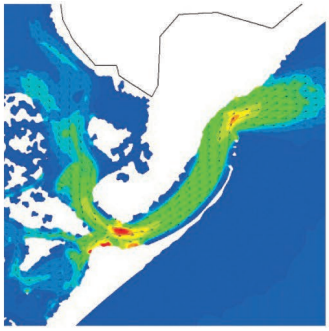
Arup

Barmouth North Promenade

Coastal Processes

February 2019

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Barmouth is located in Cardigan Bay, between Llanaber in the north, and River Mawddach to the south (Figure 1). The North Promenade frontage is approximately 1,300 m long and faces south south-west. It extends from a residential housing estate at Heol y Llan to the northern extent of the promenade wall. The defence protects a mixture of commercial and residential developments and the beach fronting the defences is used extensively by tourists and helps contribute significantly to the local economy.

ABPmer has been commissioned by Ove Arup and Partners Limited (Arup) to review the coastal processes at Barmouth, to determine the nearshore wave and water level conditions and to undertake overtopping analysis. The overtopping analysis has been undertaken for the existing defence and a series of defence options for present day (epoch 2019) and with an allowance for climate change over 50 and 100 years (epoch 2069 and 2119 respectively). The work contributes to the development of an Outline Business Case (OBC) for flood and erosion protection at Barmouth. The OBC was commissioned by Ymgynghoriaeth Gwynedd Consultancy (YGC); part of Cyngor Gwynedd Council (CGC). Understanding the wave climate and overtopping volumes are essential for CGC in developing options available for the North Promenade.

This work is reported in two separate deliverables:

- **Process Understanding** (this document) - A summary of the coastal processes affecting the defences and the conceptual understanding of the dynamics at North Promenade, and the wider area.
- **Wave modelling, Extremes Analysis and Wave overtopping** (separate document, ABPmer 2018) - A report which sets out the modelling results for the wave, water level and wave overtopping criteria of the Barmouth North Promenade frontage.

The analysis and associated documents provide information to support the assessment of the existing situation, the flood inundation modelling being undertaken by Arup, and the development of protection options.

2 General Overview

Barmouth is located in Cardigan Bay, between Llanaber in the north, and River Mawddach to the south (Figure 1). The North Promenade frontage is approximately 1,300 m long and faces south south-west (SSW). It extends from a residential housing estate at Heol y Llan to the northern extent of the promenade wall. The defence protects a mixture of commercial and residential developments and the beach fronting the defences is used extensively by tourists and helps contribute significantly to the local economy.

The beach north of North Promenade is comprised of a shingle/cobbles bank that fronts the railway line. Along North Promenade and to the south of North Promenade, the sediments are mainly comprised of sand with isolated pockets of shingle/cobbles along the upper foreshore.

To the south, the Mawddach Estuary, is designated as a Site of Special Scientific Interest (SSSI) and as a Special Area of Conservation (SAC), whilst the whole of Cardigan Bay forms part of the Llŷn Peninsula and Sarnau SAC. Most of the beach is above mean high water and the dunes do not have nature conservation designation, but the dunes are priority Biodiversity Action Plan (BAP) features which are now relatively scarce in Wales and across Europe. These dunes consist of dynamic foredunes and embryo dunes.

Figure 1. **Location of Barmouth North Promenade with historical names and sediment regions (sand and shingle) and Shoreline Management Plan (SMP2) Policy units: Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14)**

3 Offshore Seabed Description

At the outer edge of Cardigan Bay, the sea bed depth is approximately 30 m. Depths then decrease eastwards in towards Barmouth Bay.

Barmouth Bay itself is located between two headlands which extend offshore as shallow causeways. To the north the headland forms a continuous ridge running in a south westerly direction from Morchras Point along Sarn Badrig (St Patrick's Causeway). To the south the shallow causeway Sarn-y-Bwch, extends from Pen Bwch Point. The Mawddach River and Estuary are situated between these two constraining geological features (Figure 2).

The shallow ridges to the north and south (Figure 2) influence the wave energy that reaches Barmouth, restricting wave energy that can reach the site from more north westerly and southerly direction sectors. At the mouth of the Mawddach estuary a series of large sandy shoals exist. These sandy shoals form part of the ebb delta system that fronts the estuary mouth. These sandy shoals are highly dynamic.

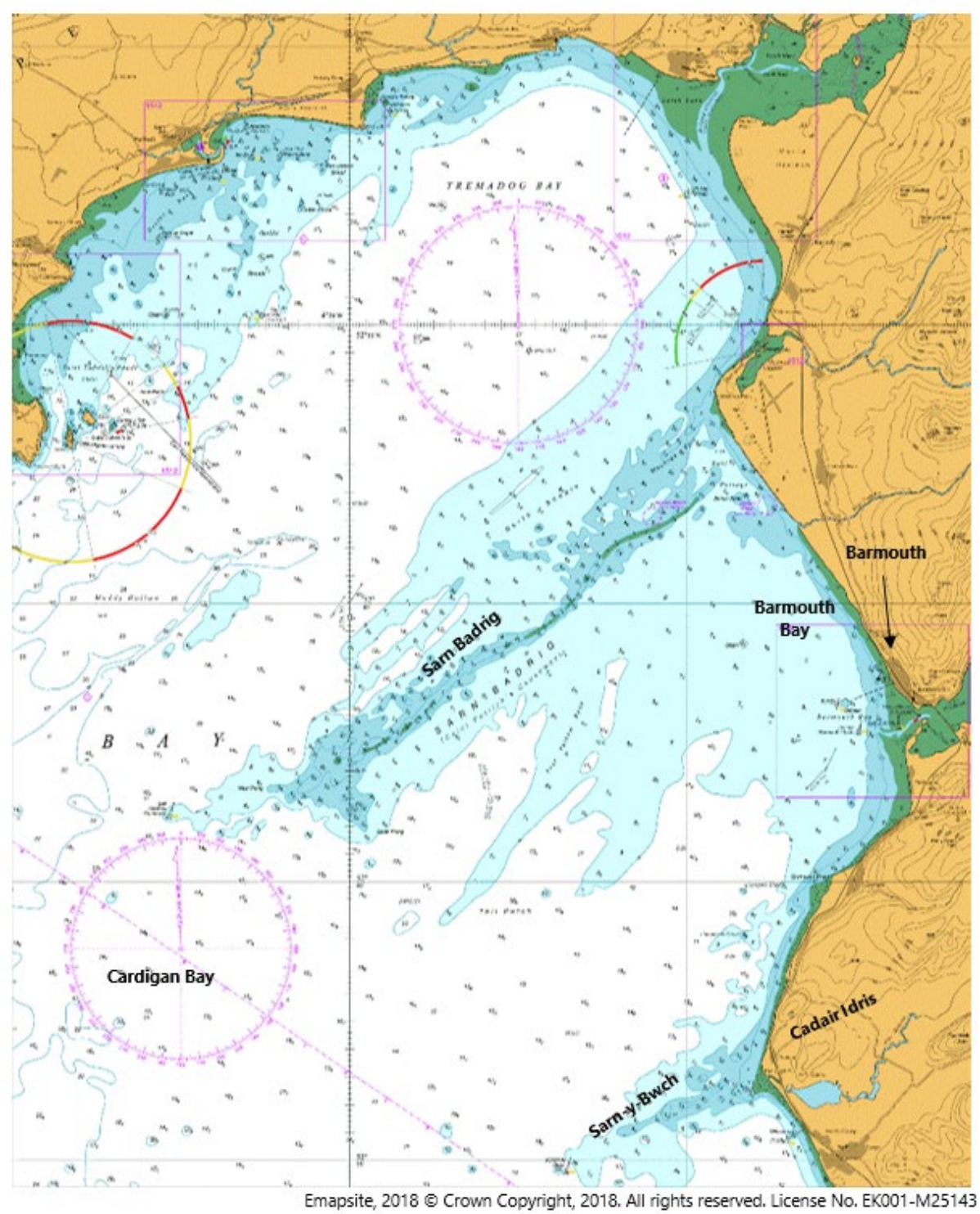


Figure 2. Bathymetric chart from 1971

4 Historical Context

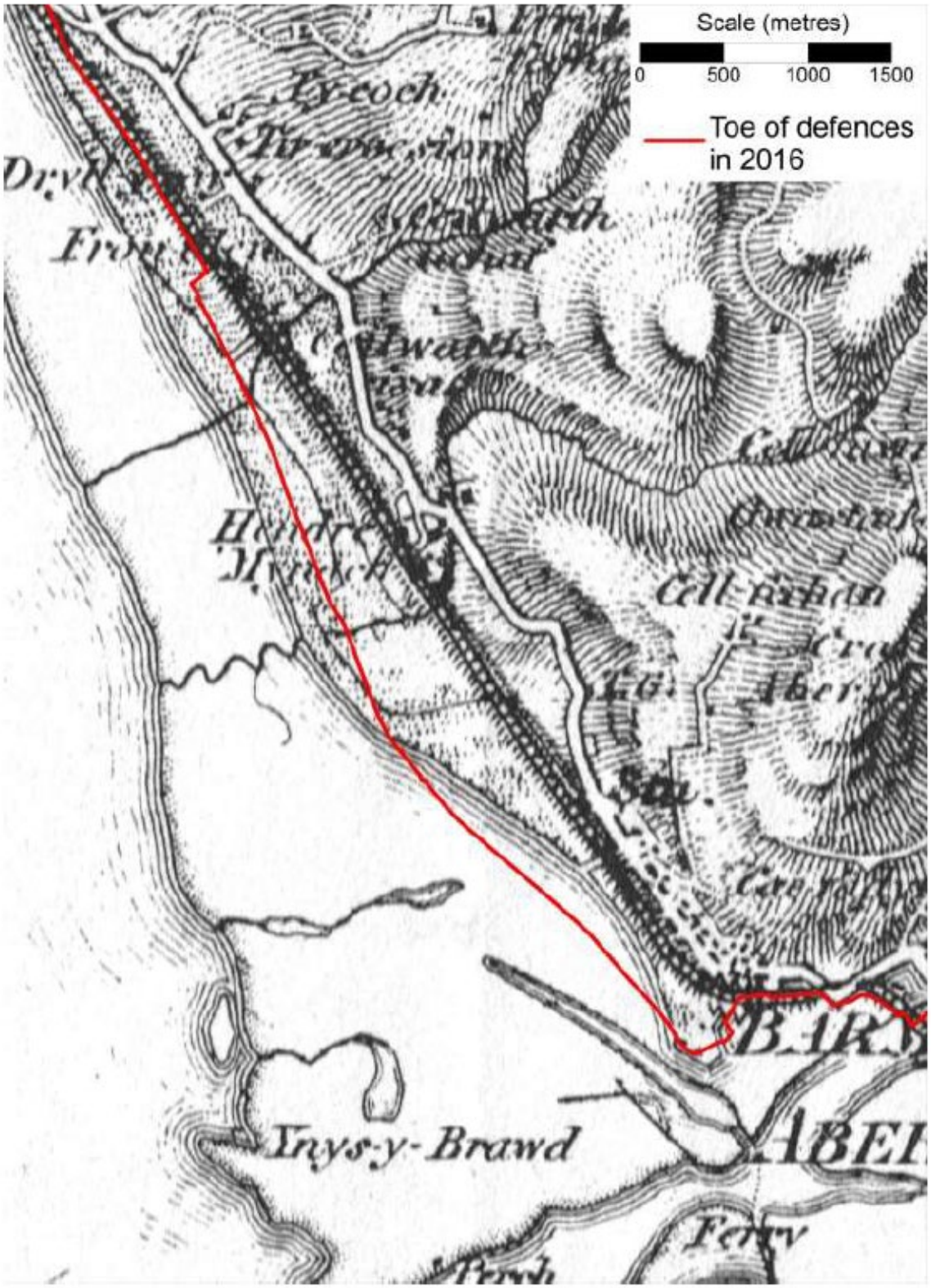
A historical overview of the changes in Barmouth and the Mawddach Estuary is provided by Kenneth Pye Associates Ltd (2016), based on analysis of charts and historical photographs. As a general summary, Kenneth Pye Associates Ltd (2016) states the following:

> *"The northern part of Barmouth Beach has experienced sediment loss and falling levels for decades, whereas the southern part of the beach has experienced sediment accretion and rising beach levels, especially since construction of a causeway across the former Bar Bach channel to Ynys y Brawd in the early 1970's. Rising beach levels have favoured colonisation by vegetation and growth of dunes."*

A more detailed summary of the past historical changes is provided below. This summary, is based on the key points identified in Kenneth Pye Associates Ltd (2016) and a Geotechnical Desk study undertaken by Arup (Arup, 2018a). Historic maps from this study are found in Appendix A. The historical place names described in this summary are shown on Figure 1:

- 1700's:
  - 1748 the two main channels at the mouth of Mawddach Estuary are flowing to the north and south of Ynys y Brawd. The north channel was in a similar position to that shown in Figure 7. Sand dunes northwest of Barmouth Old Town are present and a quay existed in the same position as present. It can be assumed from historical accounts that navigation to the harbour was often difficult due to shifting sand banks and bars, and the harbour gained limited shelter from storm waves.
  - A breakwater was built on Ynys y Brawd in 1797 providing more shelter for the harbour which was completed in 1802.

- 1800's:
  - The First Edition One-Inch map (Figure 3) shows a relatively wide beach which decreases in width towards North Promenade. This map should be considered with caution as it is largely schematic.
  - The main Trywn y Gwaith masonry breakwater was constructed between 1826 and 1840, with the primary purpose to regulate movement of the South Channel.
  - Between 1833-1835 two narrow breakwaters (forming a y-shape in plan view) were completed, with a curved linking structure on the landward side. By 1835, two narrow groyne structures are partially buried by sand. A larger structure was constructed at Trwyn y Gwaith post 1835.
  - 1835 a well-developed ebb-tidal delta at the mouth of the Mawddach is observed, with a large low water channel running in a NW - SE direction away from Barmouth Harbour.
  - 1887-1892 images indicate the northern channel had undergone shoaling, there is no clear connection to the sea at low water. A bar (Bar Bach) had started to grow across the mouth of the North Channel east of Ynys y Brawd.
  - 1835-1890 images show the northern part of the of Barmouth frontage, north of the "Drainpipe" and Recreation Ground have undergone significant erosion. To the south of the drainpipe erosion was much less severe, presumably due to construction of lengths of *ad hoc* sea defences.



Kenneth Pye Associates Ltd, 2016

Figure 3. **First edition One-Inch Ordnance Survey map, surveyed 1833-35, with the railway line added later**

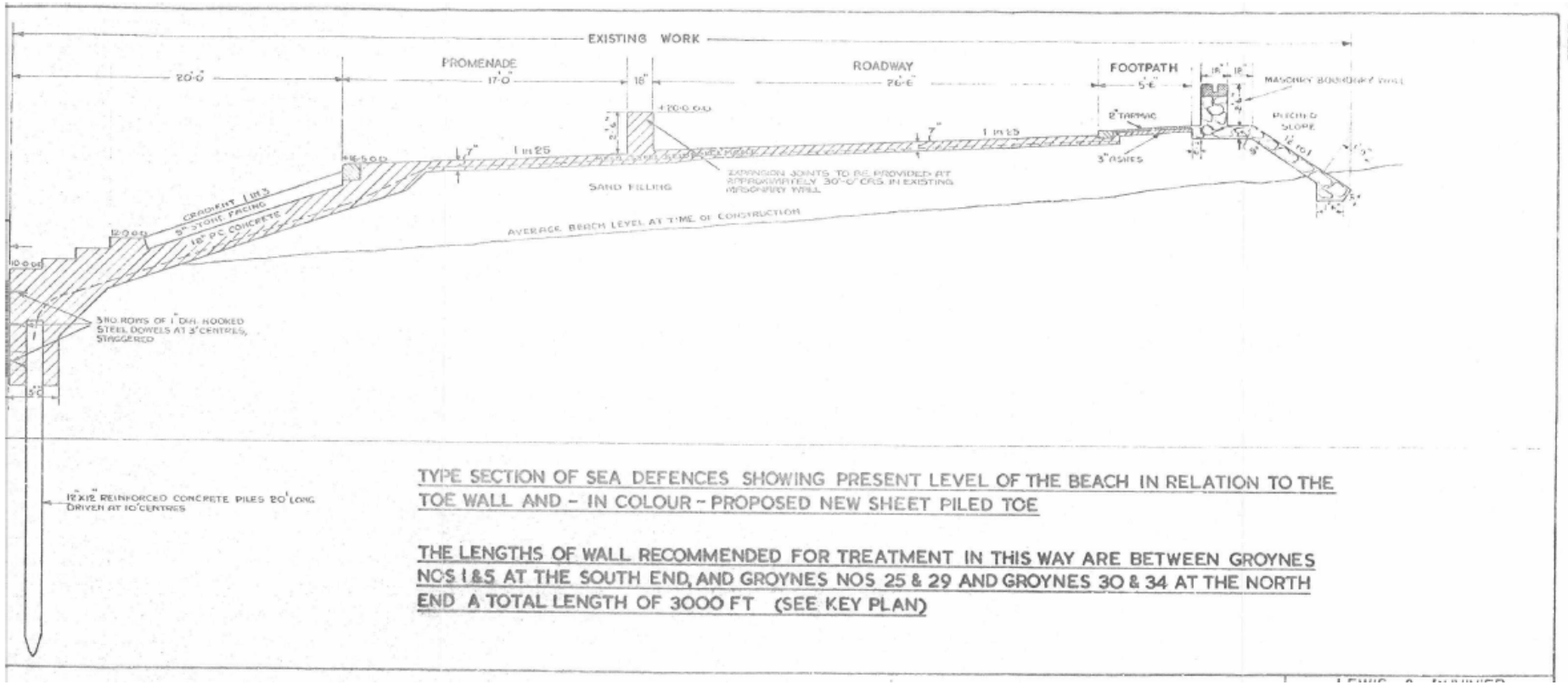
- 1900's:
  - 1900, images show relatively little change since 1890, it was noted that erosion persisted on the northern part of the frontage but the exact location is unknown. By the late 1920s the early *ad hoc* sea defences were falling into disrepair.
  - 1930 improvements were commissioned which consisted of 48 timber groynes and a sloping / stepped revetment extending 1.5 miles from the quay, south of the Bath House, to the northern end of the present promenade. Construction of the promenade itself followed shortly afterwards. The promenade was constructed to protrude beyond the previous coastline. The works resulted in large areas of beach being reclaimed between the railway station and the Bath House.
  - 1940-1950 the northern (Bar Bach) channel was not continuous to the sea at the level of mean low water (MLW), although a shallower channel above this level apparently extended almost parallel to the shore as far as the drainage pipe opposite the Recreation Ground. The shoaling of the Bar Bach Channel in the later 19th and early 20th centuries may have been triggered by the construction of the Mawddach railway viaduct in 1866-67. Shortly after the 1950's concerns were expressed about falling beach levels in front of a section of vertical sea wall at the northern end, and in 1956 the wall between groynes 25 (middle of North Promenade) and 34 (north of the caravan site) was provided with strengthened toe protection using sheet piling encased in concrete. Aerial photography taken in 1954 that show the groynes at North Promenade are presented in Figure 4 and Figure 5. A schematization of the sheet piling, which also shows indicative beach levels is shown in Figure 6.

Kenneth Pye Associates Ltd, 2016

Figure 4. Oblique aerial photography, taken 1950

Kenneth Pye Associates Ltd, 2016

Figure 5. Oblique aerial photography, taken 1950



Lewis & Duvivier Consulting Engineers, 1954

Figure 6. Defence schematisation including beach level at time of construction

- 1960's exposed groynes all along the frontage and a narrow low water channel (Bar Bach) extending from the Harbour to the sea. An aerial photograph from 1971 (Figure 7) shows that the north channel was relatively wide but shallow towards its seaward end, and a small area of partially vegetated dunes is shown adjacent to the breakwater on Ynys y Brawd.
- In the 1960's and 1970's because of drowning fatalities in "Bar Bach" channel and the progressive silting of Mawddach Estuary main channel and to aid general navigation in the harbour area a decision was taken to block off the existing northern channel by constructing a causeway linking the Ynys y Brawd island to the mainland. It is widely considered that the implementation of the causeway has had a profound effect over time on the coastal processes along the frontage, with accretion of material being predominant at the southern extents (Martin Wright, 2015).
- 1970-72 rock was used to build a causeway, topped by a concrete walkway across the Bar Bach channel between a point north of the old Bath House and Ynys y Brawd and a wave return wall was constructed between the causeway and the end of the promenade. Many of the groynes were rebuilt and 3,000 tons of quarried granite was placed to nourish the beach at the northern end, the exact location of the nourishment is unclear.
- In 1981 strengthening work on the Trwyn y Gwaith breakwater at the southern end of Ynys y Brawd was undertaken. A stepped concrete revetment and three groynes were built on the seaward side, the level of the connecting causeway was raised and a wave return parapet wall built to match the one constructed along the promenade in 1972-74.
- 1983 further improvements were made to the seawall at the northern end of the promenade by extending the wave return parapet to provide greater protection to the railway level crossing.

- 2000's:
  - Between 2000 and 2006, the first pioneer dune vegetation began to appear with large areas of low dunes had developed to the south of the Min y Mor Hotel and on the western side of the Ynys y Brawd causeway.

Kenneth Pye Associates Ltd, 2016

Figure 7. Vertical aerial photograph of the Barmouth frontage, flown 10/04/1971

5 Sediments

The Shoreline Management Plan (SMP2) (Royal Haskoning, 2011) provides a good regional overview of the coastal description and morphology of the area (Figure 8). Two rock headlands define the morphology; in the north, the headland forms a continuous ridge running in a south westerly direction from Morchras and Sarn Badrig. In the south, the site is constrained by Cadair Idris. The Mawddach River and Estuary are situated between these two constraining geological features.

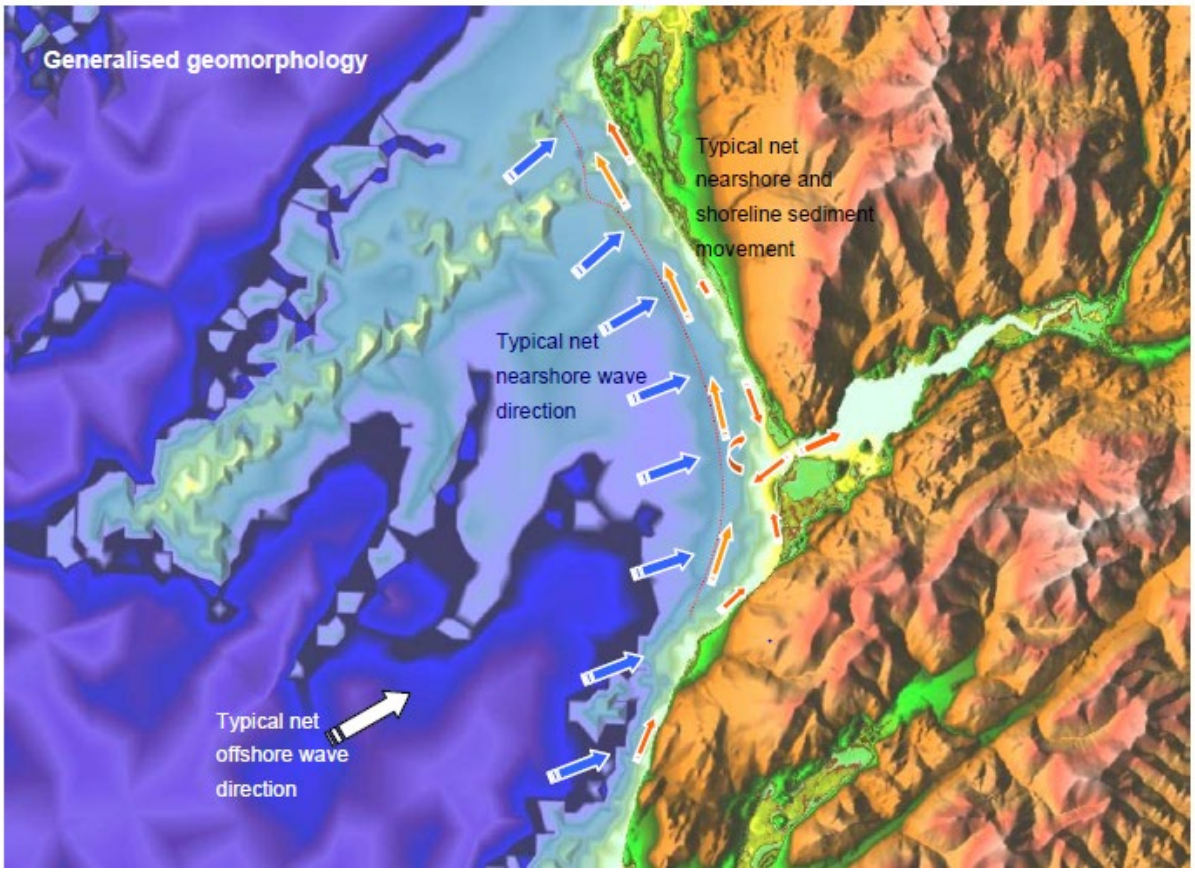


Image source: Royal Haskoning, 2011

Figure 8. Generalised coastal processes

The foreshore generally comprises of sand with localised areas of shingle/cobbles along the upper foreshore. At a few locations where there is limited mobile surface deposits, clay or hard rock outcrops are visible along the lower foreshore.

North of North Promenade a shingle/cobble bank serves as the primary defence in front of the railway line (Figure 9).

Along North Promenade the foreshore is primarily comprised of sand with isolated pockets of shingle/cobbles (Figure 10). This continues along the northern section of South Promenade, where shingle/cobbles are constrained within the groyne bays. Along the southern section of South Promenade, an extensive sand beach exists, on which an extensive dune system has formed (Figure 11).

Photo courtesy Arup - October 2018

Figure 9. Shingle/cobbles to the north of North Promenade

Photo courtesy Arup - October 2018

Figure 10. Photo taken looking in a northerly direction in front of North Promenade defences showing a sandy beach with a small shingle pocket

Photo courtesy of Arup - October 2018

Figure 11. Photo taken looking in a southerly direction in front of South Barmouth defences showing a sandy beach with dunes and occasional shingle clasts

6 Morphological Changes

6.1 North Promenade

Figure 12 and Figure 14 show how beach levels vary along North Promenade from a composite Digital Surface Model (DSM). Beach levels at the toe of the coastal defence structure range between 0.6 mODN (Profile 1 - at the northern end of North Promenade) to 3 mODN (Profile 6 - at the middle section of North Promenade). This is a marked change with increasing beach levels in a southerly direction.

At the southern end of North Promenade around Profile 7 and Profile 8, hard outcrops are situated just off the frontage. These outcrops may provide some protection to the frontage, by helping to attract and maintain sediment in the lee. It is noted that the promenade protrudes seawards at this location which is an artefact of the historical natural shoreline (Figure 3), which also extended seawards at this location, possibly due to the presence of the shoals.

Figure 15 to Figure 18 show historical changes at Profiles 1, 3, 6 and 8 based on LiDAR data for 2006, 2013 and 2014 respectively. All three of these profiles show a general lowering of the foreshore from 2006 to 2014. However, the past changes are more complex than this. For example, at Profile 1, there was limited overall change in the foreshore levels between 2006 and 2013, with extensive lowering then occurring between 2013 and 2014. This latter period included the winter of 2013/2014 which is notable for the large number of very severe storms that occurred. This extensive lowering occurred around 40-140 m offshore of the sea wall, whilst here was limited change in bed level directly at the sea wall. Similarly, at Profile 6, whilst the bed level 30 m offshore of the sea wall lowered by around 0.8 m, bed level inshore of this increased.

Figure 12 shows the differences between the three LiDAR surveys focussed around the North Promenade frontage. Caution should be adopted when reviewing the results offshore, as the differences may result from the difference in sea level at the time of the surveys. These images show a lowering of the foreshore, between 2006 and 2013 of up to around 0.4 m. This lowering generally occurred around 15-60 m from the sea wall. Inshore and offshore of this bed level changes are much less pronounced.

A much more significant reduction in bed level then occurred, between 2013 and 2014, a period notable for the number and severity of storms that were experienced (as also seen in Figure 15 and Figure 16). Over this period, substantial bed lowering is again observed some 30 to 140 m offshore of the seawall, with the bed lowering increasing to the northern end of North Promenade. This lowering appears to be linked to the development of a ridge/runnel feature that runs near parallel to the defence. It is hypothesised that this ridge/runnel feature may have been developed as a result of one or more of these extreme events, which had resulted in increasing northerly transport along North Promenade. However, it is not possible to confirm if this were the case or not. Interestingly, over this same period (2013 to 2014), the LiDAR surveys indicate that the upper foreshore level had generally increased along North Promenade and the northern extent of South Promenade.

Similar analysis undertaken by Kenneth Pye Associates Ltd (2016), compared bed level changes along the Barmouth frontage using 2003 and 2014 LiDAR surveys and a 2016 UAV. This assessment generally confirms the changes identified above and also identifies that the ridge/runnel feature that was developed over the 2013/2014 winter, off North Promenade, had smoothed out significantly by 2016.

Analysis of tidal contours between 2003-2016 by Kenneth Pye Associates Ltd (2016) suggest that the position of the HAT and MHWS contours at North Promenade remained stable over this 13-year period. The MHWN and OD contours showed a next landward movement, and Kenneth Pye Associates Ltd

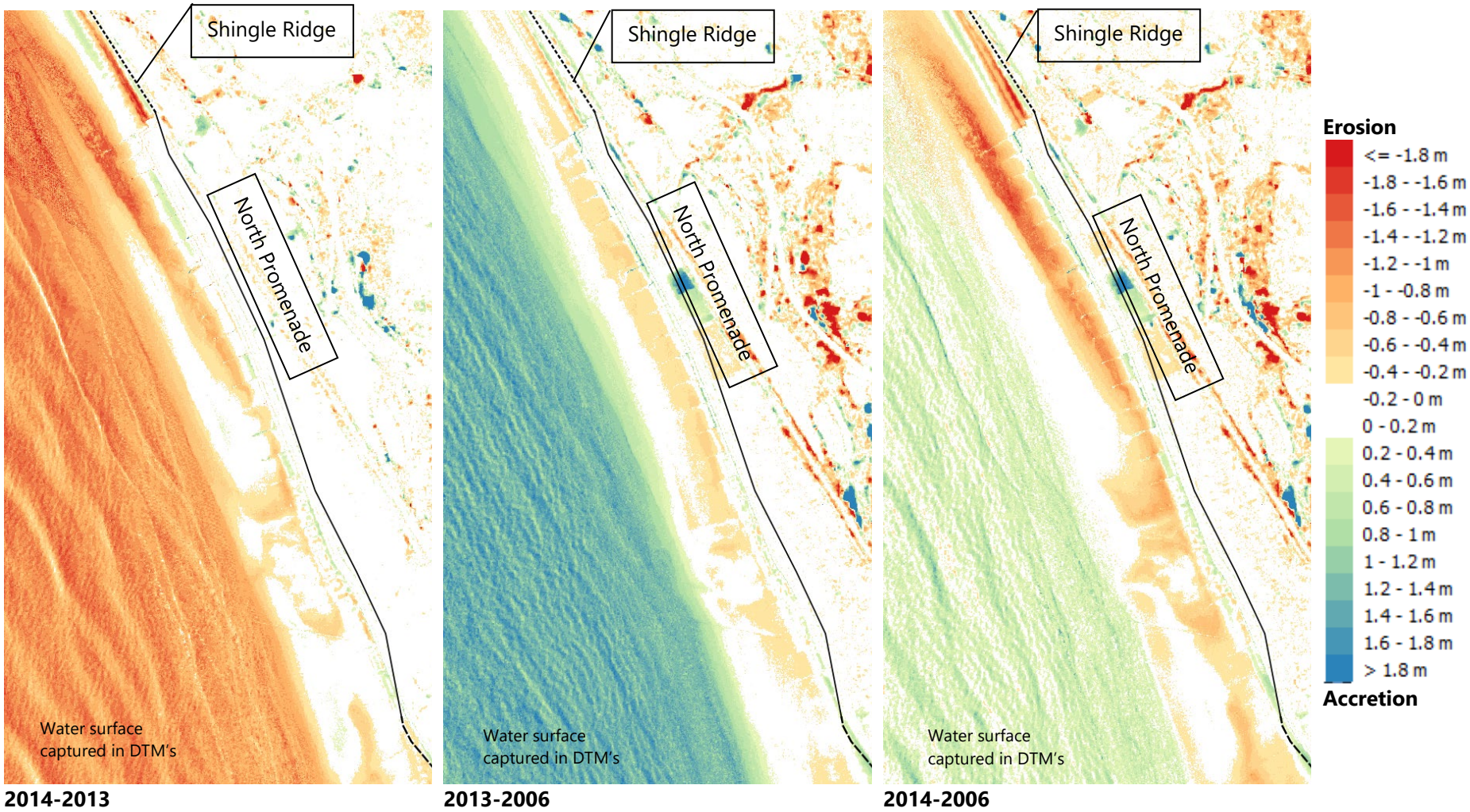
(2016) therefore suggests, that the active beach has shown a tendency for steepening (Figure 19). However, it should be also be noted that the HAT and MHWS contours are often located along structures, rather than on the mobile seabed. Changes in the sediment volume above each contour are summarized for the North Beach in Table 1. Kenneth Pye Associates Ltd (2016) states that the North Beach above the levels of HAT, MHWS and MHWN experienced small increases in sediment volume, 1,000-2,000 m^3, between 2003 and 2016, whereas the beach below MHWN experienced a net loss of approximately 20,000 m^3.

Table 1. Volumes of sediment ($x10^3m^3$) above selected tidal contours on the North Beach at Barmouth

Location	North Beach					
	2003		2016		2003-2016 Change	
HAT (3.26 mODN)	1	±<0.5	2	±0	1	±<0.5
MHWS (2.56 mODN)	3	±<0.5	6	±1	3	±1
MHWN (1.26 mODN)	17	±2	22	±2	5	±2
OD (0 m ODN)	73	±8	69	±6	-4	±7
MLWN (-0.54 mODN)	127	±12	112	±10	-15	±11
MLWS (-1.74 mODN)			280	±18		
Location	**North Beach**					
	2003		**2016**		**2003-2016 Change**	
> HAT	1	±<0.5	2	±0	1	±<0.5
MHWS-HAT	2	±<0.5	4	±0	2	±<0.5
MHWN-MHWS	14	±2	16	±1	2	±1
OD-MHWN	56	±6	47	±4	-9	±5
MLWN-OD	54	±4	43	±3	-11	±4
MLWS-MLWN			168	±8		

Note: Error limits for the 2003 and 2016 surveys (expressed as ±) have been calculated assuming an error in elevations of ±10 cm, and the error shown for the 2003-2016 changes is the average of the errors in the two surveys

Source: Kenneth Pye Associates Ltd, 2016



With SMP2 Policy units overlaid: Llanaber (11.16) dotted line, Barmouth North (11.15) full line and Barmouth South (11.14) dashed line
[Levels offshore should be considered with Caution as LiDAR data may be recording water level and not foreshore bed level]
Source https://nrw.maps.arcgis.com))

Figure 12. DTM difference plots for Barmouth North Promenade

Figure 13. Barmouth North Promenade with cross profiles 1 to 9 (Natural Resources Wales 1 m LiDAR Composite Dataset (http://lle.gov.wales)) and SMP2 Policy units: Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14)

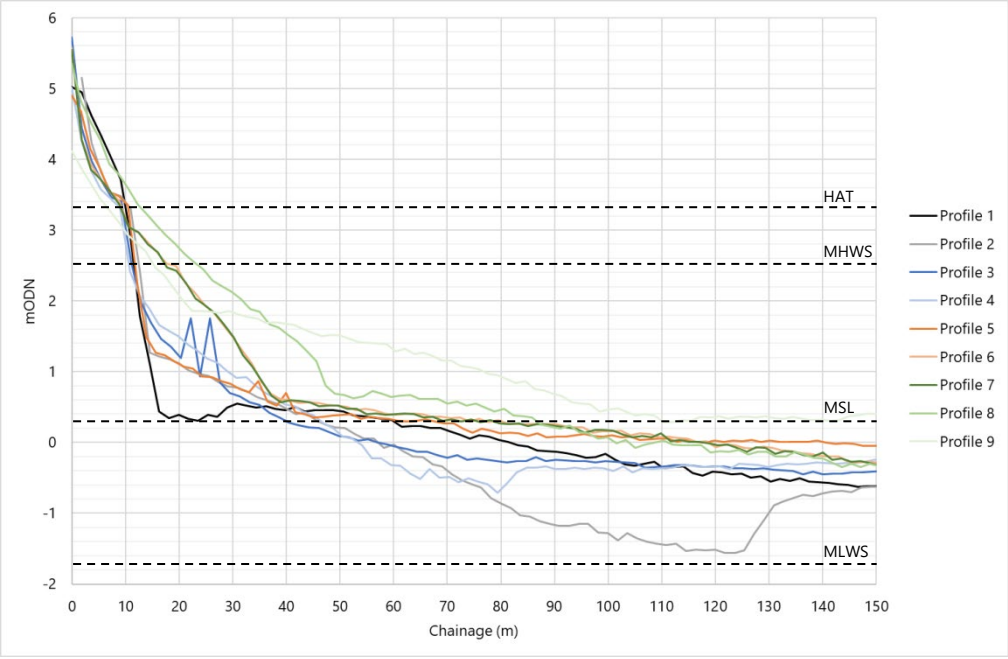


Figure 14. Cross-profiles 1 to 6 normalised to the primary crest position using composite DSM[1]

[1] The composite Digital Surface Model contains LiDAR data flown on different dates (http://lle.gov.wales) and therefore the profiles should only be considered indicative of change.

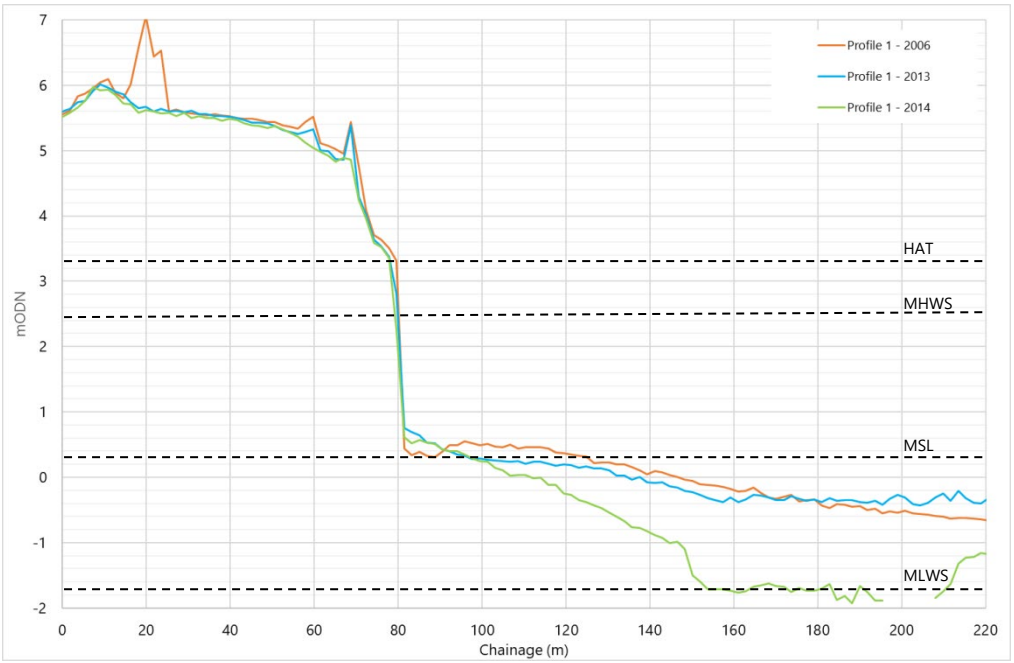


Figure 15. Historical profile plots, Profile 1 (northern section of North Promenade)

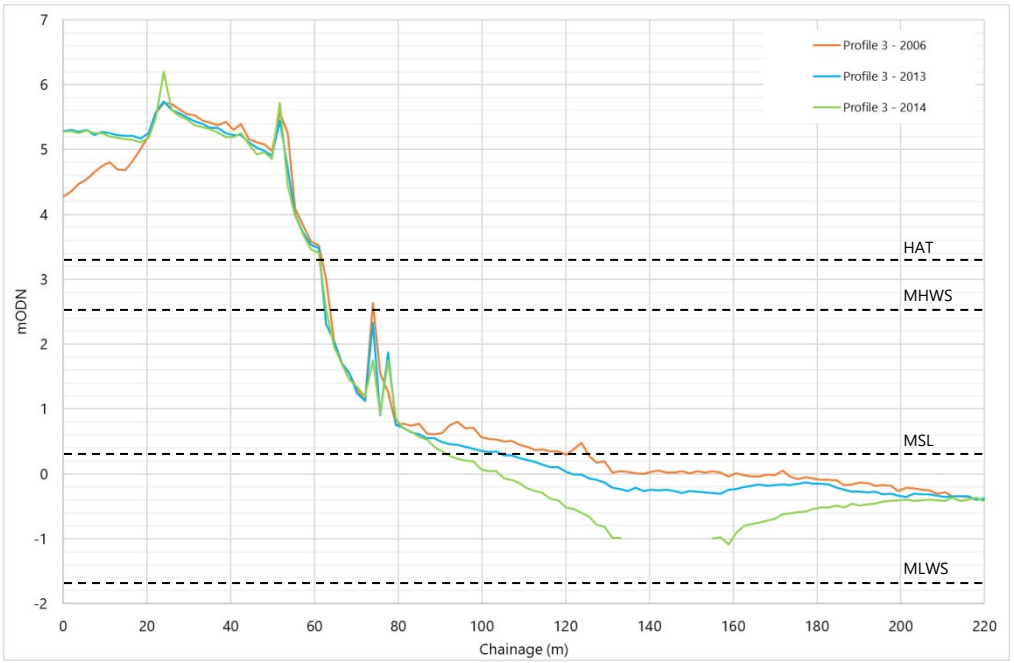


Figure 16. Historical profile plots, Profile 3 (middle section of North Promenade)

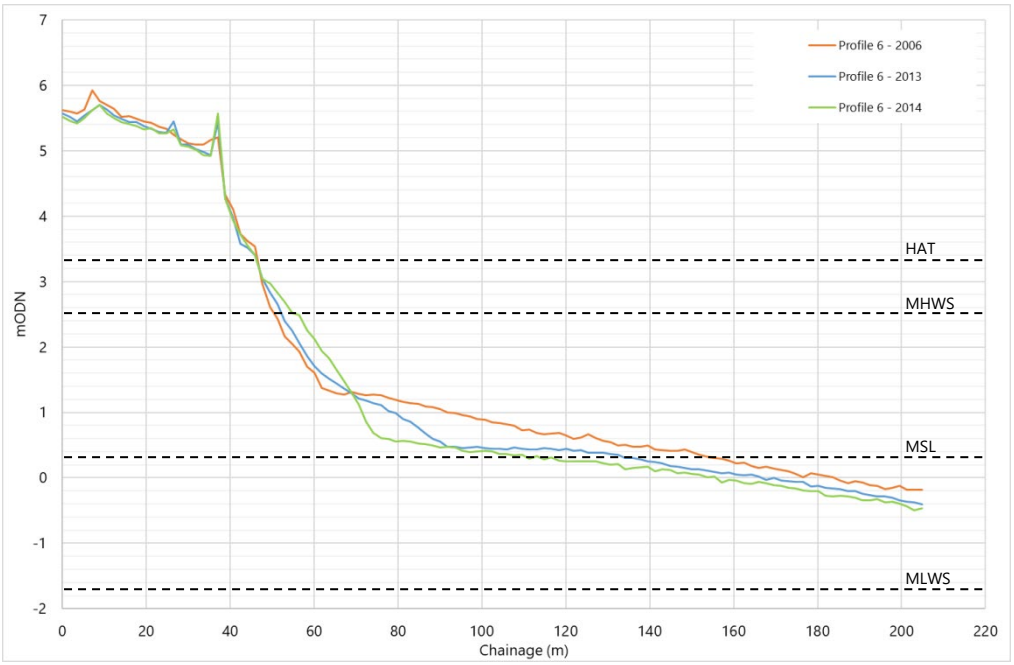


Figure 17. Historical profile plots, Profile 6 (middle section of North Promenade)

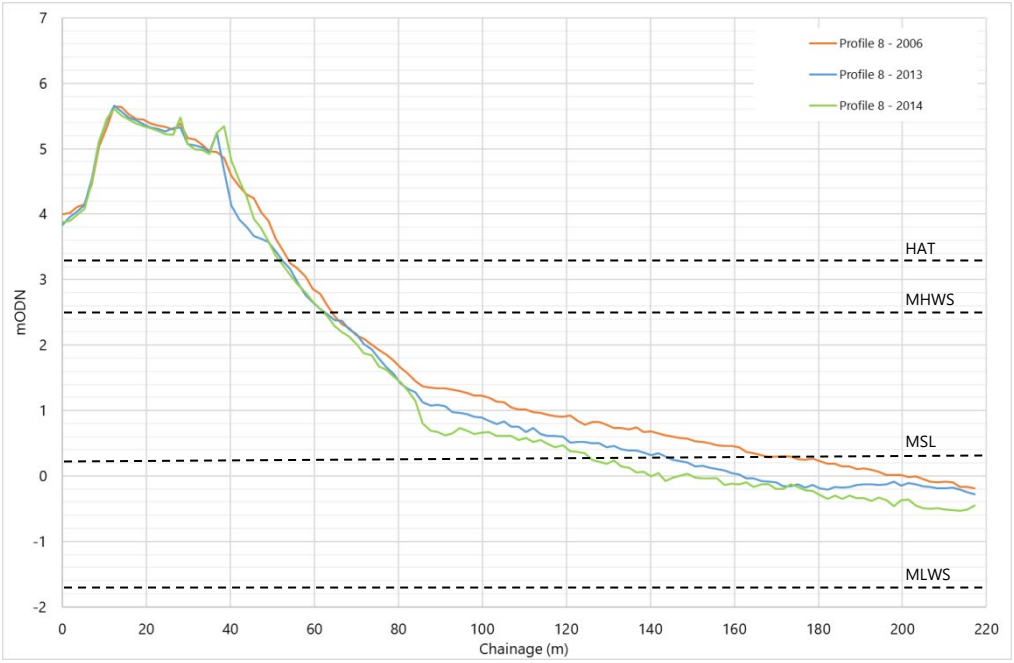
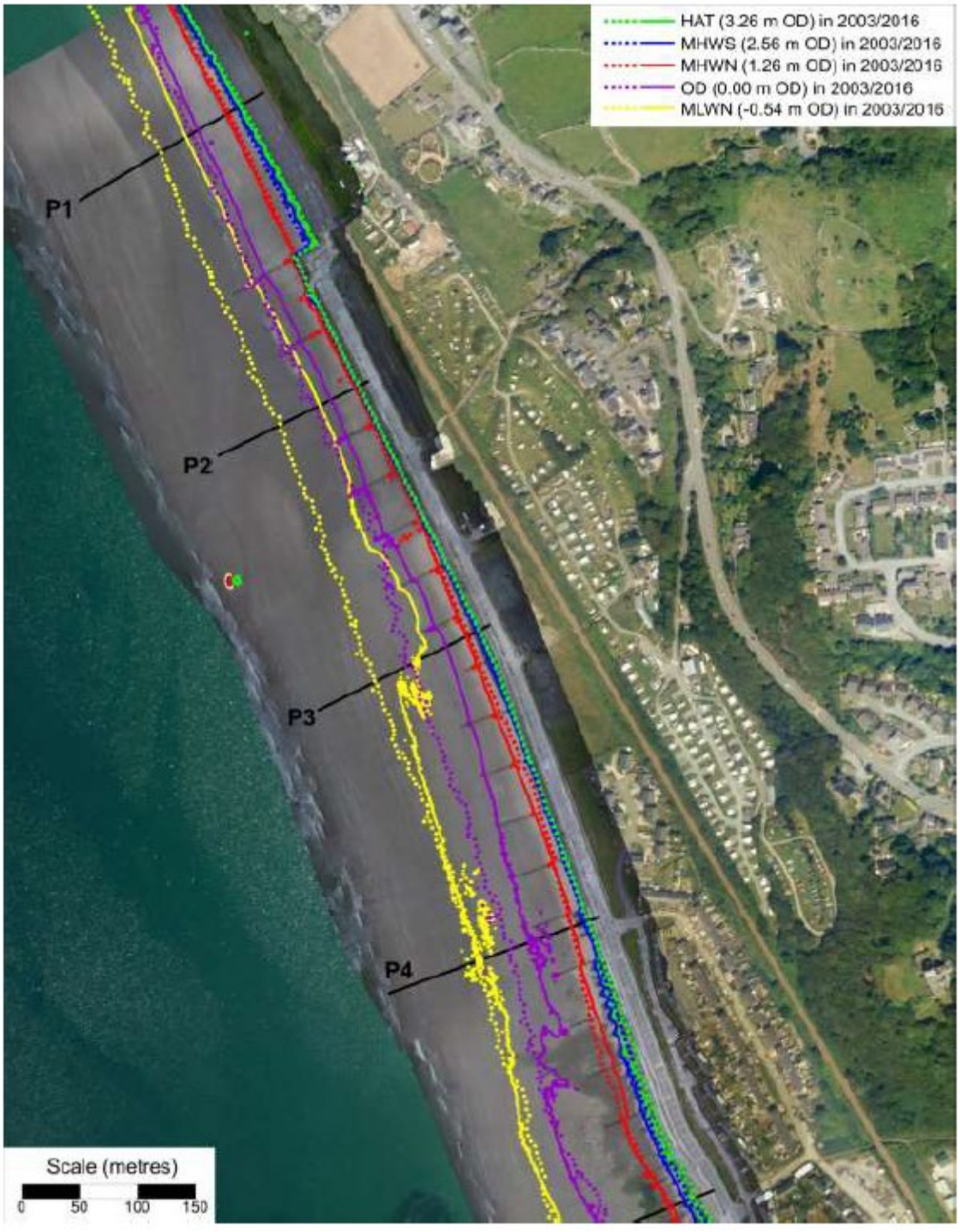


Figure 18. Historical profile plots, Profile 8 (southern section of North Promenade)



Kenneth Pye Associates Ltd, 2016

Figure 19. Changes in the position of tidal contours, from 2003 LiDAR and 2016 UAV surveys,

6.2 Wider Frontage

The SMP2 states that the Llanaber and Barmouth South policy units should be considered alongside the Barmouth North Unit.

> *"While the Barmouth Frontage through to Llanaber would be defined as three policy units, the policies need to be progressed as one overall area. The manner in which Llanaber Point is managed influences the way in which the north Barmouth frontage and the manner in which the apex between north Barmouth and south Barmouth is approached needs to be integrating management to both north and south."*
>
> Extract from: Royal Haskoning, 2011

Comparisons of the three LiDAR surveys for 2006, 2013 and 2014 for the wider Barmouth frontage are shown in Figure 20. Caution should be used when examining levels offshore, since it is understood that the LiDAR data has not been processed to remove reflections from the sea surface. Thus, the levels presented offshore may be representing the sea surface level at the time of the LiDAR flight and not foreshore bed levels. Historic profile plots of the shingle ridge to the north of North Promenade and of the dunes at Barmouth South are shown in Figure 21 and Figure 22 respectively.

The shingle/cobble area to the north of North Promenade shows minimal change between 2006 and 2013, with a possible pushing up (cross-shore) adjustment to the bank. However, from 2013 to 2014 it appears a significant amount of material may have been lost from the shingle/cobble bank, particularly along the southern extent of the bank, which lies immediately adjacent to North Promenade.

Figure 20 and Figure 22 shows how the dunes have developed over the beach along South Promenade since 2006. The series also shows, that whilst the shoals in the mouth of the Mawddach Estuary are dynamic, the general entrance configuration is similar across all three surveys.

Changes in the sediment volume above each contour are summarized for the South Beach in Table 2. The South Beach showed a net overall sediment gain above HAT which was mainly located in the dunes, a net gain on the beach between MHWS and HAT and a net loss below the level of MHWS (Kenneth Pye Associates Ltd (2016)).

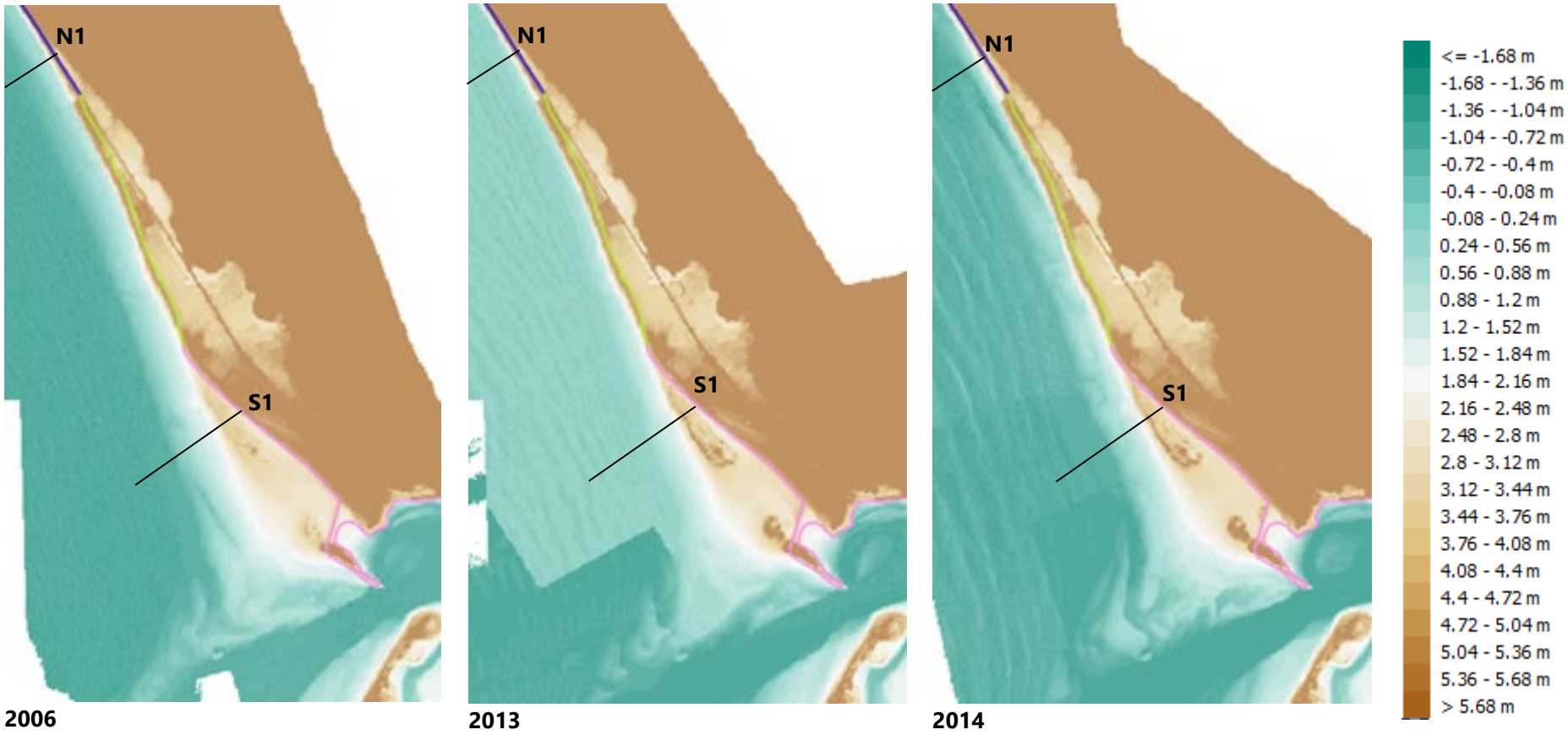
The accreting beach in front of the dunes now lies above MHWS, with a large area above HAT. This causes windblown sand transport with associated maintenance requirements for the promenade, highway and car park. Kenneth Pye Associates Ltd. (2016) assessed several options for windblown sand management including the removal of the Ynys Y Brawd causeway and reopening of the Bar Bach Channel, both of which were rejected. The recommended option was lowering parts of the beach and localised excavation to enlarge and deepen an existing shallow channel to the north of the causeway. This was combined with limited extension of the two existing outer dune ridges to provide a more effective wind barrier.

Table 2. Volumes of sediment (x10³m³) above selected tidal contours on the South Beach at Barmouth

Location	South Beach					
	2003		2016		2003-2016 Change	
HAT (3.26 mODN)	25	±6	114	±11	90	±8
MHWS (2.56 mODN)	103	±15	212	±16	109	±16
MHWN (1.26 mODN)	358	±25	457	±23	99	±24
OD (0 m ODN)	750	±36	865	±37	85	±36
MLWN (-0.54 mODN)	956	±40				
MLWS (-1.74 mODN)						
Location	**South Beach**					
	2003		2016		2003-2016 Change	
> HAT	25	±6	114	±11	90	±8
MHWS-HAT	79	±10	98	±5	19	±7
MHWN-MHWS	254	±10	245	±7	-9	±9
OD-MHWN	392	±11	378	±13	-15	±12
MLWN-OD	206	±3				
MLWS-MLWN						

Note: Error limits for the 2003 and 2016 surveys (expressed as ±) have been calculated assuming an error in elevations of ±10 cm, and the error shown for the 2003-2016 changes is the average of the errors in the two surveys

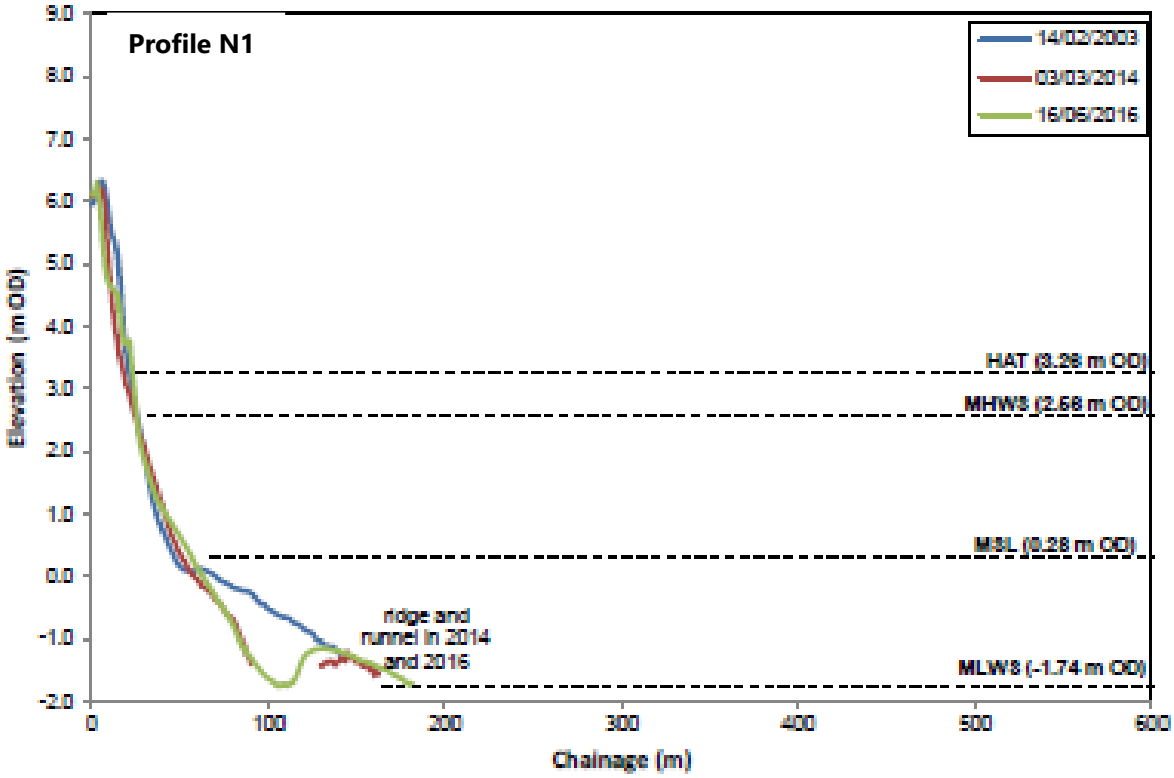
Source: Kenneth Pye Associates Ltd, 2016



With SMP2 Policy units overlaid: Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14)

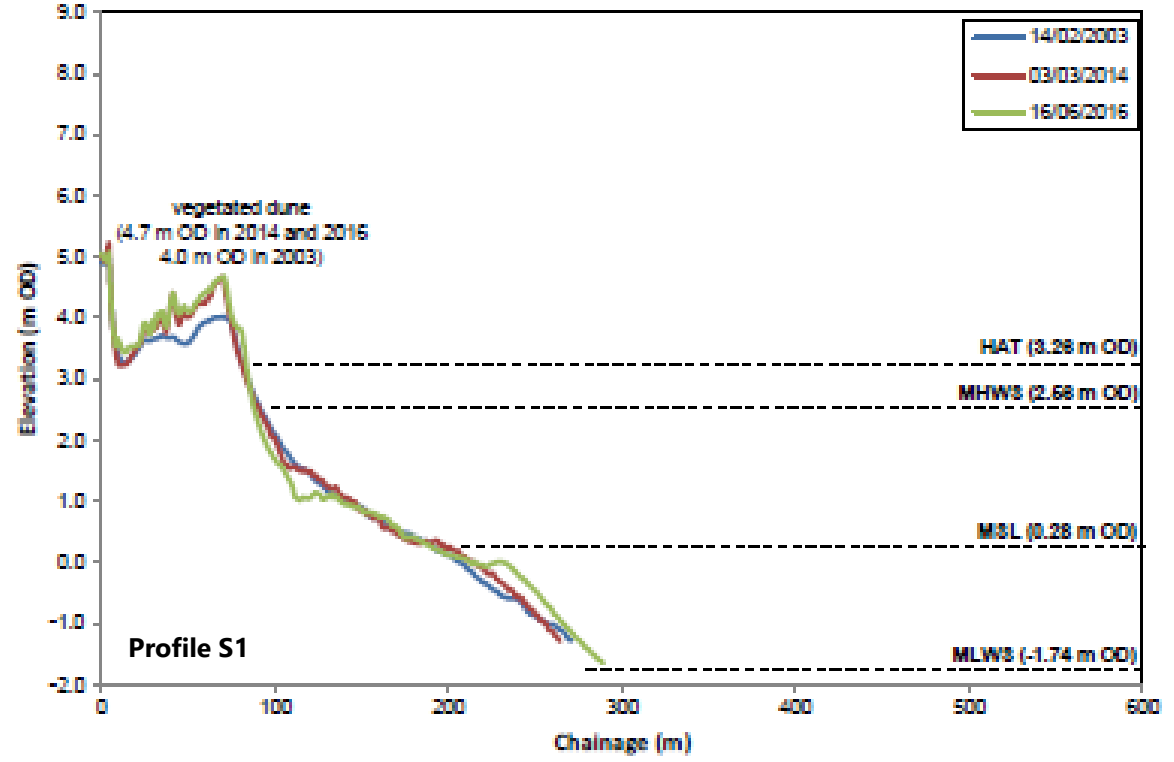
Source: https://nrw.maps.arcgis.com

Figure 20. Historic DTM plots for wider Barmouth area



Kenneth Pye Associates Ltd, 2016

Figure 21. Historical profile plots, shingle ridge north of promenade



Kenneth Pye Associates Ltd, 2016

Figure 22. Historical profile plots, dunes south of North promenade

6.3 Future evolution

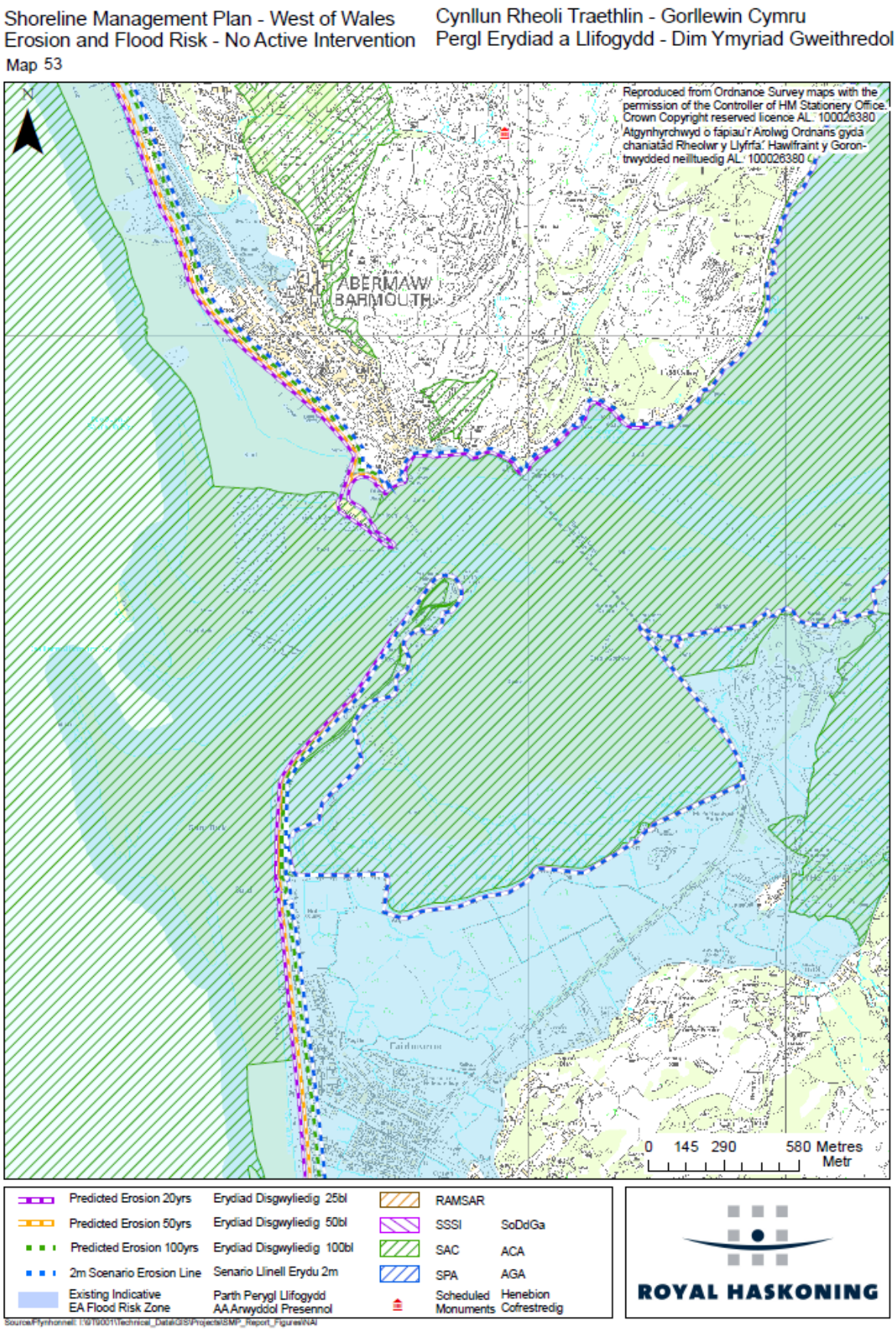
Beach evolution is very difficult to predict but assuming No Active Intervention (NAI), erosion is predicted to continue at North Promenade. The rate of erosion is likely to increase with sea level rise which will result in larger waves reaching the promenade and in turn increasing beach lowering. The SMP2 suggests the rate of erosion could increase by a factor of 1.7 to 2.5 times the existing base rate over the next 100 years.

Potential erosion rates have been estimated in the SMP2 by Royal Haskoning, assuming NAI at Barmouth and surrounding areas. These erosion rates are shown in Table 3 with predicted erosion lines shown in Figure 23 and Figure 24.

The rate of erosion for Barmouth North is predicted to be between 30 and 120 m. With the Cambrian Railway line just 50 m inland of Barmouth North Promenade, 120 m of lateral erosion would have a significant impact. From the SMP2 it is not clear exactly how these rates of erosion have been calculated since an existing lateral erosion rate is provided for North Promenade although the actual shoreline has not changed due to the presence of the hard defence. However, it is acknowledged, as per Section 6.1, that the MSL and MLWN contours have receded over the recent past. This is associated with a general lowering of the seabed in front of the existing defence.

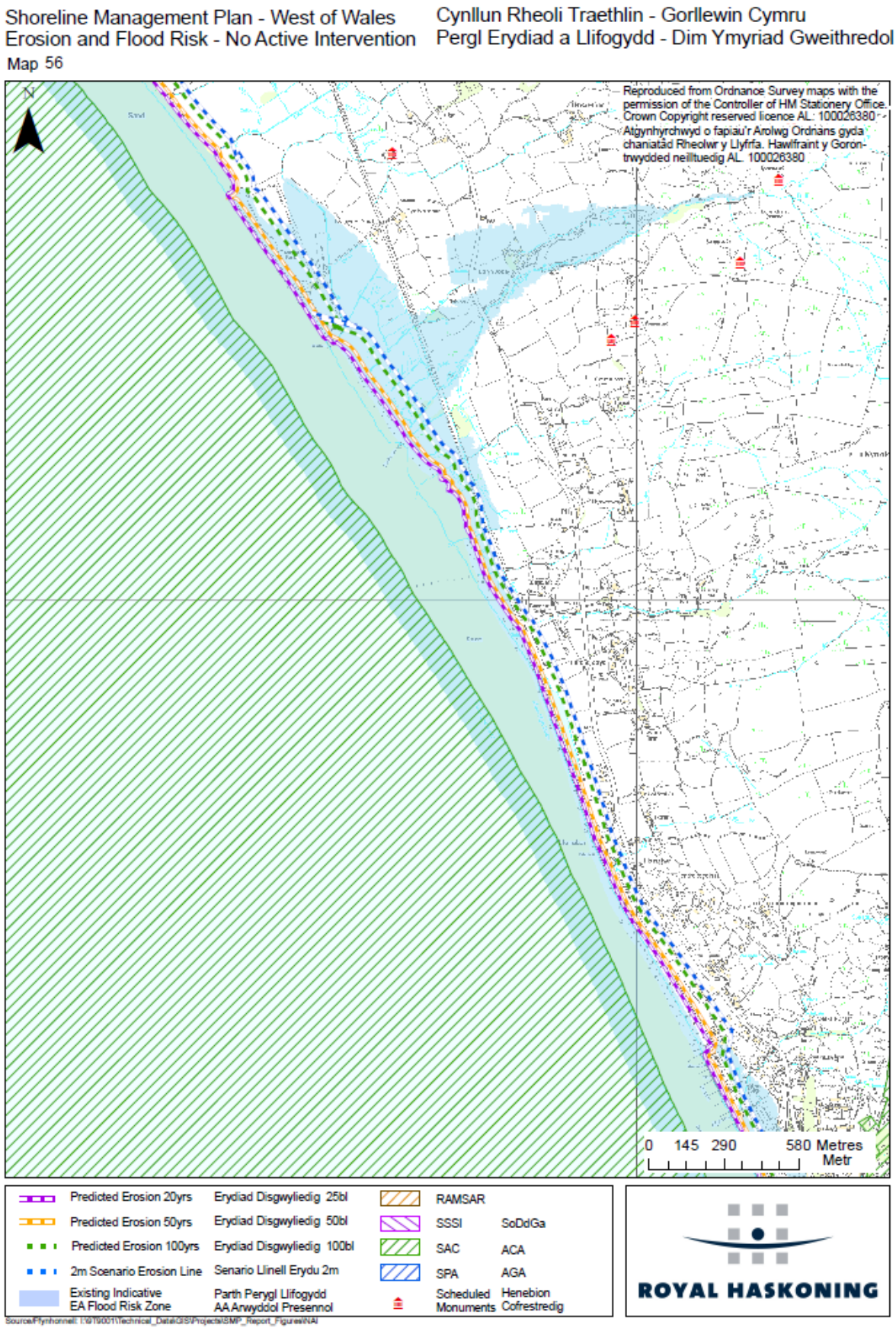
Table 3. Potential erosion rates at Barmouth and surrounding areas (Royal Haskoning, 2011)

Location	NAI Base Rate (m/yr)	Notes	100 yr. Erosion Range (m)
Rola	0.1	Slow erosion of cliff	10-20
Borthwen	0.2	Roll back of shingle ridge very sensitive to SLR	30-80
Fairbourne	0.2-0.3	Roll back of shingle ridge very sensitive to SLR	30-100
Ro Wen	0.05-0.1	Influenced by estuary channel	15-50
Barmouth S	0.05	Defended area recently accreting	20-40
Barmouth N	**0.2-0.4**	**Defended but historically reducing beach levels**	**30-120**
Llanaber	0.2	Heavily defenced with no longer term record	40-100
Egryn Marsh	0.5	Managed shingle ridge	50-120
Tal y Bont	0.3	Defended shingle ridge backed by cliff	30-100
Morga Dyffryn	0.2-0.2	Natural shingle and dune frontage	30-100



Royal Haskoning ,2011

Figure 23. Predicted erosion at Barmouth South assuming No Active Intervention



Royal Haskoning ,2011

Figure 24. Predicted erosion at Barmouth North assuming No Active Intervention

As the SMP2 predicts lateral erosion of between 30-120 m over a 100 year period, it can be expected that the bed level at the location of the present defence toe will continue to lower over the same period. To estimate the bed lowering that may occur over the next 100 years the mean lateral erosion estimate of 75 m (average of 30 -120m), has been overlaid over present day composite bed profiles (Figure 25). This shows that for Barmouth N (Profile 1), an average lateral erosion of 75 m is likely to reduce the bed level at the location of the present defence toe by 0.7 m.

To estimate the bed lowering that would occur at the location of the present defence toe by 2069, (over the next 50 years) the same approach has been adopted. In this case the mean lateral erosion up to 2069 has been estimated by factoring the 100 year mean lateral erosion value of 75 m by 0.38. The factor of 0.38 that has been applied is based on the relative change in SLR, between 2019 and 2069, compared to that between 2019 and 2119. This is because erosion rates can be expected to increase with SLR. Thus by 2069, mean lateral erosion is estimated to be 28 m.

The results of this assessment are summarised in Table 4, with mean lateral erosion provided for the two epoch's 2069 and 2119, together with estimated bed level lowering estimates at toe of Profile 1 and Profile 7 (derived from Figure 25). Potential erosion maps using the results of this assessment are presented in Figure 26 and Figure 27.

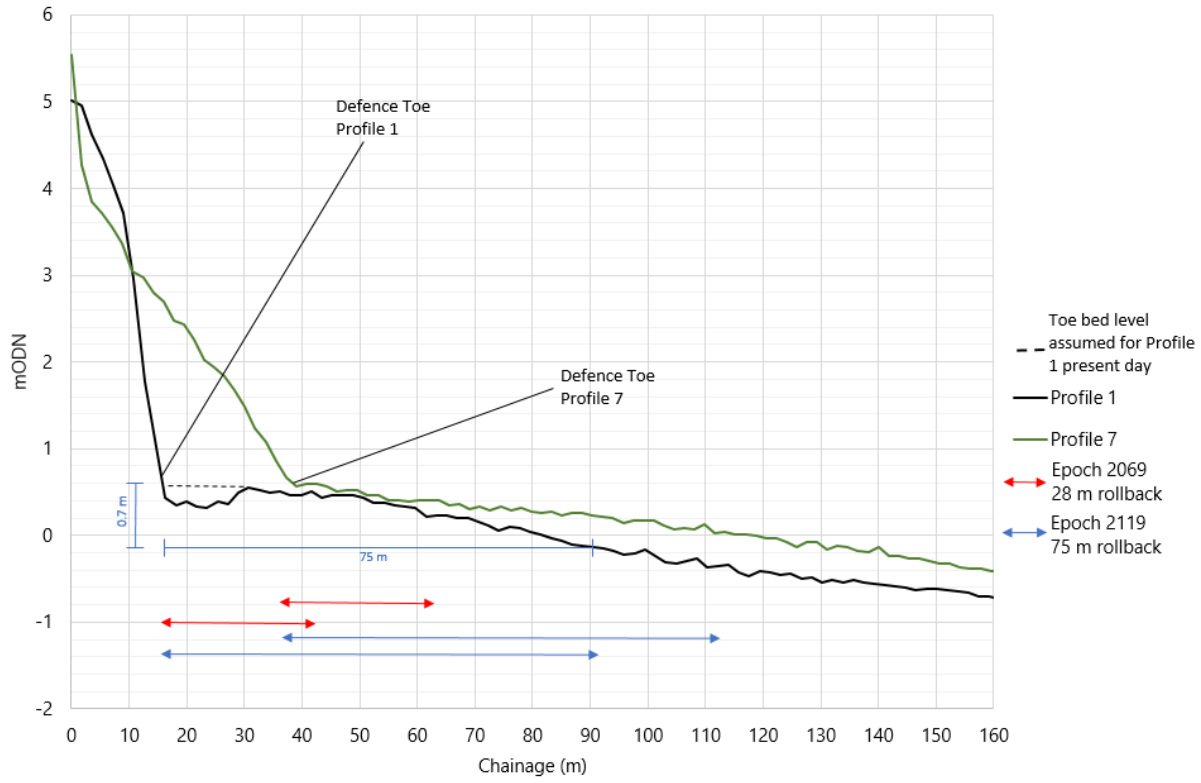


Figure 25 **Cross-shore profiles 1 and 7 normalised to the primary crest position using a composite Digital Surface Model[2] with average lateral erosion estimates for future epochs overlaid. Example shown for Profile 1, epoch 2119 in blue**

[2] The composite Digital Surface Model contains LiDAR data flown on different dates (http://lle.gov.wales) and therefore the profiles should only be considered indicative of change.

It should be noted that a number of assumptions have been made whilst providing these high level estimates of lateral erosion/beach lowering:

- The lateral erosion that will occur over the next 100 years is the average of the range estimated (30 m-120 m);
- That the estimated range in lateral erosion of 30-120 m over the 100 years, is still applicable to the present base date of 2019, noting that these rates were estimated in 2011; and
- That erosion rates increase proportionally with SLR.

Table 4 Estimates of lateral erosion and bed level lowering at Barmouth based on SMP2 NAI scenario

Location	Estimated Lateral Erosion by Epoch 2069 (m)	Estimated Predicted Beach Lowering by Epoch 2069 (m)	Estimated Lateral Erosion by Epoch 2119 (m)	Estimated Predicted Beach Lowering by Epoch 2119 (m)
Barmouth N (Profile 1)	28 m	~0.2 m	75 m	~0.7 m
Barmouth N (Profile 7)	28 m	~0.2 m	75 m	~ 0.5 m

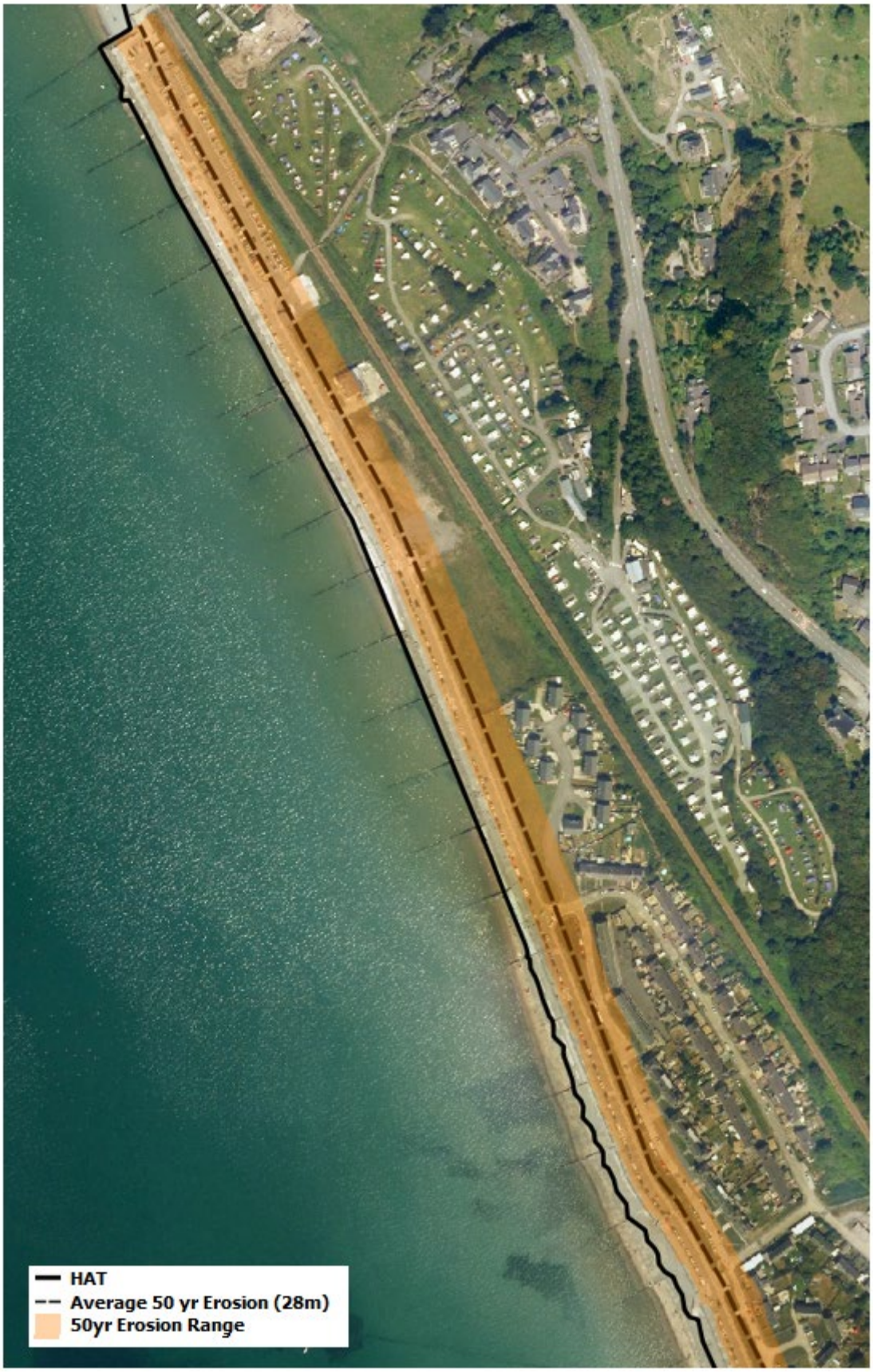


Figure 26 Potential erosion over 50 year period based on SMP2 NAI scenario

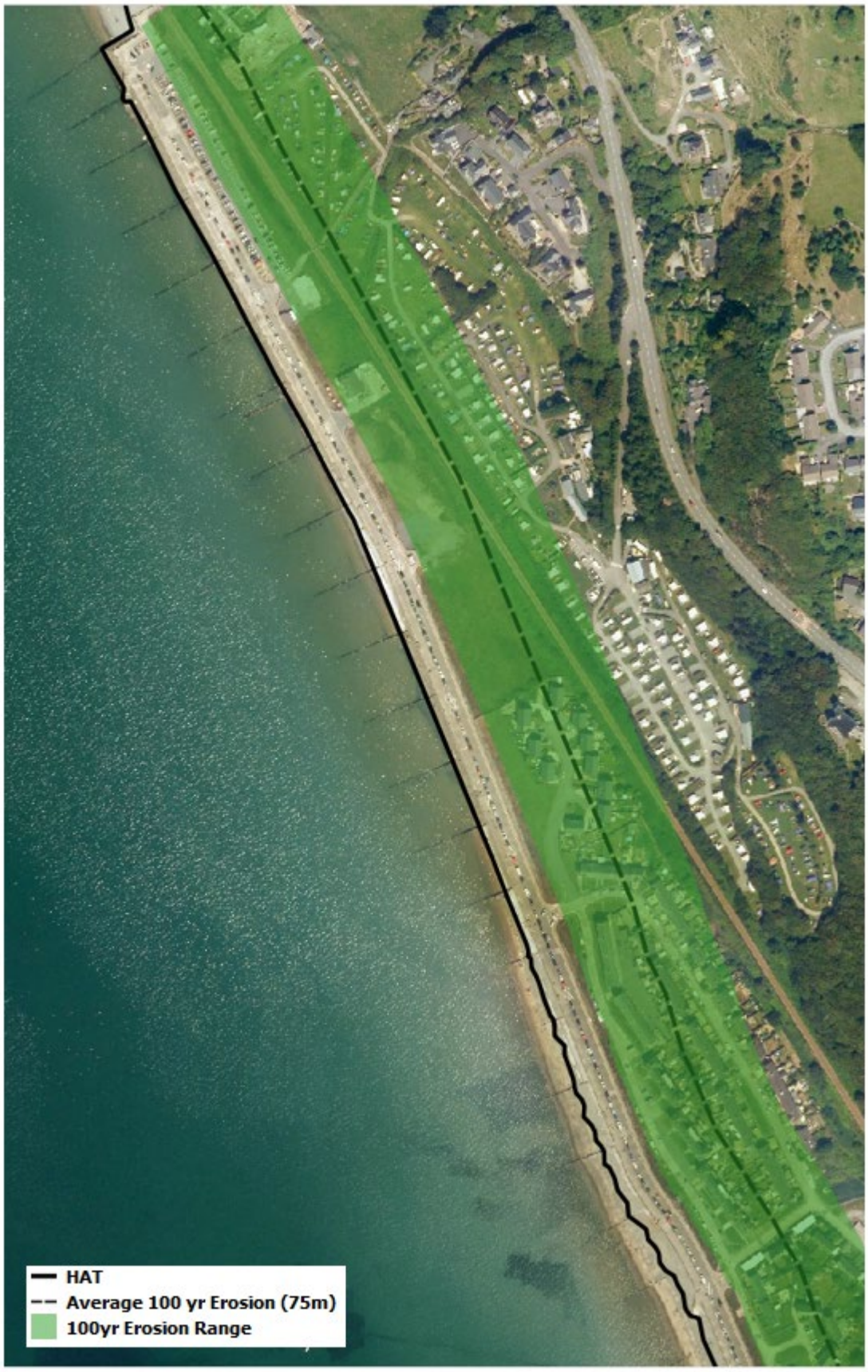


Figure 27 Potential erosion over 100 year period based on SMP2 NAI scenario

7 Water Levels

7.1 Tidal water levels

The study site lies within Cardigan Bay, where the tide is macrotidal, with a spring tidal range of more than 4 m (Table 5).

The conversion from chart datum (mCD) to Ordnance Datum Newlyn (mODN) for Barmouth is -2.44 m (Admiralty Tide Tables 2018).

Table 5. Tidal characteristics at Barmouth

Reference Sill Water Level				
Highest astronomical tide (HAT)	5.70	mCD	3.26	mODN
Mean high water springs (MHWS)	5.00	mCD	2.56	mODN
Mean high water neaps (MHWN)	3.70	mCD	1.26	mODN
Mean sea level (MSL)	2.72	mCD	0.28	mODN
Mean low water neaps (MLWN)	1.90	mCD	-0.54	mODN
Mean low water springs (MLWS)	0.70	mCD	-1.74	mODN
Lowest astronomical tide (LAT)	0.30	mCD	-2.14	mODN
Mean Spring Range	4.30 m			
Mean Neap Range	1.80 m			

Source: 2018 Admiralty Tide Tables

Given the tidal range at Barmouth, the existing sea defences along North Promenade are exposed to the incident wave climate for significant periods over the tidal cycle, therefore exposing the defence to wave overtopping and hinterland flooding.

This is demonstrated in Figure 28, where the location of the MHWN, MHWS and HAT water levels are overlaid on the aerial image of the frontage based on the bed levels in the composite DSM.

Figure 28. **Aerial Image of North Promenade showing coastline for different existing tidal levels (MHWN =1.3 mODN in blue, MHWS = 2.6 mODN in red, HAT 3.3 mODN in black), based on the composite DSM**

7.2 Extreme water levels and surge

The Environment Agency coastal flood boundary dataset (CFBD) (Environment Agency, 2011) provides an assessment of extreme water levels offshore of Barmouth. Levels are summarised in Table 7 for location 834, which lies offshore of North Promenade (Figure 29), for three epochs. The CFBD provides extreme still water levels associated with different Annual Exceedance Probability (AEP) ranging from 100% to 0.10%. It should be noted that the Environment Agency states that these levels are considered accurate only to one decimal place. Generally, it is the coincident occurrence of extreme surge heights with high water levels that is considered to bring about extreme water levels within the study region.

The Environment Agency CFBD is supplied to a base year of 2008. To correct the levels to the required epochs to be considered under this study, Welsh Government (2017) climate change guidance has been used. The guidance values provided by Welsh Government (2017) are presented in Table 8. These values have been used to derive the values presented in Table 7, for 2019, 2069 and 2119.

The highest 25 water levels recorded at the Barmouth Class A tide gauge between 1991-2017 are given in Table 6. Data flagged as improbable by the British Oceanography Data Centre (BODC) has been removed from the analysis.

Table 6. Highest 25 tides recorded at Barmouth Class A tide gauge between 1991-2017 (data sourced from National Tidal and Sea Level Facility (NTSLF))

Date and Time	Observed Level (mODN)	Residual at Observed High Water (m)
03/01/2014 09:15	3.92	0.81
10/02/1997 10:00	3.92	0.73
30/03/2006 08:45	3.75	0.68
25/11/2000 20:15	3.71	1.21
01/02/2002 10:45	3.71	0.76
03/02/2014 10:30	3.69	0.61
10/03/2008 09:45	3.68	0.74
01/02/2014 09:15	3.62	0.47
23/12/1999 20:45	3.62	0.71
03/01/2014 21:45	3.61	0.79
12/01/1993 10:45	3.61	0.66
08/10/2006 20:45	3.57	0.42
06/01/2014 11:30	3.55	0.80
03/01/1998 11:00	3.55	0.94
02/03/2014 08:45	3.55	0.44
08/10/2014 20:00	3.53	0.43
29/08/1992 21:00	3.52	0.38
10/03/2001 08:30	3.51	0.54
12/12/2000 21:00	3.51	0.67
27/02/1994 09:00	3.51	0.50
01/02/2014 21:30	3.50	0.64
30/08/1992 22:00	3.50	0.42
07/10/2006 20:15	3.49	0.33
09/09/1998 22:15	3.49	0.47
07/09/1998 21:00	3.49	0.44

Table 7. Extreme water levels for base year of 2008 (Environment Agency CFBD, 2011) and adjusted to include sea level rise for three different epochs - (Environment Agency Location Chainage 834)

AEP (%)	Return Period	2008	2019	2069	2119
		CFBD Base	PD Epoch	50 yr Epoch	100 yr Epoch
100	T1	3.48	3.52	3.94	4.62
50	T2	3.58	3.62	4.04	4.72
20	T5	3.72	3.76	4.18	4.86
10	T10	3.82	3.86	4.28	4.96
5	T20	3.91	3.95	4.37	5.05
4	T25	3.94	3.98	4.40	5.08
2	T50	4.03	4.07	4.49	5.17
1.33	T75	4.08	4.12	4.54	5.22
1	T100	4.11	4.15	4.57	5.25
0.667	T150	4.16	4.20	4.62	5.30
0.5	T200	4.20	4.24	4.66	5.34
0.4	T250	4.23	4.27	4.69	5.37
0.33	T300	4.25	4.29	4.71	5.39
0.2	T500	4.31	4.35	4.77	5.45
0.1	T1,000	4.39	4.43	4.85	5.53
0.01	T10,000	4.66	4.70	5.12	5.80

Source: Environment Agency, 2011

Table 8. Sea level rise predictions (Source: Natural Resources Wales, 2017)

	Sea Level Rise (mm/yr)			
	Up to 2025	2026 to 2055	2056 to 2085	2086 to 2116
H++	6.0	12.5	24.0	33.0
Annual change (mm/yr)	3.5	8.0	11.5	14.5

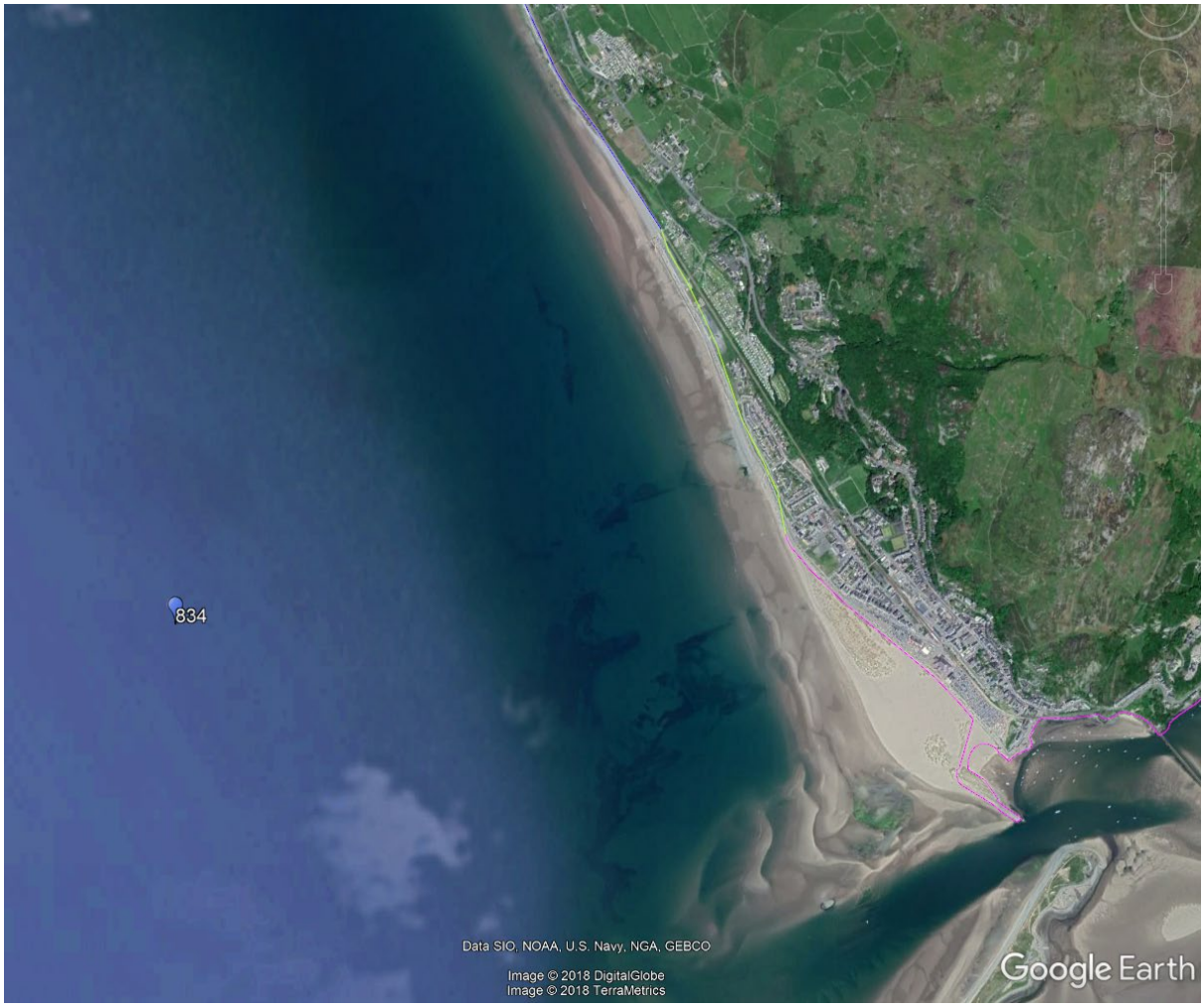


Figure 29. **Environment Agency CFBD location and SMP2 Policy units: Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14)**

7.3 Tidal flows

There is little information available on tidal flows in Barmouth Bay. To provide an understanding of the likely hydrodynamic environment, data have been extracted from a coarse version of ABPmer's Cardigan Bay model which does not include the Mawddach Estuary. The model data indicate that flow speeds can exceed 0.4 m/s offshore of the Barmouth Frontage with peak flows occurring during the flood tide (Figure 30).

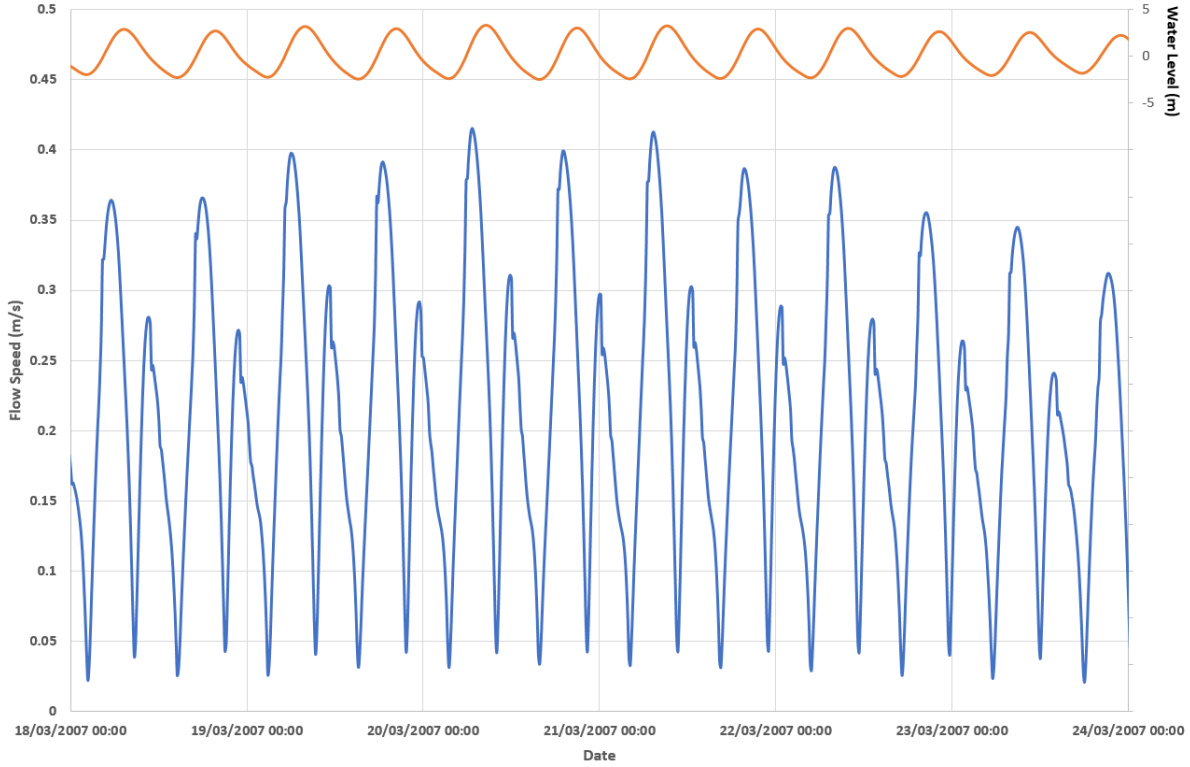


Figure 30. Indicative flow speeds during spring tide

8 Waves

For this study ABPmer has undertaken wave modelling, transforming a 39-year SEASTATES (https://www.seastates.net/[3]) hindcast inshore using a regional MIKE 21 SW flexible mesh model. The model has boundaries at the western tip of the Llyn Peninsula in the north and Cardigan in the south. The model incorporates the most up to date bathymetry from the EMODnet Portal, supplemented with digitised data from UKHO Chart 1971 around the area of interest. Full details on the Cardigan Bay model can be found in the accompanying Wave modelling, Extremes Analysis and Wave overtopping report (ABPmer, 2018)

A 39-year time-series of wave parameters at a single extraction location, at -7 mODN, shown in Figure 29 has been extracted for the 2019, 2069 and 2119[4] epochs. The wave climate at this extraction point is presented in Figure 31 to Figure 33. The wave conditions over the wider area are presented in Figure 34, for a significant south westerly event during 2014.

The Barmouth Frontage is affected by a mixture of swell waves originating in the Atlantic and wind waves from the Irish sea and Cardigan Bay, with the maximum significant wave height (Hs) in the present epoch (2019) 39-year model record being 4.2 m at the -7 mODN contour. This event has a corresponding mean energy wave period ($Tm_{-1,0}$) of 12 s.

Nearshore the dominant wave direction is from the southwest with a mean wave direction of 244°, due to the offshore prevailing wave conditions. Sarn Badrig to the north also inhibits the wave energy reaching the site from more north westerly direction sectors.

The wave climate at the Barmouth North frontage is predicted to increase in 2069 and 2119 due to sea level rise. Wave direction is largely unaffected by increases in water level.

Other than the local shoals near the mouth of the Mawddach Estuary, the bathymetry directly off the North Promenade frontage is relatively smooth and featureless. Therefore, the dominant wave energy approach the frontage from a relatively consistent angle that is close to shore normal. (Figure 34).

[3] SEASTATES (www.seastates.net/) is a service provided by ABPmer to supply metocean information to support site characterisation, project design or operational planning around the UK (ABPmer, 2013). SEASTATES includes a long-term (39 year) wave hindcast database driven by wind fields derived from the NCEP 'Reanalysis II' hindcast datasets of spatially and temporally varying winds. This allows a long term hourly dataset of wave parameters, including significant wave height, maximum wave height, wave period and wave direction to be created for a specific location. In addition to the standard wave parameters, spectral wave parameters are available along fixed boundary locations around the UK coastline. Full details of the setup, calibration and validation of the SEASTATES Wave Hindcast model can be found in ABPmer, 2013.

[4] Details on the wave model setup including the climate change allowances made for future epochs can be found in the accompanying Coastal Modelling report (ABPmer, 2018)

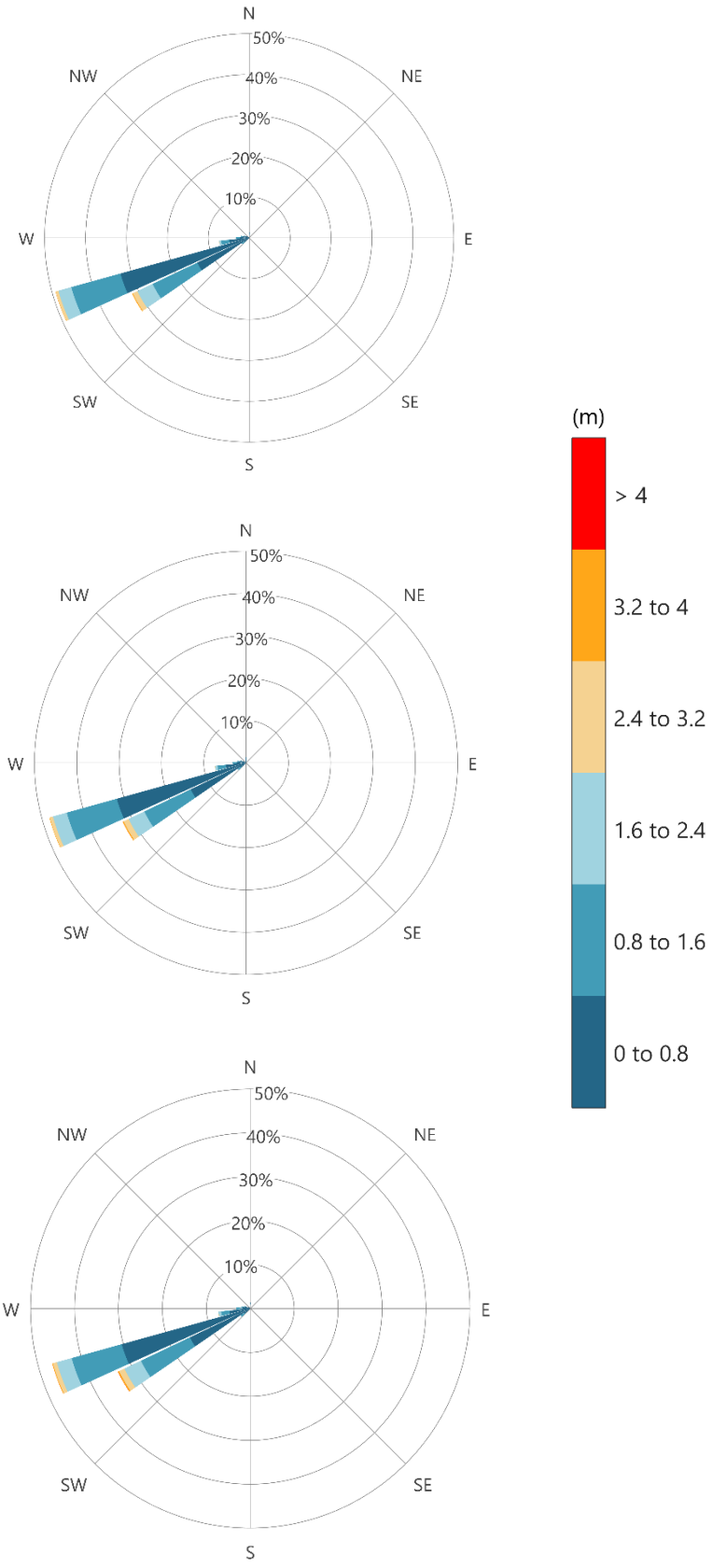


Figure 31. **Wave roses showing significant wave height at circa -7 mODN: epoch 2019 (upper), epoch 2069 (middle), epoch 2119 (upper)**

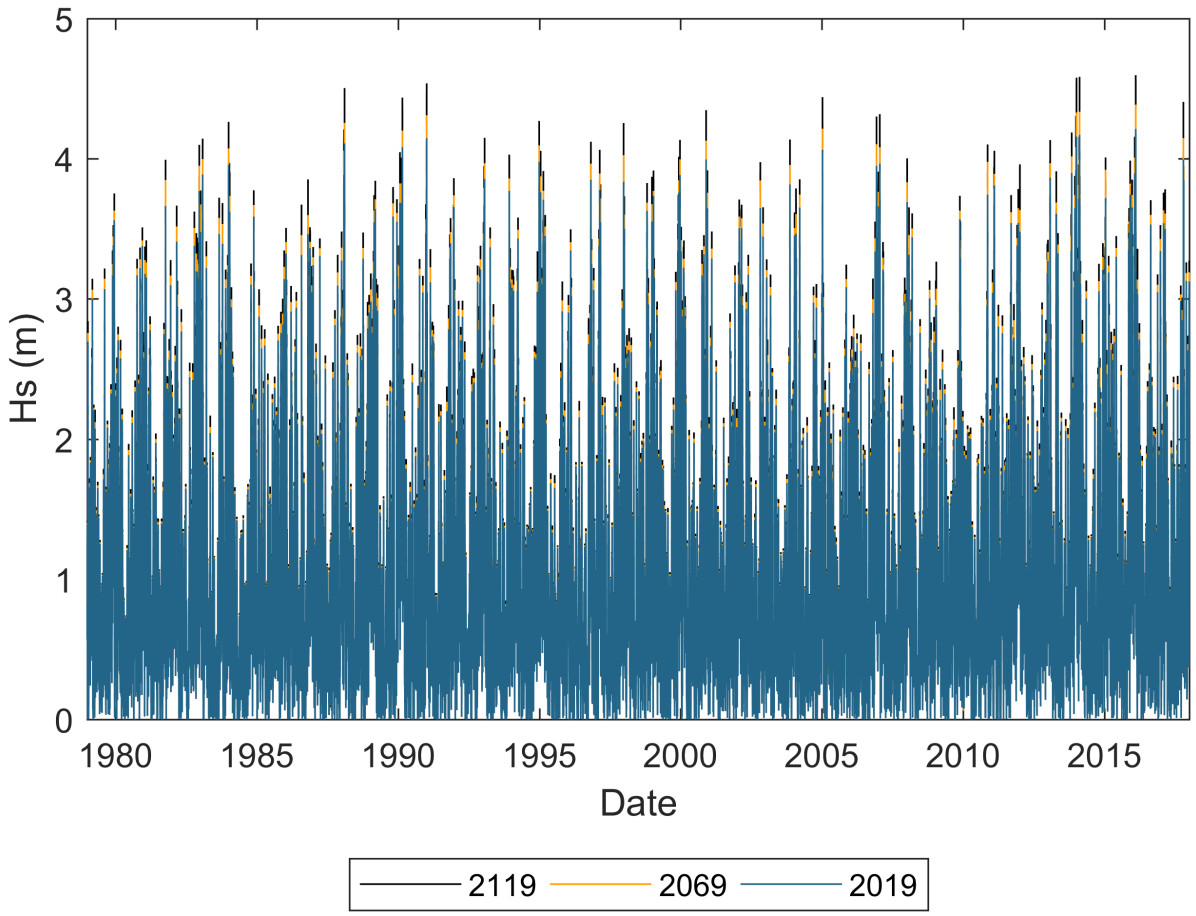


Figure 32. **Time series of significant wave height at -7 mODN extraction point, epoch 2019**

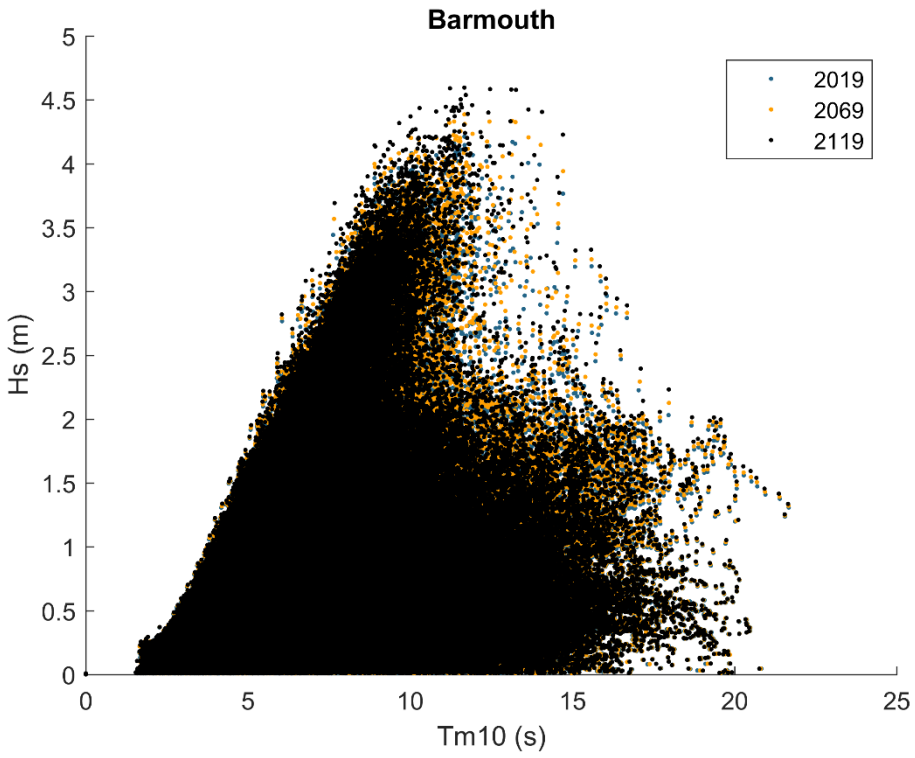


Figure 33. **Scatter plot of Hs vs $Tm_{-1,0}$ at -7 mODN extraction point**

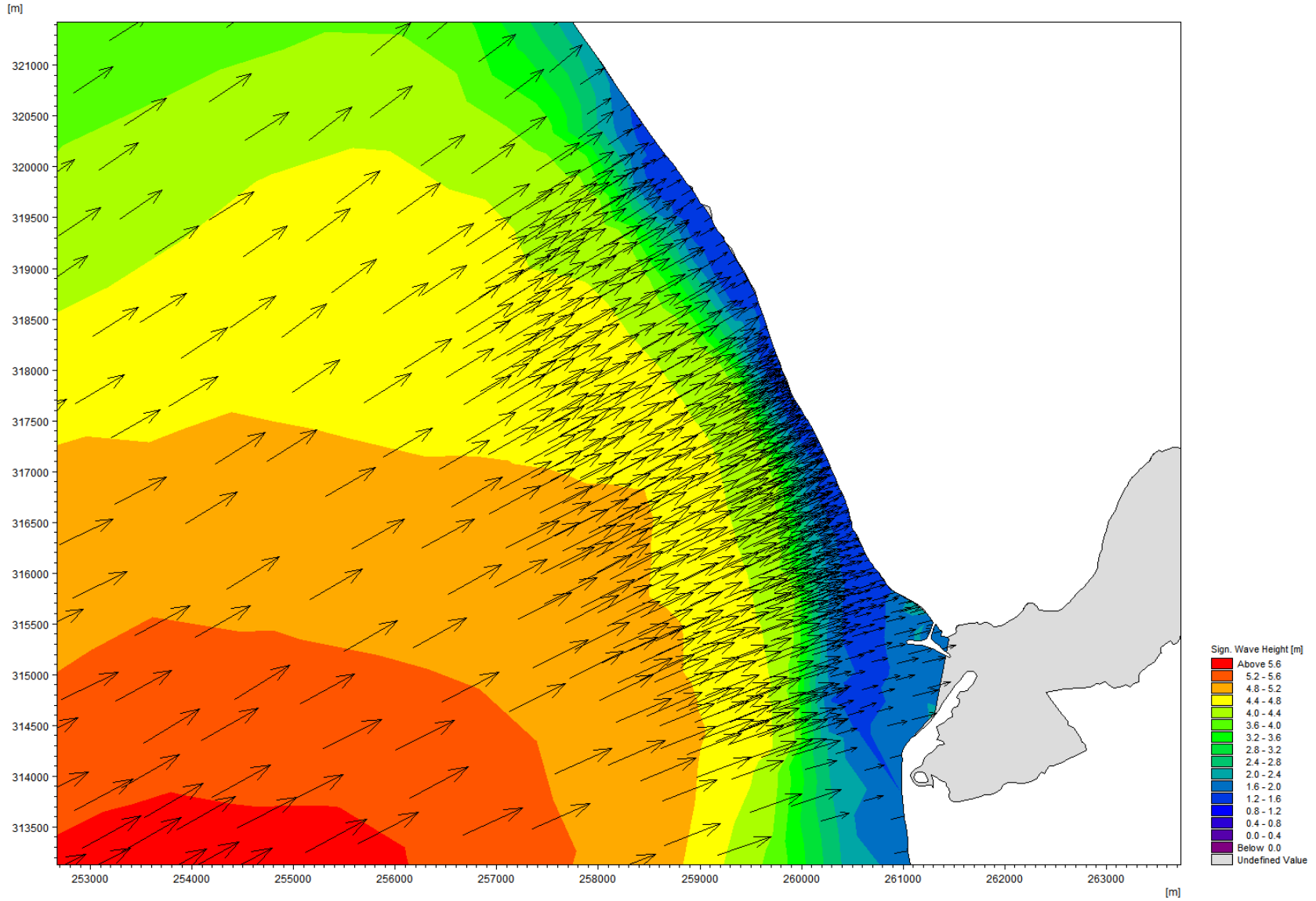


Figure 34. Map of modelled significant wave height during February 2014 storm

9 Flood and Erosion Risk Management

9.1 Coastal defence assets

The Barmouth coastline consists of a mixture of hard defence structures and groynes. The current condition of these assets are described below based upon a site walkover by Arup, (2018a) and Mott MacDonald, (2018):

9.1.1 Sea wall

- Defences vary along the frontage but generally consists of a vertical sheet piled sea wall, a concrete platform, stone blockwork revetment, and precast concrete wave recurve wall units Figure 35;
- Older secondary and tertiary setback walls (on either side of Marine Parade coastal road), constructed *circa* 1933, thought to help to protect against coastal flooding caused by wave overtopping;
- The sea wall is generally in good condition where undermining of the sea wall does not occur;
- At the northern end of the promenade sheet piles are exposed and corrosion of the sheet piling was occurring; and
- Low beach levels and wave action is causing undermining of concrete access steps and the sea wall.

Photo source: Arup, 2018a

Figure 35. Defence of North Barmouth showing wave return wall, exposed sheet piling and groynes missing timber planks

9.1.2 Groynes

- Timber groynes are in place in front of the promenade to control the longshore movement of sediment, the groynes condition varies from north to south;
- The groynes' in the north have limited functionality in trapping sediments due to missing timber planks and are almost completely exposed; and
- The groynes in the south are almost completely covered in sediment and are in good condition. In-between each of the groynes there are small pocket of sand-shingle beaches which become sandier in a southerly direction.

The typical defence levels along North Promenade are as follows (YGC, 2018):

- Promenade footpath = 5.15 mODN.
- Top of wave wall = 5.8 mODN.
- Top of secondary wall = 5.65 mODN.
- Top of tertiary wall = 6.35 mODN.

CGC's conducts regular asset inspection regime where minor repairs are undertaken on an as required basis. The repairs and minor works that are undertaken constitute a "Do Minimum" approach which is in line with the overall SMP2 policy of HTL within the current epoch (Civil Engineering Solutions Ltd, 2017).

9.2 Flood risk

Recent winter storms have highlighted that wave overtopping can be significant along North Promenade. Some notable events are 1 February 2014, 26 December 2015 and 21 October 2017. These wave overtopping events have resulted in flooding of properties and road closures along North Promenade. Figure 36 shows a still image of the primary defences of North Promenade overtopping during Storm Brian (21 October 2017). Figure 37 and Figure 38 show photographs of wave overtopping at Barmouth North Promenade taken by Mike Alexander.

Image from a video https://youtu.be/gVtJ8t7T7uQ

Figure 36. Wave overtopping at North Barmouth during Storm Brian (21 October 2017)

Figure 37. **Wave overtopping near Promenade Cafe & Wine Bar on Barmouth North Promenade during February 2014 storm**

Figure 38 **Wave overtopping near Heol-y-Llan during February 2014 storm**

The Natural Resources Wales (NRW) Flood Map Figure 39, shows that Barmouth is located within Flood Zone 2 and Flood Zone 3. Where:

- Zone 1 (low probability) comprises land assessed as having a less than 0.1% AEP of flooding from the sea (i.e. is at risk from flooding for events with 1 in 1,000 year return period or greater).
- Zone 2 (medium probability) comprises land assessed as having between 0.1% and 0.5% AEP of flooding from the sea (i.e. is at risk from flooding for an event with a return period of between 1:200 years and 1:1000 years).
- Zone 3 (high probability) comprises land assessed to have a greater than 0.5% AEP of flooding from the sea (i.e. is at risk from flooding for events with a return period of less than 1 in 200 years).

This highlights that North Promenade has a greater than 0.5% chance of being flooded in any given year (e.g. it could be flooded with a return period of event of 1 in 200 years or less).

Source: NRW, https://maps.cyfoethnaturiolcymru.gov.uk

Figure 39. Natural Resources Wales (NRW) Flood Maps

9.3 Shoreline management policy

North Promenade lies within Sub Cell 9, Policy Unit 11.15 of the current Shoreline Management Plan (SMP2) (Royal Haskoning, 2011). The extent of the policy unit and the adjacent policy units are shown in Figure 40.

The policy for Policy Unit 11.15, is to Hold the Line (HTL) by maintaining the existing defences up until the end of the current management epoch (i.e. until 2025). The SMP2 identifies significant pressures on the shoreline defences to the north of Barmouth, and with the additional implications of climate change and sea-level rise, it suggests the present alignment is likely to become increasingly difficult to sustain. For the second epoch (medium term, 2025 to 2055) and the third epoch (long term, 2055 to 2105) the policy is therefore Managed Realignment (MR) (Table 9).

There is potential that defence works will be required near the end of Epoch 1 and, therefore, if works are to adhere to SMP2, then planning for adaptive management may need to be undertaken in Epoch 1. In this context, the following is also taken from SMP2:

> *"Consideration should be given to widening the overall defence system in this area. This may require nearshore or shore connected structures to reduce wave energy but is also likely to require some future realignment of the defences, quite probably with the loss of property. This would require a more integrated approach to management, considering how the northern seafront could be developed to better advantage both in term of use and shoreline management."*

Barmouth North, Policy Unit 11.15 lies between Barmouth South and Llanaber, policy units 11.14 and 11.16 respectively (Figure 40). The SMP2 notes that an adaptive approach to management is needed and although Barmouth North, Barmouth South and Llanaber are classed as three separate units, the policies need to be progressed as one. The three units have consistent policies until 2025 (HTL) but policies for Llanaber and Barmouth South remain as HTL in the medium and long term and therefore consideration of how a MR could be implemented in this context is required.

Table 9. Summary of specific policies from Porth Aberamffra to Llanaber Point

Policy Unit		Policy Plan		
		2025	2055	2105
11.14	Barmouth South	HTL	HTL	HTL
11.15	Barmouth North	HTL	MR	MR
11.16	Llanaber	HTL	HTL	HTL

Royal Haskoning, 2011

Shapefile data from https://lle.gov.wales/

Figure 40. SMP2 policy units of Barmouth. Llanaber (11.16), Barmouth North (11.15) and Barmouth South (11.14)

10 Conceptual Understanding

Prior to entering the nearshore, waves are filtered from more north westerly and southerly direction sectors by the series of offshore ridges and headlands to the north and south of Barmouth (Figure 2). These features, together with the prevailing wave conditions offshore, limit the wave energy approaching the frontage to a relatively narrow direction sector from the SW. Upon entering the nearshore, dissipation and refraction occur over the shore platform.

Given the alignment of the nearshore bed contours and the incident wave directions, further wave refraction occurs as the waves are transformed further inshore to the toe of the beach, thus the waves refract and become slightly more westerly. This is depicted in Figure 41, where offshore the waves from the south west interact with the nearshore bathymetry, inducing northerly transport offshore. It is expected that this transport is maintained as the ebb tide delta from the Mawddach Estuary, results in shallow bathymetry further offshore to the south of Barmouth. However, as the waves continue to be transformed further inshore they become more westerly, becoming more shore normal and can then induce more southerly dominated transport (as indicated on Figure 41).

A southerly transport direction nearshore has been inferred from numerous site visits in the past (e.g. Royal Haskoning, (2011) and Mott Mac Donald (2018)). These site visits have noted a minor build-up of sediment on the north facing side of the groynes, suggesting a southerly transport nearshore. Increasing beach levels and width in a southerly direction (Figure 15), may also be indicative of an overall southerly longshore drift direction in the nearshore. However, the location and alignment of shingle/cobble bank to the north of North Parade, does not suggest a strong southerly transport, but rather suggest the shingle banks could be in a state of dynamic equilibrium, being held by the North Promenade to the south and the headland at Llanber to the north.

Furthermore, the significant changes observed in bed levels between 2013 and 2014, including the development of the ridge/runnel system of North Promenade and change to the shingle/cobble bank to the north of North Promenade, suggest that there may have been more dominant northerly transport nearshore during some of the events that occurred during 2013-2014. Such variability with both northerly and southerly transport close inshore, could still be expected even with the narrow range of incident wave conditions. As such it is expected that the sediment transport regime will act to smooth out major perturbations as seen with the smoothing out of the ridge/runnel system since 2014. Short-term changes to the frontage are also therefore expected due to both northerly and southerly transport.

In addition, it is noted that the shore platform is not uniform and there are numerous outcrops in the nearshore area that are starved of mobile material. This includes the outcrop just off the northern section of South Promenade, where there is a step in the alignment of the promenade with the promenade sitting seawards of the remaining defence. This alignment, whilst now developed as a hard defence, is likely to have resulted from a natural feature originally. This may also help to explain why the upper foreshore bed levels generally remain higher at this location, even though the promenade protrudes seaward. These features and outcrops along the foreshore and within the subtidal zone will therefore also have impacts on the local sediment transport regime.

Nevertheless, overall foreshore bed levels along North Promenade are lowering and this lowering is expected to continue. The lack of credible groynes and coarser material in the upper foreshore along North Promenade is likely to have accelerated the rate at which the foreshore has lowered with additional wave energy being reflected off the sea wall.

Effects of future climate change particularly in the longer term will increase the general water depths within the bay. Therefore, there is greater potential for higher waves to reach the defences at increased frequency, and hence an expected increase in wave overtopping, flood risk and potential sea wall damage.

Beach evolution is very difficult to predict but assuming NAI, erosion is predicted to continue at North Promenade. The rate of erosion is likely to increase with sea level rise as a result of the larger waves reaching the Promenade and in turn increasing drawdown. The SMP2 suggests the rate of erosion could increase by a factor of 1.7 to 2.5 times the existing base rate over the next 100 years.

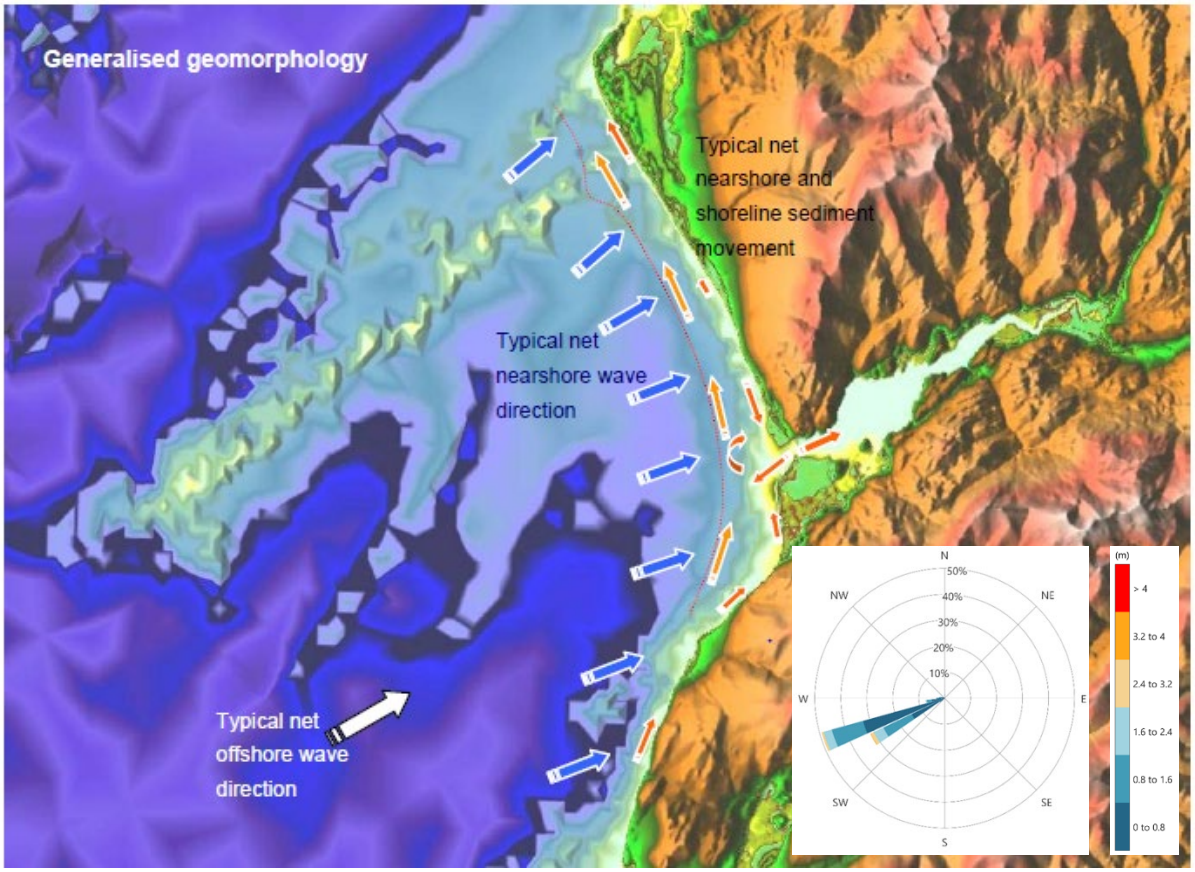


Image source: Royal Haskoning, 2011

Figure 41. Generalised coastal processes adapted from the SMP2 and including ABPmer wave rose from -7 mODN water depth

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12 Abbreviations/Acronyms

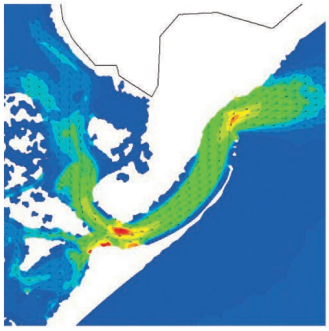
AEP	Annual Exceedance Probability
BAP	Biodiversity Action Plan
BODC	British Oceanographic Data Centre
CFBD	Coastal Flood Boundary Dataset
CGC	Cyngor Gwynedd Council
DSM	Digital Surface Model
DTM	Digital Terrain Model
EMODnet	European Marine Observation and Data Network
HAT	Highest Astronomical Tide
HTL	Hold the Line
MR	Manage Realignment
Hs	Significant Wave Height
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
LW	Low Water
mCD	Metres Relative to Chart Datum
mODN	Metres Relative to Ordnance Datum Newlyn
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLW	Mean Low Water
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
NAI	No Active Intervention
NCEP	National Centers for Environmental Prediction
NRW	Natural Resources Wales
NTSLF	National Tidal and Sea Level Facility
OBC	Outline Business Case
OD	Ordnance Datum
PAR	Project Appraisal Report
SAC	Special Area of Conservation
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SW	Spectral Wave
SSSI	Sites of Specific Scientific Interest
Tm	Mean Wave Period
UAV	Unmanned Aerial Vehicle
UKHO	United Kingdom Hydrographic Office
YGC	Ymgynghoriaeth Gwynedd Consultancy

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendix

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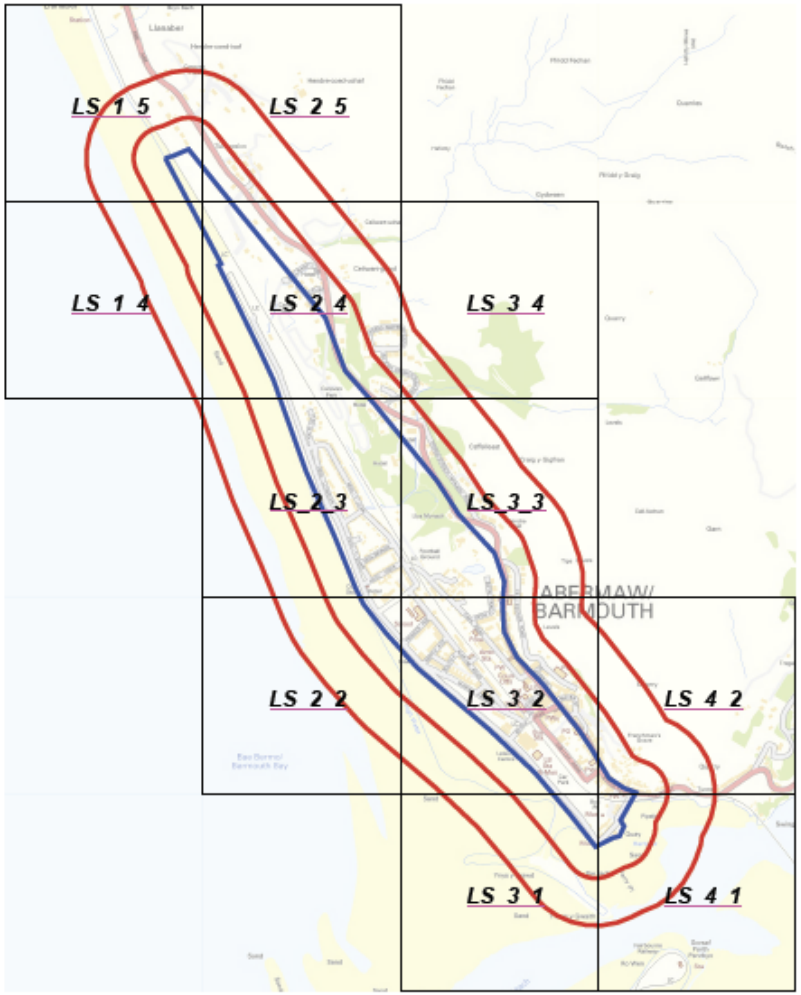

Groundsure INSIGHTS

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1:2500 Scale Grid Index

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Figure A1. Location references

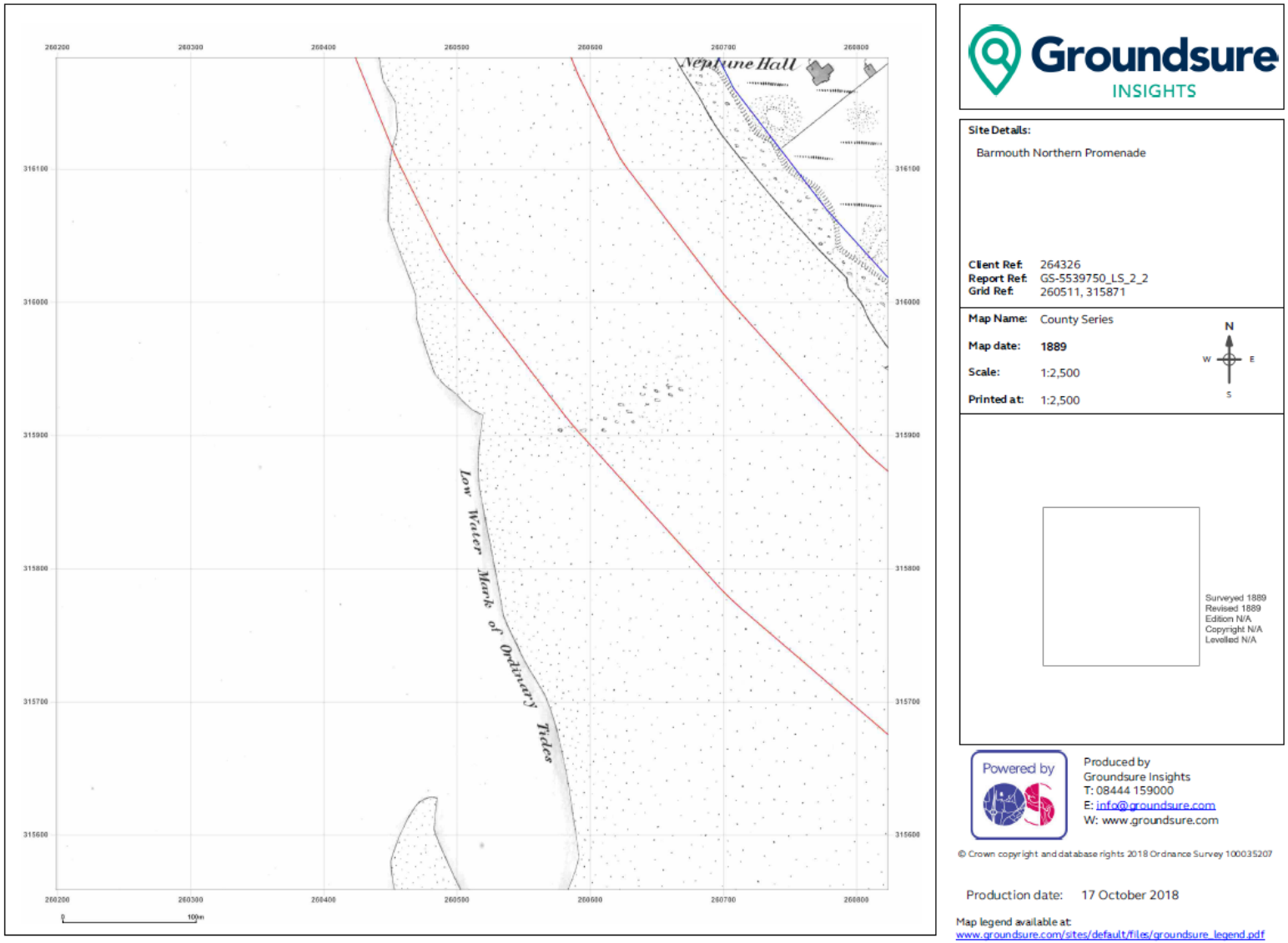

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Figure A2. Map of Barmouth North Promenade. Location: LS_2_2, Map date: 1889

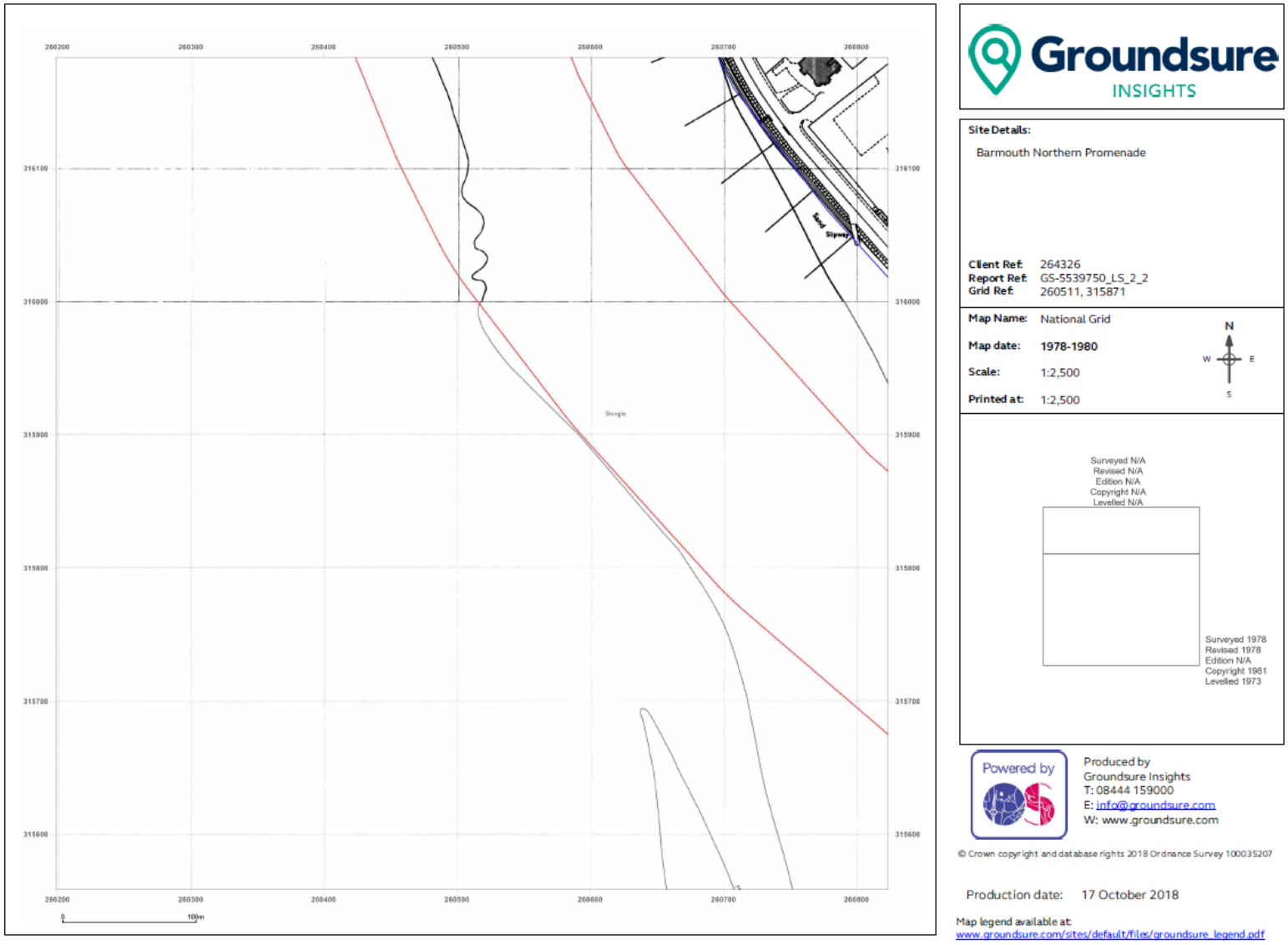

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Figure A3. Map of Barmouth North Promenade. Location: LS_2_2, Map date: 1978-1980

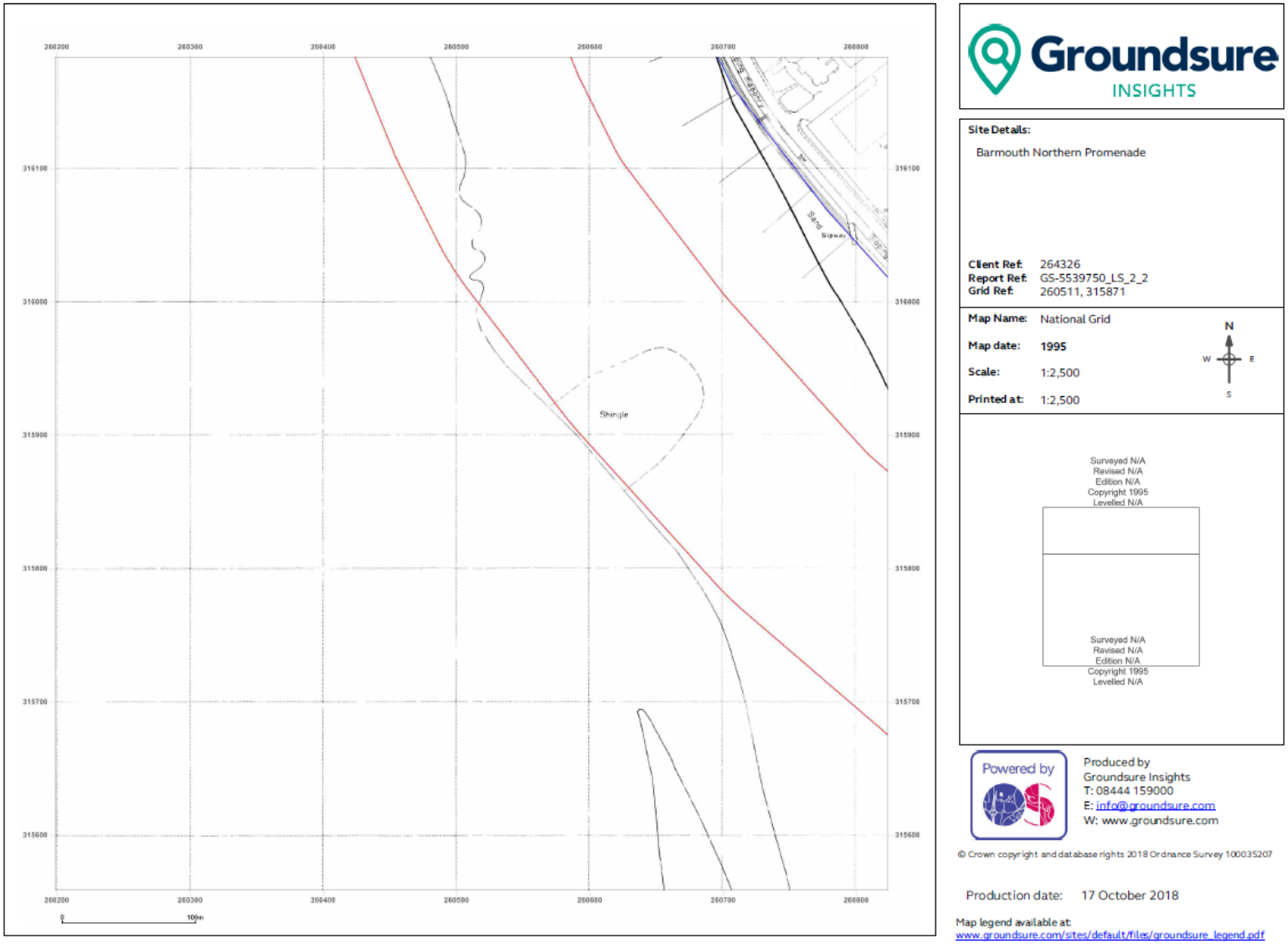

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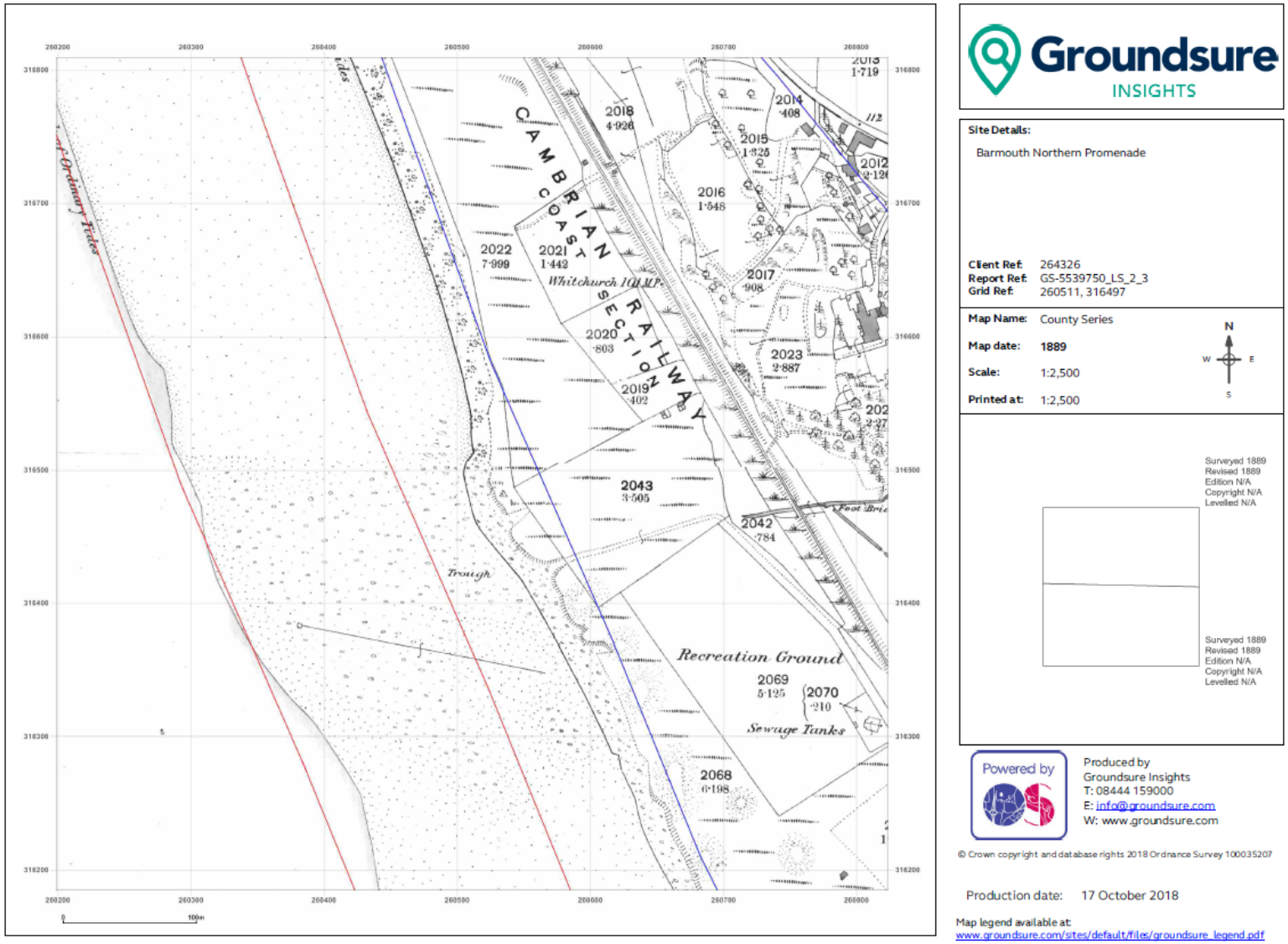
Figure A4. Map of Barmouth North Promenade. Location: LS_2_2, Map date: 1995



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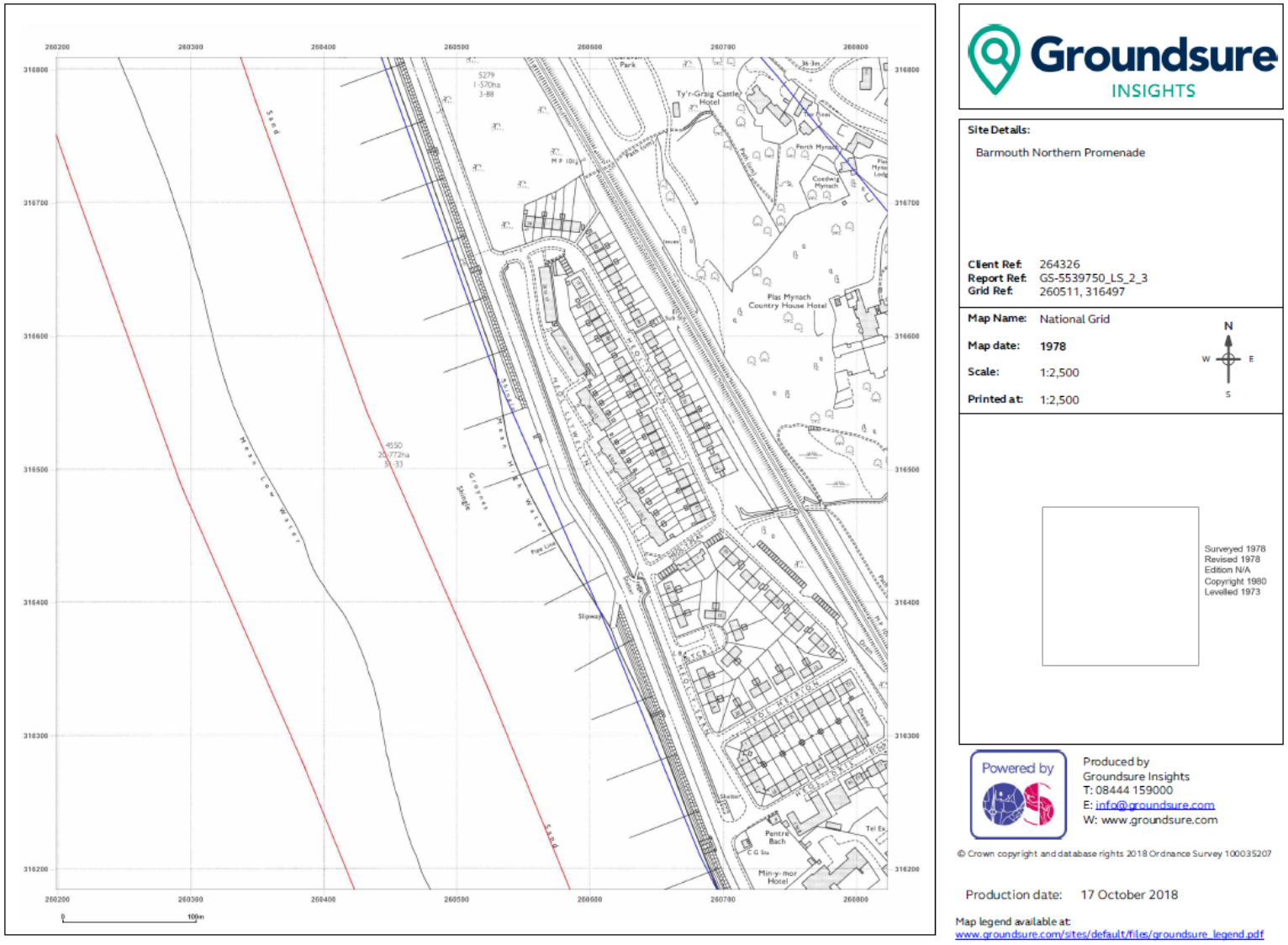

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Figure A6. Map of Barmouth North Promenade. Location: LS_2_3, Map date: 1978

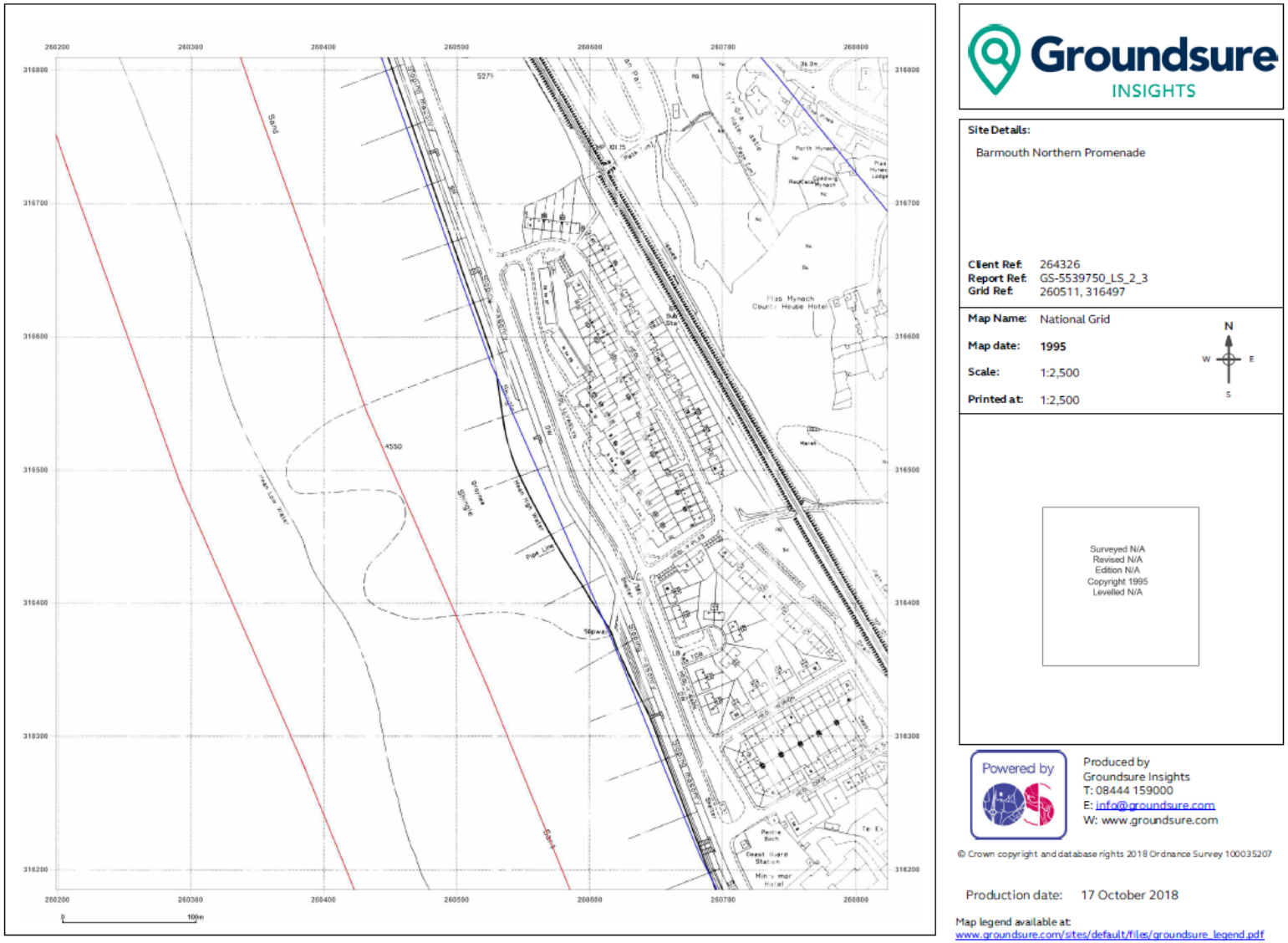

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Figure A7. Map of Barmouth North Promenade. Location: LS_2_3, Map date: 1995

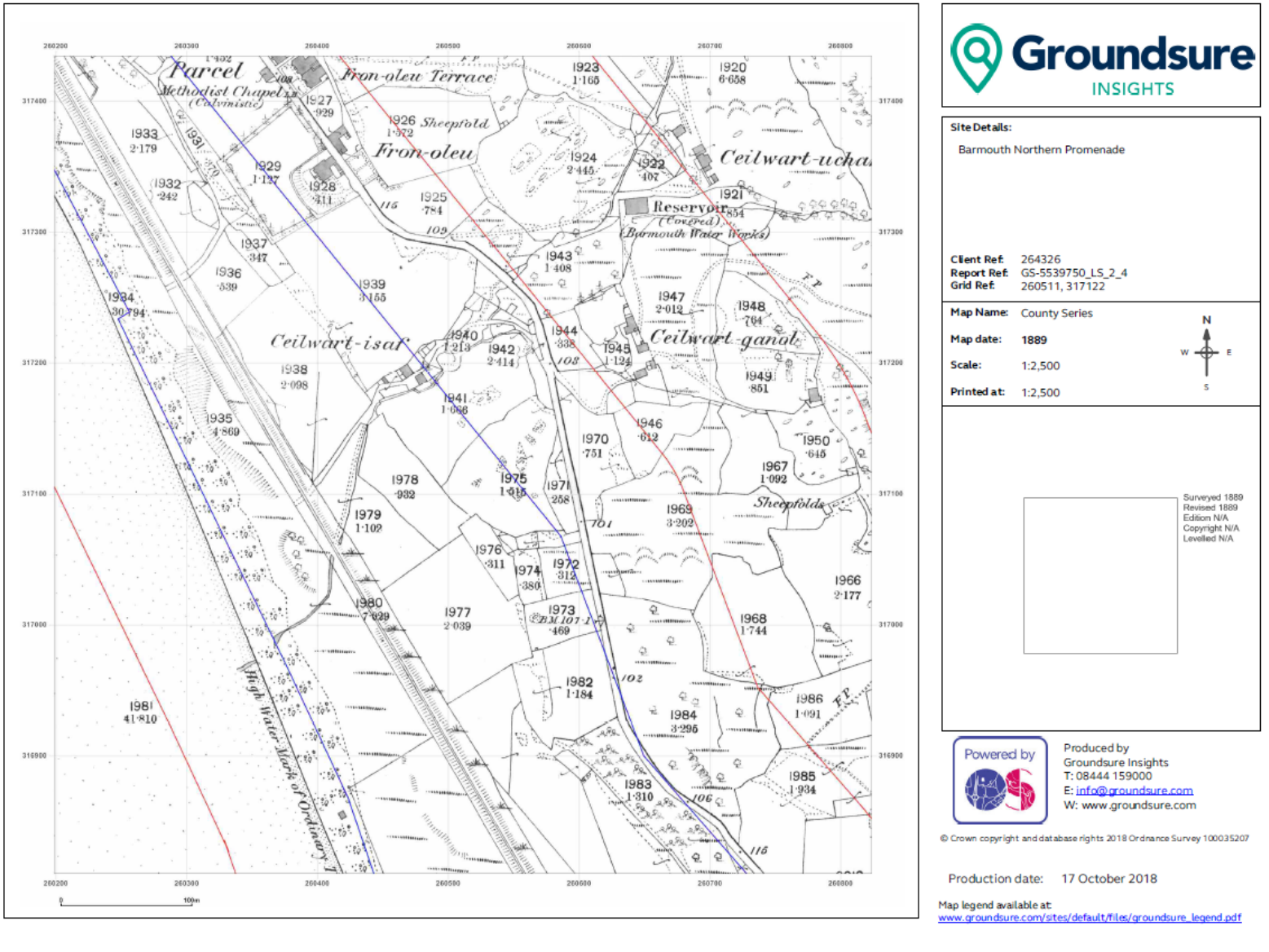

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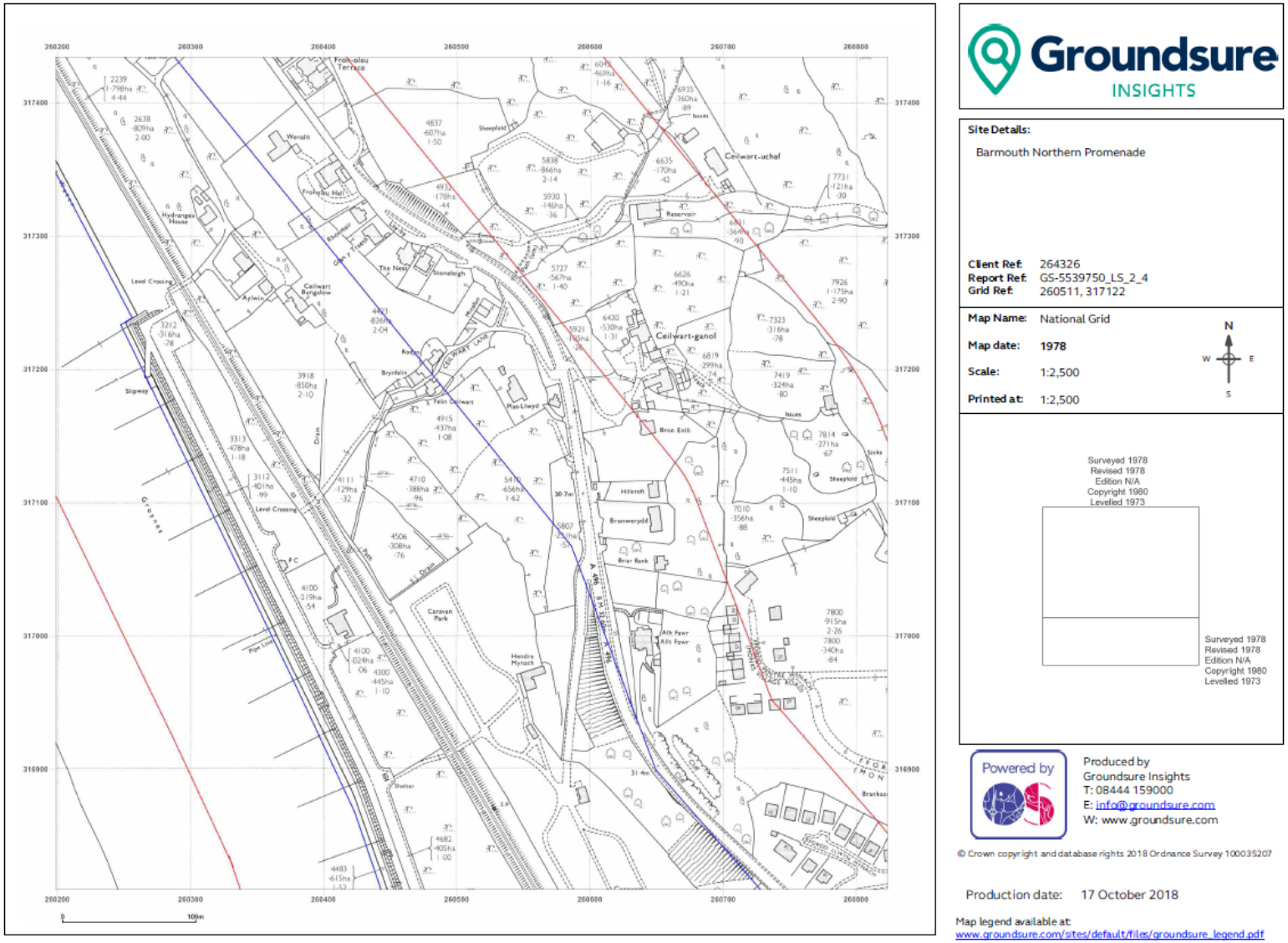
Figure A8. Map of Barmouth North Promenade. Location: LS_2_4, Map date: 1889



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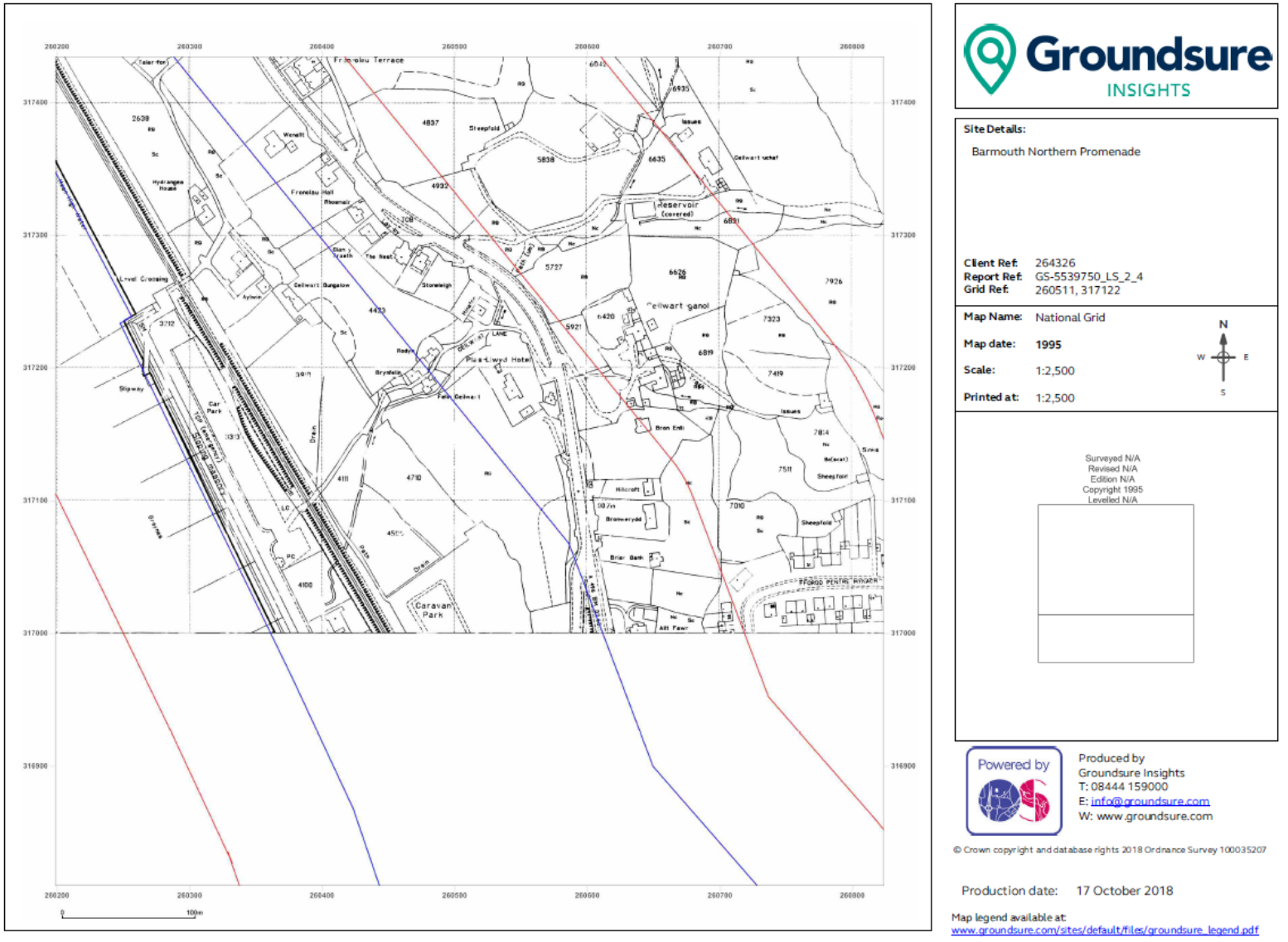

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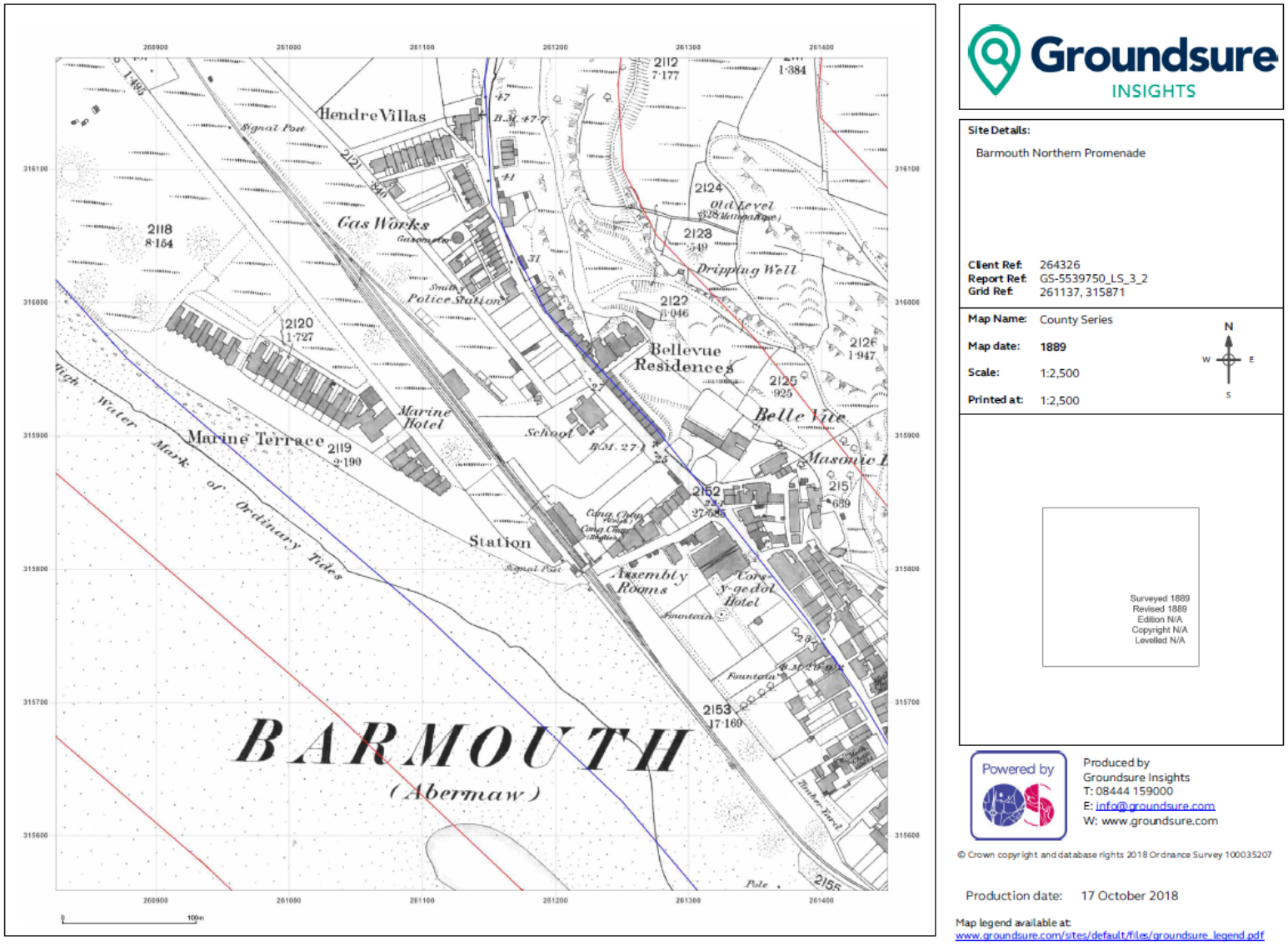

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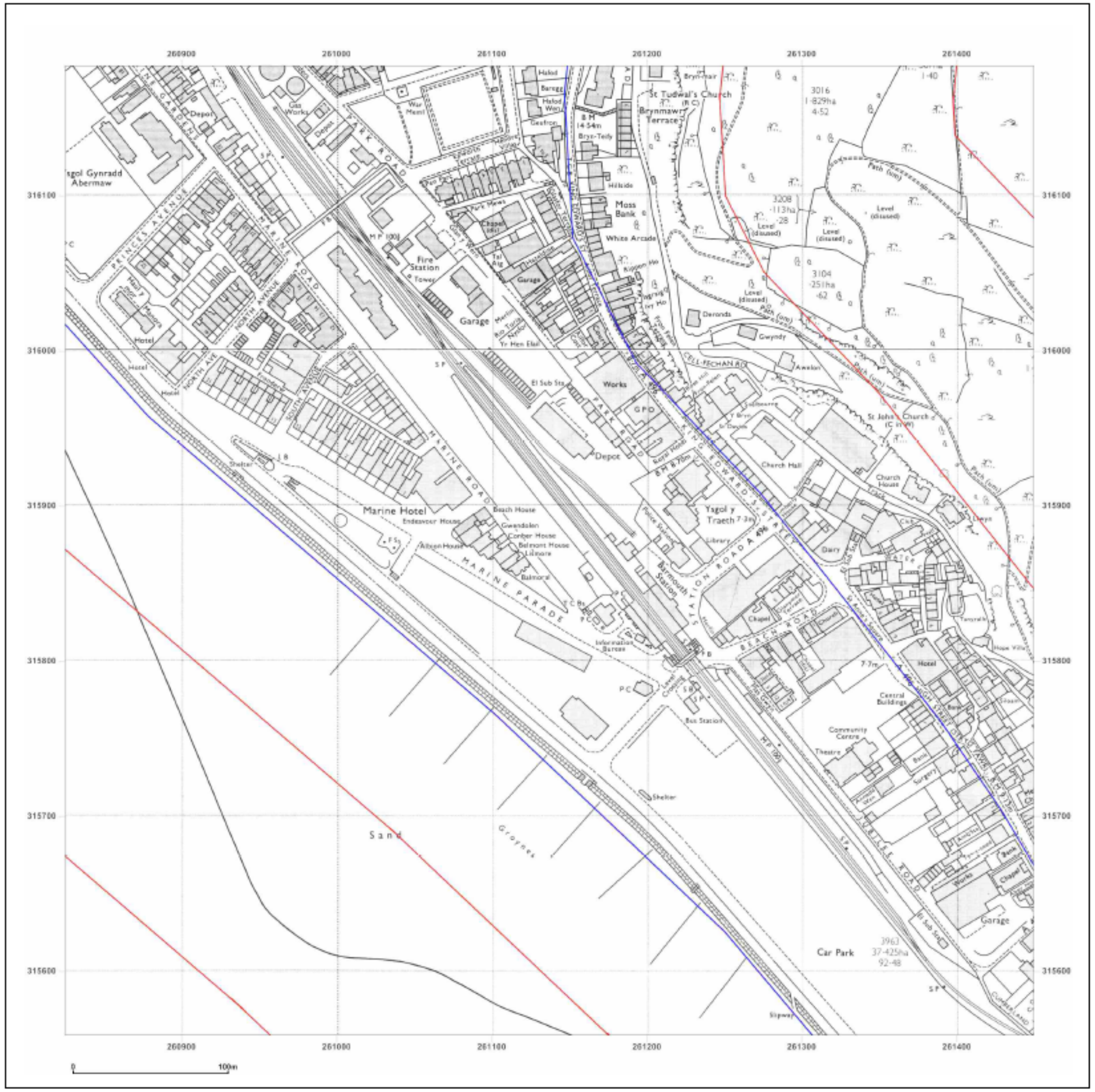
Figure A11. Map of Barmouth North Promenade. Location: LS_3_2, Map date: 1889



Groundsure INSIGHTS

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Barmouth Northern Promenade

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Report Ref: GS-5539750_LS_3_2
Grid Ref: 261137, 315871

Map Name: National Grid
Map date: 1978
Scale: 1:2,500
Printed at: 1:2,500

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Edition N/A
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Figure A12. Map of Barmouth North Promenade. Location: LS_3_2, Map date: 1978

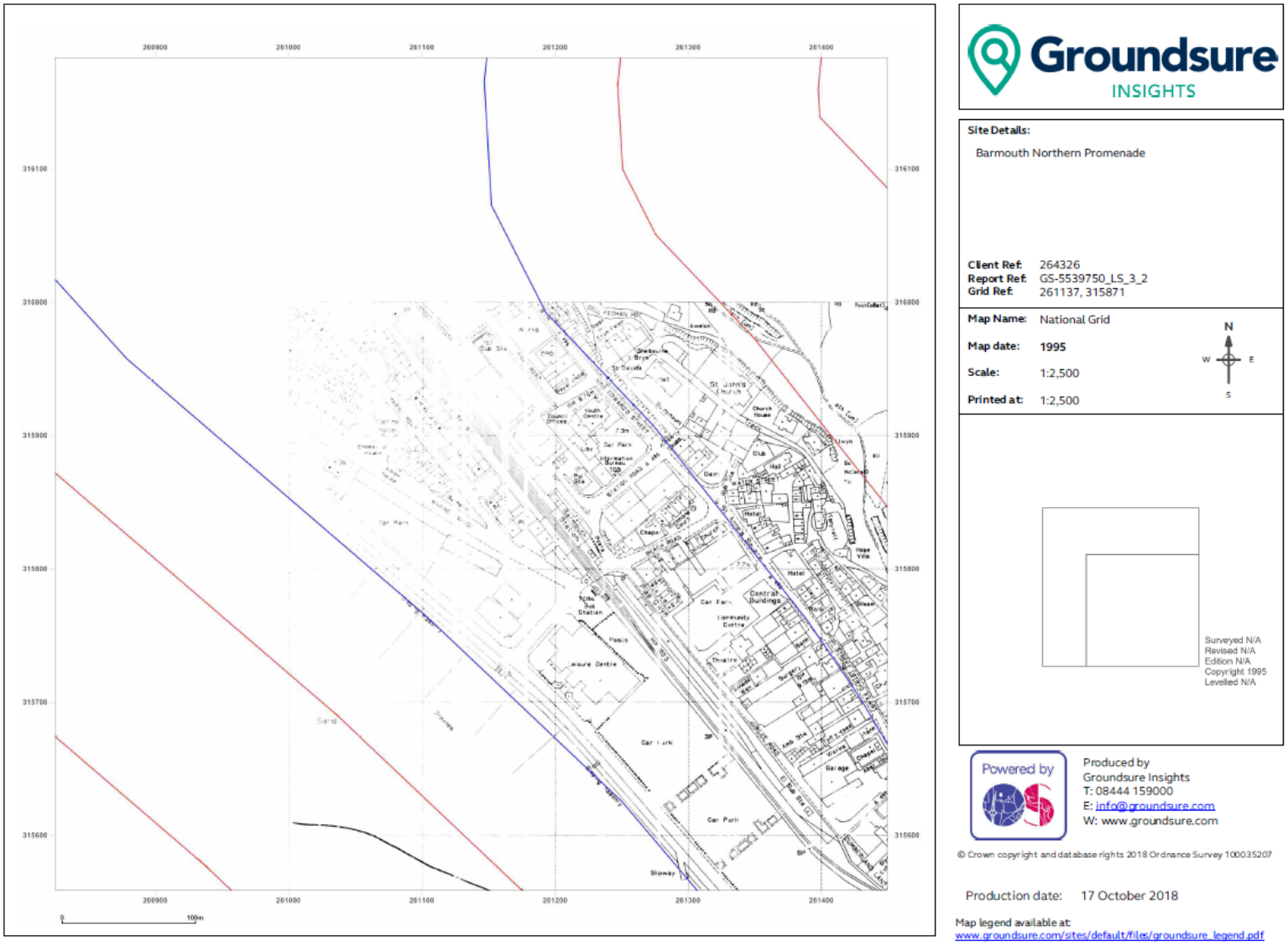

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Figure A13. Map of Barmouth North Promenade. Location: LS_3_2, Map date: 1995

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