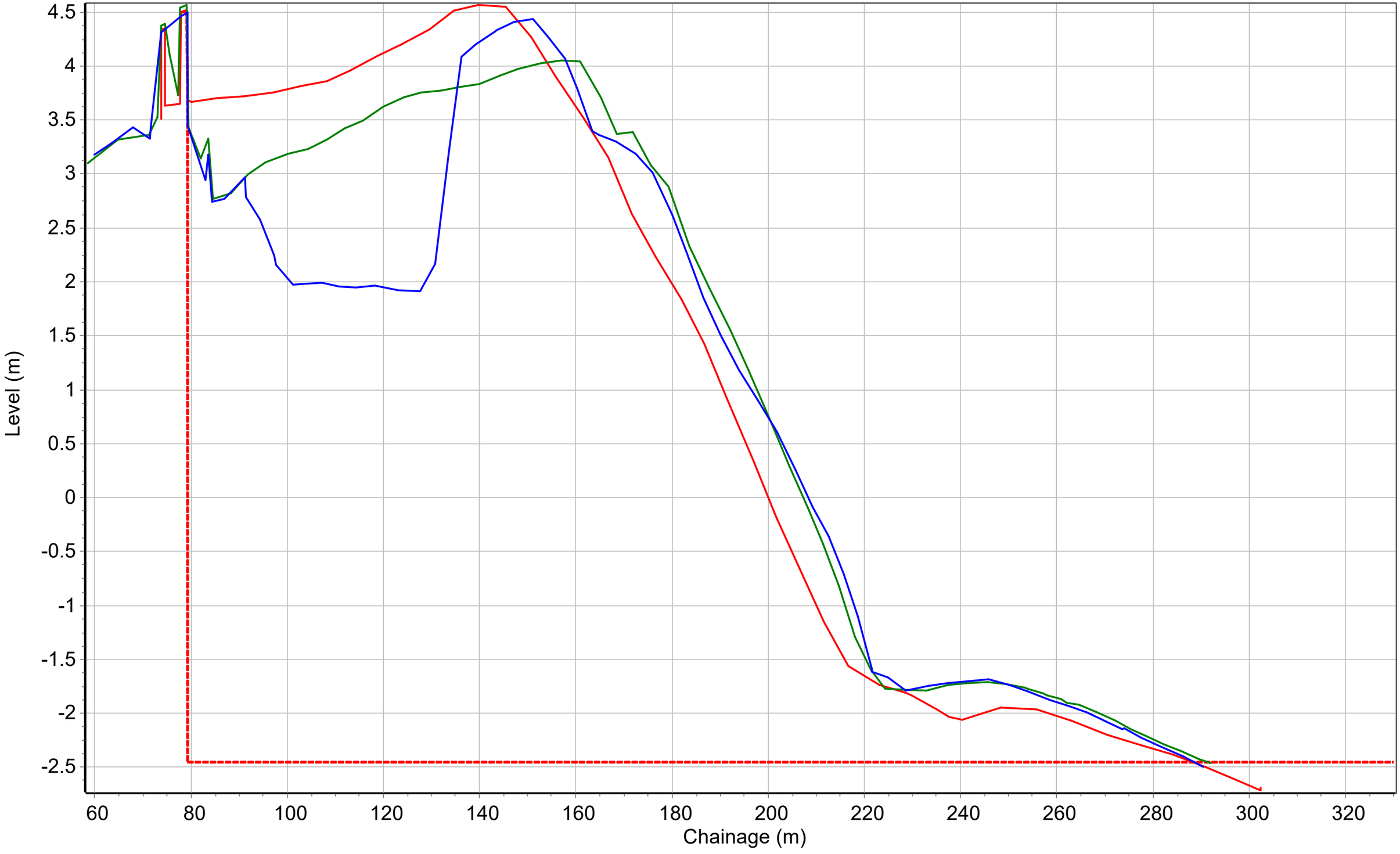
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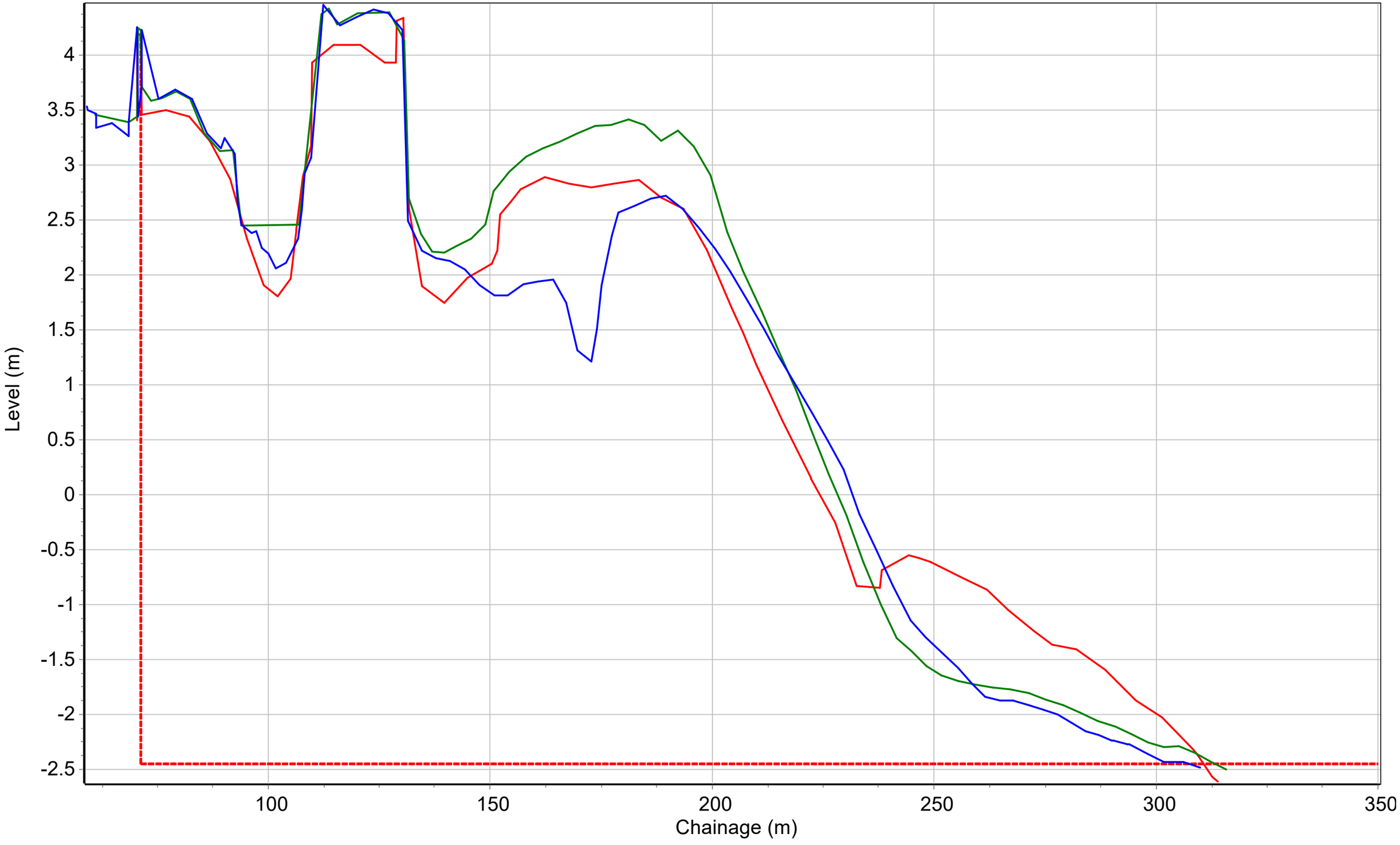
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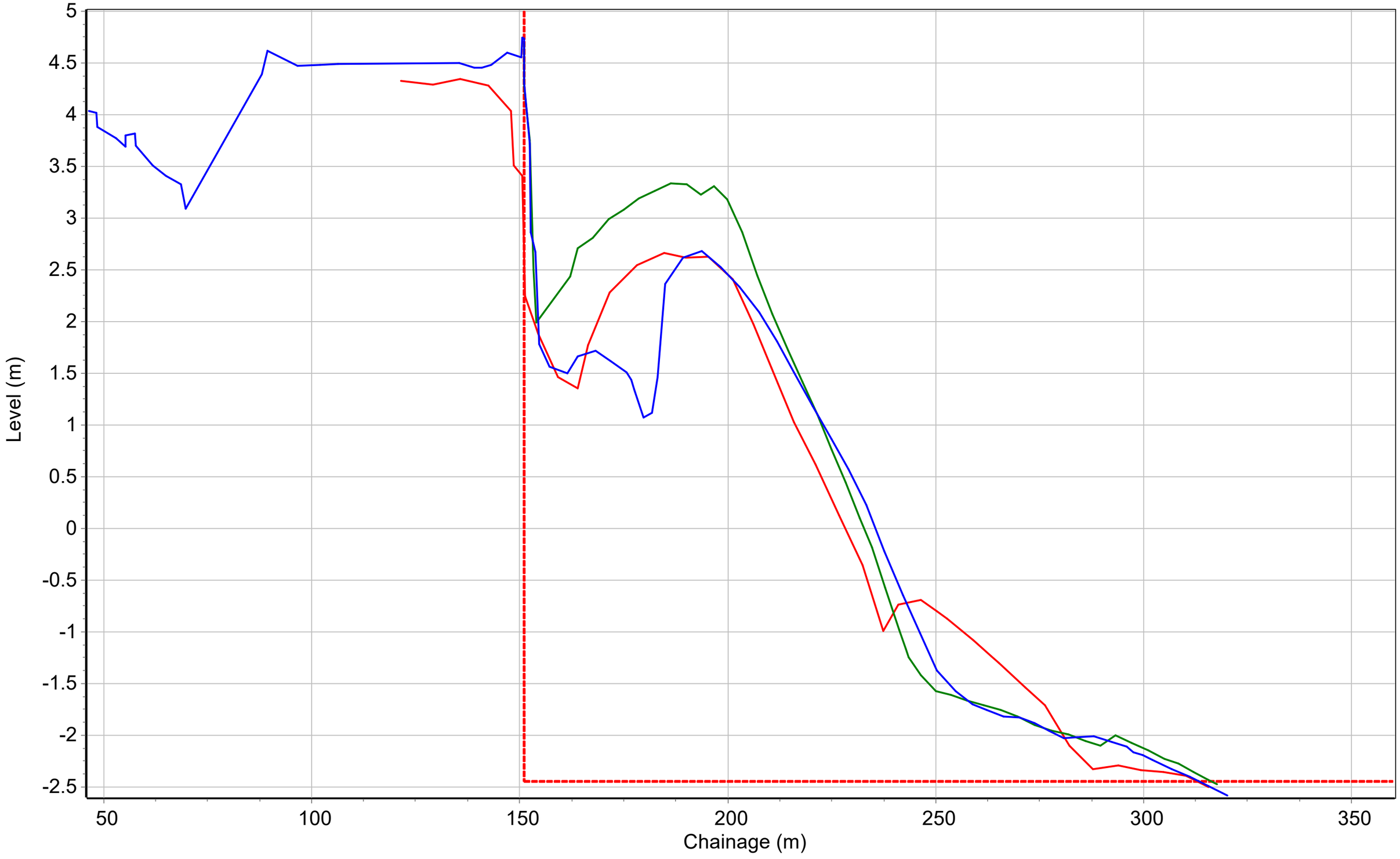
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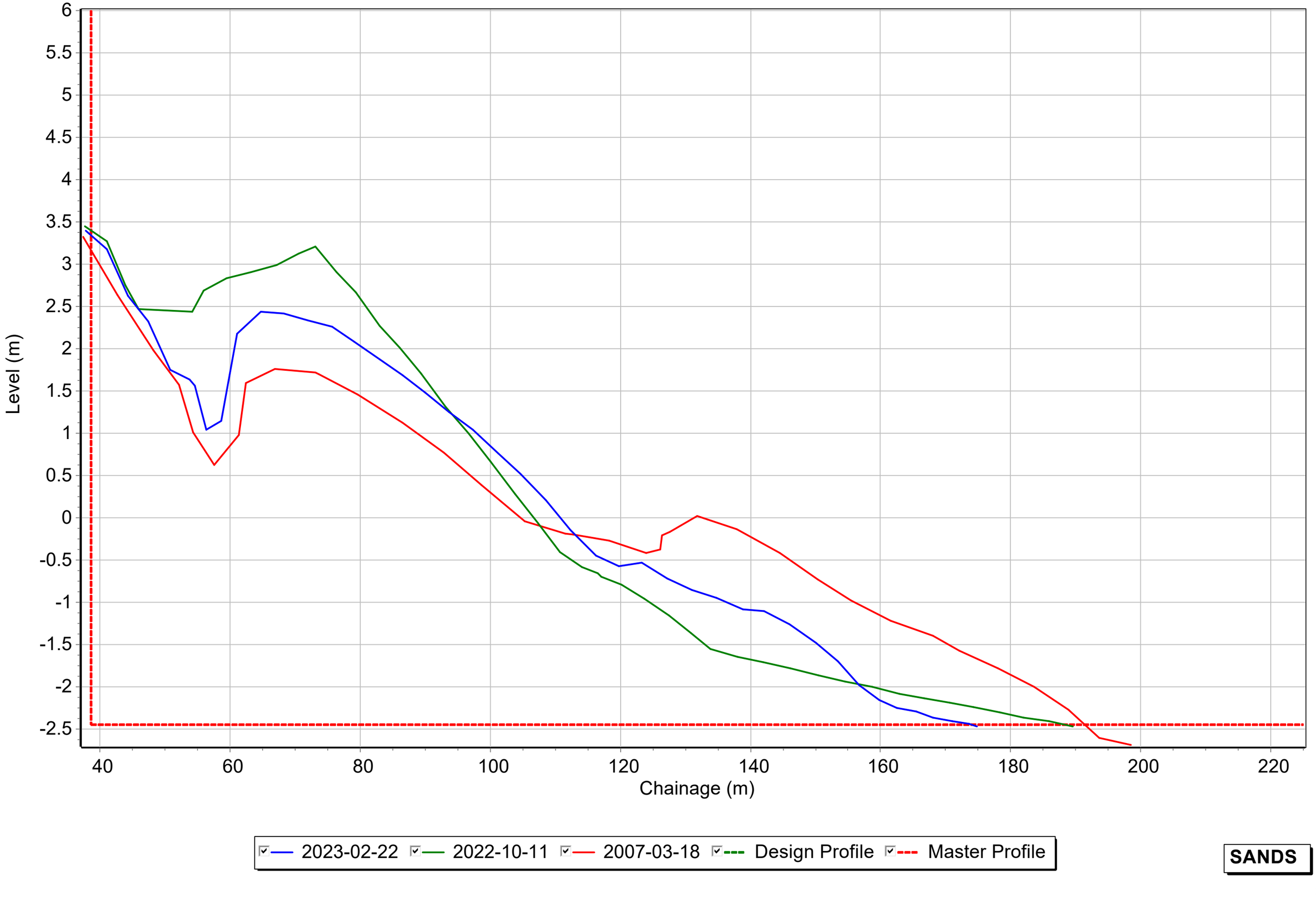
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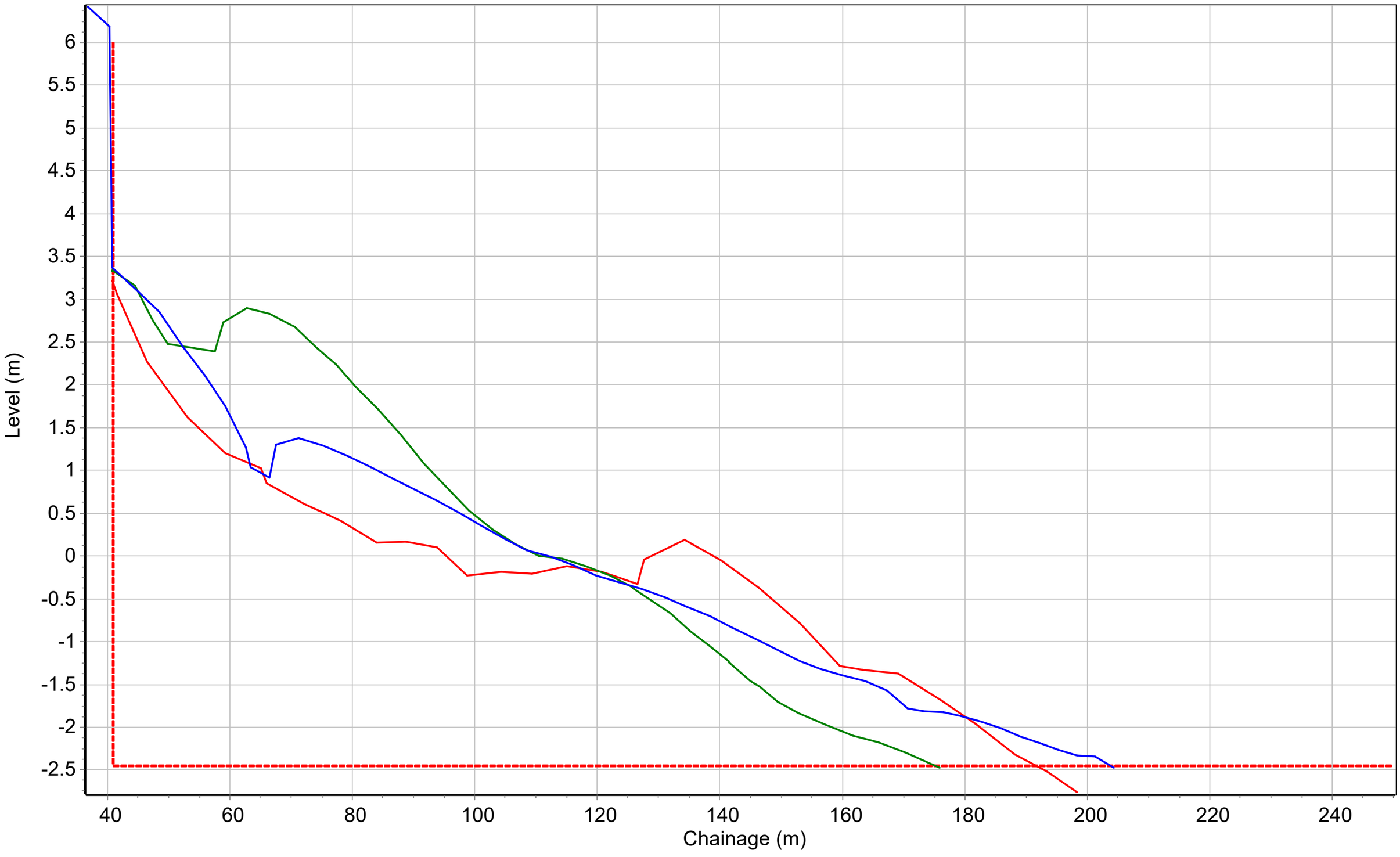
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