From:	Pearson, John
To:	Wylfa Newydd
Subject:	Deadline 4 Submission for Wylfa Newydd Development Consent Order EN010007
Date:	17 January 2019 13:29:01
Attachments:	image001.png NT Wylfa Deadline 4 Intro letter FINAL.docx NWWT and eNGO oral case FINAL.pdf Post ISH Note on Coastal Processes and Geomorphology Wylfa DCO Deadline 4.pdf Post-hearing note eNGO - Biodiversity FINAL.pdf Wylfa DCO Post Hearing Note Section 106 Jan 2019 Final.docx

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Please find attached communication in relation to Deadline 4 for the above.

Thank you.

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17/1/2019

By email. Attention of Kay Sully

Dear Ms Sully.

EN010007 Wylfa Newydd Nuclear Power Station: Deadline 4.

I refer to the above consideration.

I attach for your information a submission provided on behalf of the Environmental Non-Governmental Organisations (eNGO's), National Trust, North Wales Wildlife Trust and The RSPB. The attachments include:

-post hearing note on Coastal Processes and Geomorphology including Kenneth Pye Associates Ltd Report on Cemlyn Wave Regime and Sediment Demand;

-post hearing note on the proposed Section 106 Agreement;

-post hearing note on biodiversity and oral case.

In accordance with Item 10 of the Revised Timetable which was annexed to PINS' letter dated 18 December 2018, the National Trust notifies the ExA of its wish to speak at the Compulsory Purchase Hearing (CAH). The Trust and Horizon intend to enter into one or more legal agreements which, it is hoped, will satisfy the Trust's compulsory purchase concerns. If this is the case, the Trust might not need to speak at the CAH. The Trust will provide the ExA with an update closer to the CAH.

Thank you for your considerations.

Yours sincerely,

John Pearson
Planning Adviser National Trust

HORIZON NUCLEAR POWER LIMITED
WYLFA NEWYDD DEVELOPMENT CONSENT ORDER

POST HEARING NOTE PREPARED FOR DEADLINE 4
COASTAL PROCESSES AND GEOMORPHOLOGY

Kenneth Pye ScD PhD MA CGeol FGS

16 January 2019

1. Introduction

1.1 This post hearing written statement has been prepared by Professor Kenneth Pye, Director of Kenneth Pye Associates Ltd (KPAL), on behalf of the National Trust (NT) following the First and Second Issue Specific Hearings (ISH) on Biodiversity held on 10th and 11th January 2019. It relates principally to Item 3c on the First ISH on Biodiversity agenda (Habitats Regulations Assessment, Coastal Processes and Geomorphological Monitoring) and Item 3 on the Second ISH on Biodiversity agenda (Coastal Change), and incorporates points made verbally on behalf of the NT at the hearings.

1.2 The NT is the landowner of the Cemlyn Lagoon, Esgair Gemlyn and the surrounding land, and therefore has a legitimate interest in its future. NT has commissioned field survey and modelling work from KPAL because of its legitimate interest and the need for independent verification of the veracity of Horizon's work on coastal processes.

2. Limitations of Horizon's assessment of Coastal Processes and Coastal Change

2.1 Significant differences remain between Horizon and NT positions relating to coastal processes and requirements for geomorphological monitoring.

2.2 As stated in paragraph 2.1.2 of Horizon's Response to the NT's Written Representation (REP3-028), *"Horizon considers its work undertaken on coastal processes and coastal geomorphology to be comprehensive and robust. The scale of work undertaken reflects the activities and infrastructure of the Wylfa Newydd Project with consideration of environmental conditions and sensitivities along the north Anglesey coastline"*. A Supplementary Information note on coastal processes was submitted by Horizon at Deadline 2 (REP2-007). Horizon confirmed at the ISH on 10 January 2019 that no further investigations, baseline data collection or modelling is proposed.

2.3 The NT position, as summarised in its written representation at Deadline 2 (REP2-316), is that significant gaps exist in the baseline assessment relating to coastal processes and geomorphology undertaken to support the EIA, sHRA and Marine Licence applications. The risk of significant sediment movement within Cemlyn Bay, which could affect the stability of Esgair Gemlyn and threaten the functional integrity of Cemlyn Lagoon, including its SAC/ SPA interest features, has not been assessed in sufficient detail. The NT submission at Deadline 3 (REP3-056) pointed out that Horizon's Supplementary Information Note on coastal processes submitted at Deadline 2 (REP2-007) goes only a small way towards addressing the gaps in the assessment.

2.4 Horizon's modelling has shown that the proposed marine works are likely to cause increased bed shear stress within inner Cemlyn Bay due to the combined effect of tidal currents and wave reflection from the western breakwater. The predicted increases in bed shear stress for large (99th percentile) winter waves on a spring tide are considered by Horizon unlikely to pose a significant threat to the stability of the shingle ridge. However, as pointed out in NT's REP3-056, this assessment is based on a mis-representation of sediment characteristics within the inner part of Cemlyn Bay, and does not consider the potential cumulative effect of moderate to large (e.g. 50th - 99th percentile) waves to mobilise fine sand close to the toe of the ridge, or mixed sand and gravel sediments on the lower part of the ridge itself. A lowering of the sea bed to seaward of the ridge, increased seaward movement of sediment from the ridge face during storms, or a change in the direction or magnitude of alongshore sediment transport, could have a significant effect on the frequency and magnitude of wave over-topping and the risk of ridge breaching during storm events. Over a period of years, changes to the ridge could threaten the integrity of the tern nesting islands and the operation of the weir which provides the main mechanisms for tidal exchange between the lagoon and open sea.

2.5 Horizon's baseline assessment, as summarised in the ES and supporting documents (PP132, APP216, APP217, APP218 and APP226), did not include bathymetric and sediment surveys of the inner part of Cemlyn Bay, Esgair Gemlyn or Cemlyn Lagoon. No investigations of the structure of the shingle ridge, the thickness of superficial sediments immediately to seaward of it, or any monitoring of waves, water levels and sediment transport were undertaken. Only very limited water sampling was undertaken within Cemlyn Bay and Cemlyn Lagoon, principally for water quality assessment purposes, and only a small amount of background information has been obtained relating to suspended sediment concentrations, particle size characteristics and composition. The modelling undertaken of construction discharges within and around Cemlyn Bay is relatively limited in scope and is based on assumptions about background sediment concentrations, size and transport behaviour which are not adequately supported by baseline survey or monitoring data. Very limited sediment and wider water quality data have been gathered from the Nant Cemlyn which feeds into Cemlyn Lagoon and drains land adjacent to Mound E, and little detail has been provided about the proposed measures to control run-off from Mound E into the Lagoon via this route.

2.6 In view of the above, the NT has concluded that an adverse effect on the integrity of the SAC and SPA cannot be ruled out, contrary to the conclusion reached by Horizon in the Environmental Statement. The NT is also of the opinion that additional data collection and modelling should be undertaken to improve the assessment of likely project effects, to provide an adequate baseline against which future monitoring results can be compared, and to inform the development of a suitable adaptive management plan.

2.7 NRW (paragraph 7.4.28 of REP2-325) has also advised that "further information is required to demonstrate that Cemlyn Lagoon will not be affected by impacts on water quality due to surface water run-off from Mound E. Further information is also required to demonstrate that changes in coastal processes due to the presence of marine structures will not affect the shingle ridge, which supports the functioning of Cemlyn Lagoon. NRW is therefore unable to agree with the conclusion that *"the Wylfa Newydd*

Project would neither cause deterioration in the status of Cemlyn Lagoon water body, nor compromise the ongoing achievement of its objectives"."Esgair Gemlyn shingle ridge, which is critical to the functioning of the lagoon and in supporting the shingle ridge vegetation, may be affected by changes in coastal processes as a result of the marine works" (paragraph 7.10.10 of REP2-325), and "further information is required to demonstrate that changes in coastal processes due to the presence of the marine structures will not affect the shingle ridge" (paragraph 7.8.44 of REP2-325).

3. Requirements for further data collection, monitoring and adaptive management

3.1 Section F of the NT's written representation on coastal processes and geomorphology (REP2-316) provided a summary of the categories of additional data required to provide an adequate information baseline and monitoring framework for coastal processes and coastal geomorphological change.

3.2 It is NT's understanding that discussions have recently taken place between the Applicant and NRW regarding requirements for further data collection and monitoring, and that Horizon has now agreed to address residual risk associated with the Project through a programme of monitoring and adaptive management. The NT has not been party to these discussions and clarification is awaited regarding any proposals. The NT welcomes the proposal for monitoring and adaptive management but it is of critical importance that the proposals are fit for purpose, sufficient in scope, firmly based on adequate baseline data, and adequately secured (including funding mechanisms) and will be enforced for a sufficiently long period of time.

3.3 NT's REP2-316 referred to two recent reports by Kenneth Pye Associates Ltd (Pye & Blott 2018a and 2018 b) which present the results of additional field surveys and preliminary modelling undertaken on behalf of the NT during 2018. These reports, which are included as Annex 1 and Annex 2 to this Deadline 4 statement, provide further information relating to the types of data which the pre- and post-works monitoring programme should seek to obtain. The NT would welcome an opportunity to discuss previous work and future proposals with Horizon and NRW. It would be to the benefit of all parties to ensure that monitoring carried out in relation to the shingle ridge, water quality and benthic habitats within Cemlyn Bay, and within Cemlyn Lagoon and its tributary streams (e.g. Nant Cemlyn and the drainage around Mound E), is undertaken in an integrated way to ensure maximum utility of the data. The procedures for securing the monitoring programme, and for assessment and reporting of the monitoring data, should be clear and transparent to ensure general confidence.

3.4 The NT and other eNGOs await clarification on the nature of proposals which may be being developed by Horizon for adaptive management of the shingle ridge, Lagoon, tern nesting islands or other features within the neighbouring areas. A number of options were identified in NT REP2-316, including the beneficial use of shingle removed from Porth-y-Pistyll, MOLF and Harbour areas during construction of the marine works. Such beneficial use would be consistent with OSPAR Guidelines for the Management of Dredged Material at Sea (OSPAR Commission 2014) and could contribute significantly to the provision of increased resilience and ecological enhancement. The NT recommends that discussion of this and other options for adaptive management should involve the eNGOs, Horizon, NRW and any other relevant interested parties. The NT as landowner, and the North Wales Wildlife Trust (NWWT) as tenant with joint responsibility for management of the tern breeding islands, have a legitimate interest in any proposals which may affect the use of their land and/or their management responsibilities. Attention is also drawn here to the interests of the NWWT and other eNGOs, including the role of the Precautionary Principle, highlighted in Ms. Hughes' oral presentation at the Issue Specific Hearings.

4. Climate Change

4.1 The request made by the ExA at the ISH on 11 January 2019 that Horizon examine the implications of the latest climate change assessments made by the UKCP-18 programme is welcomed by the NT. Specific aspects relevant to coastal processes, sediment transport, water quality and coastal morphological change include changes to estimates in the rate of mean sea level, storm frequency (as affecting waves and coastal water levels), and changes in rainfall intensity and associated surface water runoff. The suitability of the assumptions made in previous modelling regarding the frequency and magnitude of terrestrial runoff events, suspended sediment concentrations, high tidal events and high wave events need assessment and reporting by Horizon at Deadline 5.

5. References

OSPAR Commission (204) *OSPAR Guidelines for the Management of Dredged Material at Sea (Agreement 2014-06).* OSPAR Commission, London 39pp.

Pye, K. & Blott, S.J. (2018) *Cemlyn Shingle Ridge, Anglesey: Wave Regime and Sediment Demand Assessments*. External Investigation Report No. EX 21470, Kenneth Pye Associates Ltd, Solihull, 6 February 2018.

Pye, K. & Blott, S.J. (2018b) *Cemlyn Bay, Anglesey: Topographic Survey and Tidal Level Investigation Summary Report*. KPAL Report No: 181118, 19 November 2018, Kenneth Pye Associates Ltd., Reading.

ANNEX 1

Kenneth Pye Associates Ltd Report on Cemlyn Wave Regime and Sediment Demand

Cemlyn Shingle Ridge, Anglesey:
Wave Regime and Sediment Demand Assessments

Kenneth Pye **ScD PhD MA FGS CGeol**
&
Simon J. Blott **PhD MRes BSc FGS**

KPAL External Investigation Report No. EX 21470

Report history		
Version 1.0	Draft	26 January 2018
Version 2.0	Revised	6 February 2018

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Summary

This report builds on previous work undertaken on behalf of the National Trust (NT) in connection with the future management of the Trust's Cemlyn property, including issues related to the Wylfa Newydd New Nuclear Build project. It presents results relating to:

(1) further evaluation of the wave conditions acting on the Esgair Gemlyn shingle ridge and the risk of over-washing

(2) assessment of the sediment volume potentially required to increase the resilience of the shingle ridge to over-washing at the present time and allowing for possible future sea level rise

(3) assessment of the sediment volume potentially required to infill, raise and extend the tern nesting islands at present and allowing for sea level rise.

These issues have been addressed by (a) further analysis of historical marine water level data for Class A locations close to Cemlyn, (b) further analysis of hindcast wave data for the offshore area close to Cemlyn , (c) modelling of wave behaviour within Cemlyn Bay using the Mike 21 SW model, (d) XBeach-G modelling of the likely critical still water and wave conditions for over-washing on the shingle ridge, (e) a review of available photographic and other information relating to the impact of past storms on the shingle ridge, (f) analysis of May 2017 Lidar survey data of the Esgair Gemlyn ridge and comparison with earlier (2010) LiDAR survey data and (2016) ground survey data to provide information about recent morphological change, (g) use of the 2017 LiDAR DEM to calculate the volume of additional shingle which would be required within each section of the barrier to maintain a more storm-resilient cross-sectional profile, allowing for sea level rise by 2030, 2050 and 2100, and use of the 2017 LIDAR DEM and historical maps to estimate the volume of sediment which would be required to raise or extend the two existing tern islands in line with sea level rise.

Parts of the Esgair shingle ridge presently experience over-washing when high tides coincide with waves of sufficient height and period to create run-up which passes over the ridge crest. Different combinations of still water level, wave height and wave period can be responsible for such occurrences, and within any single event there may significant alongshore variations in wave conditions, dependent partly on offshore wave approach direction. In general, offshore waves approaching from the W and NW generate higher wave energy conditions in eastern Cemlyn Bay, while offshore waves approaching from the NE and E generate higher energy conditions in the western part of the Bay. At present there are two areas where the ridge crest is relatively low and there is a high risk of over-washing: (a) between the tern nesting islands and the southern end of the tidal inlet, and (b) near the eastern car park. These risks are likely to increase in future due to sea level rise, and could be exacerbated by a change in storm surge frequency / magnitude or offshore wind/wave conditions.

The capability of the Esgair Cemlyn shingle ridge to retain constant morphology and crest height in the face of sea level rise will be limited by low rates of new sediment supply and the low-lying, relatively level nature of the lagoon floor over which it must migrate. As such, the risk of over-washing, blockage of the existing lagoon inlet / outlet and potential breaching will increase over time. The risk of closure of the channel separating the shingle ridge from the tern nesting islands will also increase over time.

One possible way to address this problem would be to increase the volume of the shingle ridge using suitable imported sediment. The sediment volume required to create a sloping ridge, ranging in crest elevation from 5.7 m ODN in the east to 5.2 m ODN at the northwest end, would be approximately 5100 m^3. To increase the height crest height of the ridge by a seal level rise allowance of 37.5 cm, while maintaining the same average seaward and landward gradients, would require an additional 19332 m^3 of sediment.

The larger of the two tern nesting islands has experienced significant erosion and the ground area now available for nesting is considerably less than that during the 1960s. Approximately 1000 m^3 of sediment would need to be imported or locally sourced to completely infill the eroded areas and raise the island to a uniform level of 2.80 m within the footprint of the surrounding brick skirt. To infill the eroded areas and raise the entire island level by a sea level rise allowance of 37.5 cm within this footprint would require approximately 2975 m^3 of additional sediment. If the area of both nesting islands is extended beyond the boundaries originally created additional sediment would be required. The feasibility of sourcing such volumes of shingle from the proposed Horizon Wylfa Newydd marine works or other sources requires further detailed study.

Assessment of processes affecting the shingle ridge and Cemlyn Lagoon is hampered by a lack of local still water level and wave data. It is recommended that portable water level gauges are installed at two locations (one outside lagoon and one inside the lagoon) over two neap –spring tidal cycles to provide information about water level variations (including short term wave sand longer term tides). There is also a requirement to obtain bathymetric data for the lagoon and for the inshore area close to the shingle ridge.

Cemlyn Shingle Ridge, Anglesey: Wave Regime and Sediment Demand Assessments

1.0 Introduction: scope and purpose

This report builds on previous work undertaken by Kenneth Pye Associates Ltd (KPAL) on behalf of the National Trust (NT) in connection with the future management of the Trust's Cemlyn property, including issues related to the proposed Wylfa Newydd New Nuclear Build project (Pye & Blott, 2010, 2016). It presents results relating to three tasks which were agreed with the National Trust in December 2017:

(1) further evaluation of the likely resilience / vulnerability of the Esgair Gemlyn shingle ridge to wave action during storm events, both at the present day and in the future, taking account of potential sea level rise and change in wave conditions

(2) assessment of the feasibility of increasing the resilience and sustainability of the shingle ridge by using dredged marine shingle derived from the proposed Wylfa Newydd marine works or other sources

(3) assessment of the feasibility of increasing the resilience of the existing tern nesting islands, or creating new islands, using imported or locally sourced sediment.

These issues have been addressed using the following methods:

(1) further analysis of historical marine water level data for Class A locations close to Cemlyn

(2) further analysis of hindcast wave data for the offshore area close to Cemlyn

(3) modelling of wave behaviour within and close to Cemlyn Bay, using the Mike 21 SW and XBeach-G models, to provide better information about changes in wave conditions close to the shingle ridge with offshore waves from different directions

(4) a review of available photographic and other information relating to the impact of past storms on the shingle ridge, and comparison with modelled wave data in order to identify critical conditions which have greatest impact

(5) analysis of May 2017 Lidar survey data of the Esgair Gemlyn area provided by Horizon PLC, and comparison with earlier (2010) Environment Agency

Wales (EAW) LiDAR survey data and ground survey data obtained by KPAL in 2016 to obtain information about recent morphological change along the shingle ridge

(6) use of the 2017 LiDAR DEM to calculate the volume of additional shingle which would be required within each section of the barrier to maintain a more storm- resilient cross-sectional profile, allowing for estimated sea level rise by the years 2030, 2050 and 2100

(7) use of the 2017 LIDAR DEM and historical maps to estimate the volume of sediment which would be required to raise or extend the two existing tern islands in line with sea level rise, assuming that the sluice and relative water levels in the lagoon are maintained.

Information provided by Horizon PLC as part of the Pre-DCO consultation process suggested that up to 242,000 m^3 of unconsolidated sediments would need to be dredged from the Marine Offshore Landing Facility (MOLF) area as part of the construction works. Horizon currently propose to dispose of this material by dumping at the Holyhead Deep licensed disposal site. However, OSPAR Guidance requires that alternative potential beneficial uses for the material should be considered. It is not presently clear how much of the dredged sediment from the proposed MOLF area might consist predominantly of shingle which could be used to raise the shingle ridge and/or extend the tern islands, and further investigation of this question would be required as part of a full feasibility assessment of such alterative use.

Cemlyn Bay and Lagoon is a Site of Special Scientific Interest (SSSI) designated for primary features of interest which include the saline Cemlyn Lagoon and associated fauna, the Esgair Grmlyn shingle ridge and its associated vegetation, areas of fringing saltmarsh, and breeding birds which include Artic, Common, Sandwich and Roseate Terns. The site, managed as a nature reserve by the North Wales Wildlife Trust (NWWT), also forms part of the Ynys Feurig and The Skerries Special Protection Area (SPA) for wild birds and the Cemlyn Bay Special Area of Conservation (SAC) notified primarily for its "Coastal lagoons" priority habitat and "Perennial vegetation of stony banks" qualifying feature. The site also lies within the Isle of Anglesey Area of Outstanding Natural Beauty and the North Anglesey Heritage Coast. The Anglesey Coastal Path runs along the shingle barrier, across a linking bridge to Trwyn Cemlyn headland, and then along the rocky coast to Hen Borth at the western end of the NT property. Any proposed changes which might impact on the designated features of the lagoon and shingle ridge would therefore require rigorous assessment as part of a consenting process. Careful consideration would also need to be given to how intervention proposals would fit within the context of wider National Trust coastal management policy.

2.0 Environmental context

The environmental setting and general character of the Cemlyn Lagoon and Esgair Gemlyn shingle ridge have been discussed in two previous KPAL (Pye & Blott, 2010, 2016) and therefore only a brief summary is provided here.

The upper part of the ridge, located towards the head of Cemlyn Bay, is composed mainly of medium and fine gravel. The northwestern end of the ridge is fronted by a bedrock platform which is partially covered by a thin layer of sand and shingle. The remainder of the ridge is fronted by a greater thickness of sandy sediment containing some fine gravel and shell. Behind the ridge is a man-modified brackish lagoon (Cemlyn Lagoon).

Appendix 1 includes a series of historical maps and aerial photographs which illustrate changes to the ridge and adjoining lagoon features since the late 19th century. Before the first weir was built in the early 1930s the Lagoon was linked to the open sea by a narrow, shallow inlet at the northwestern end of the shingle ridge. Late 19th century Six Inch and Twelve Inch Ordnance Survey maps indicate only small differences in the positions of the high and low water marks of ordinary tides within the lagoon, suggesting it may not have fully drained on neap ebb tides due to the restrictive effect of gravel deposits around the inlet. However, Captain Vivian Hewitt, who acquired the neighbouring Bryn Aber property in the late 1920s, decided to build a concrete weir to ensure a retained depth of water of one to two and half feet of water at low tide, increasing to five feet just behind the weir (Hywel, 1973, p.140). The sill level of the weir was subsequently raised by a further foot later in the 1930s. The maximum sill level of the original weir is estimated to have been about 2.6 m ODN, approximately 5 - 10 cm above the sill level of the present weir constructed by the North Wales Wildlife Trust in April – May 1978 (Rees, 2018). A concrete side wall was also constructed by Hewitt's workmen on the eastern side of the weir and could also be overtopped on very high spring tides.

Measured tidal level data for Cemlyn Bay and Cemlyn Lagoon are not currently available, but based on interpolation between Admiralty predictions for Holyhead and Cemaes Bay the mean high water spring (MHWS) tide level in Cemlyn Bay is estimated to be about 2.92 m ODN (Table 1). The respective values for mean high water neap (NHWN) tides and mean tide level (MTL) are 2.0 m and 2.52 m ODN, respectively. The highest astronomical tide (HAT) level at Cemlyn is estimated to be approximately 3.79 m, and water levels exceeding this value are occasionally encountered during storm surges. Based on statistical modelling McMillan *et al*. (2011) estimated the 1 in 200 extreme still water level offshore from Cemlyn Bay to be approximately 4.25 m ODN (Table 2). The highest recorded water level at Holyhead since 1964 is 3.81 m ODN, including a skew surge component of 0.88 m (Table 3), which would equate approximately to a level of 4.26 m ODN at Cemlyn Bay. Analysis of the tide gauge data for Holyhead suggests average rates of mean sea level rise (MSL) of between 2.16 and 2.80 mm/yr for different periods since 1938 (Figure 1), while the average rate of rise in MHW has been considerably higher (3.50 – 4.01 mm/yr). Extrapolation of the trend in for the period 1938 – 2017 would indicate increases in MSL of 6.2 cm, 11.8 cm and 25.8 cm by the years 2030, 2050 and 2100, respectively (Table 4). UKCP09 climate change projections suggest that the rate of sea level rise is likely to accelerate in the future, and could lead to increases in MSL of 10.5 cm, 22 cm and 58.2 cm by 2030, 2050 and 2100 using the 95th percentile medium emissions scenario model output values (Table 4). No updated sea level rise forecasts for the UK have been published since UKCP09, although updated recommended sea level rise allowances for infrastructure construction were provided by the Environment Agency (England) and Welsh Government (WG) in 2016 (Table 4). The WG advice suggests sea level rise allowances for capital infrastructure projects (such as Wylfa Newydd)of 14.4 cm, 37.5 cm and 124 cm by 203, 2050 and 2100, respectively (Table 4). Increases in MSL anywhere within these ranges would be likely to increase significantly the frequency of overtopping of the shingle ridge and accelerate its rate of landward movement into the lagoon, especially since the evidence from measured tidal data suggests that increases in MHW and MHWS may be larger than those in MSL.

The National Trust purchased the Lagoon and parts of the surrounding land from Captain Hewitt's estate in 1967, using Enterprise Neptune funds. An area of approximately 25.2 ha, including the Lagoon, was leased to the North Wales Wildlife Trust (NWWT) in 1971 and has subsequently been managed by them as a nature reserve. Temporary measures were initially used to control water levels in the lagoon during the tern breeding season, consisting of metal posts and wooden boards installed on top of Hewitt's weir. However, following damage to the top step of the weir during a high tide in June 1977 the structure was entirely rebuilt by the NWWT in April – May 1978 (Rees, 2018). A new sill and ten flow gates, four equipped with tidal flaps to allow flood water discharge, was built. Tidal inflow through the other six gates can be controlled by the installation of stop-logs. At the same time the likelihood of flow over the concrete side wall was reduced by depositing shingle to raise its level. Following partial scour of this material during high tides in the 1990s imported rock was placed adjacent to the wall.

The northwestern end of the Esgair Gemlyn ridge was modified significantly by these works. Few details are available regarding the construction methods in the 1930s, but it is known that in 1978 a by-pass channel was cut through the end of the shingle ridge to allow construction of the new weir and sluices (Rees, 2018). This was back-filled at the end of the works. In 2011-12 a new masonry and concrete footbridge was built between the northern end of the ridge and the western car park. The combined effect of these constructions has been to significantly reduce the ingress of tidal water into the lagoon compared with the pre-1978 situation, contributing to a reduction in overall salinity (Rees, 2018).

The southeastern end of the shingle ridge has also been modified by human activities. An informal vehicle parking area has existed in this area for over a century and a protective wall was built on the seaward side in the 1930s. By the early 1960s this had partially collapsed and a new wall and gravel surfaced car park was constructed in the 1970s. Higher parts of the shingle ridge to the west of this car park are well vegetated and were fenced to allow grazing well before the 1880s. In the 1930s a series of concrete posts and wire fence were erected by

Captain Hewitt along the seaward side of the ridge crest to mark the boundary of his land. Their remains can be seen today on the upper beach face.

The first Six Edition OS map, published in 1890 based on survey in 1887, shows the existence of salting islands in the area now occupied by the two tern nesting islands. These saltings appear in broadly similar form on the 1948 RAF aerial photography, despite modifications made by Hewitt in the 1930s, but by the early 1960s the southern island had disappeared and the extent of the northern island had been much reduced by erosion. It is likely that the higher standing water level in the lagoon following construction of the weir led to greater wave action within the lagoon. The main island was reconstructed and a new southern island created by the NWWT in the late 1970s, involving the construction of brick perimeter walls and infilling with sediment dredged from the lagoon floor. Further repair work was undertaken in the early 1990s, and more recently in the 2017-18 winter when 50 tonnes of crushed granitic rock was imported from an Anglesey quarry to infill part of the eroded area with the Main Island as part of the Roseate Tern *Life* Project (Wynne, 2018, pers. comm.).

The present elevation of the ridge crest ranges from c. 4.5 m ODN near the eastern car park, c. 4.6 m ODN to the northwest of the tern islands, 4.8 m ODN opposite the tern islands, to c. 5.6 m ODN at the northwestern end and along the south-central part of the barrier. Historical map evidence suggests that the ridge crest opposite the tern islands has been relatively low at least since the late 19th century, and there is a possibility that the original saltings on which the tern islands now sit were formed on old gravel over-wash lobes. The large wash-over event(s) responsible for the formation of these lobes effectively removed a significant quantity of shingle from the mobile beach / ridge crest system, and the ridge crest has never fully recovered in elevation and volume along this section of the barrier. A second low point in the shingle ridge crest occurs adjacent to the eastern car park at the point where vehicles, boats and pedestrians have crossed the ridge to gain access to the shore, and where shingle has been moved from the ridge crest to create the car park and possible for other uses elsewhere. Observational and photographic evidence indicates that both low areas have experienced over-washing during numerous storm events since the 1960s, including in 1990, 2010, 2013, 2014 and January 2018.

The likelihood of barrier over-washing is dependent on the coincidence of energetic waves and relatively high still water levels. High wave energy waves have capacity for greater run-up, potentially overtopping the barrier crest, than lower energy waves. Wave energy in turn, reflects both wave height and wave period (related to wave speed). No long-term inshore wave data exist for inner Cemlyn Bay and assessment can therefore only be made on the basis of consideration of modelled data for both offshore and inshore areas (see below).

The frequency and magnitude of over-washing events are important in terms of the degree of surface mobility of the barrier sediment, and hence the impact on vegetation communities, and also the long-term rate of landward movement of the ridge. Based on evidence from historical maps, aerial photographs and ground features, Pye & Blott (2010) estimated that the central part of the barrier crest has moved landwards at an average rate of 0.1 - 0.2 m / yr over the past 70 – 80 years, and suggested that the barrier could recede by a further 3.4 to 8.1 m by 2100, allowing for the effects of climate change and sea level rise forecast by UKCP09. Rees (2018) has recently suggested that the distance travelled by over-wash lobes into the lagoon may have increased since 1978 since the water levels maintained in the lagoon, which control the lateral spread of over-washed shingle, are now lower than in the 1930s –70s period.

Accelerated landward movement of the barrier and lowering of the crest height relative to high tide levels would pose a significant threat to the tern / gull islands in the medium to longer term, and a potentially catastrophic event, leading to large-scale over-washing and possible breaching of low sections of the barrier, could occur at any time, even under present sea level conditions. More frequent over-washing of the low section of ridge to the northwest of the tern islands would also increase the risk of blockage of the inlet close to the sluice.

There is apparently very little supply of new gravel-size sediment to Cemlyn Bay at the present day. The shingle ridge was probably formed many tens or hundreds of metres seaward of its present position early in the early to mid-Holocene as rising sea levels and waves reworked sea floor sediments derived largely from glacial and glacial outwash deposits. Given the very restricted supply of new sediment, and the generally level, low-lying nature of the lagoon floor, it is very unlikely that the barrier crest and cross-sectional area will remain constant in relation to the upwardly moving tidal frame, and hence the frequency and severity of over-wash events are likely to increase. Within minimal intervention, there is a strong possibility that the open water channel between the ridge and the islands will be eliminated, increasing the risk posed by predators to breeding birds. Additionally, without any modification to the sluice, an increase in MSL of 10 – 60 cm would cause a significant increase in maximum water levels in the lagoon, leading to potential drowning and erosion of the tern islands.

3.0 Impact of previous storms on the shingle ridge and management response

Historical aerial photographs and the present-day morphology of the shingle ridge (see Appendix 1) show clear evidence of past over-washing events, during which waves and sediment pass over the ridge crest and form depositional lobes on the landward side. These over-wash features are best developed near the north-western end of the ridge and just to the west of the eastern car park where the ridge crest in un-naturally low due to artificial removal of shingle around the beach access point. Historical photographs from the 1940s to 2000s period provide evidence of waves reaching and over-topping the ridge crest in these areas, which remain largely bare of vegetation to frequent sediment mobilization. Significant fresh-looking over-wash lobes are evident on the 1948 aerial photography at the north-western end of the barrier and may partly reflect the effect of construction of the by-pass channel and tern islands. However, this part of the barrier appears to have been low for a longer period, possibly due to the effects of very large historical storms and/or the nature of wave of the modal waves which affect this part of the barrier. As noted above, the beach access area adjacent to the eastern car park provides another weak point which has been over-washed on numerous occasions. Over-washed shingle lobes are evident within the eastern car park on the 1972 aerial photography, possibly indicating failure of the wall on the seaward side of the car park. During storms in February1990, waves transported a significant volume of water and sediment across the ridge and down the approach road to the eastern car park. Some of this material was returned to the beach, but anecdotal evidence suggests that some was removed from the area and used for local construction purposes. Large-scale bull-dozing to raise the ridge crest following storms appears not to have been undertaken, although relatively small amounts of sediment have been moved on occasions from the back-side of the ridge onto the ridge crest to maintain the shallow open water channel separating the tern islands from the ridge.

4.0 Analysis of hind-cast offshore wave data

No wave measurements have been undertaken (or at least reported) within inner Cemlyn Bay, and only short term wave data have been collected (mainly since 2010) near the entrance to the Bay and off Wylfa Head as part of the Wylfa Newydd studies. However, an indication of offshore wave conditions in the area is provided by hind-cast modelled wave data for the period 1980-2016 available on the Wavenet Hindcast website, funded by the Environment Agency and hosted by CEFAS. This service supplies hindcast wave parameters at numerous offshore points around the British Isles, calculated using the Met Office UK Waters Wave Model, at three-hourly intervals for the years 1980 to 2000, and at hourly-intervals for the years 2001 onwards. The parameters supplied include significant wave height, wave direction, directional spread, and the mean, peak and zero up-crossing wave periods. A summary of the hindcast data for significant wave height, zero up-crossing period and wave power averaged over this period at the offshore model grid point (1464) closest to Cemlyn Bay (location shown on Figure 2) is provided in Table 5. The average hindcast wave rose for this point is shown in Figure 3 and the frequencies of occurrence of waves of different height, direction, zero-up crossing period and wave power are shown in Figures 4 – 7. Large offshore waves from the NNW, N and NNE can enter Cemlyn Bay directly with relatively little refraction and energy dissipation but are relatively rare. The largest values of hindcast significant wave height (H_s>5 m) at Point 1464 are most commonly associated with SW, W and NW wave approach directions; those approaching from the N and NE typically have H_s <4.7 m and during the period of record have rarely associated with very high still water levels (Table 6). The largest hindcast waves occurred during storms on 12 February 2014, 9 December 1993, 27 December 2013, 6 January 1991 and 12 March 2008 (Table 6; Figure 8). In general, the highest waves are also associated with relatively larger zero up-crossing periods (T_{0z}) of 6 – 8 seconds (Figure 9). However, these values are for offshore waves and waves entering Cemlyn Bay lose much of their energy due to shoaling and refraction before they reach the shingle barrier.

A marked seasonal variation in wave energy (and wave power) is evident over the period of hind-cast record, 'winter' being defined here as the months October to March and 'summer' as the period April to September (Figure 10). The winters of 2013-14, 2015-16, 1982-83, 1989-90, 1983-84, 2011-12 and 2006-07 stand out as being particularly energetic. A much weaker seasonal pattern is apparent in average wave direction (all waves) and average wave direction scaled for wave power (Figures 11 & 12). The average seasonal approach direction for all waves at offshore point 1464 mostly ranges between 220^o and 240^{o,} while the average approach direction for waves scaled by wave power mostly ranges between 250^o and 300^o. However, Figure 12 shows that winter periods with average wave approach direction (scaled for wave power) from the NNW, N and NNE (340^o to 25^o) are not uncommon.

Sediment movement and morphological change on the shingle ridge, including over-washing of the crest, is most likely when large waves from the NNW, N or NNE coincide with high water levels. Given the relatively large tidal range in the area, such conditions may only occur for a relatively short time period (2 to 4 hours). By way of example, Figure 13 shows the time-relation between hind-cast offshore wave conditions and water level during the stormy period of 26 – 27 February 1990. On 26 February 1990 the maximum water level of 3.48 m recorded at Holyhead coincided with offshore waves with Hs >4.0, T_z of 6 s and approach direction of 260^o. A further high still water level at Holyhead of 3.12 m ODN on 27 February coincided with waves at offshore Point 1464 of H_s >4.2 m, T_z of 6 s and approach direction of 283^o (Figure 14). Some wave over-washing of parts of the Cemlyn shingle barrier occurred during both tides but would have been considerably greater had the offshore wave approach direction been more northerly / northeasterly. On 13 February 2005, waves of H_s = 4 m, T_z 6 s and approach direction of 340^o occurred but in combination with a lower still water level (2.5 m ODN at Holyhead (Figure 15). Larger waves (H_s = 5 m and T_z = 7 s) occurred on 27 December 2013 but had an approach direction of 257^o coincident with the time of high water (2.5 m ODN) at Holyhead. Large waves (H_s > 5 m, T_z = 7.1 s) with an approach direction of 278^o also occurred on 12 February 2014 but again did not coincide with maximum high water (Figure 16). Hence neither of these events caused significant over-washing at Cemlyn.

Figures 17 & 18 illustrate a condition on 27 November 2010 of waves approaching Cemlyn Bay form the northeast, close to the angle of the axis of the Bay. The approach direction recorded at offshore point 1464 around the time of the LiDAR overflight changed from NNW through N to NNE, and at the time of overflight was very close to the central axis of Cemlyn Bay. On this occasion the maximum H_s was approximately 1.1 m and the maximum T_z approximately 3.5 s (Figure 19). A degree of refraction and spreading of approaching wave crests into Porth-y-pystll and Cemlyn Bay is clearly evident in Figures 17 & 18. Larger wave events from this direction, coincident with high still water levels, are relatively rare.

5.0 Wave modelling

In order to provide further insight into wave conditions within Cemlyn Bay, modelling was undertaken using the DHI MIKE21 SW, Delft SwanOne and XBeach-G models. For use in the modelling a composite bathymetric digital elevation model (DEM) was constructed using the 2010 LiDAR topographic survey data, bathymetric data collected by Triton Surveys and the Royal Navy in 2010 and 2013, respectively, and older bathymetric data for the offshore area taken from digitized Admiralty charts (Figures 20 – 23). In the offshore area, spot heights were taken from the Admiralty Chart fair sheet produced during the 1987 survey (digitized by the Environment Agency and made available on the UKHO INSPIRE website portal). Within the headlands of the bay, data from the 2013 Royal Navy multi-beam survey were used. This survey composed of hundreds of thousands of individual points, and to speed the eventual bathymetry gridding process, semi random points were taken across the bay at a spacing a little higher than for the 1987 offshore area. Within 500 m of the beach, data points were extracted from the depth contours on the 2009 and 2011 surveys by Triton Surveys. The MIKE Mesh Generator was then used to generate a flexible mesh across the area, with sufficient resolution to model the expected wave field but also to allow an efficient model run time.

Wave parameters at the model boundaries were taken as follows: H_s = 4.0 m; T_p = 8 s; wave spread of 5^o; mean wave approach direction = 270^o to 90^o in 10^o increments, with a spread of 5^o. Although not corresponding to the worst conditions hindcast at Point 1464 (Table 5, which included a maximum H_s of 6.59 m), the selected values represent a significant storm event. A static water level (4.00 m ODN) just above the level of HAT in Cemlyn Bay was assumed, with no wind forcing, currents or ice coverage.

The results of this modelling exercise are presented in plan form in Figures 24 – 42. In addition, significant wave height (H_s), peak wave period (T_p), wave direction and wave power were calculated at three inshore points near the shingle ridge (shown in Figure 43). The results are summarized in Table 7. Inshore H_s showed a general tendency to increase from northwest (location 1) to southeast (location 3) when offshore wave approach direction ranges between 270^o and 350^o (W to NNW). Under such conditions values of H_s within Cemlyn Bay are relatively small but T_p is relatively large, indicating low steepness waves which will tend to cause surging breakers and forward movement of sediment up the seaward face of the ridge towards the crest, potentially leading to overtopping by the largest low frequency waves.

In the case of waves at the model boundary with approach angles of 360^o to 90^o (N to E) there is a reverse trend with relatively higher waves at the north-western end of the barrier. The highest inshore waves are indicated at locations 1 and 2 when waves approach from the NE (20^o – 50^o). Although H_s is relatively large, T_p is relatively smaller than for NW waves, resulting in greater wave steepness and wave power which are more likely to cause erosion of the beach face and seaward movement of sediment. However, if erosion of the upper beach face is sufficient to cause localised breaching of the ridge crest, over-washing may occur through the ‘throats’ so-created. The risk of overtopping versus erosional breaching is governed to a large degree by the joint probability of still water level, wave height and wave period, and several different combinations of these factors may create the same degree of likelihood of wave over-washing. By way of example, the XBeach-G Modelling results summarised in Figure 44 indicate that, with a still water level of 4.0 m ODN, a combination of nearshore T_p = 7 s and H_s of 1.0 m would be sufficient to cause over-washing at Point 1. With a still water level of 3.0 m ODN and nearshore T_p of 7 s, waves with H_s of about 1.7 m would be required for over-washing. In practice, the risk of overtopping or breaching is also influenced by other factors at the time of a water level / wave event, such as cross-shore and alongshore variation in particle size distribution, shape and packing (and hence hydraulic conductivity), beach water table levels and groundwater pressures which are sometimes related to the presence or otherwise of an impermeable fine-grained ‘core’ within the gravel barrier structure.

Tables 8 and 9 provide an indication of the likely combined effects of historical high water levels and coincident modelled wave conditions at Hindcast Point 1464 and Point 2 within Cemlyn Bay, respectively. These tables are indicative in that they only show a simple addition of recorded / estimated still water levels and time-equivalent modelled H_s values. There are significant differences in the ranking of events between the two locations, reflecting the differences in exposure to wave conditions. For inner Cemlyn Bay, the highest ‘combined’ events are indicated to have occurred on (1) 31 March 2010, (2) 9 December 1990, (3) 12 February 2014, (4) 2 November 2013, (5) 9 December 1993, (6) 27 December 2013 and (7) 13 January 2004 . Events (3), (5) and (6) are notable in having large values (>10 s) of peak wave period (T_p) at the hindcast point and are therefore likely to have favoured high wave run-up and potential for overtopping of the shingle ridge. It should be noted, however, that during each of these events the wave height and wave period characteristics are likely to have varied around the Bay, dependent on the offshore wave approach direction which itself may have varied during the course of an individual storm.

6.0 LiDAR analysis: barrier morphology and sediment volumes

6.1 Shingle ridge morphology

The Cemlyn shingle ridge has greatest width towards its eastern end. The width is smallest and the elevation lowest between profile lines P8 and P10 shown on Figures 45 & 46 (opposite the tern nesting islands). The alongshore variation in width, cross-sectional area and crest height of the ridge imply a long term net drift of sediment towards the southeastern corner of the Bay, and to a lesser extent in a northwesterly direction towards the entrance to the tidal inlet. The existence of the low, narrow ‘neck’ in the north-central part of the ridge probably mainly reflects the fact that this area is an area of long-term net alongshore sediment transport divergence, but may also in part reflect a degree of wave focussing onto this part of the barrier arising from the intertidal rock platform to the north.

In order to evaluate short-term changes in the morphology of the barrier, digital elevation models based on airborne LiDAR surveys in November 2010 (1m resolution) and May 2017 (50 cm resolution) were compared. Both data sets were reportedly filtered (i.e. algorithms used to 'remove' buildings, other structures and trees), but the filtering process was evidently more effective in the case of the 2017 data set. The relative accuracy of the two surveys was assessed by comparison with 17 points measured by KPAL personnel along the tarmac road at the south-eastern end of the barrier using RTK ground surveying equipment on 1st February 2016. This showed a very good agreement between the 2010 LiDAR survey and the RTK survey (the LiDAR being 0 to 1cm higher than the RTK survey, on average), while the 2017 LiDAR was 2 to 3 cm higher than the RTK, on average. Elevation data for two areas of generally level ground (the large tern nesting island and the eastern car park) were initially compared and indicated only small relative differences, well within the generally accepted error limits for airborne LiDAR surveys (Table 10). The results of the 2017 survey for these two areas indicated mean elevation values 2 cm higher than the 2010 survey, an on this basis the data for the 2017 survey were adjusted downwards by this amount prior to further analysis being undertaken.

The present (May 2017) morphology of the barrier was quantified in terms of the maximum crest elevation, barrier width and 3.0 m ODN and cross-sectional area at each of the 13 profile locations shown in Figure 45. The lowest crest elevations (4.45 – 4.54 m ODN) were recorded at profiles 11 and 12, while the minimum barrier width and cross-sectional areas were recorded at profiles 9 and 10. A second low point occurs at Profiles 1 and 2, by the eastern car park, but the barrier width and cross-sectional area are large. The risk of barrier over-washing and/or breaching is therefore greatest between Profiles 9 and 12.

An elevation difference map between the 2010 and 2017 surveys is presented in Figure 47. Some of the apparent differences in elevation relate to the fact that the 2010 survey data are 'unfiltered' (i.e. artefacts such as structures and large bushes have not been removed by the data processing algorithms while the 2017 survey data are 'filtered'. The filtering process also cannot remove all differences due to different vegetation growth states at different times of the year, or variations in the lagoon area which are due to varying water levels and degree of margin sediment exposure at the time of the two surveys (the return Lidar signal is largely reflected off a water surface). However, the difference map does show significant 'real' changes in the elevation of the beach between the two surveys. Notable differences are (a) a net erosion of the upper beach and recession of low cliff let at the top of the beach, associated with net slight lowering or no change on the lower beach between profiles P2 and P6, (b) net accumulation of sediment on the lower beach at the extreme eastern end between profiles P1 and P3, (c) marked reduction in elevation of the lower part of the beach between profiles P5 and P13, (d) net increase in levels due to sediment accretion on the upper beach between profiles P6 and P13, being least marked between P8 and P9 and most marked between P10 and P13; (e) increase in levels on the lagoon side of the ridge around profiles P11 and P12, apparently due to over-wash. More detailed information regarding the changes at individual profile locations, and in the level of the barrier crest overall, is provided in Figure 48. Interestingly, Figure 48n demonstrates a significant increase in the height of the crest between profile P6 and P12 on account of sediment deposition after November 2010. At profiles P11 and P12, where the ridge crest was lowest in November 2010, over-washing during the 2013-14 winter resulted in the deposition of significant quantities of gravel in the form of lobes extending into the lagoon (Figure 48 l).

6.2 Sediment volumes in 2010 and 2017

Quantification of sediment volumes in twenty seven 'cells', each 30 m wide, along the barrier was also undertaken using the Golden Software GIS package Surfer™ . The two LiDAR surveys were first converted to a common 1 m resolution grid for comparability. The Grid|Blank command was then used to exclude areas below 3 m OD on either side of the barrier, this level being just above the water level of the Cemlyn Lagoon at the time of the surveys and Visual Basic macros used to calculate the volumes of sediment above the base level of 3.00 m ODN and tidal levels of 3.79 m ODN (HAT level), 4.25 m ODN (the level of the 1 in 200 year surge event suggested by McMillan *et al*., 2011), and 5.00 m ODN (an extreme tidal level with wave run-up). The volumes were calculated separately seaward and landward of the barrier crest, and summed for the whole barrier (Tables 12 to 15). In Both 2010 and 2017 the sediment volume of the barrier above 3.00 m ODN was greatest in cell 23 and showed a progressive reduction towards the northwest, reaching a minimum in cells 7 & 8 (Figures 49 – 52). Cells 20 to 22 showed a small net reduction in sediment volume over the period, with small gains in all other cells (the largest gains being in cells 5, 6 & 7)

Figure 55 shows that the western two-thirds of the barrier gained in sediment volume above 3.00 m ODN between 2010 and 2017, with maximum gain in cell 5. The eastern section, particularly cells 20 to 23, lost some volume above 3.00 m ODN over this period. A broadly similar pattern of change is evident in volumes above 3.79 m ODN (HAT) and above 4.25 m ODN, but with all cells south of cell 18 losing sediment volume; in large part this was due to erosion of the upper beach and seaward side of the barrier crest. Cells 9 to 19, along the central part of the barrier, showed a gain in sediment volume above 5.00 m ODN, apparently due to waves transporting sediment landward and raising the crest level but without significant over-washing and deposition on the lagoon-ward slope.

6.3 Potential increase in barrier volume to reduce over-wash risk

Despite the increase barrier crest height and sediment volume along the central and northern parts of the barrier since 2010, the lowest and narrowest parts of the ridge remain vulnerable to over-washing. As noted previously in this report, this is of concern principally opposite the tern nesting islands where there is a risk that the shallow channel separating the islands from the main ridge could be completely occluded, allowing greater access for predators during the breeding season, and close to the lagoon side of the weir / sluice where there is a risk that over-washing of the low ridge could block flow to and from the sluice.

In order to inform decisions about the possible future management of these risks, an initial assessment has been made into the possibility of increasing the width and elevation (and hence the sediment volume) of the barrier. In this assessment, an assumption was made to raise the barrier crest to reach a sloping line varying from 5.7 m ODN at the extreme southeastern end of the barrier to 5.2 m ODN at the northwestern end (Figure 59). This line intersects the present crest elevation between profiles P4 and P8 which has not been over-washed significantly in the period of known record. The mean seaward and landward slopes of the apparently ‘stable’ section of the barrier between cells 12 and 15 were taken as minimum gradients for the idealised ‘target’ barrier morphology (Figure 60). Figures 61 and 62 show details of the present (May 2017) barrier morphology at the northern and southern ends of the barrier where the lowest points exist, while Figures 63 and 64 show the equivalent ‘target’ barrier morphology for these areas. The crestline has been set back up to 3 metres in Cells 7 to 9, and up to 6 m in cells 3 to 5, to maintain a gradual curve in the plan form of the barrier crest along this section of the barrier. This setback, and the maintenance of the minimum front and rear slope angles, means that the rear toe of the barrier would need to move into the lagoon, the shore moving up to 8 m landwards between cells 6 to 10. In developing the ‘target’ morphology, the eastern car park and its protective wall have been removed, since these features presently are located too far to seaward of the equilibrium barrier crest alignment (Pye & Blott, 2010). Figures 65 and 66 show the additional thicknss of sediment required to achieve the idealised ‘target’ barrier morphology (compared to 2017 levels). Note that no parts of the barrier which are currently above the ‘target’ morphology have been lowered, and it is assumed that these areas will not be re-profiled, or act as sacrificial sources of sediment for lower areas. Table 16 shows the volumes of gravel required in each of the 27 cells, and for the barrier as a whole, to attain the ‘target’ morphology. In total, c. 5100 m^3 of gravel would be required to achieve the idealised ‘target’ barrier morphology.

In order to take into account potential future sea level rise (cf. Table 4) and provide longer term resilience against over-washing, it could be argued that the whole barrier should be built to a higher level. Table 16 therefore also provides a summary of the volumes of additional gravel which would be required to maintain the same barrier morphology adjusted for illustrative future higher mean sea level allowances of 22 cm, 26 cm, 31.8 cm and 37.5 cm. Respectively, these scenarios would require the addition of approximately 13450, 14970, 17170 and 19330 m^3 of gravel to the present barrier morphology.

It should be noted that, if the barrier was raised and locally widened to attain the ‘target’ morphology suggested above, there is no guarantee that all sections of the barrier would maintain this morphology. The upper beach face is naturally dynamic, and both cross-shore and along-shore re-distribution of sediment would be expected, especially towards the northwestern end of the barrier when the beach below 3.00 m ODN is relatively narrow and the foreshore consist in large part of a rock platform covered by a thin veneer of sediment.

6.4 Potential increases in sediment volume of the tern islands

Consideration has been given to possible enlargement of the tern nesting islands in the lagoon. Several options exist:

- full re-instatement of the original design areas of the two islands (Main Island and New Island) by infilling of the eroded channels and depressions within the perimeter walls, maintaining the present level (some infilling work has been undertaken as part of the Roseate Tern *Life* project during the 2017-18 winter, but more work could be done)
- as above but also raising of the levels of the existing retaining walls and ground island surfaces by allowances for projected sea level rise
- extension of the existing islands into the lagoon while retaining the present seaward boundary, maintaining the present ground surface level
- as above, but also raising level of the islands (and potentially the boundary walls) to allow for sea level rise
- extension of the islands into the lagoon, maintaining present levels, but also removal and re-use of sediment from the barrier side in order to widen the channel and crest space for the barrier to move westwards has the barrier moves landward
- as above, but raising the islands to allow for sea level rise.

Figure 67 illustrates possible landward extension of the two tern islands without removal of any sediment from their eastern ends, while Figure 68 illustrates a scenario where the islands have been moved further into the lagoon along the alignment of the former saltmarsh islands shown on the 1826 and 1926 Ordnance Survey maps, thereby creating a wider channel between the islands and the shingle ridge.

Table 17 shows the volumes of additional sediment which would be required to (a) raise the level of the islands to keep pace with increases in lagoon water level indexed for sea level rise, and (b) to extend the islands landward to the lagoon to match approximately the mid-1920s footprint. To raise both islands by 37.5 cm while retaining the present footprint would require approximately 2250 m^3 of sediment. To increase the area of the Main Island and to raise it by 37.5 cm would require approximately 7243 m^3 of sediment, while a similar extension / raising of the New Island would require 5249 m^3 of sediment.

7.0 Conclusions and recommendations

Parts of the Esgair shingle ridge presently experience over-washing when high tides coincide with waves of sufficient height and period to create run-up which can pass over the crest of the ridge and/or lower the crest level locally through erosion. Different combinations of still water level, wave height and wave period can be responsible for such occurrences. Meteorological surges associated with the passage of low pressure centres are important in raising the observed high water levels by up to approximately a metre (occasionally more). At such times large waves typically approach the area offshore from Cemlyn from the southwest, west or northwest, and are refracted into Cemlyn Bay. As they enter the Bay they lose energy due to refraction and shoaling, such that wave heights and period close to the shore are considerably smaller than offshore. Nevertheless, the height and period of the largest 1% of waves, if coincident with high a still water level of 3.2 m or more, may be sufficient to cause over-washing of the lower parts of the barrier (<4.8 m ODN). Larger waves can be experienced near the shoreline when the offshore approach direction is from the north to northeast quadrant, but such waves occur less frequently and even more rarely in association with high water of surge tides. Wave approach angle at the entrance to Cemlyn Bay exerts an important influence on the along-shore variation in wave conditions experienced at the beach, and therefore on the likely impact of the waves on sediment transport and beach morphology (i.e. whether they move sediment landwards towards the crest or over the crest, or erode it from the beach face and move it seaward). In general, offshore wave approaching from the W and NW generate higher wave energy conditions in eastern Cemlyn Bay, while offshore waves approaching from the NE and E generate higher energy conditions in the western part of the Bay. During any given storm the likelihood of over-washing at any particular point along the ridge is governed by a combination of the local wave conditions, the elevation and cross-sectional area of the upper part of the ridge, and the degree of stability of the surface sediment (e.g. whether or not it is vegetated). At the present time there are two areas where the ridge crest is relatively low and there is a high risk of over-washing: (a) between the tern nesting islands and the southern end of the tidal inlet, and (b) near the eastern car park. These risks are likely to increase in future due to sea level rise and could be exacerbated by a change in storm surge frequency / magnitude or offshore wind/wave conditions.

The capability of the Esgair Cemlyn shingle ridge to retain constant morphology and crest height relative to the tidal frame and storm surge levels in the face of potential future sea level rise will be limited by low rates of new sediment supply and the low-lying, relatively level nature of the lagoon floor over which it must migrate. As such, the risk of over-washing, blockage of the existing lagoon inlet / outlet and potential breaching will increase over time. The risk of closure of the channel separating the shingle ridge from the tern nesting islands will also increase over time.

One possible way to address this problem would be to increase the volume of the shingle ridge using suitable imported sediment. If undertaken, natural marine, or similar rounded natural sedimentary gravel from an onshore source, should be used rather than angular / sub-angular quarried rock out of keeping with the natural material found on the ridge. The sediment volume required to create a uniform sloping ridge, ranging in crest elevation from 5.7 m ODN in the east to 5.2 m ODN at the northwest end, would be relatively small (approximately 5100 m^3), since the main works required would be to infill low points on the present shingle ridge to the northwest of the tern nesting islands and near the eastern car park. To increase the height crest height of the ridge by a sea level rise allowance of 37.5 cm, while maintaining the same average seaward and landward gradients, would require an additional 19332 m^3 of sediment.

The larger of the two tern nesting islands has experienced significant marginal and internal erosion such that the present ground area available for nesting and roosting is considerably smaller than that during the 1960s. Approximately 50 tons (c. 37 m^3) of crushed rock has recently been placed within one of the eroded areas as part of the Roseate Tern *Life* project, but this is relatively minor compared with the total volume of approximately 1000 m^3 which would be required to completely infill the eroded areas and raise the island to a uniform level of 2.80 m within the footprint of the surrounding brick skirt. To infill the eroded areas and raise the entire island level by 37.5 cm within this footprint would require approximately 2975 m^3 of additional sediment. If the area of both nesting islands is extended beyond the boundaries originally created (as illustrated in Figure 68), additional sediment would be required (up to 8330 m^3 for the Main Island and 5250m^3 for the New Island in the example used in this study).

The feasibility of sourcing practically useful volumes of shingle from the Horizon marine works or other sources requires further detailed study.

Assessment of processes affecting the shingle ridge and Cemlyn Lagoon is presently hampered by a lack of measured still water level data in the inner part of the Bay and in the Lagoon. It is recommended that portable tide gauges are installed at two locations (one outside the lagoon and one inside) and over two neap –spring tidal cycles to rectify this situation.

Assessment is also hampered by an absence of measured nearshore wave data close to the ridge which can be used to calibrate and validate numerical wave models. The preliminary wave modelling reported in this initial assessment has not been validated by field data and should be treated as indicative only. It is therefore recommended that at least one wave monitoring device should be installed within inner Cemlyn Bay for a minimum period of 30 days, and ideally much longer.

Currently there is limited information about water depths in Cemlyn Lagoon and it is therefore recommended that depth should be determined at a number of grid points across the Lagoon to assist accurate volume and potential discharge calculations. There is also a requirement for additional nearshore bathymetric data in Cemlyn Bay close to the shingle ridge. It is therefore recommended that a ground RTK GPS topography survey of the beach should be undertaken on a low spring tide (combined with sampling of sediments of laboratory analysis), or single beam or multi-beam acoustic bathymetric survey is undertaken off the beach at a time of high water.

8.0 References

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Tables

Table 1. Predicted tidal levels at Holyhead and Cemaes Bay quoted by NTSLF and Admiralty Tide Tables (UKHO, 2015). Elevations are expressed in m above Chart Datum, and then converted to Ordnance Datum Newlyn using conversion factors quoted on NTSLF website and Admiralty Tide Tables. MHW and MLW (in brackets) are obtained by averaging the spring and neap levels. LAT at Cemaes Bay is obtained by extrapolating the linear trend between MLWN and MLWS. Values for Cemlyn Bay are estimated, assuming the relative distances to Holyhead (82%) and Cemaes Bay (18%).

	Holyhead		**Cemaes Bay**	**Cemlyn Bay**
	NTSLF predictions 2008-2026 (NTSLF website)	Admiralty predictions 1988-2006 (2016 Tide Tables)	Admiralty predictions 1988-2006 (2016 Tide Tables)	Estimate
Values expressed relative to local Chart Datum				
HAT	6.33	6.3	7.50	
MHWS	5.66	5.6	6.6	
MHW	no data	no data	no data	
MHWN	4.51	4.4	5.1	
MSL	no data	3.27	3.67	
MLWN	2.02	2.0	2.3	
MLW	no data	no data	no data	
MLWS	0.71	0.7	0.8	
LAT	0.00	0.0	no data	
OD	3.05	3.05	3.60	
Values expressed relative to Ordnance Datum (Newlyn)				
HAT	3.28	3.25	3.90	3.79
MHWS	2.61	2.55	3.00	2.92
MHW	(2.11)	(1.95)	(2.25)	2.20
MHWN	1.46	1.35	1.50	1.47
MSL	(0.24)	0.22	0.07	0.10
MLWN	-1.03	-1.05	-1.30	-1.26
MLW	(-1.69)	(-1.70)	(-2.05)	-1.99
MLWS	-2.34	-2.35	-2.80	-2.72
LAT	-3.05	-3.05	(-3.61)	-3.51
MTR	(3.80)	(3.65)	(4.30)	4.19
MSR	4.95	4.90	5.80	5.64
MNR	2.49	2.40	2.80	2.73

Table 2. Return periods of extreme high water levels at Cemlyn Bay and nearby locations, estimated by McMillan et al (2011).

Return Period (years)	Holyhead (Chainage 1014)	Cemlyn Bay (Chainage 1030)	Wylfa Head (Chainage 1032)	Cemaes Bay (Chainage 1034)
1	3.40 ± 0.1	3.70 ± 0.1	3.73 ± 0.1	3.81 ± 0.1
2	3.47 ± 0.1	3.78 ± 0.1	3.81 ± 0.1	3.89 ± 0.1
5	3.57 ± 0.1	3.88 ± 0.1	3.92 ± 0.1	4.00 ± 0.1
10	3.65 ± 0.1	3.95 ± 0.1	3.99 ± 0.1	4.07 ± 0.1
20	3.72 ± 0.1	4.03 ± 0.1	4.07 ± 0.1	4.14 ± 0.1
25	3.74 ± 0.1	4.05 ± 0.1	4.09 ± 0.1	4.16 ± 0.1
50	3.81 ± 0.1	4.12 ± 0.1	4.16 ± 0.1	4.23 ± 0.1
75	3.84 ± 0.1	4.15 ± 0.1	4.19 ± 0.1	4.27 ± 0.1
100	3.87 ± 0.2	4.19 ± 0.2	4.23 ± 0.2	4.30 ± 0.2
150	3.91 ± 0.2	4.23 ± 0.2	4.27 ± 0.2	4.34 ± 0.2
200	3.93 ± 0.2	4.25 ± 0.2	4.29 ± 0.2	4.36 ± 0.2
250	3.95 ± 0.2	4.27 ± 0.2	4.31 ± 0.2	4.38 ± 0.2
300	3.97 ± 0.2	4.29 ± 0.2	4.33 ± 0.2	4.40 ± 0.2
500	4.02 ± 0.2	4.34 ± 0.2	4.38 ± 0.2	4.45 ± 0.2
1000	4.07 ± 0.3	4.39 ± 0.3	4.43 ± 0.3	4.50 ± 0.3
10000	4.26 ± 0.3	4.56 ± 0.3	4.59 ± 0.3	4.67 ± 0.3

Table 3. The highest 50 water levels recorded at Holyhead during the period January 1964 to January 2018, with the surge residual at the time of observed high water and the skew surge recorded at Holyhead. Original data source: NTSLF.

Date and time	Observed level at Holyhead (m OD)	Surge residual (m)	Skew surge (m)
01/02/2002 12:45	3.81	0.88	0.88
03/01/2014 11:45	3.78	0.69	0.64
10/02/1997 12:15	3.63	0.46	0.46
12/12/2000 23:30	3.59	0.88	0.79
04/01/2018 11:53	3.56	no data	0.51
03/02/2014 12:30	3.56	0.50	0.49
23/12/1999 22:45	3.55	0.65	0.65
30/03/2006 10:45	3.54	0.44	0.44
10/03/2008 12:00	3.53	0.59	0.59
06/01/2014 14:00	3.51	0.77	0.77
08/10/2006 23:00	3.50	0.29	0.29
05/12/2013 11:45	3.50	0.49	0.48
01/02/2014 11:30	3.49	0.35	0.30
26/02/1990 11:00	3.48	0.63	0.63
07/10/1987 22:00	3.44	0.43	0.43
10/03/2001 10:45	3.43	0.42	0.42
02/01/2018 22:38	3.43	no data	0.58
20/02/2007 12:00	3.42	0.33	0.33
09/03/1989 11:00	3.42	0.26	0.26
25/12/1999 00:00	3.41	0.63	0.58
17/10/2012 11:15	3.41	0.44	0.42
27/09/1988 23:00	3.40	0.21	0.21
28/10/2015 22:45	3.39	0.21	0.21
07/10/2006 22:15	3.39	0.18	0.18
01/01/1991 23:00	3.39	0.72	0.72
19/02/2007 11:30	3.39	0.34	0.34
29/01/1990 12:00	3.38	0.60	0.60
03/01/1998 13:15	3.38	0.75	0.74
13/12/1981 12:00	3.38	0.57	0.47
15/09/1989 22:00	3.38	0.38	0.38
26/11/1999 12:00	3.38	0.52	0.52
02/03/2014 10:45	3.38	0.24	0.24
27/10/2015 22:00	3.37	0.19	0.19
16/10/1997 22:15	3.37	0.16	0.16
08/09/1998 23:45	3.36	0.26	0.26
25/09/1988 22:00	3.36	0.29	0.29
19/03/1988 11:00	3.36	0.23	0.23
31/03/2006 11:30	3.35	0.29	0.29
26/01/2016 11:45	3.35	0.68	0.68
16/10/2016 22:15	3.35	0.16	0.16
06/11/2014 21:45	3.34	0.45	0.45
08/02/1966 12:00	3.34	0.30	0.30
07/02/1970 11:00	3.34	0.31	0.31
04/01/2014 12:15	3.34	0.21	0.21
07/03/1981 11:00	3.33	0.41	0.41
07/04/1985 11:00	3.33	0.32	0.32
01/02/1983 01:00	3.33	0.79	0.78
08/10/2010 22:30	3.32	0.17	0.17
16/10/1982 22:00	3.32	0.51	0.51
17/10/1997 23:00	3.32	0.13	0.13

Table 4. Predictions of future increases in relative mean sea level (MSL), based on extrapolation of historical linear trends (NTSLF class A tide gauge data for Holyhead), UKCP09 predictions up to 2100 for Cell 18745 (assuming low, medium and high emissions scenarios), Welsh Government (2016) allowances, and Environment Agency (2016) allowances inferred from the H^{++} scenario lower and upper estimates presented in UKCP09. In addition, changes in mean high waters (MHW) are estimated by extrapolating the relative differences in MSL and MHW increases from the historical record (MHW = 1.4434 x MSL). All increases are relative to 2008. The recommendation by the Environment Agency (2016) is the take the UKCP09 95^{th} percentile values of the medium emissions scenario (values in bold), and to only consider upper end of H^{++} estimates where the consequences of rare events would be extreme.

Site	Increase in sea level (cm) relative to a base year of 2008: 50% value of the medium emissions scenario (5-95% range in brackets)		
	2030	2050	2100
Changes in MSL from 2008			
Extrapolation of 1938-2008 trend (2.80 mm/yr)	6.2	11.8	25.8
Extrapolation of 1964-2008 trend (2.26 mm/yr)	5.2	12.3	21.7
Extrapolation of 1980-2008 trend (2.16 mm/yr)	4.8	7.8	19.5
UKCP09 low emissions scenario	5.2 (2.1 - 8.4)	10.9 (4.4 - 17.4)	28.8 (11.5 - 46.2)
UKCP09 medium emissions scenario	6.5 (2.3 - **10.5**)	13.5 (4.9 - **22.0**)	35.6 (12.9 - **58.2**)
UKCP09 high emissions scenario	8.0 (2.8 - 13.2)	16.6 (5.8 - 27.4)	43.9 (15.1 - 72.7)
Welsh Government (2016) allowance	10.0	26.0	86.2
Upper end estimate (EA, 2016)	10.3	24.3	87.3
H++ scenario (EA, 2016)	16.5	41.5	179.5
Changes in MHW from 2008			
Extrapolation of 1964-2008 trend (3.22 mm/yr)	7.1	13.5	29.6
UKCP09 low emissions scenario	7.5 (3.0 - 12.1)	15.7 (6.4 - 25.1)	41.6 (16.6 - 66.7)
UKCP09 medium emissions scenario	9.4 (3.3 - **15.2**)	19.5 (7.1 - **31.8**)	51.4 (18.6 - **84.0**)
UKCP09 high emissions scenario	11.5 (4.0 - 19.1)	24.0 (8.4 - 39.5)	63.4 (21.8 - 104.9)
Welsh Government (2016) allowance	14.4	37.5	124.4
Upper end estimate (EA, 2016)	14.9	35.1	126.0
H++ scenario (EA, 2016)	23.7	59.8	259.0

Table 5. Frequency distribution and maximum and minimum recorded values for significant wave height (Hs), zero up-crossing period (T_z) and wave power, hindcast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

Percentile	Number of 3-hourly observations exceeding Hs value	Hs (metres)	Tz (seconds)	Power (kWm-1)
Min	324351	0.03	1.34	0.0
1	320989	0.08	2.00	0.0
5	307969	0.16	2.25	0.0
10	291910	0.22	2.40	0.1
25	243260	0.39	2.72	0.3
50	162133	0.69	3.18	0.9
75	81012	1.13	3.76	3.0
90	32411	1.70	4.41	7.7
95	16208	2.10	4.84	12.7
99	3237	2.96	5.67	28.4
99.9	323	3.90	7.04	55.1
99.99	33	4.72	8.81	89.6
99.999	3	5.83	11.02	142.4
99.9999	1	6.49	11.22	187.7
Max	0	6.59	11.24	194.4

Table 6. The highest wave events (H_s >4 m), ordered by significant wave height, hindcast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016. H_s: significant wave height; Dir: mean wave direction; T_z: zero up-crossing period; and T_p: peak wave period. Water level and surge residual are taken from the tide gauge at Holyhead. Events shaded grey are dominated by waves approaching from between 330^o and 030^o. Water levels in 1991 and 1993 marked with an asterisk are estimated from Liverpool Gladstone Dock, as the gauges at Holyhead and Llandudno were not working. No water levels are available for the two events in 1986 due to no data at Holyhead, Llandudno, Liverpool Gladstone Dock or Liverpool Princes Pier.

Date	Hs (metres)	Dir (degrees)	Tz (seconds)	Tp (seconds)	Water level (m OD)	Surge residual (m)
12/02/2014 18:00	6.59	265.8	7.28	8.40	1.06	1.03
09/12/1993 00:00	5.83	285.2	6.59	7.75	-1.21*	1.34*
27/12/2013 08:00	5.33	258.8	7.12	8.26	1.58	1.15
06/01/1991 00:00	5.16	277.7	6.85	8.00	1.85	0.68
12/03/2008 05:00	5.10	287.7	6.95	8.55	-0.46	0.71
10/02/1988 00:00	4.78	281.5	6.54	8.47	0.94	0.21
31/03/2010 06:00	4.63	337.7	6.50	8.40	-2.12	-0.13
12/11/2010 00:00	4.60	281.8	6.57	8.85	1.77	0.72
08/12/1990 21:00	4.56	1.7	6.34	8.26	-2.10	-0.45
13/01/2004 09:00	4.52	286.0	6.61	8.47	-0.60	0.49
26/08/1986 12:00	4.51	0.5	6.31	9.43	no data	no data
14/01/1986 18:00	4.45	292.9	6.24	8.13	no data	no data
17/11/2015 21:00	4.43	282.8	6.19	9.09	-0.72	0.47
08/01/1982 18:00	4.41	76.1	5.57	8.33	0.28	-0.10
02/11/2013 21:00	4.40	284.7	6.18	8.33	2.99	0.41
02/03/1984 18:00	4.38	333.4	6.31	8.47	-1.73	-0.27
25/11/2005 17:00	4.37	341.6	6.37	8.85	1.08	-0.39
18/04/2013 03:00	4.36	253.7	6.46	8.47	1.97	0.48
09/10/1981 21:00	4.34	293.0	6.29	8.40	1.41	0.16
16/01/2004 03:00	4.33	300.8	6.30	8.40	1.70	0.42
27/02/1990 12:00	4.33	285.7	5.96	8.62	3.12	0.25
21/11/2016 22:00	4.30	17.5	6.08	10.53	-1.60	-0.20
03/12/2006 15:00	4.28	259.8	6.82	8.70	-1.33	0.55
03/01/2012 20:00	4.24	277.8	5.85	9.35	0.79	-0.02
14/01/1984 12:00	4.22	288.5	5.95	9.01	-0.34	0.54
09/01/2008 05:00	4.19	276.5	6.43	8.77	-1.19	0.48
29/01/2003 06:00	4.18	340.0	6.28	8.40	0.78	-0.53
27/02/2001 17:00	4.17	7.8	6.14	7.87	-1.57	-0.37
06/02/2013 00:00	4.17	332.4	6.06	7.81	-1.54	-0.24
13/12/2011 17:00	4.15	262.9	5.79	8.40	-0.96	0.65
02/12/2002 07:00	4.14	297.5	6.24	10.87	1.93	-0.02
26/12/2004 07:00	4.14	333.4	6.25	8.20	0.21	-0.27
20/11/2013 21:00	4.14	345.1	6.14	8.33	-0.04	-0.55
24/12/2013 15:00	4.13	254.5	6.44	10.31	2.43	0.53
13/02/2005 14:00	4.08	338.9	6.13	11.36	2.14	-0.42
21/10/2014 12:00	4.06	309.4	6.09	11.49	0.05	0.03
20/12/1991 09:00	4.04	294.0	6.06	8.06	2.49*	0.39*
05/01/2012 11:00	4.04	303.2	5.96	8.70	0.06	-0.07
03/01/1984 06:00	4.02	276.0	5.90	8.26	-0.56	0.23
26/02/1990 12:00	4.02	283.9	6.12	8.26	3.48	0.63

Table 7. Significant wave height, peak wave period, direction and estimated wave power at three points positioned approximately 100 m seaward of the Cemlyn barrier, interpolated from MIKE 21 modelling with offshore wave direction varying between 270 and 090 degrees.

Offshore Wave Direction (degrees)	Significant wave height (m)			Peak wave period (s)			Wave direction (degrees)			Wave power ($Jm^{-1}s^{-1}$)		
	1	2	3	1	2	3	1	2	3	1	2	3
270	0.59	0.73	0.78	7.98	7.96	7.88	33.2	12.6	350.6	2.7	4.1	4.6
280	0.70	0.86	0.92	7.88	7.81	7.61	33.2	12.6	350.8	3.7	5.5	6.2
290	0.76	0.94	0.99	7.87	7.81	7.66	33.3	12.7	350.9	4.4	6.6	7.2
300	0.83	1.03	1.07	7.75	7.62	7.36	33.3	12.8	351.1	5.1	7.7	8.1
310	0.93	1.16	1.17	7.64	7.48	7.20	33.3	13.0	331.6	6.3	9.6	9.4
320	0.96	1.20	1.21	7.56	7.37	7.07	33.4	13.1	332.0	6.7	10.2	9.9
330	1.07	1.37	1.32	7.10	6.84	6.62	33.6	14.0	293.0	7.8	12.3	11.0
340	1.10	1.41	1.35	7.19	6.96	6.78	33.8	14.5	275.3	8.3	13.2	11.8
350	1.31	1.67	1.70	6.31	6.30	6.71	35.0	33.7	256.4	10.4	16.8	18.6
360	1.37	1.76	1.76	6.67	6.62	6.72	35.5	35.3	212.6	12.0	19.6	19.9
10	1.69	2.07	1.68	6.32	6.90	6.70	37.4	22.5	103.4	17.3	28.3	18.1
20	1.86	2.15	1.64	6.42	6.90	6.50	37.9	24.4	109.7	21.3	30.5	16.7
30	1.99	2.15	1.53	6.52	6.99	6.37	43.9	28.0	109.1	24.7	30.9	14.3
40	2.19	2.08	1.27	6.41	6.82	6.81	46.1	36.2	80.1	29.4	28.2	10.5
50	2.15	2.02	1.20	6.35	6.71	6.54	47.6	37.0	80.4	28.1	26.2	9.0
60	1.50	1.39	0.73	7.04	7.16	7.18	47.8	34.0	80.8	15.2	13.2	3.7
70	1.36	1.24	0.62	7.13	7.39	7.51	48.4	34.3	80.6	12.6	10.9	2.8
80	0.81	0.68	0.33	7.27	7.54	7.75	48.9	35.3	104.8	4.6	3.3	0.8
90	0.53	0.43	0.21	7.64	7.87	7.94	49.7	36.4	81.0	2.1	1.4	0.3

Table 8. Indicative combination of still water level and wave height in the period 1980-2016: combined levels calculated by adding the still water level recorded at Holyhead and the significant wave height hindcast at offshore point 1494.

Date	Water level at Holyhead (m OD)	Wave parameters at offshore point				Total water level at Holyhead + H_s at offshore point (m)
		Hs (m)	Dir (deg.)	T_z (sec)	T_p (sec)	
15/06/1995 09:00	2.40	5.72	273.0	7.4	10.3	8.11
07/01/1992 00:00	2.35	5.72	273.0	7.4	10.3	8.06
12/04/2006 10:00	2.21	5.72	273.0	7.4	10.3	7.93
11/10/2011 02:00	2.56	5.22	275.2	7.2	9.7	7.77
09/03/2016 07:00	2.54	5.22	275.2	7.2	9.7	7.76
17/09/2013 07:00	2.55	5.19	251.0	6.6	11.0	7.73
24/02/2005 08:00	2.52	5.19	251.0	6.6	11.0	7.70
27/04/2012 01:00	2.46	5.22	275.2	7.2	9.7	7.68
23/10/2016 12:00	2.48	5.19	251.0	6.6	11.0	7.66
18/12/2014 21:00	2.41	5.19	251.0	6.6	11.0	7.60
18/12/2008 11:00	2.38	5.19	251.0	6.6	11.0	7.57
24/11/2007 06:00	2.36	5.16	277.7	6.9	9.4	7.52
06/02/1983 06:00	3.19	4.33	285.7	6.0	8.3	7.52
09/12/1990 00:00	3.48	4.02	283.9	6.1	8.3	7.50
25/02/2002 12:00	2.52	4.96	255.9	7.2	11.1	7.49
03/05/1982 18:00	2.49	4.96	255.9	7.2	11.1	7.46
29/11/2015 12:00	3.12	4.33	285.7	6.0	8.3	7.45
31/03/2010 07:00	3.50	3.91	289.8	5.8	7.8	7.42
19/12/1986 21:00	2.99	4.40	284.7	6.2	8.2	7.40
11/02/2002 17:00	2.30	5.07	257.8	7.2	11.2	7.37
13/02/2005 01:00	2.96	4.40	284.7	6.2	8.2	7.36
06/04/2016 19:00	2.84	4.51	271.8	6.4	8.8	7.36
05/01/1983 00:00	2.37	4.96	255.9	7.2	11.1	7.34
12/02/2014 20:00	3.70	3.64	253.9	6.6	10.3	7.34
02/11/2013 22:00	3.42	3.91	289.8	5.8	7.8	7.34
07/11/2005 14:00	2.26	5.07	257.8	7.2	11.2	7.34
09/12/1993 03:00	3.70	3.64	253.9	6.6	10.3	7.33
30/12/2009 15:00	2.92	4.40	284.7	6.2	8.2	7.33
27/12/2013 09:00	3.69	3.64	253.9	6.6	10.3	7.33
10/04/1983 15:00	2.97	4.34	288.4	6.3	8.4	7.31
13/01/2004 08:00	3.47	3.81	279.3	5.8	7.8	7.28
19/03/2007 04:00	2.94	4.34	288.4	6.3	8.4	7.28
30/04/1980 18:00	2.32	4.94	248.4	6.4	10.5	7.26
19/12/1991 12:00	2.75	4.51	271.8	6.4	8.8	7.26
18/07/2001 21:00	2.51	4.73	275.6	6.9	9.3	7.24
25/11/2005 17:00	3.43	3.81	279.3	5.8	7.8	7.24
12/11/2010 17:00	2.52	4.71	281.2	6.5	9.0	7.23
12/03/2008 03:00	3.55	3.64	253.9	6.6	10.3	7.18
18/09/1989 18:00	2.45	4.73	275.6	6.9	9.3	7.18
12/08/2010 15:00	2.22	4.94	248.4	6.4	10.5	7.16
17/11/2015 22:00	3.34	3.81	279.3	5.8	7.8	7.15
05/12/2015 21:00	3.22	3.91	289.8	5.8	7.8	7.13
26/03/1991 06:00	2.38	4.73	275.6	6.9	9.3	7.11
23/03/1992 18:00	2.77	4.34	288.4	6.3	8.4	7.11
17/04/2012 00:00	2.57	4.51	271.8	6.4	8.8	7.08
11/11/2010 23:00	3.50	3.56	254.3	5.8	9.5	7.06
26/12/1980 06:00	2.89	4.16	268.0	6.2	8.6	7.06
19/12/1983 06:00	2.88	4.16	268.0	6.2	8.6	7.04
03/01/2012 22:00	3.35	3.69	253.1	6.8	10.5	7.03
20/11/2013 22:00	3.34	3.69	253.1	6.8	10.5	7.03

Table 9. Indicative combined of water level and wave height in the period 1980-2016: combined levels calculated by adding the still water level estimated at Cemlyn Bay (using formula CB = 1.216 x HH) - 0.1712), and the significant wave height estimated 100 m seaward of the Cemlyn Barrier (at Point 2) from MIKE21 modelling

Date	Water level at Holyhead (m OD)	Water level at Cemlyn (m OD)	Wave parameters at offshore point				Hs estimated near Cemlyn barrier (m)	Total water level estimated at Cemlyn + Hs estimated at near Cemlyn barrier (m)
			Hs (m)	Dir (deg.)	Tz (sec)	Tp (sec)		
31/03/2010 07:00	3.50	4.09	3.91	289.8	5.8	7.8	0.92	5.01
09/12/1990 00:00	3.48	4.06	4.02	283.9	6.1	8.3	0.89	4.95
12/02/2014 19:00	3.78	4.42	3.43	255.0	6.7	10.4	0.52	4.94
02/11/2013 22:00	3.42	3.99	3.91	289.8	5.8	7.8	0.92	4.91
09/12/1993 03:00	3.70	4.32	3.64	253.9	6.6	10.3	0.54	4.87
27/12/2013 09:00	3.69	4.31	3.64	253.9	6.6	10.3	0.54	4.86
13/01/2004 08:00	3.47	4.05	3.81	279.3	5.8	7.8	0.80	4.85
25/11/2005 17:00	3.43	4.00	3.81	279.3	5.8	7.8	0.80	4.80
06/01/1991 00:00	3.63	4.25	3.20	253.1	6.5	10.5	0.47	4.72
17/11/2015 22:00	3.34	3.89	3.81	279.3	5.8	7.8	0.80	4.69
12/03/2008 03:00	3.55	4.14	3.64	253.9	6.6	10.3	0.54	4.69
06/02/1983 06:00	3.19	3.70	4.33	285.7	6.0	8.3	0.97	4.68
05/12/2015 21:00	3.22	3.74	3.91	289.8	5.8	7.8	0.92	4.66
12/11/2010 00:00	3.51	4.10	3.56	254.3	5.8	9.5	0.54	4.63
10/02/1988 03:00	3.50	4.09	3.43	255.0	6.7	10.4	0.52	4.61
29/11/2015 12:00	3.12	3.62	4.33	285.7	6.0	8.3	0.97	4.60
23/11/2009 02:00	3.11	3.61	3.80	298.6	5.9	7.9	0.97	4.58
23/12/2011 20:00	2.93	3.39	2.39	8.0	4.6	5.9	1.19	4.58
13/03/1994 09:00	2.91	3.37	2.39	8.0	4.6	5.9	1.19	4.56
07/12/2007 20:00	2.90	3.35	2.39	8.0	4.6	5.9	1.19	4.54
17/12/1999 03:00	2.78	3.20	2.06	148.3	5.0	11.2	1.34	4.54
12/04/1999 21:00	3.11	3.61	2.60	336.8	5.5	7.9	0.90	4.51
14/09/1998 21:00	2.42	2.77	3.31	16.0	5.4	7.2	1.74	4.51
11/01/2009 22:00	2.87	3.31	2.39	8.0	4.6	5.9	1.19	4.51
02/12/2002 08:00	3.33	3.88	3.34	269.2	5.6	7.8	0.62	4.50
06/02/2001 20:00	3.10	3.59	2.60	336.8	5.5	7.9	0.90	4.49
27/02/1990 15:00	3.42	3.98	3.30	254.2	6.9	10.9	0.50	4.48
30/12/2015 13:00	3.15	3.66	2.04	57.5	4.6	5.9	0.82	4.47
27/02/2001 19:00	3.33	3.87	3.40	264.6	5.5	7.6	0.59	4.47
25/03/1986 09:00	2.70	3.12	3.94	335.3	6.2	8.5	1.35	4.47
12/11/1998 21:00	3.07	3.56	2.60	336.8	5.5	7.9	0.90	4.46
07/01/2016 01:00	2.38	2.72	3.31	16.0	5.4	7.2	1.74	4.46
26/05/1993 09:00	2.70	3.12	2.06	148.3	5.0	11.2	1.34	4.45
07/12/2006 08:00	2.82	3.26	2.39	8.0	4.6	5.9	1.19	4.45
19/12/1986 21:00	2.99	3.47	4.40	284.7	6.2	8.2	0.98	4.45
14/01/1986 18:00	3.48	4.06	2.03	271.3	5.7	7.4	0.39	4.45
03/01/2012 22:00	3.35	3.90	3.69	253.1	6.8	10.5	0.54	4.44
10/04/1983 15:00	2.97	3.44	4.34	288.4	6.3	8.4	1.00	4.44
22/02/2004 14:00	2.57	2.96	3.00	6.7	5.4	7.1	1.48	4.44
20/11/2013 22:00	3.34	3.89	3.69	253.1	6.8	10.5	0.54	4.44
10/10/1981 00:00	3.30	3.84	3.40	264.6	5.5	7.6	0.59	4.43
20/12/2013 20:00	3.19	3.71	3.48	278.0	5.5	7.6	0.72	4.43
18/04/2013 03:00	3.43	4.00	3.23	246.3	6.0	9.5	0.42	4.42
09/02/1988 15:00	3.37	3.92	3.39	252.6	6.8	10.9	0.50	4.42
04/12/2015 06:00	2.55	2.93	3.00	6.7	5.4	7.1	1.48	4.41
29/01/2003 08:00	3.33	3.88	3.56	254.3	5.8	9.5	0.54	4.41
06/02/2002 15:00	2.74	3.16	3.71	332.5	6.1	8.3	1.25	4.41
26/08/1986 15:00	3.38	3.94	2.78	261.5	5.1	7.2	0.47	4.41
21/02/2016 09:00	2.54	2.92	3.00	6.7	5.4	7.1	1.48	4.41
13/02/2005 01:00	2.96	3.42	4.40	284.7	6.2	8.2	0.98	4.40

Table 10. Comparison of elevations across two relatively areas, measured by the 2010 and 2017 LiDAR surveys: the island in the lagoon towards the western end of the Cemlyn barrier (356 data points), and the car park at the eastern end of the barrier (418 data points). The 2017 LiDAR survey was re-sampled to a 1 m grid to match the preceding 2010 LiDAR survey. All values are in m relative to ODN. On the basis of this comparison, the 2017 survey was lowered by 0.02 m (2 cm), for comparability with the 2010 survey.

	Island (356 points) (m OD)			Eastern car park (418 points) (m OD)		
	2010	2017	Difference	2010	2017	Difference
1%	4.30	4.33	0.03	2.77	2.78	0.01
5%	4.33	4.36	0.03	2.79	2.81	0.02
10%	4.34	4.38	0.04	2.80	2.82	0.02
25%	4.38	4.41	0.03	2.81	2.83	0.02
50%	4.47	4.49	0.02	2.83	2.84	0.01
75%	4.54	4.55	0.01	2.84	2.86	0.02
90%	4.58	4.60	0.02	2.85	2.87	0.02
95%	4.63	4.64	0.01	2.86	2.88	0.02
99%	4.71	4.69	-0.02	2.87	2.90	0.03
Mean	4.47	4.49	0.02	2.83	2.84	0.02

Table11. The crest elevation, width and cross-sectional area of the barrier, above 3.0 m OD, measured along 13 fixed profiles, using data from the 2017 LiDAR survey. The positions of the profiles are shown in Figures 44 – 46.

Profile	Crest elevation (m OD)	Barrier width (m)	Cross-sectional area (m^2)
1	4.66	86.06	62.13
2	4.93	76.89	61.47
3	5.33	53.29	65.44
4	5.50	49.57	61.74
5	5.53	50.32	56.68
6	5.43	37.86	48.17
7	5.40	33.31	40.42
8	5.28	29.12	34.45
9	5.07	22.64	25.80
10	4.93	21.57	23.41
11	4.54	31.07	30.26
12	4.45	38.18	31.84
13	5.09	31.57	31.88

Table 12. Sediment volumes (m^3) within cells along the Cemlyn Barrier, seaward and landward of the barrier crest and for the whole barrier, calculated from LiDAR surveys flown in 2010 and 2017, and change between 2010 and 2017, for the barrier above 3.00 m ODN.

	Seaward of barrier crest			Landward of barrier crest			Whole barrier		
	2010	2017	2010- 2017	2010	2017	2010-2017	2010	2017	2010-2017
1	260	nd	nd	1010	nd	nd	1270	nd	nd
2	380	nd	nd	705	nd	nd	1085	nd	nd
3	276	378	101	401	451	50	677	829	151
4	265	304	39	479	640	161	744	944	200
5	251	299	48	417	659	242	668	957	289
6	303	385	82	310	444	134	613	829	216
7	286	309	23	278	367	89	563	676	112
8	289	282	-7	301	393	91	590	675	85
9	343	335	-8	331	422	92	673	757	84
10	439	381	-58	375	500	125	814	881	67
11	474	436	-38	478	606	128	952	1043	91
12	551	502	-49	518	652	134	1070	1154	85
13	575	534	-41	578	678	100	1152	1212	59
14	541	565	24	627	714	87	1168	1279	110
15	536	560	24	747	810	62	1283	1370	86
16	579	596	17	772	833	61	1352	1429	78
17	616	680	64	878	874	-4	1494	1554	60
18	638	717	79	956	908	-48	1595	1626	31
19	670	750	80	1018	946	-72	1688	1696	8
20	718	741	23	1054	1008	-46	1772	1749	-23
21	694	723	29	1210	1118	-92	1903	1841	-62
22	705	737	33	1205	1133	-72	1909	1870	-39
23	666	826	160	1336	1236	-100	2002	2062	59
24	604	727	122	1273	1198	-75	1877	1924	48
25	526	633	107	1183	1185	3	1709	1819	110
26	227	391	164	1389	1287	-103	1616	1678	62
27	242	nd	nd	1841	nd	nd	2083	nd	nd
Total (3-26)	11773	12792	1019	18113	19062	948	29886	31854	1968

Table 13. Sediment volumes (m^3) within cells along the Cemlyn Barrier, seaward and landward of the barrier crest and for the whole barrier, calculated from LiDAR surveys flown in 2010 and 2017, and change between 2010 and 2017, for the barrier above 3.79 m ODN (the level of highest astronomical tide).

	Seaward of barrier crest			Landward of barrier crest			Whole barrier		
	2010	2017	2010- 2017	2010	2017	2010-2017	2010	2017	2010-2017
1	83	nd	nd	242	nd	nd	325	nd	nd
2	150	nd	nd	322	nd	nd	472	nd	nd
3	90	110	20	134	150	15	224	260	36
4	70	64	-6	127	183	56	197	247	50
5	64	76	12	106	174	68	170	250	80
6	106	143	37	111	179	68	216	322	106
7	100	106	6	101	149	48	201	255	54
8	102	102	0	103	152	49	205	255	49
9	132	127	-5	129	189	60	261	316	55
10	191	160	-31	165	245	80	356	405	49
11	208	189	-19	202	290	88	410	479	68
12	249	226	-23	235	328	93	484	555	71
13	265	241	-24	254	331	77	519	572	53
14	244	256	13	281	348	67	524	604	80
15	242	250	9	332	385	53	573	635	62
16	271	274	3	328	380	52	599	654	55
17	292	315	23	346	362	16	638	677	39
18	304	331	27	382	366	-16	686	698	12
19	315	344	29	448	406	-42	763	750	-13
20	340	330	-10	473	444	-30	813	774	-39
21	323	312	-11	582	522	-61	905	834	-72
22	326	307	-19	574	530	-44	900	837	-63
23	310	356	46	662	597	-65	973	953	-19
24	277	276	0	591	547	-44	867	823	-45
25	216	222	6	502	503	1	718	726	7
26	76	91	15	455	396	-59	531	487	-44
27	113	nd	nd	768	nd	nd	882	nd	nd
Total (3-26)	5112	5211	99	7623	8154	532	0	0	631

Table 14. Sediment volumes (m^3) within cells along the Cemlyn Barrier, seaward and landward of the barrier crest and for the whole barrier, calculated from LiDAR surveys flown in 2010 and 2017, and change between 2010 and 2017, for the barrier above 4.25 m ODN (the level of the 1 in 200 year surge event estimated by McMillan et al., 2011).

	Seaward of barrier crest			Landward of barrier crest			Whole barrier		
	2010	2017	2010- 2017	2010	2017	2010-2017	2010	2017	2010-2017
1	27	nd	nd	55	nd	nd	82	nd	nd
2	71	nd	nd	156	nd	nd	227	nd	nd
3	34	38	4	44	53	9	78	91	13
4	13	15	2	18	35	17	32	50	19
5	11	14	4	11	28	17	22	43	21
6	37	56	19	37	78	41	74	134	60
7	33	35	3	33	64	31	65	99	34
8	34	36	2	32	63	31	66	99	33
9	53	48	-5	53	94	40	107	142	35
10	91	75	-16	84	138	54	175	213	38
11	101	96	-5	103	164	61	205	260	55
12	128	122	-6	125	193	68	253	314	62
13	137	128	-10	134	191	57	271	319	47
14	122	132	10	143	196	53	265	327	62
15	121	125	4	170	212	43	291	338	47
16	140	145	4	172	215	43	312	360	48
17	151	166	15	187	203	16	338	369	31
18	157	172	14	207	200	-7	364	372	8
19	152	181	29	249	220	-29	401	401	0
20	160	173	13	254	233	-20	414	407	-7
21	150	163	13	322	278	-44	472	441	-31
22	151	152	2	303	270	-33	454	423	-31
23	147	183	36	352	307	-45	498	490	-9
24	132	128	-4	300	276	-24	432	404	-28
25	83	95	13	195	199	4	278	295	17
26	24	21	-3	116	88	-28	140	109	-30
27	66	nd	nd	337	nd	nd	403	nd	nd
Total (3-26)	2362	2499	138	3644	3999	355	0	0	493

Table 15. Sediment volumes (m^3) within cells along the Cemlyn Barrier, seaward and landward of the barrier crest and for the whole barrier, calculated from LiDAR surveys flown in 2010 and 2017, and change between 2010 and 2017, for the barrier above 5.00 m ODN.

	Seaward of barrier crest			Landward of barrier crest			Whole barrier		
	2010	2017	2010- 2017	2010	2017	2010-2017	2010	2017	2010-2017
1	0	nd	nd	0	nd	nd	0	nd	nd
2	5	nd	nd	5	nd	nd	9	nd	nd
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	1	1	0	2	2	0	3	3
10	4	11	6	5	18	13	9	29	19
11	6	19	13	5	28	23	11	47	36
12	15	28	14	15	40	25	29	68	38
13	12	29	16	15	41	26	27	69	42
14	7	29	22	8	35	26	16	64	48
15	8	28	20	13	37	24	21	65	44
16	16	35	19	22	44	23	38	79	41
17	25	44	19	32	43	12	56	87	31
18	31	49	17	45	46	1	76	95	19
19	30	45	15	53	41	-11	82	86	4
20	32	41	9	46	40	-6	78	81	3
21	32	42	10	59	44	-14	90	86	-4
22	31	33	2	48	36	-12	79	69	-9
23	29	41	12	52	37	-15	80	77	-3
24	22	17	-5	41	35	-6	63	52	-11
25	8	8	0	13	9	-4	21	16	-4
26	0	0	0	1	0	-1	1	0	-1
27	16	nd	nd	35	nd	nd	51	nd	nd
Total (3-26)	307	498	190	472	577	105	0	0	295

Table 16. Estimates of additional volumes of gravel required (in m^3) along the length of the Cemlyn Barrier, calculated by maintaining a barrier profile no steeper or narrower than that in Cell 12 / Profile 7, with a crest elevation of 5.2 m ODN at the north-western end (Cell 2), rising linearly to 5.7 m OD at the south-eastern end (Cell 27). Also, the volumes required if the whole barrier were to be raised by 22cm (UKCP09 95^{th} percentile medium emissions scenario), 26 cm (Welsh Government (2016) allowance), 31.8 cm (UKCP09 95^{th} percentile medium emissions scenario with MHW extrapolation) and 37.5 cm (Welsh Government (2016) allowance with MHW extrapolation). At the north-western end of the barrier, part of Cell 2 has been included in the calculations where it is covered by the 2017 LiDAR survey. At the south-eastern end of the barrier, data from the 2010 LiDAR survey has been added to extend the calculations of the barrier to where it meets the high ground and the data presented in Cell 27.

	Specified profile	+22.0cm	+26.0cm	+31.8cm	+37.5cm
1	nd	nd	nd	nd	nd
2	71	272	309	362	414
3	348	663	720	803	885
4	283	614	674	761	847
5	299	634	695	783	870
6	368	680	737	819	900
7	532	857	916	1001	1086
8	674	998	1057	1143	1227
9	562	892	953	1040	1126
10	325	641	698	781	863
11	137	446	502	584	664
12	69	379	436	518	598
13	46	361	418	501	583
14	48	359	415	497	577
15	48	367	425	509	591
16	35	346	402	484	565
17	37	358	417	501	585
18	33	352	410	494	577
19	31	349	407	490	573
20	34	354	412	496	579
21	46	366	424	508	591
22	74	389	446	529	611
23	58	382	441	526	610
24	80	404	463	549	633
25	194	518	577	663	747
26	367	698	758	846	931
27	310	774	859	981	1102
Total (2-27)	5108	13453	14970	17170	19332

Table 17. Estimates of additional volumes of sediment required (in m^3) to enlarge the two tern islands in the lagoon; the northern island within its present walled limits; an enlarged northern island to the limits broadly similar to those shown on the Six-inch Ordnance Survey map surveyed in 1926; an enlarged southern island to the limits similar to those shown on the Six-inch Ordnance Survey map surveyed in 1926 (see boundaries shown on Figure 67). Surface levels are assumed to be the present level of 2.80 m ODN, and to higher levels to allow for future sea level rise.

	Present level (2.80 m ODN)	+22.0cm (3.02 m ODN)	+26.0cm (3.06 m ODN)	+31.8cm (3.12 m ODN)	+37.5cm (3.18 m ODN)
North island (current boundaries)	1087	2194	2396	2688	2975
South island (current boundaries)	0	220	260	318	375
North island (extended boundaries)	6606	7168	7468	7903	8330
South island (extended boundaries)	4148	4773	4892	5070	5249

Figures

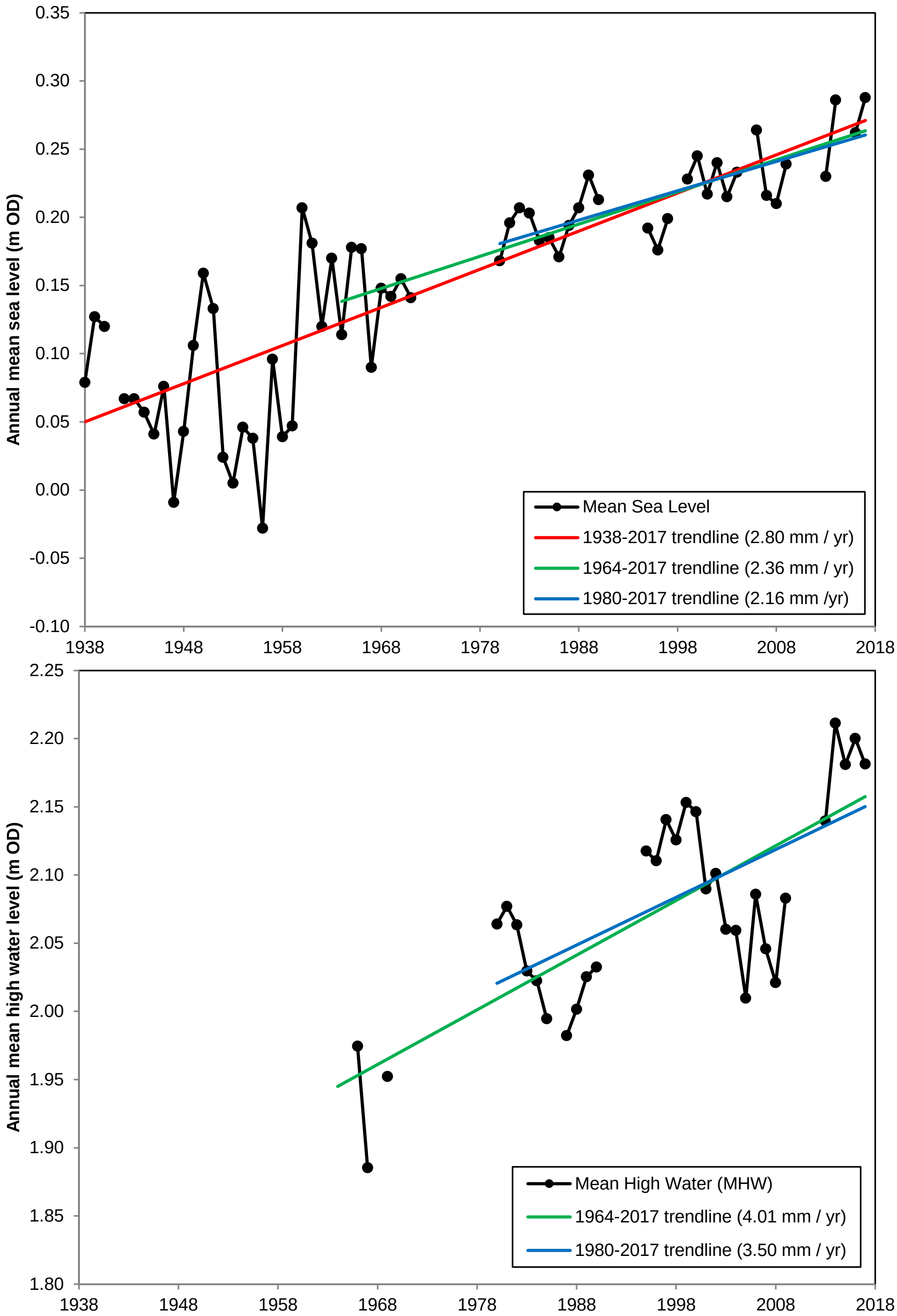


Figure 1. Long-term trends in (a) annual mean sea level and (b) annual mean high water level, recorded at the Class A tide gauge at Holyhead, January 1964 to December 2017. Linear trend lines are shown for different time periods. Only years with >80% data completeness are included.

Figure 2. Offshore CEFAS WaveNet Hindcast points in the Irish Sea (grey dots), and the closest point (1464) to Cemlyn Bay (red dot).The parameters hind-cast at the offshore point include wave mean direction (degrees), wave peak frequency (s^{-1}), significant wave height (m), directional spread (degrees), mean period Tm (seconds), energy period (seconds) and zero up-crossing period (seconds). Derivative parameters have also been calculated for the purposes of this study. The mean wave energy is calculated using the equation: $E=(1/16) \times \rho \times g \times H_s^2$, where E is the wave energy (in J m^{-2}), ρ is the water density (assumed to be 1000 kg m^{-3}), g is the acceleration due to gravity (9.81 m s^{-1}), and H_s is the significant wave height (in metres) The wave power for each data record has been calculated using the equation: $P=(\rho g^2/64\pi) \times H_s^2 \times T_e$, where P is the wave power (in W m^{-1}) and T_e is the wave energy period (in seconds). The mean wave power has then been expressed in kW m^{-1}.

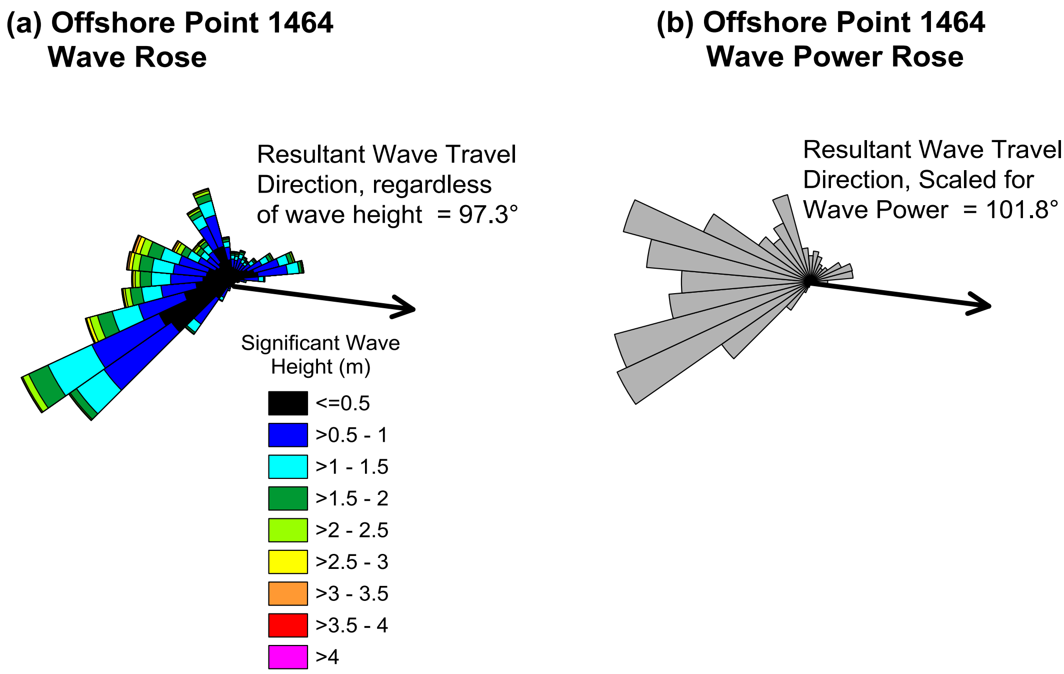


Figure 3. Wave roses for hindcast offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive: (a) approach direction and resultant travel direction scaled for all waves, with colours showing distribution of wave heights; (b) wave approach direction and result travel direction direction scaled for wave power.

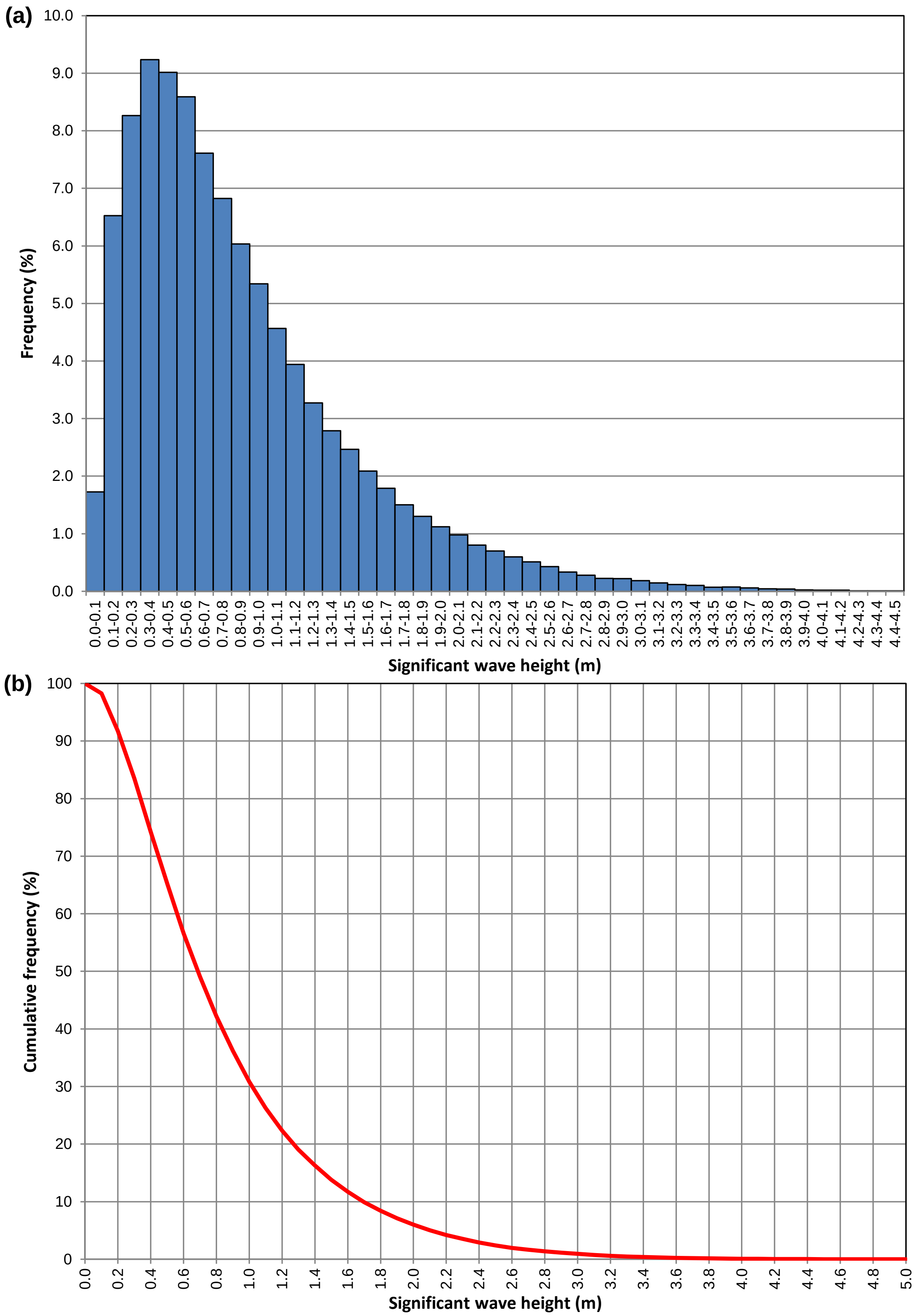


Figure 4. (a) Frequency histogram and (b) cumulative frequency curve of significant wave heights hind-cast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

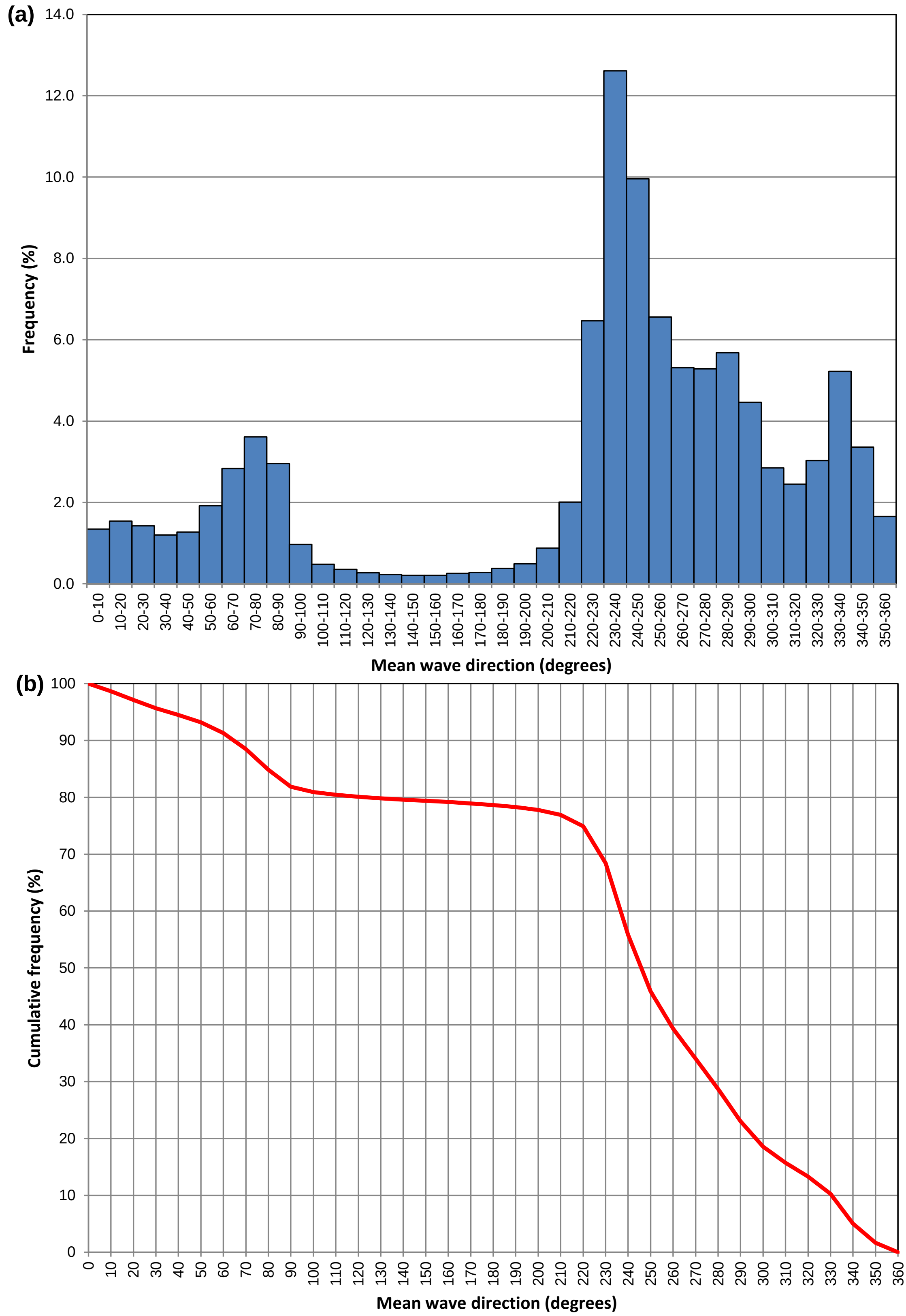


Figure 5. (a) Frequency histogram and (b) cumulative frequency curve of mean wave direction hind-cast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

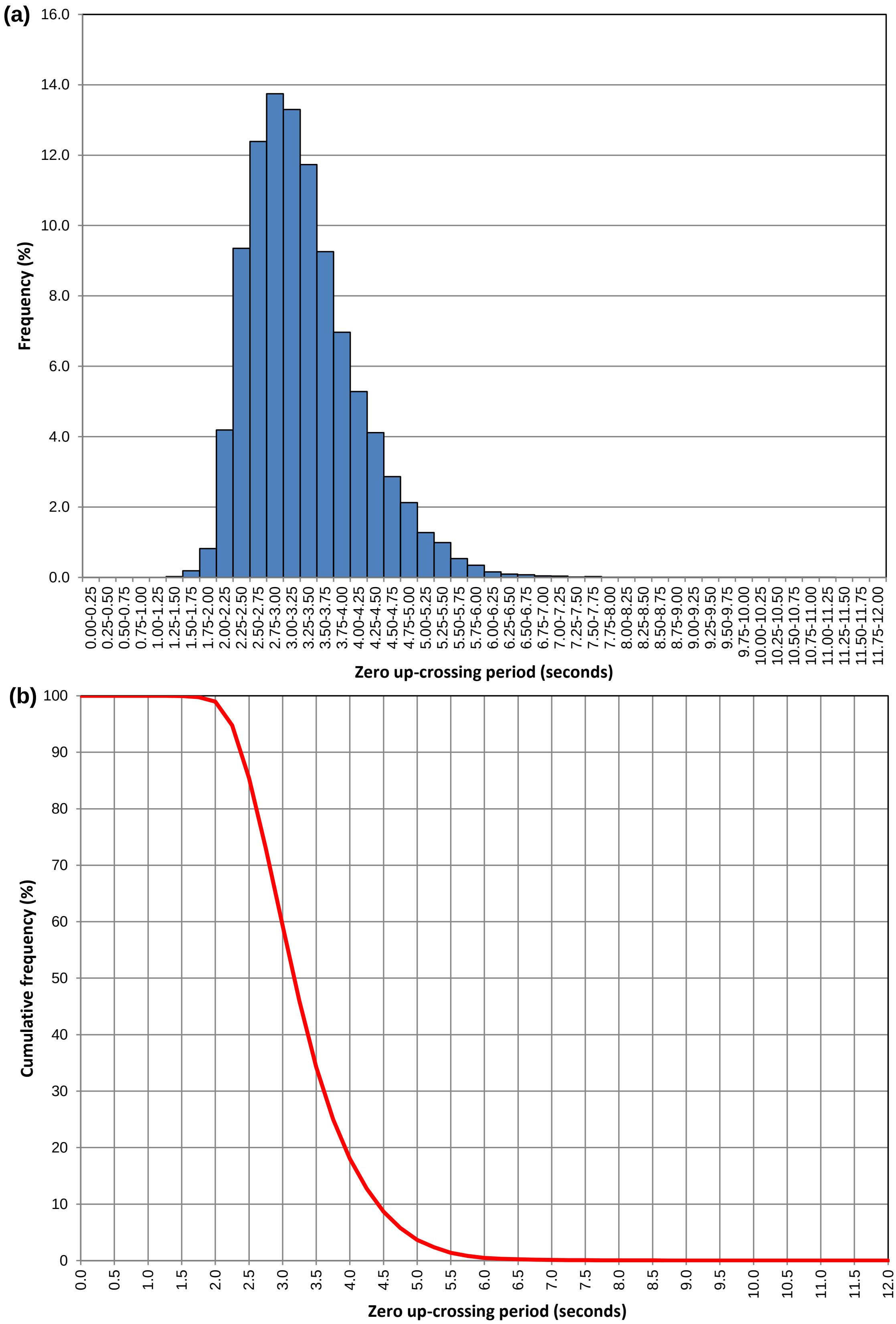


Figure 6. (a) Frequency histogram and (b) cumulative frequency curve of zero up-crossing wave period hindcast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

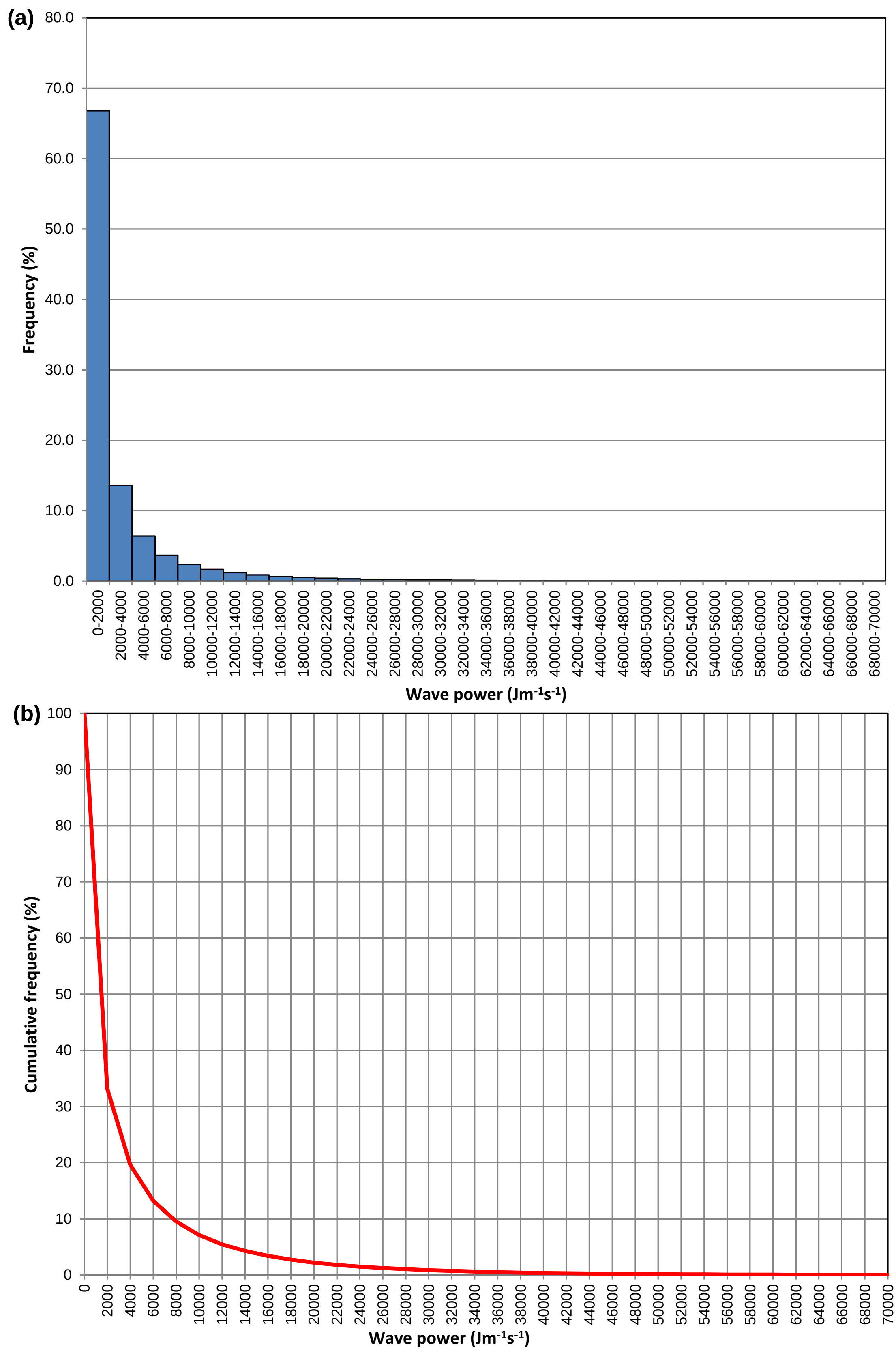


Figure 7. (a) Frequency histogram and (b) cumulative frequency curve of wave power hind-cast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

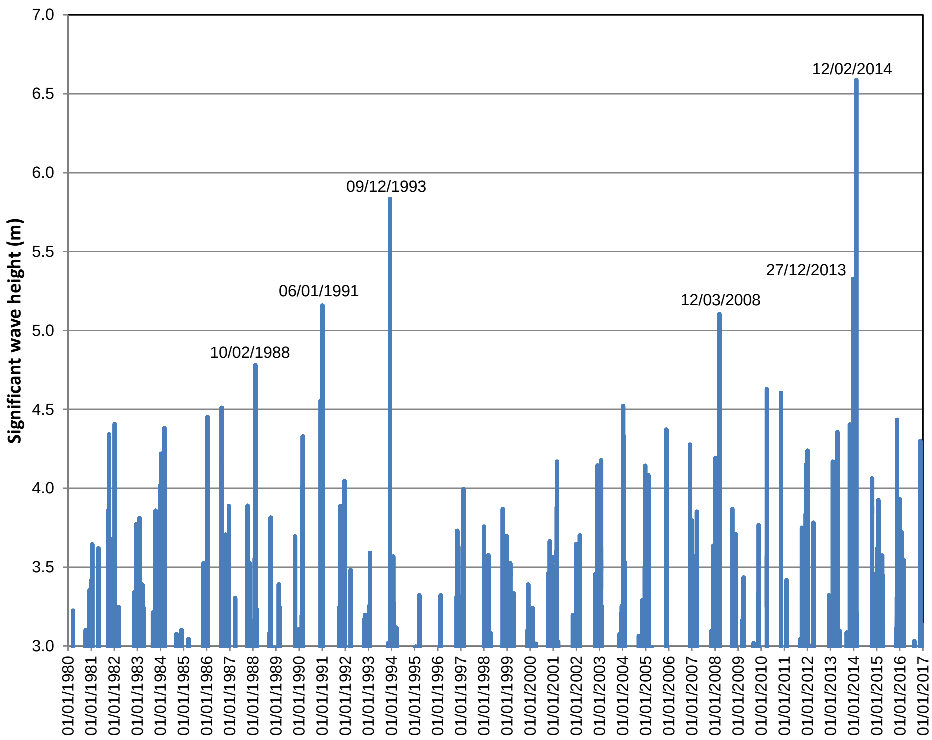


Figure 8. The largest waves (Hs >3.0 m) hind-cast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

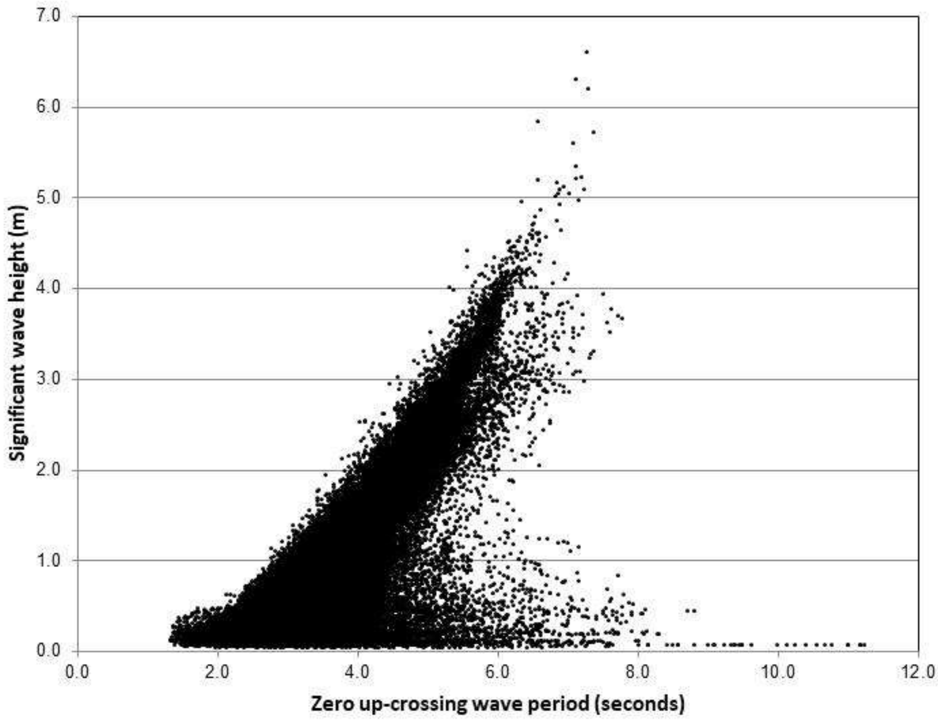


Figure 9. Cross-plot of significant wave height and zero up-crossing wave period, hind-cast at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive.

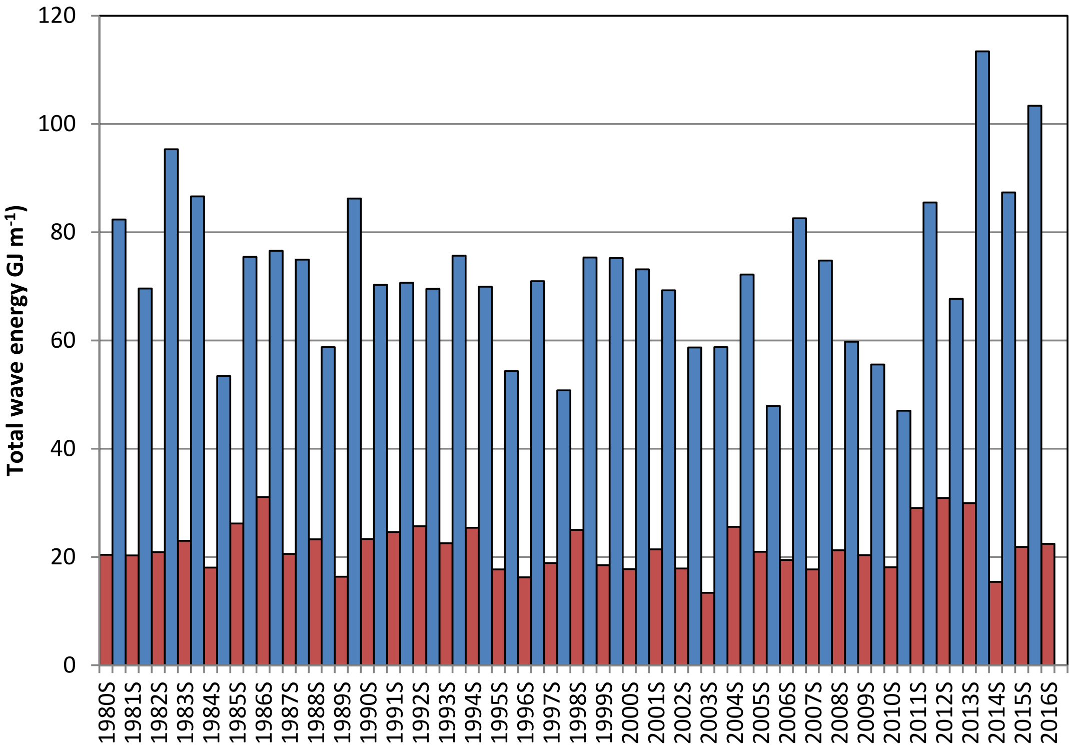


Figure 10. Average seasonal wave energy for hind-cast offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive. Winter period = October to March, Summer period = April – September.

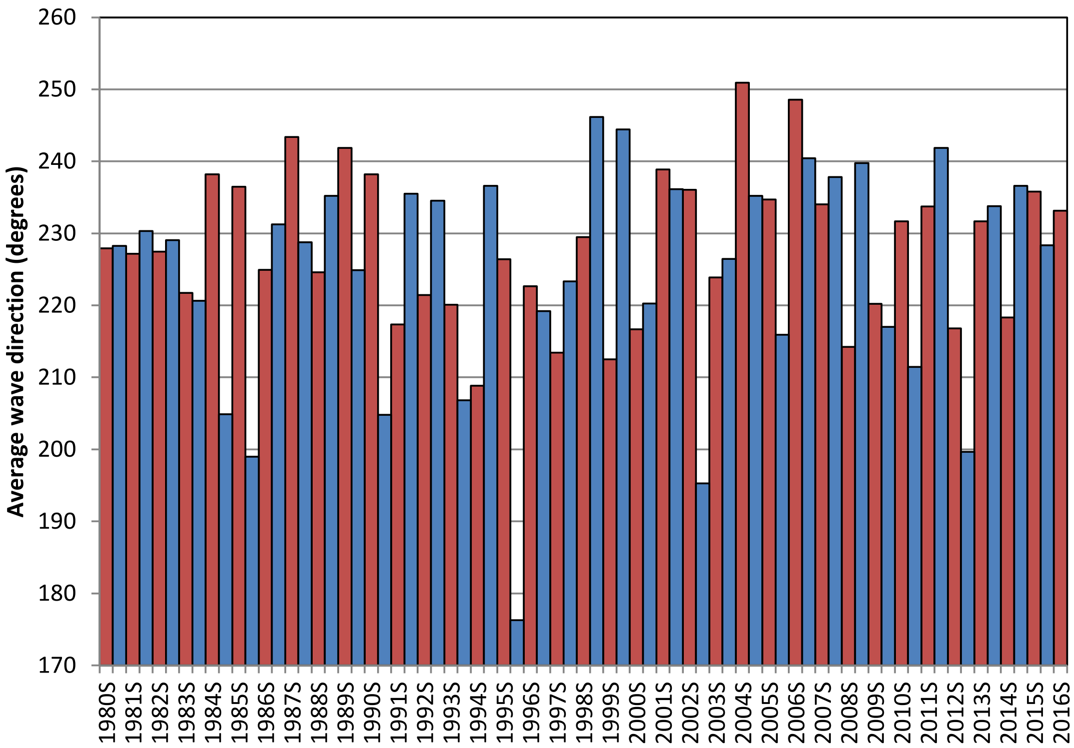


Figure 11. Average seasonal wave direction for hind-cast offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive. Winter period = October to March, Summer period = April – September.

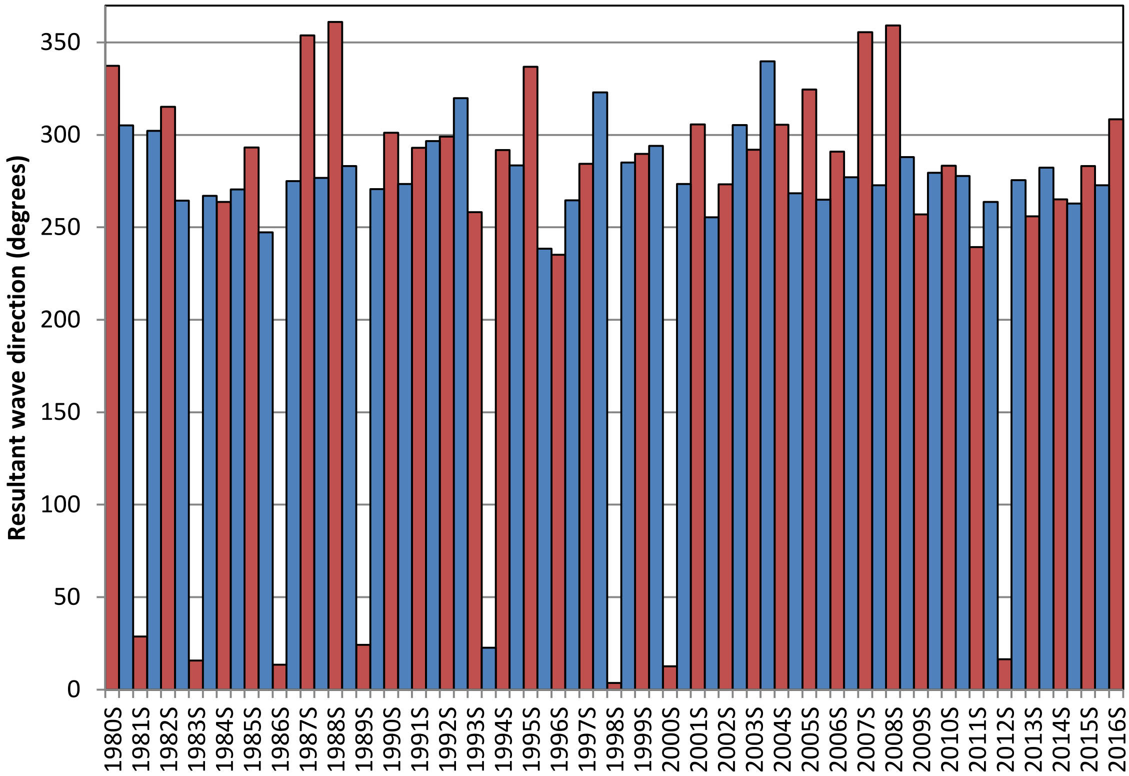


Figure 12. Resultant seasonal wave direction for hind-cast offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive, calculated by resolving three-hourly wave vectors scaled for wave power, summed for each six-month season. Winter period = October to March, Summer period = April – September.

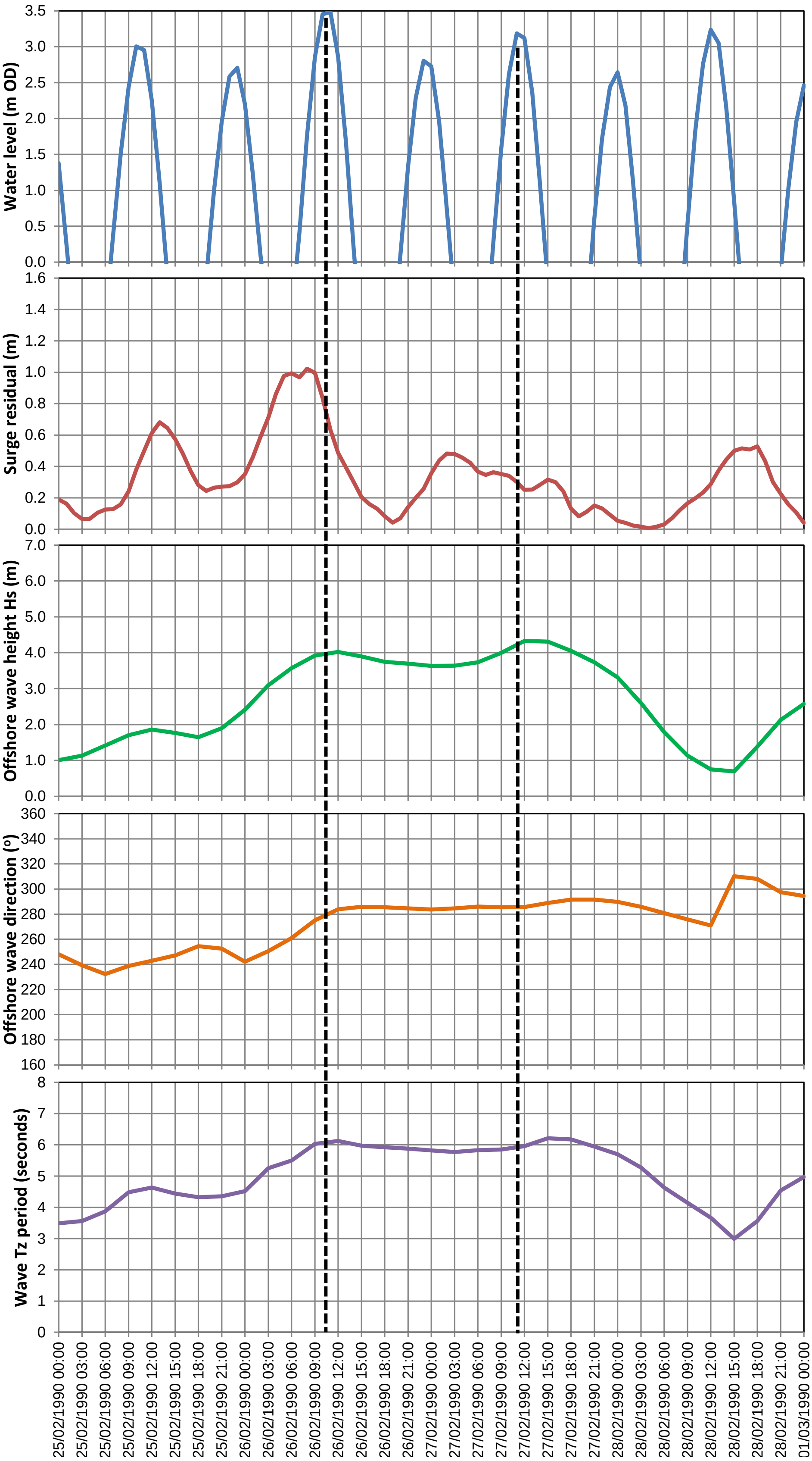


Figure 13. The high wave conditions on 26-27 February 1990: Recorded still water level and surge residual at Holyhead, and hindcast significant wave height, direction and period at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N).

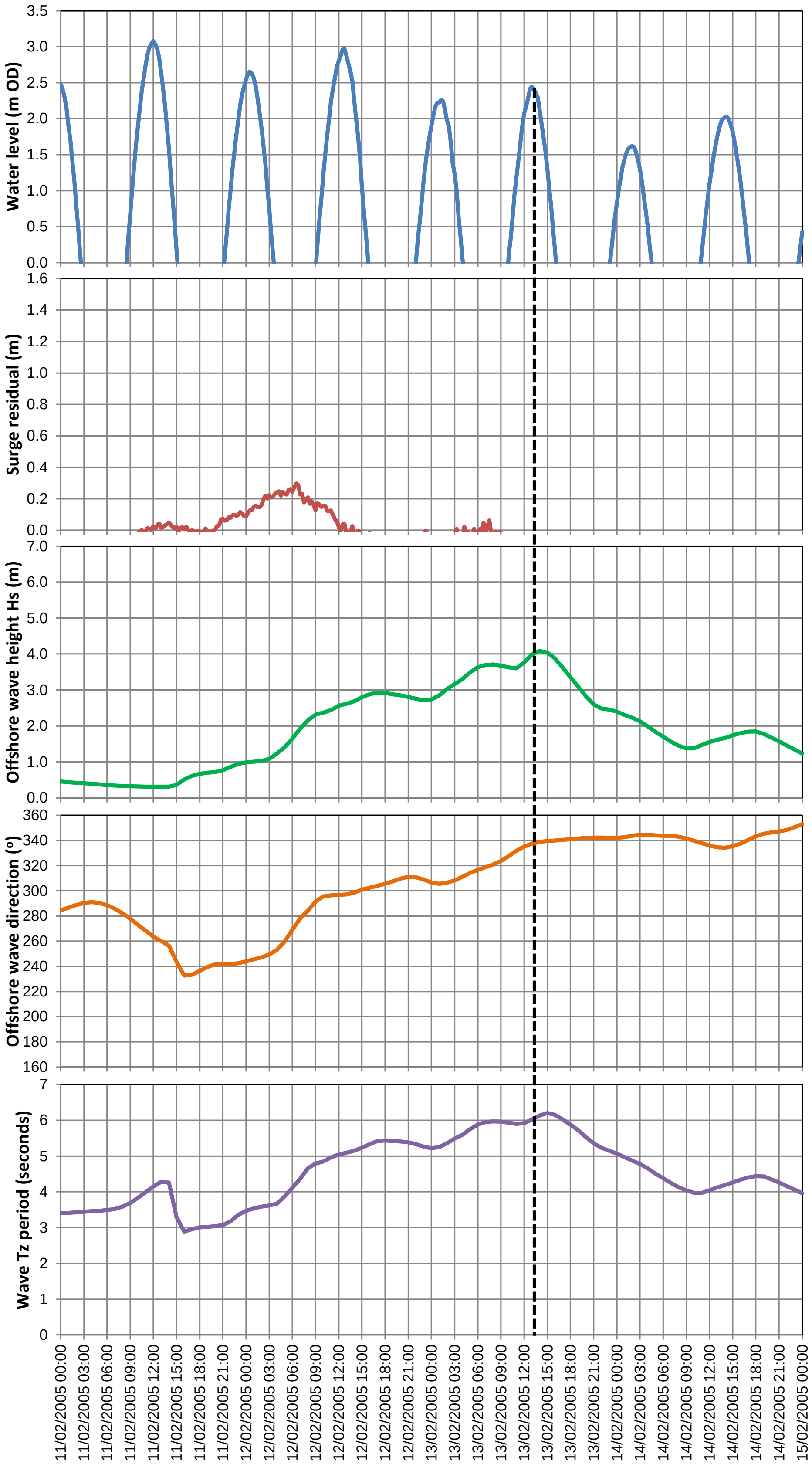


Figure 14. The high wave conditions on 13 February 2005: Recorded still water level and surge residual at Holyhead, and significant wave height, direction and period at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N).

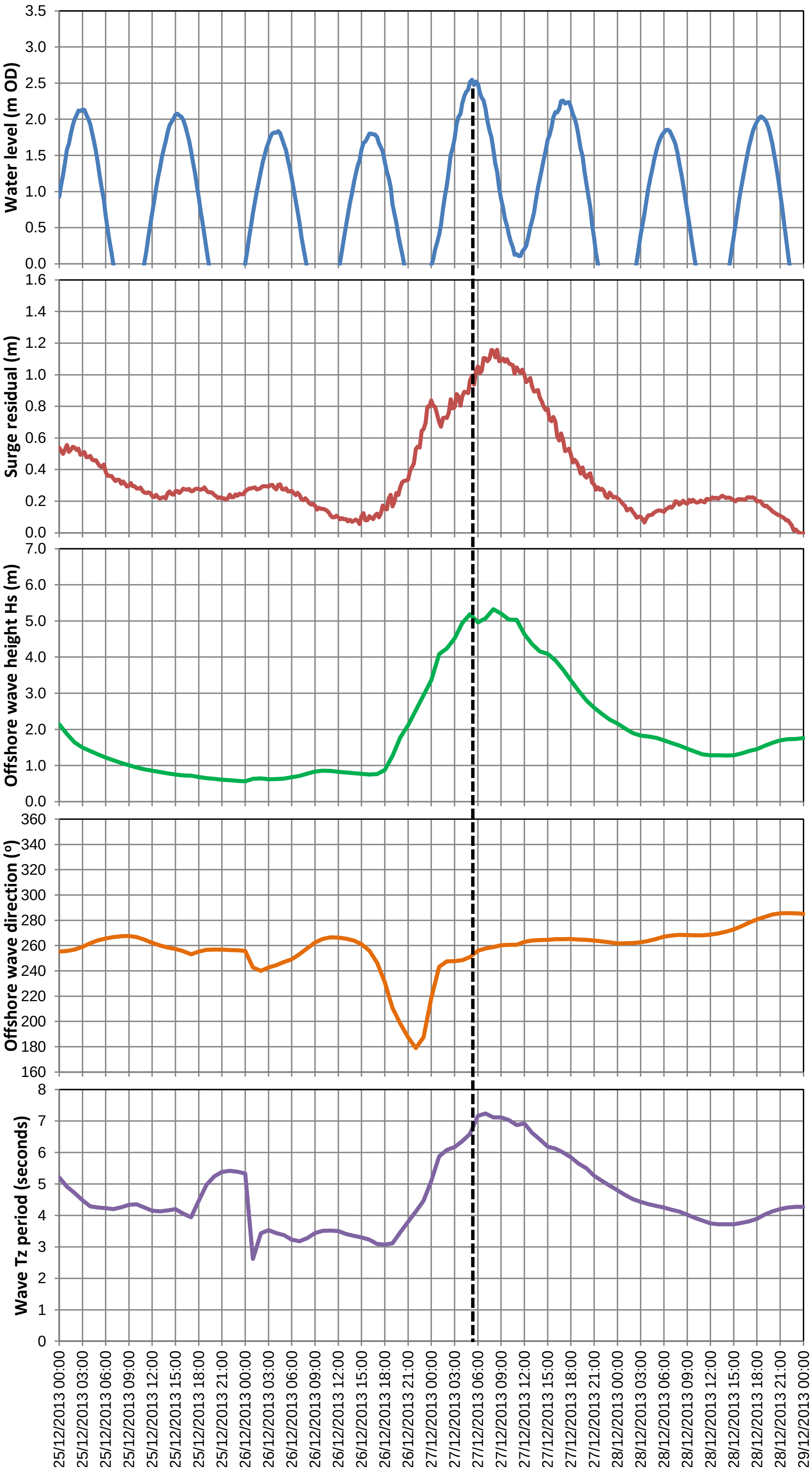


Figure 15. The high wave conditions on 27 December 2013: Recorded still water level and surge residual at Holyhead, and significant wave height, direction and period at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N).

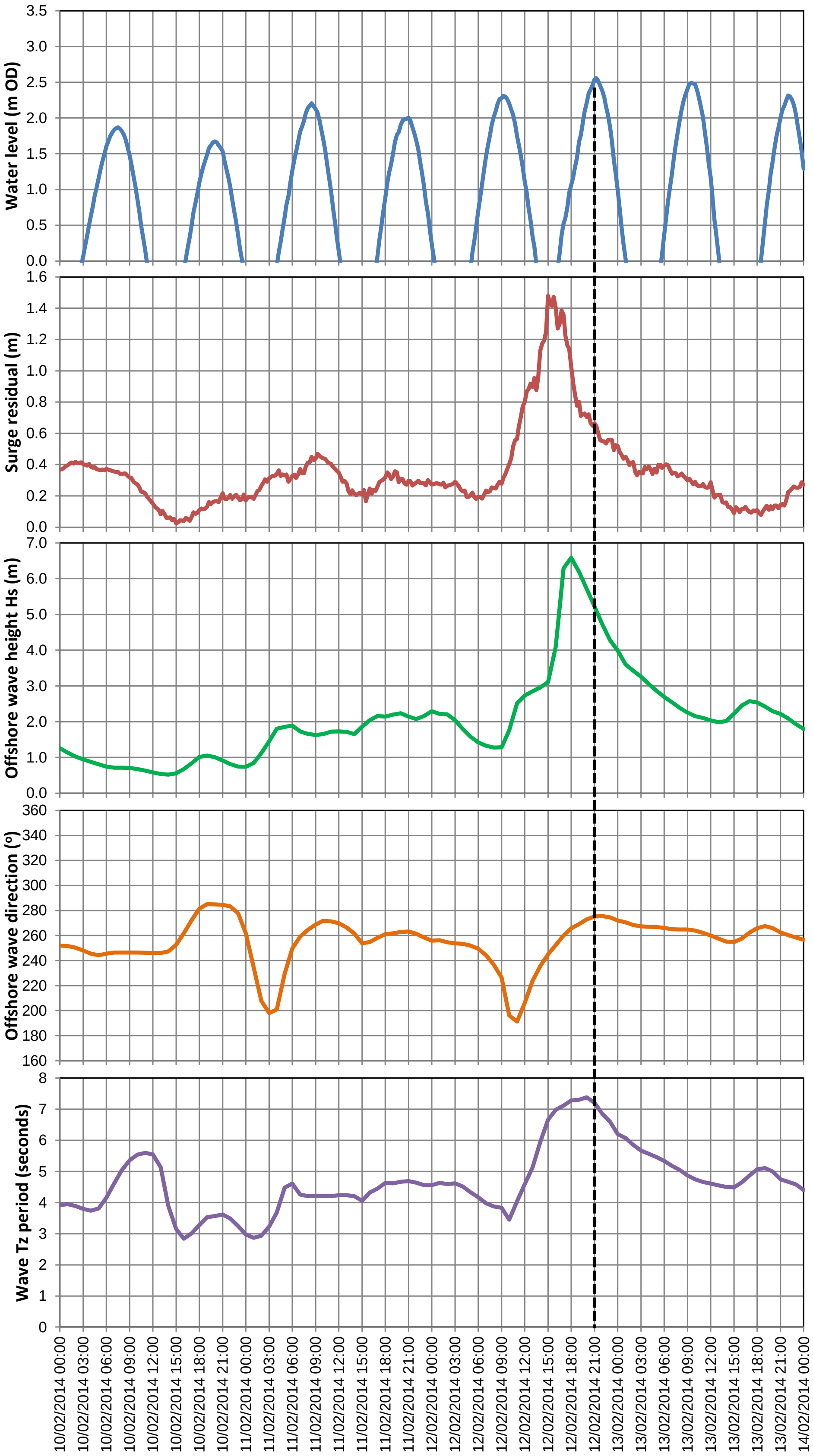


Figure 16. The high wave conditions on 12 February 2014: Recorded still water level and surge residual at Holyhead, and significant wave height, direction and period at offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N).

Figure 17. LiDAR image from airborne survey on 27th November 2010, scaled to show the wave crests observed during the flight, between Cemlyn Bay in the west and Cemaes Bay in the east. The angles of the wave crests have been highlighted, and the position of the offshore hind-cast point (number 1464) is also shown.

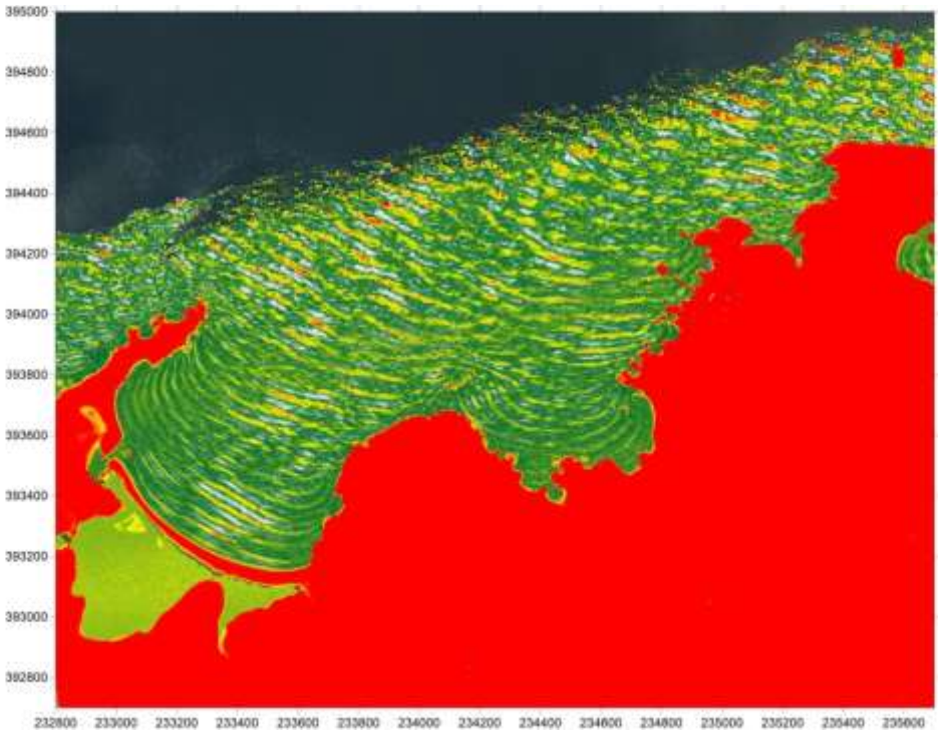


Figure 18.Enlargement of part of Figure 16, showing refraction of waves approaching Cemlyn Bay

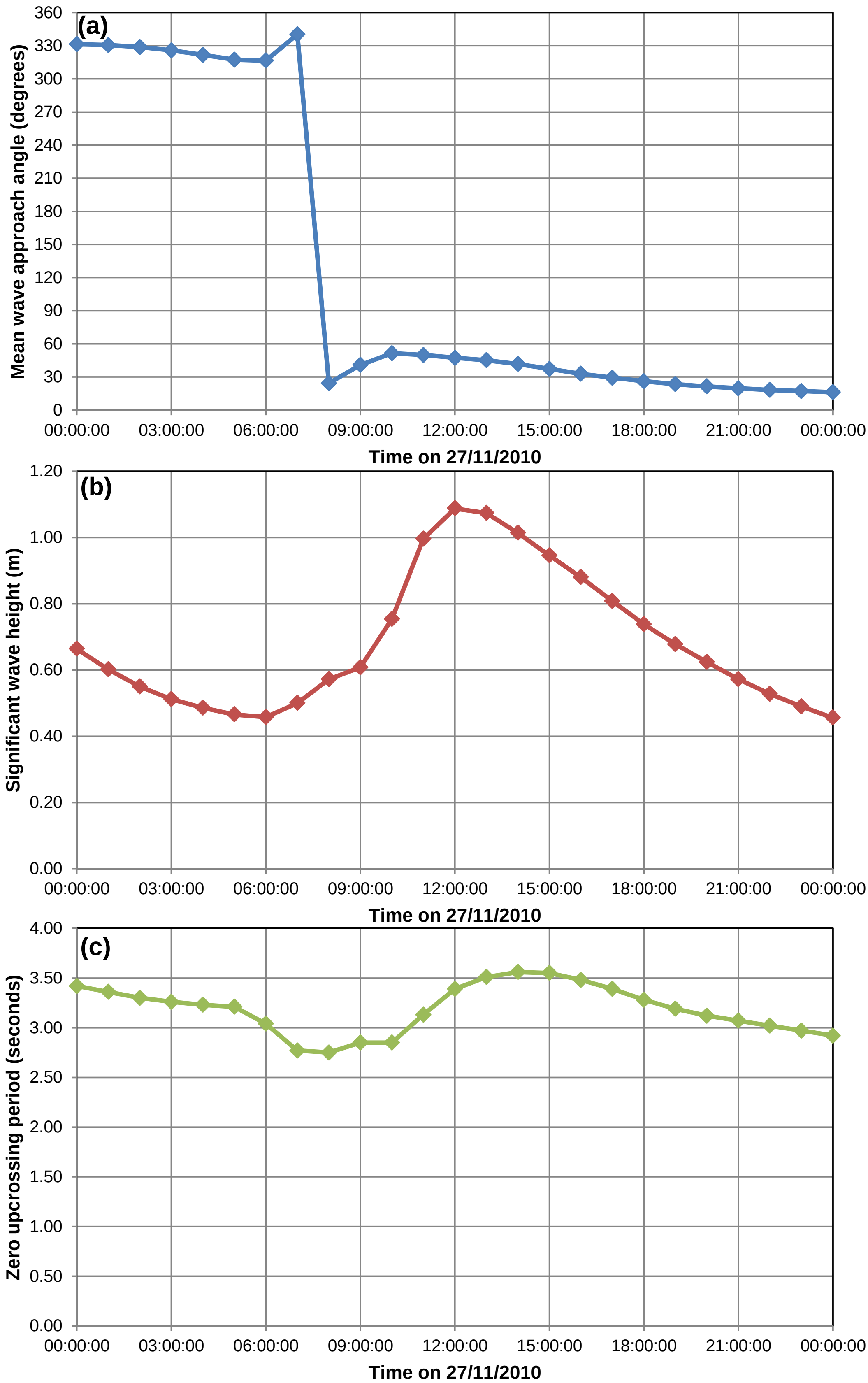


Figure 19. Wave direction, significant wave height and zero up-crossing period, hindcast at hourly intervals on 27th November 2010, the day the 2010 LiDAR survey was flown.

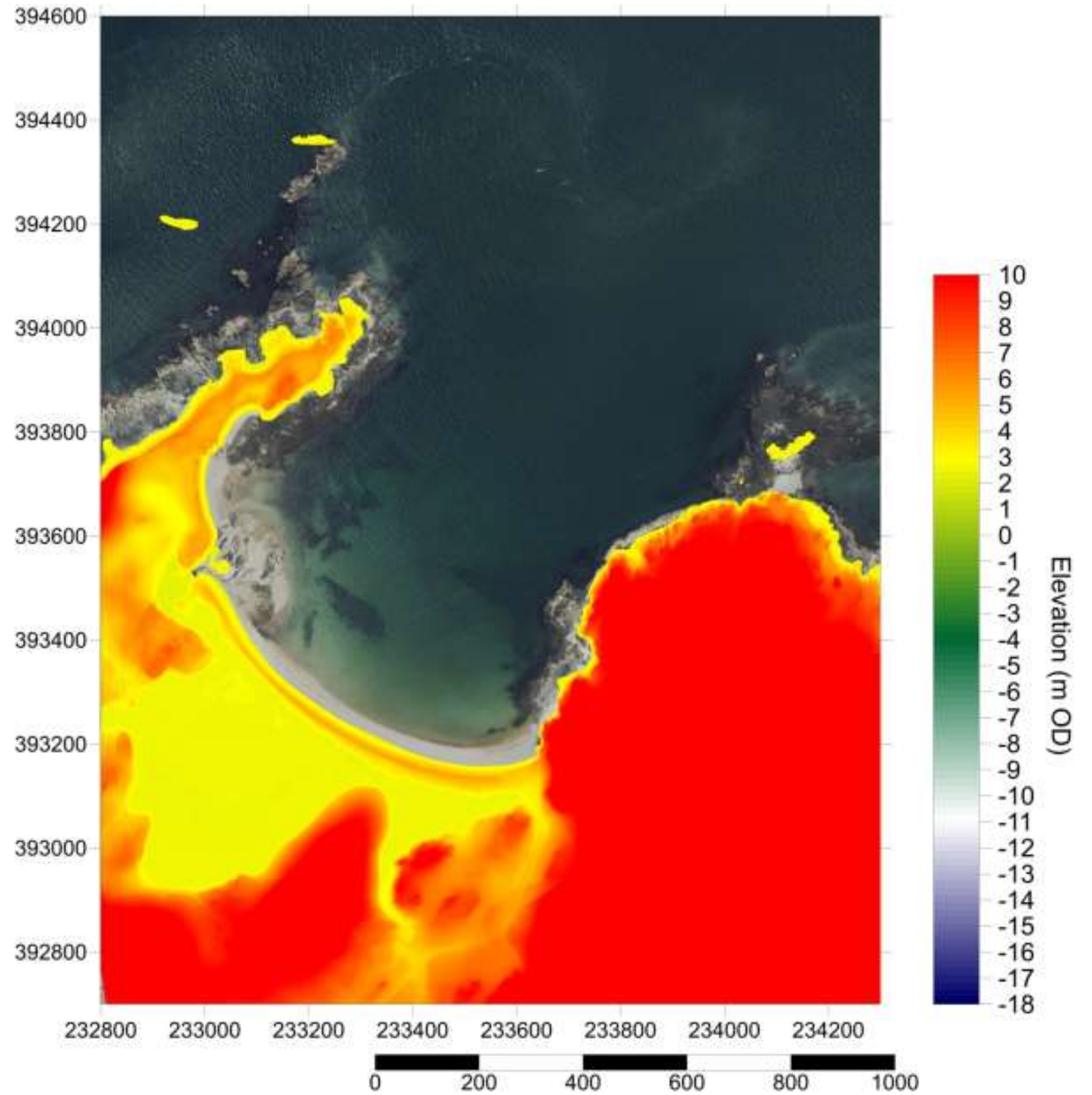


Figure 20. LiDAR data from survey flown on 27th November 2010 used in the combined bathymetric DEM

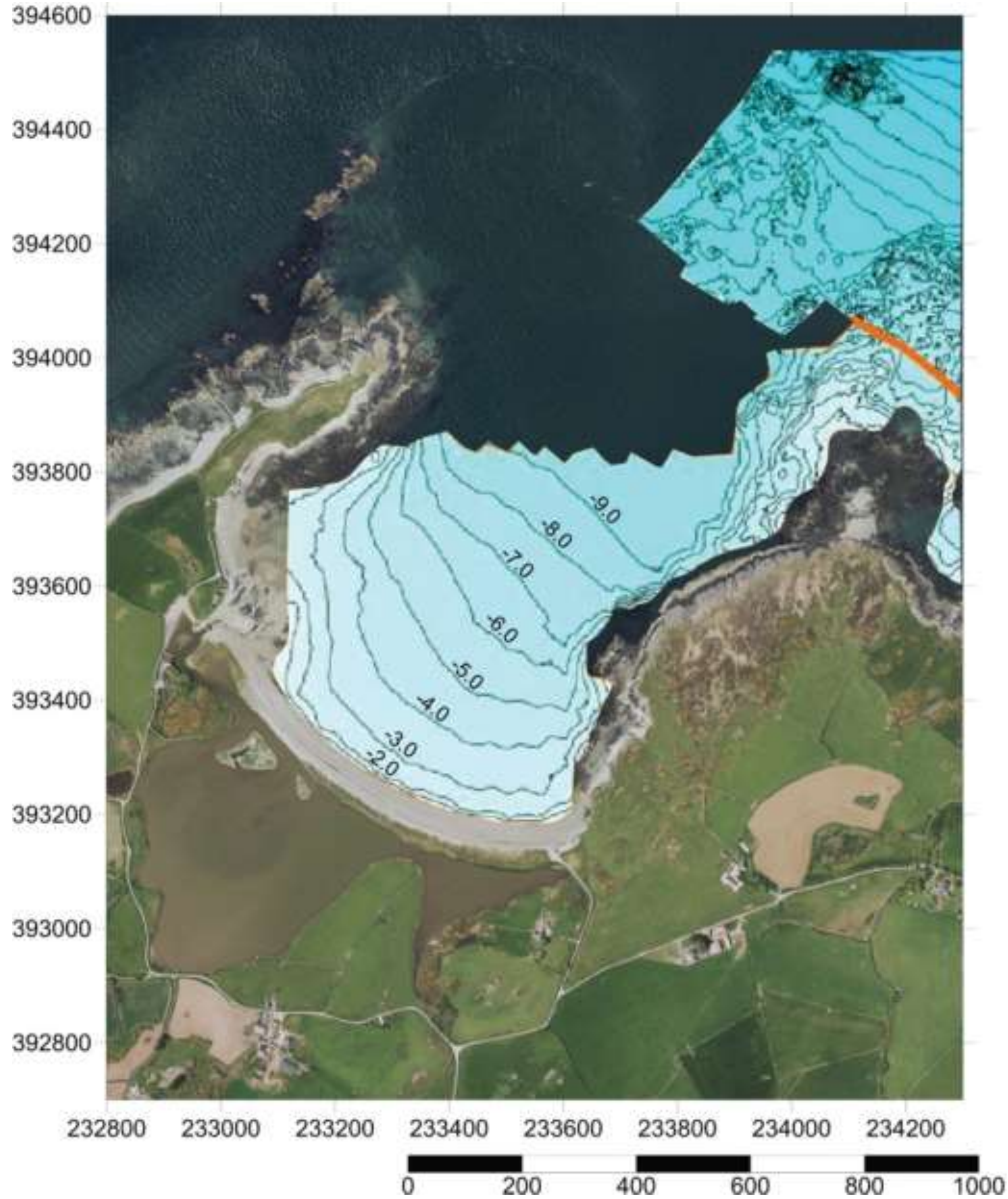


Figure 21. Bathymetic data based on surveys undertaken between 2009 and 2011 by Triton Surveys, used in the construction of the composite bathymetric DEM

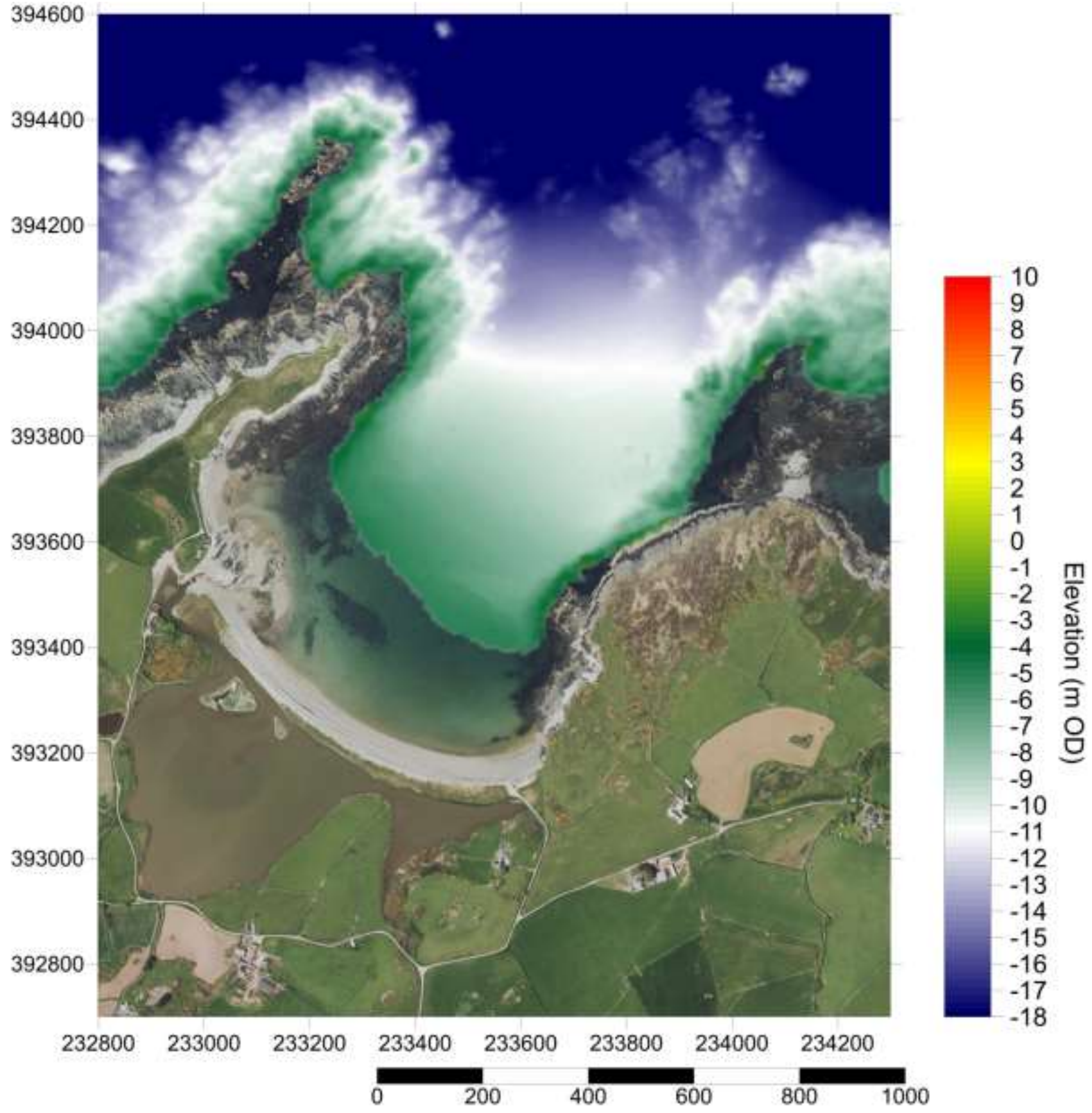


Figure 22. Bathymetric data from surveys undertaken between 24th August and 1st December 2013 by the Royal Navy, used in the construction of the composite bathymetric DEM.

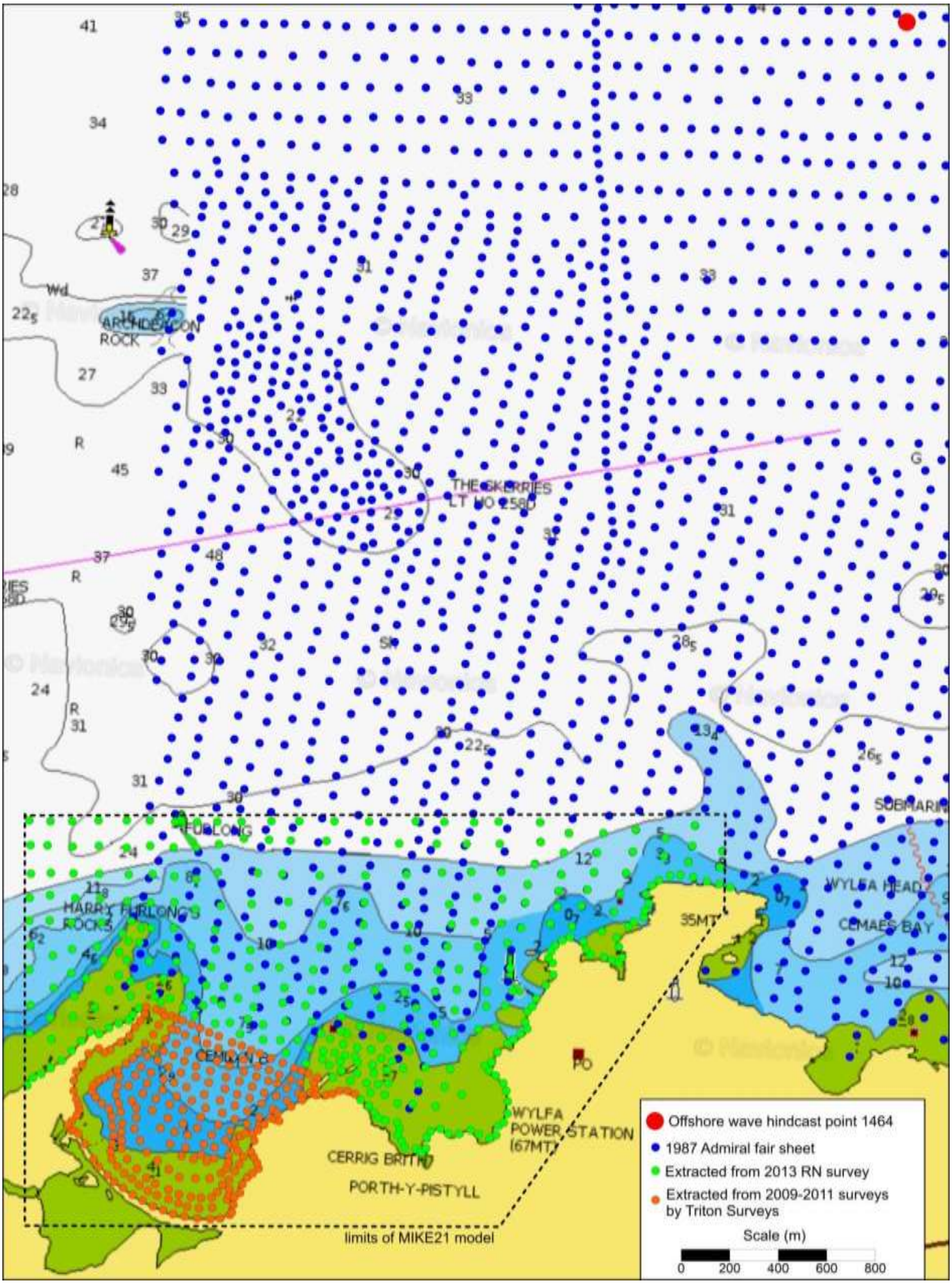


Figure 23. Bathymetry data points used in the MIKE21, SwanOne and XBeach-G modelling. Also shown is the extent of the Mike 21 modelling domain.

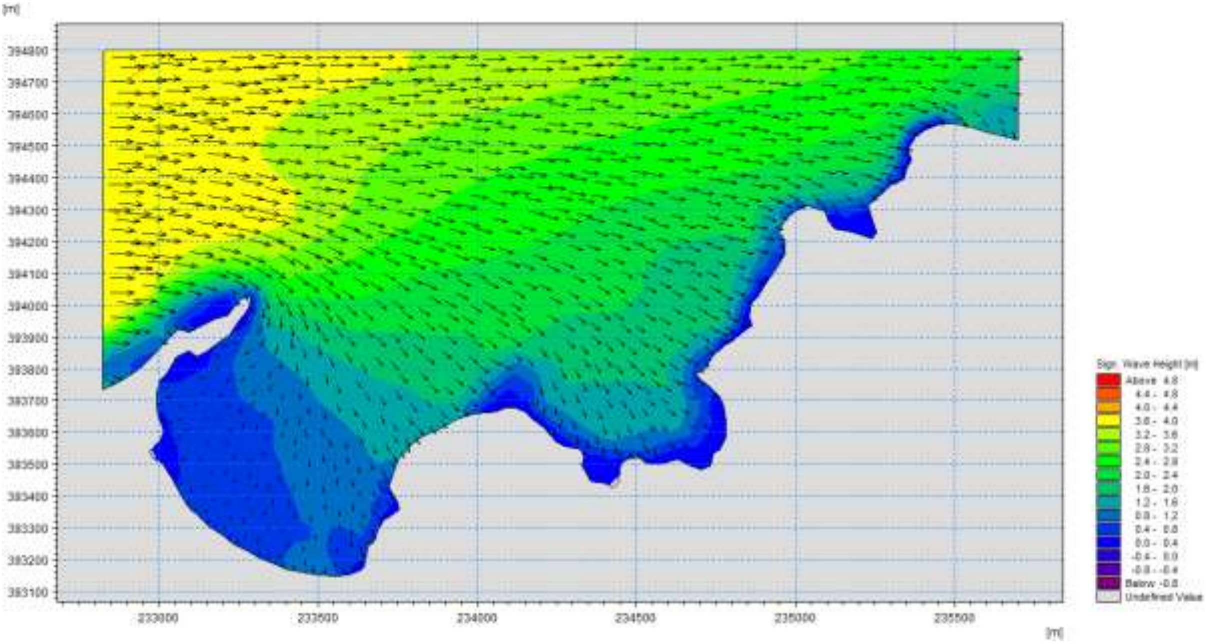


Figure 24. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=270deg.

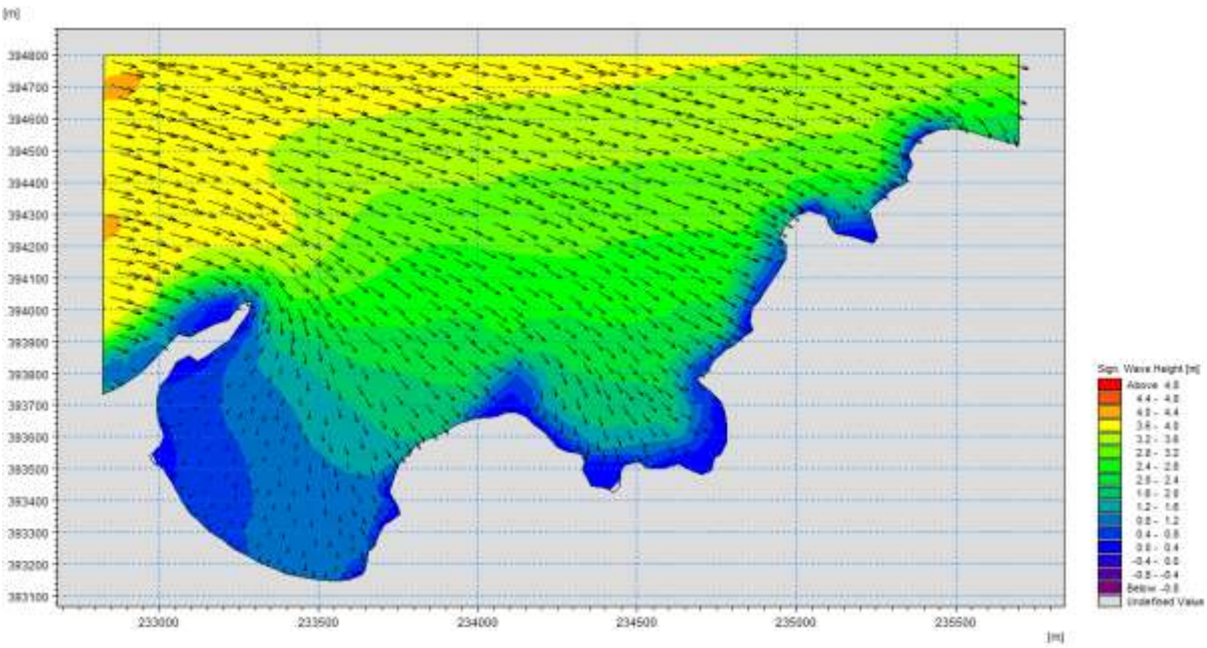


Figure 25. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=280deg.

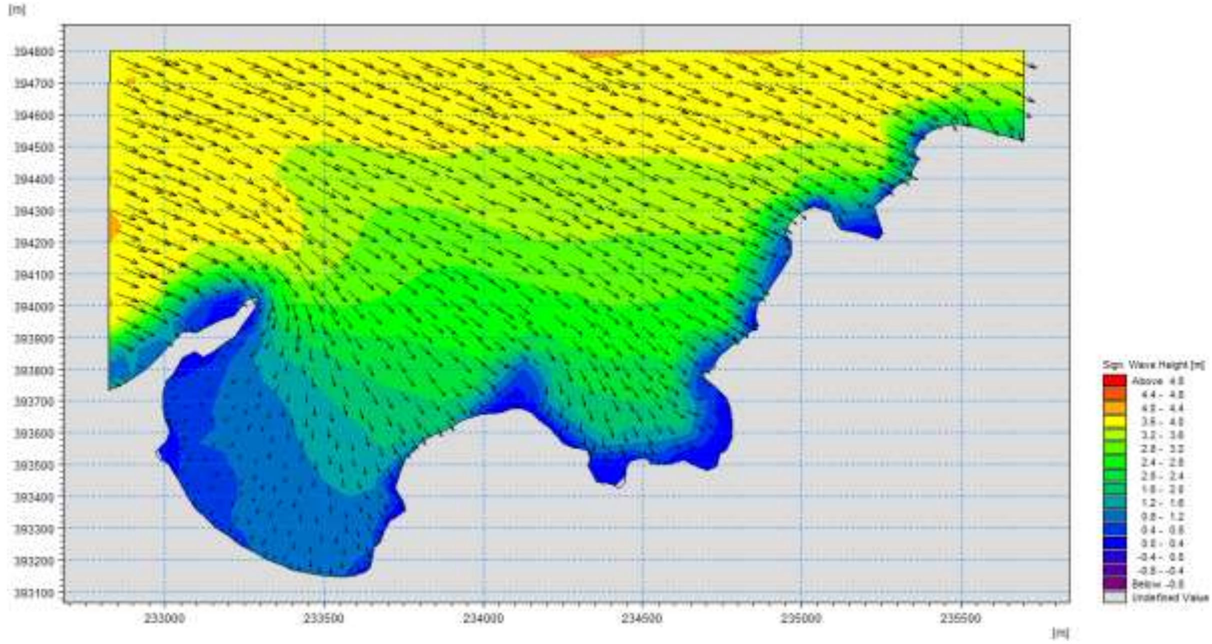


Figure 26. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=290deg.

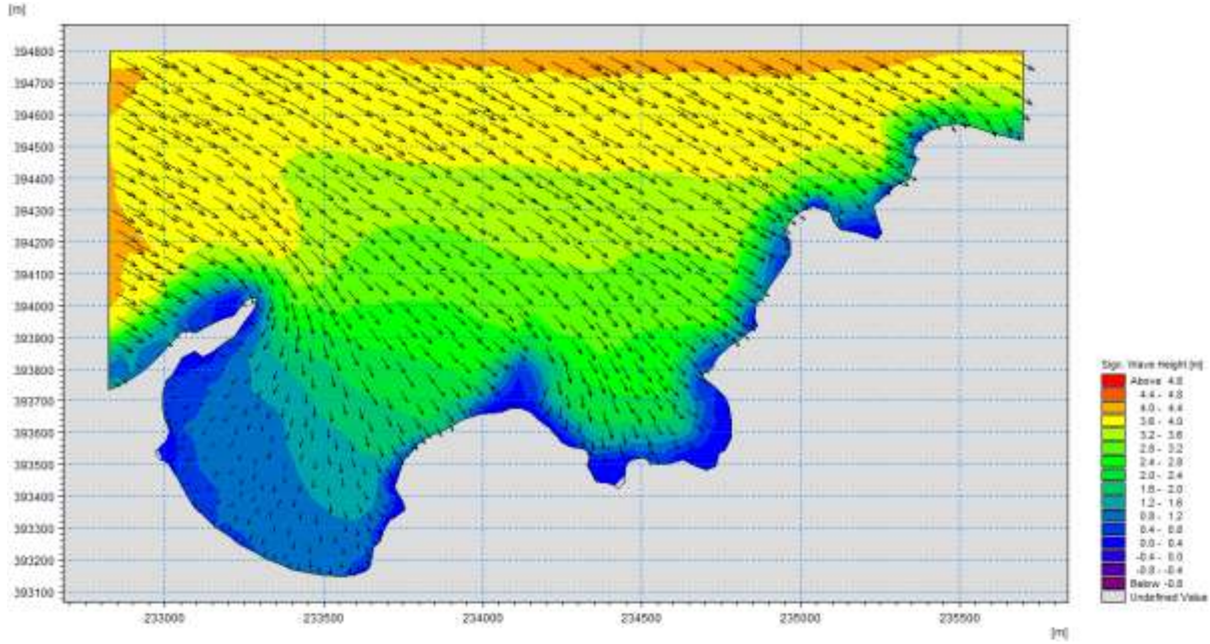


Figure 27. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=300deg.

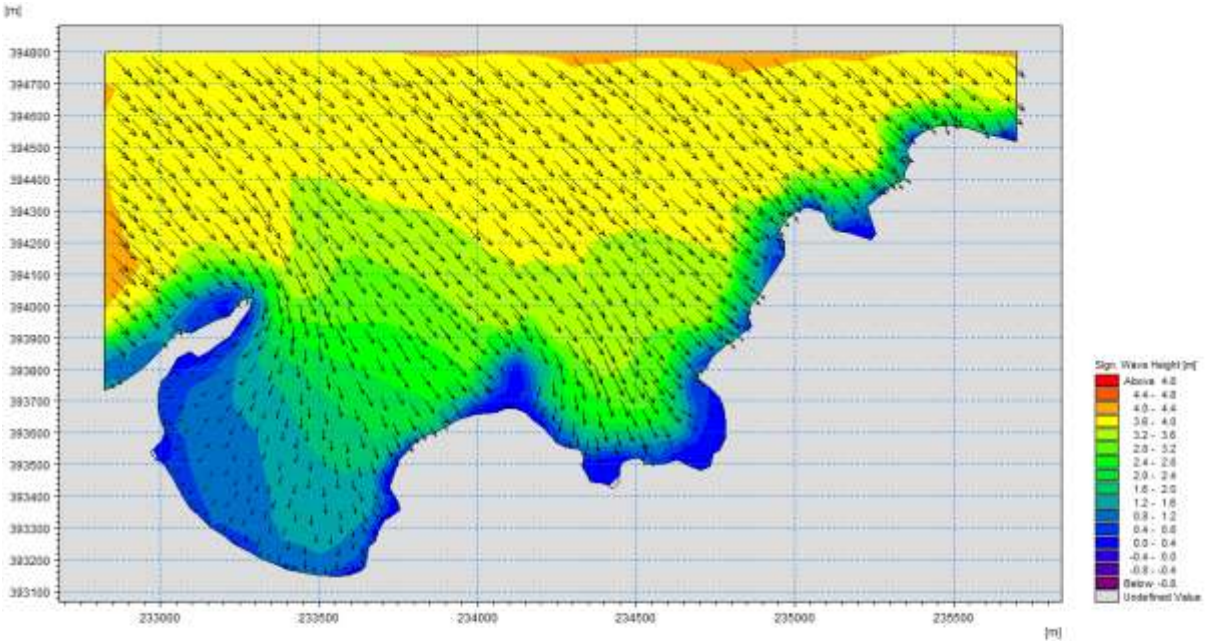


Figure 28. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=310deg.

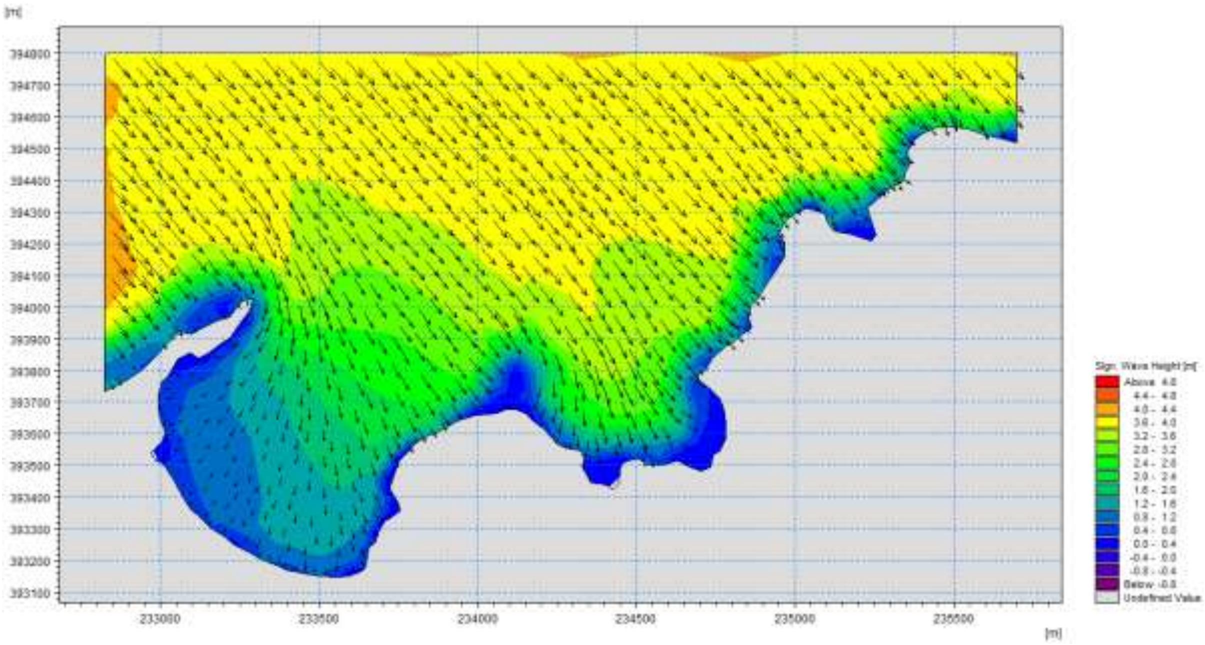


Figure 29. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=320deg.

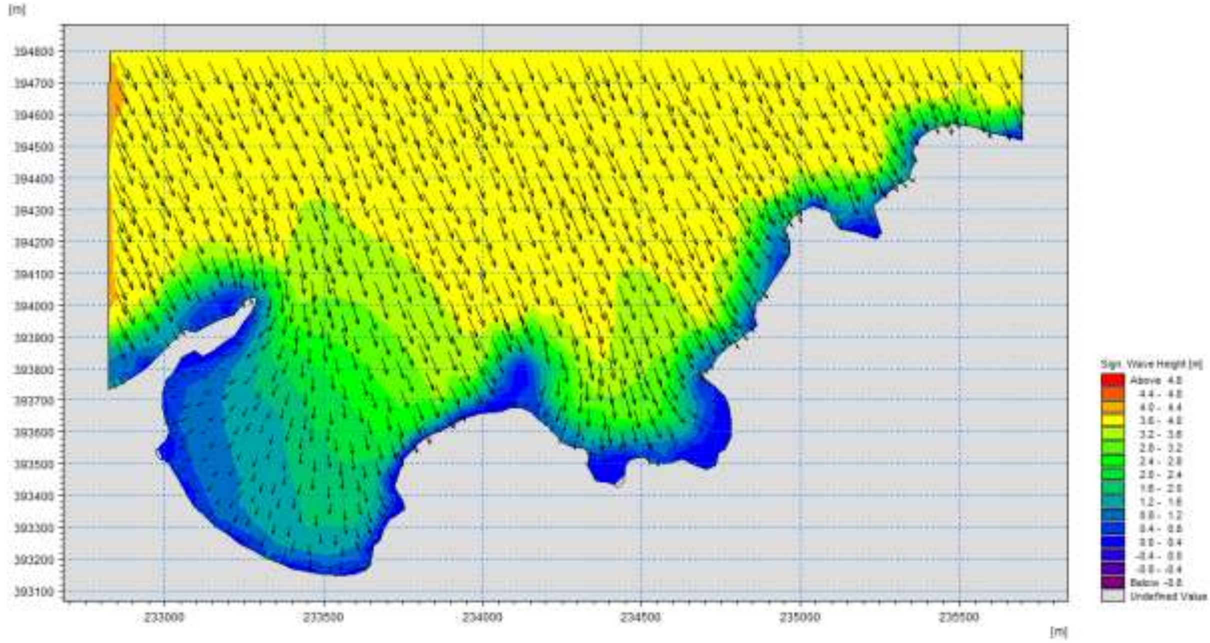


Figure 30. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=330deg.

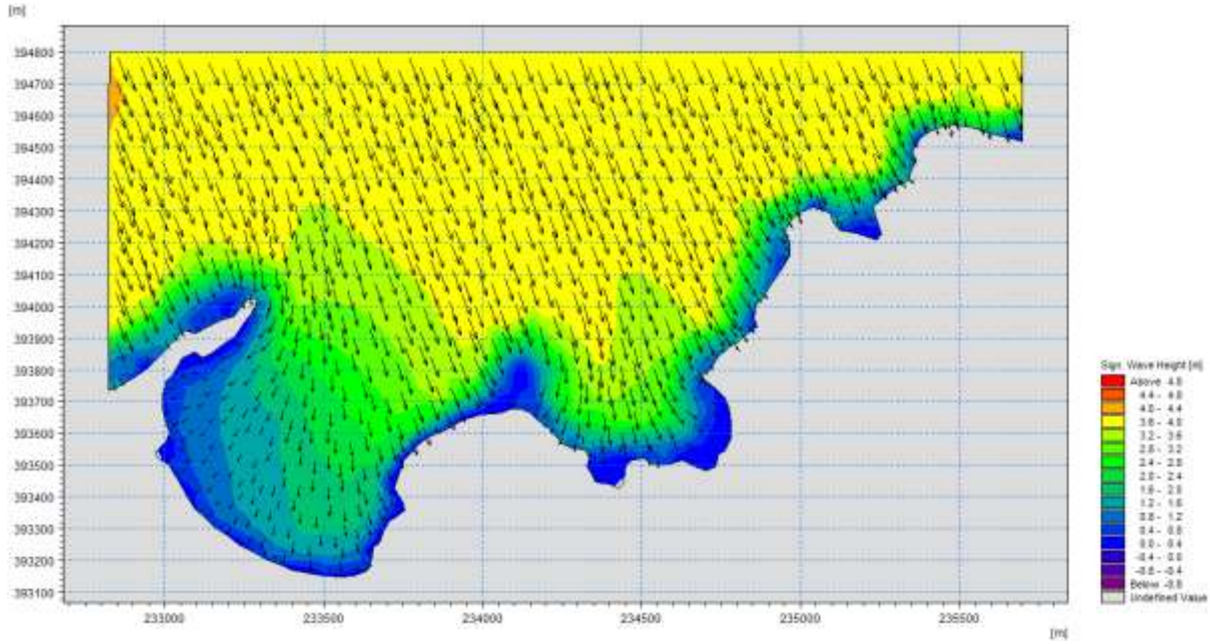


Figure 31. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=340deg.

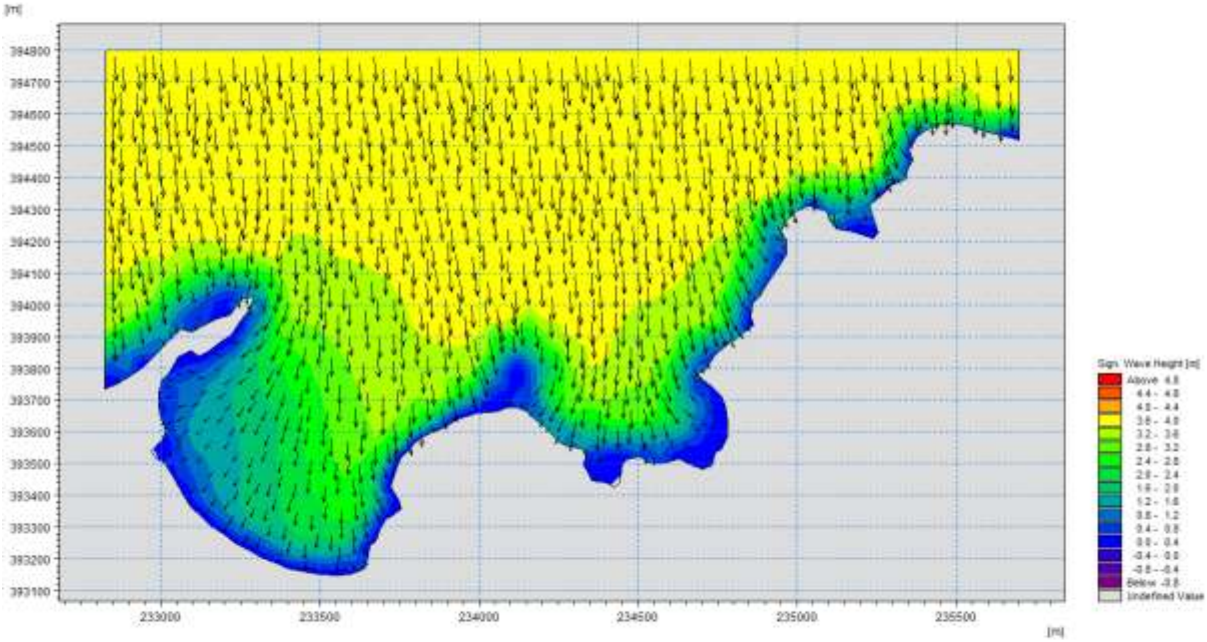


Figure 32. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=350deg.

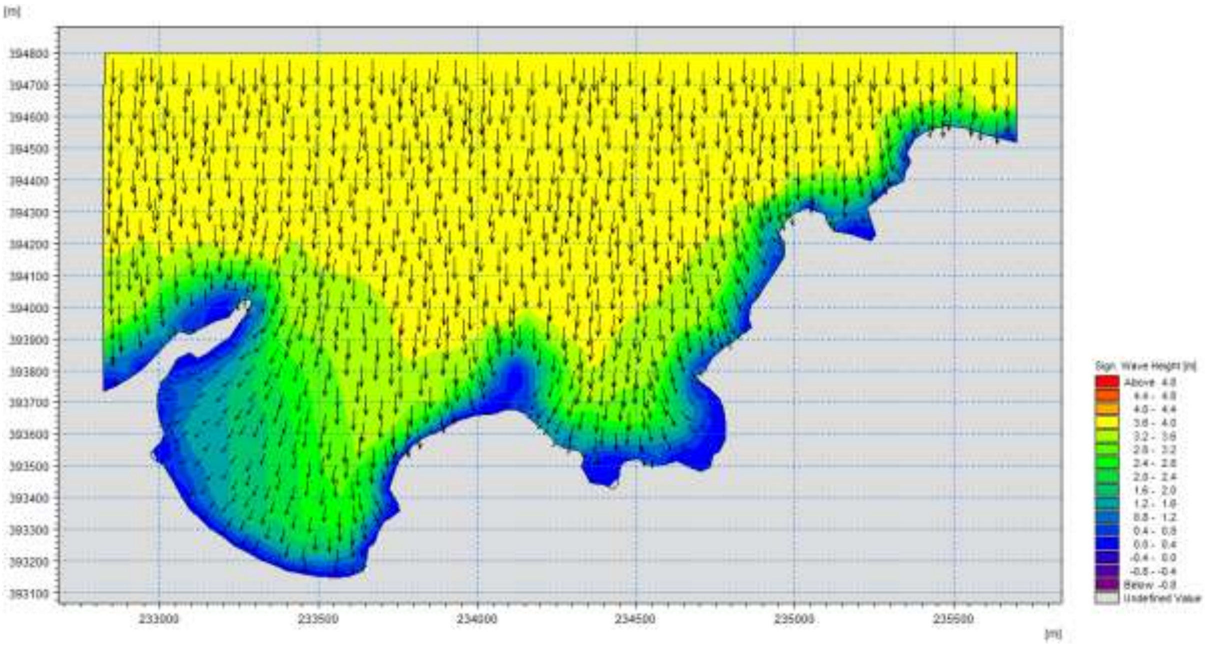


Figure 33. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=360deg.

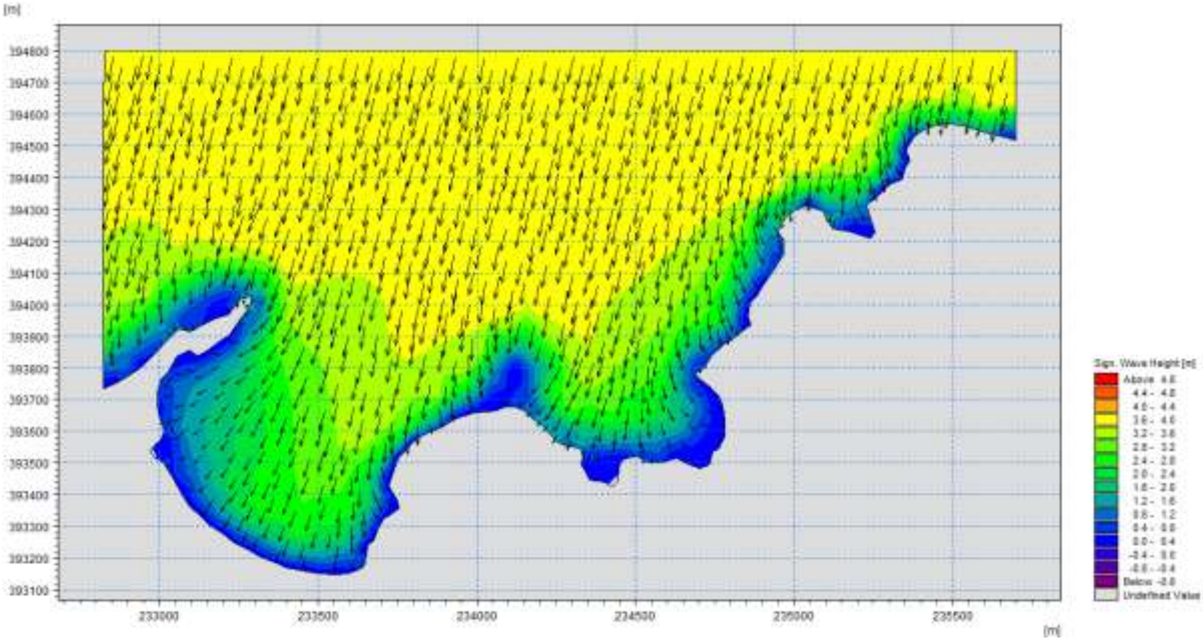


Figure 34. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=010deg.

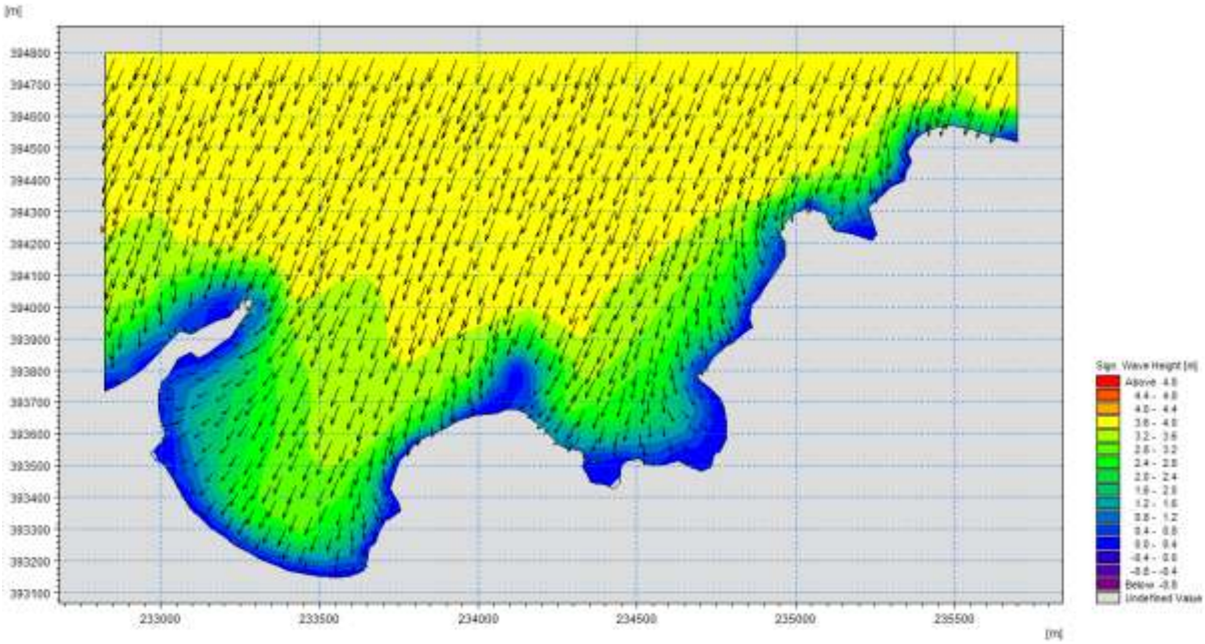


Figure 35. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=020deg.

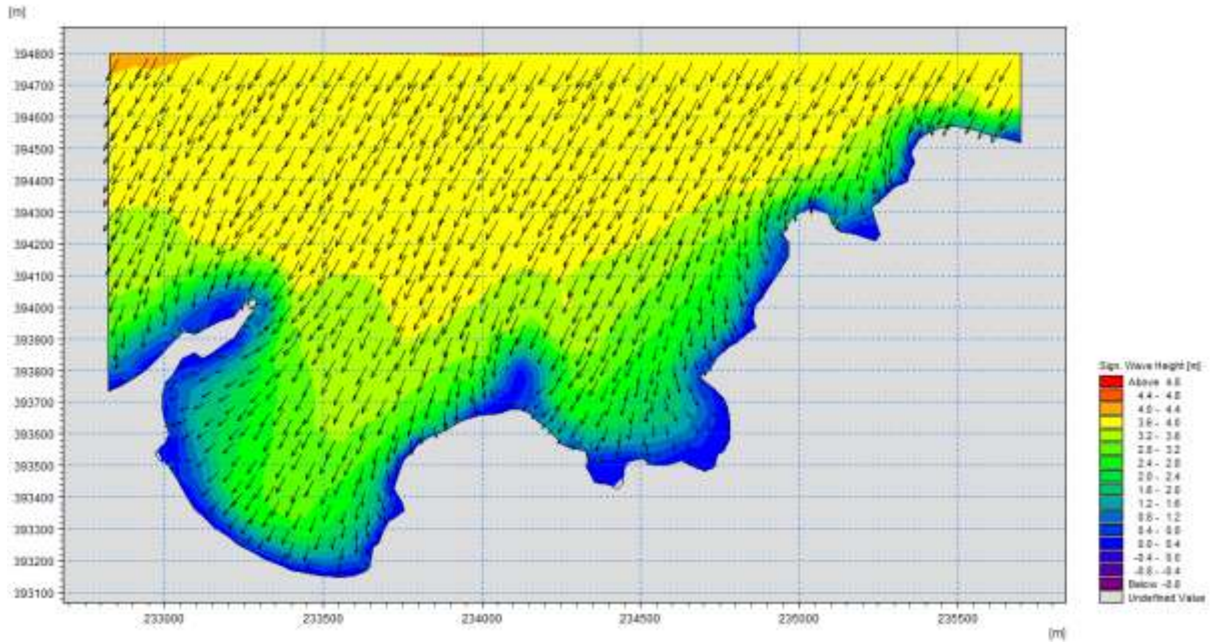


Figure 36. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=030deg.

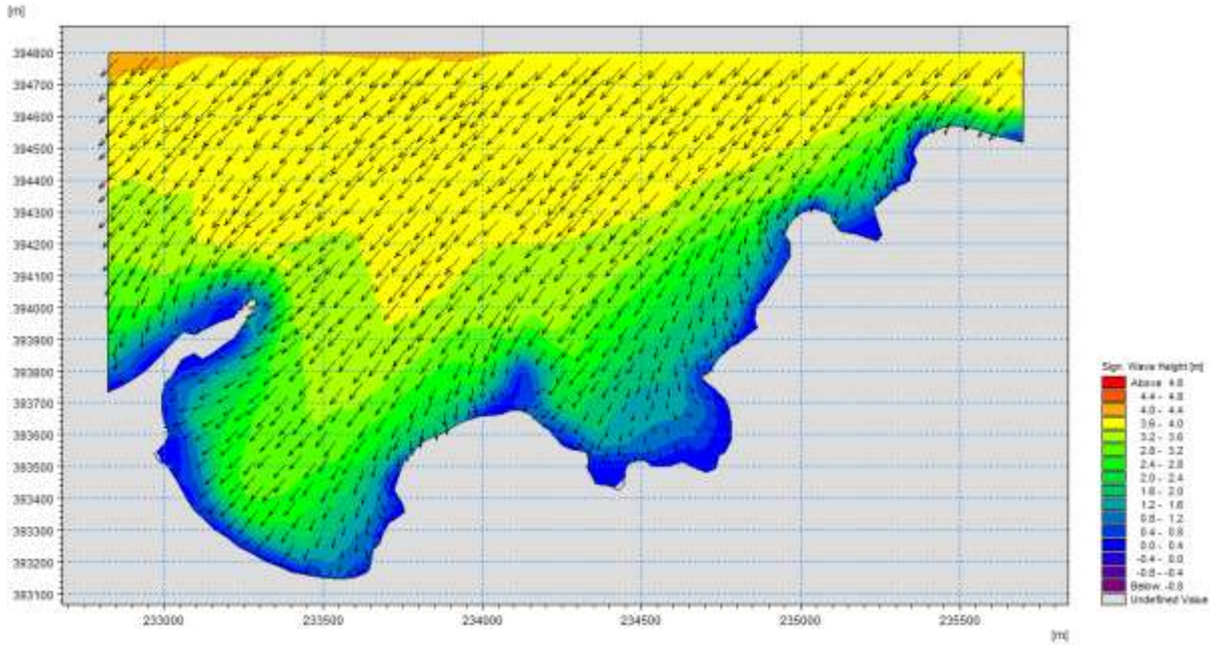


Figure 37. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=040deg.

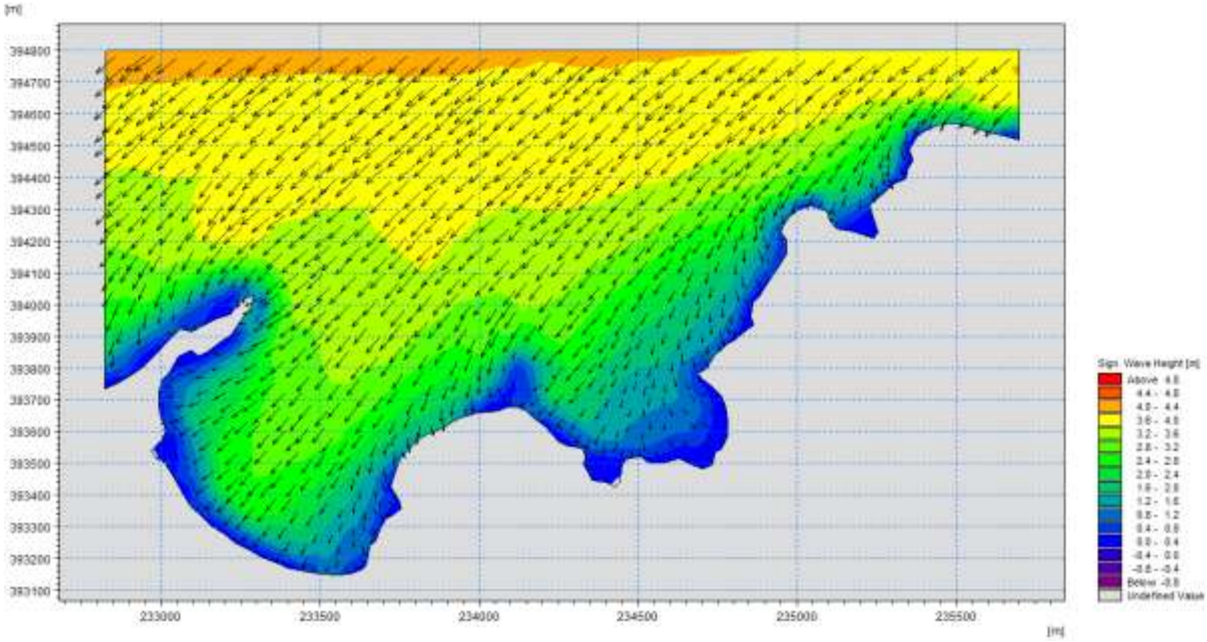


Figure 38. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=050deg.

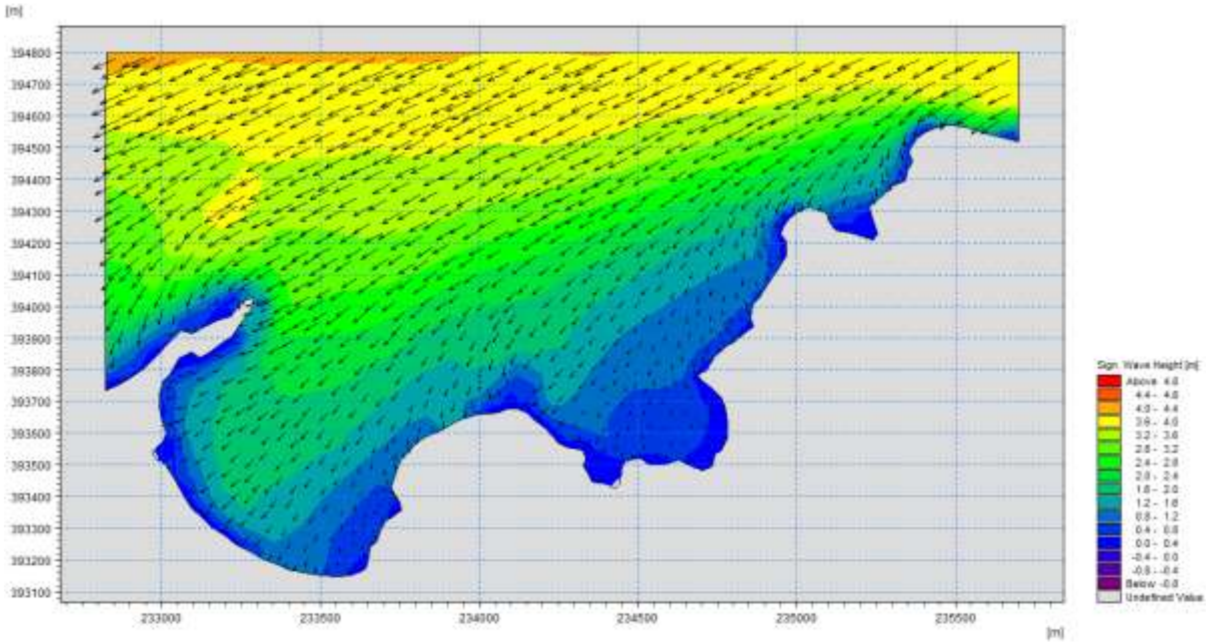


Figure 39. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=060deg.

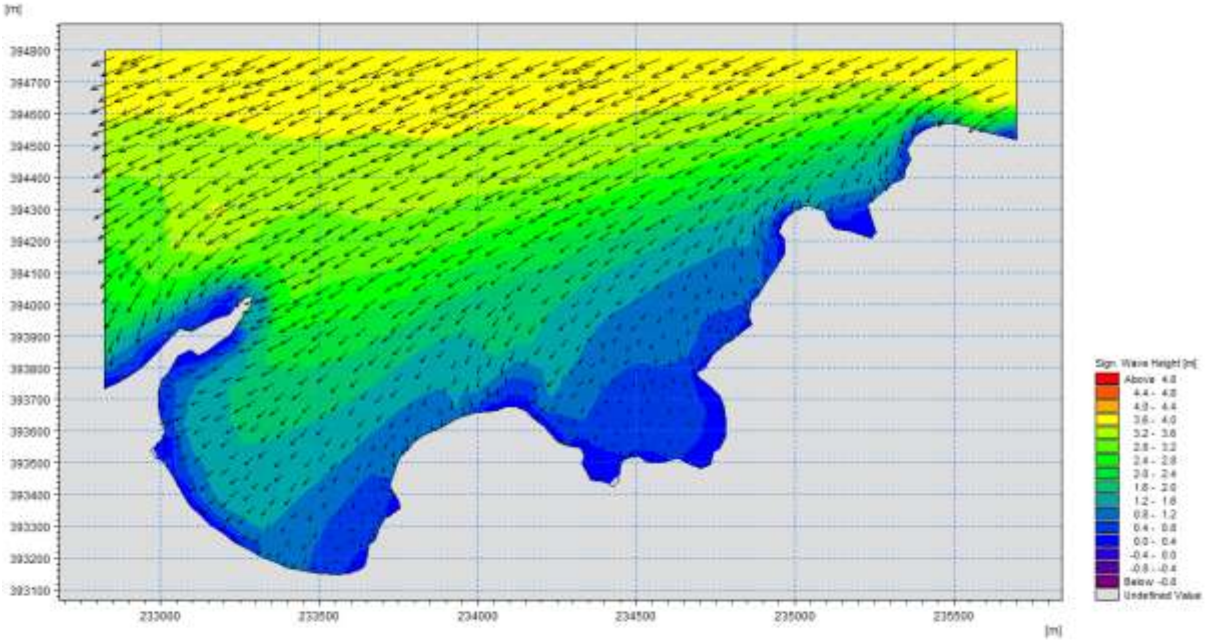


Figure 40. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=070deg.

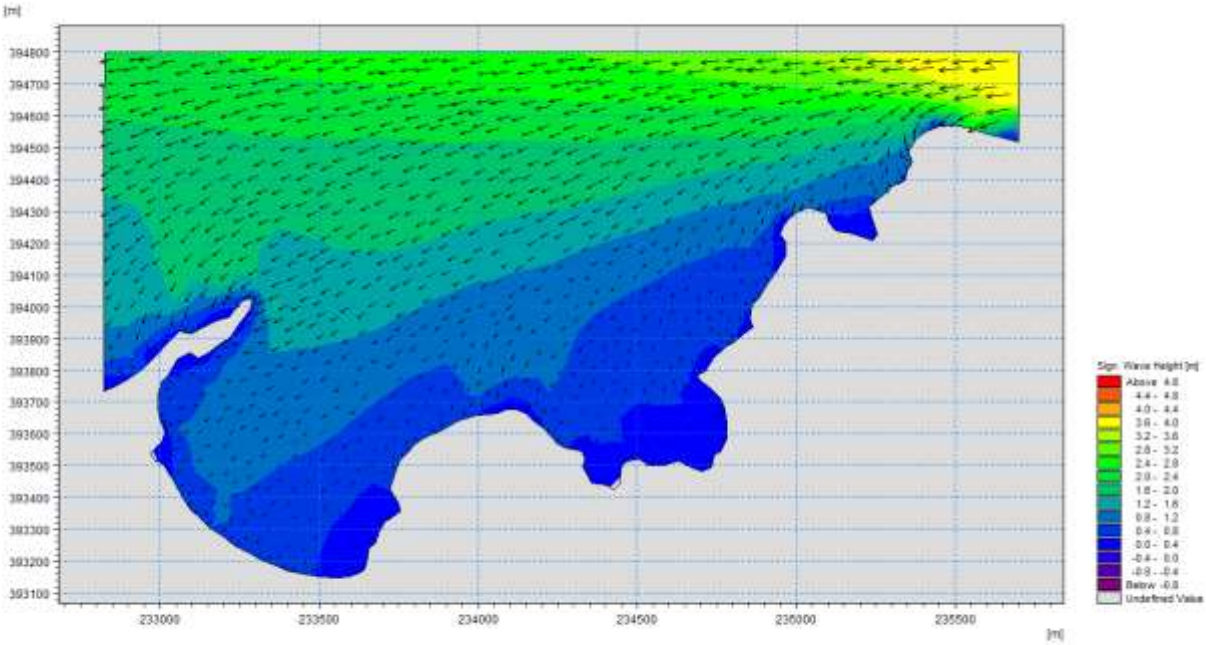


Figure 41. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=080deg.

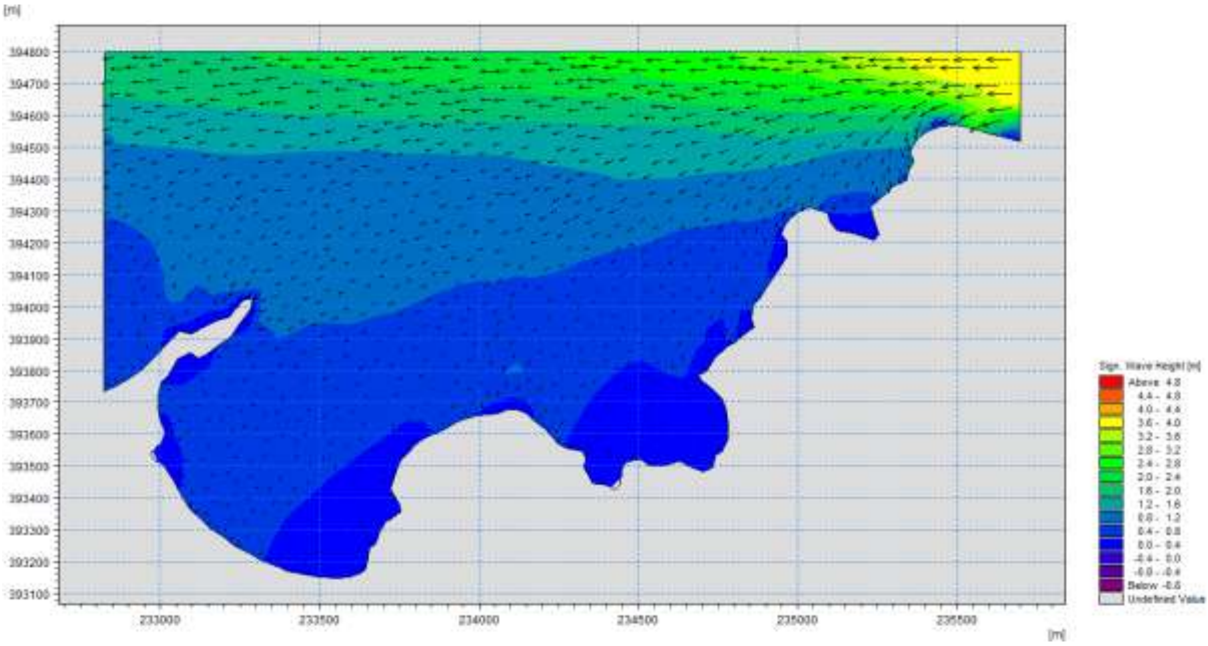


Figure 42. Mike21SW model out for waves at the model boundaries with the following parameters: Hs=4.0m, Tp=8s, WDir=090deg.

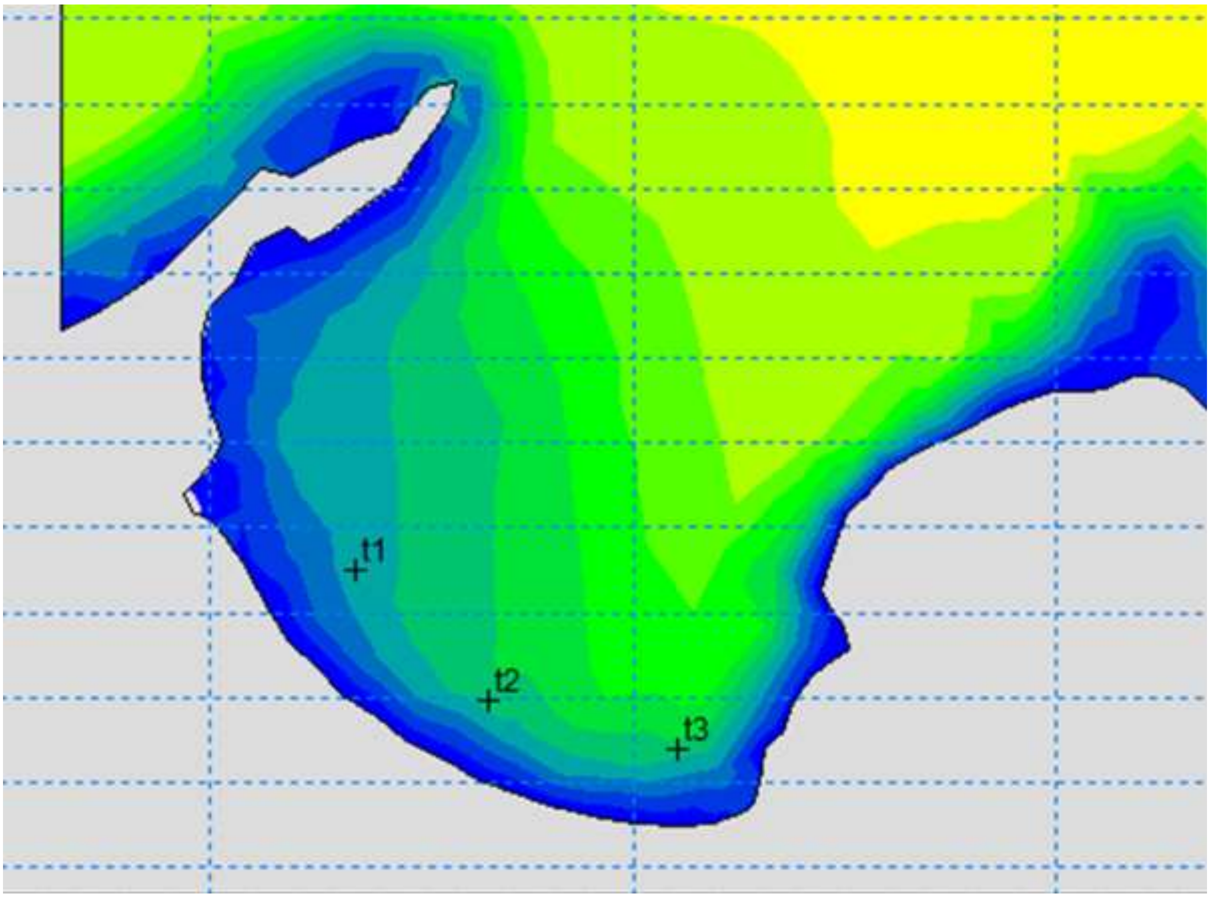


Figure 43. Locations where wave parameters have been interpolated

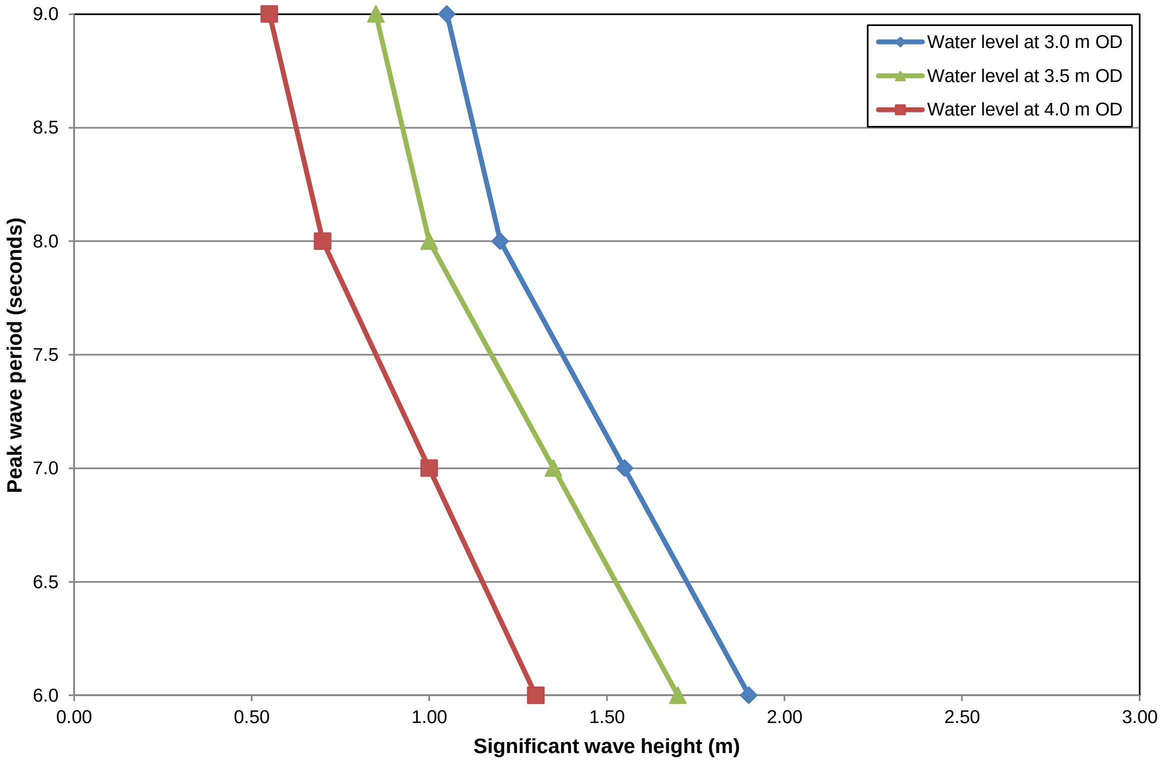


Figure 44. Combinations of significant wave height, zero up crossing wave period, and water level, which cause overtopping of the Cemlyn barrier, assuming a crest level of 4.8 m OD (Point 1 in Figure 42, almost opposite the tern islands). Calculated using XBeach-G.

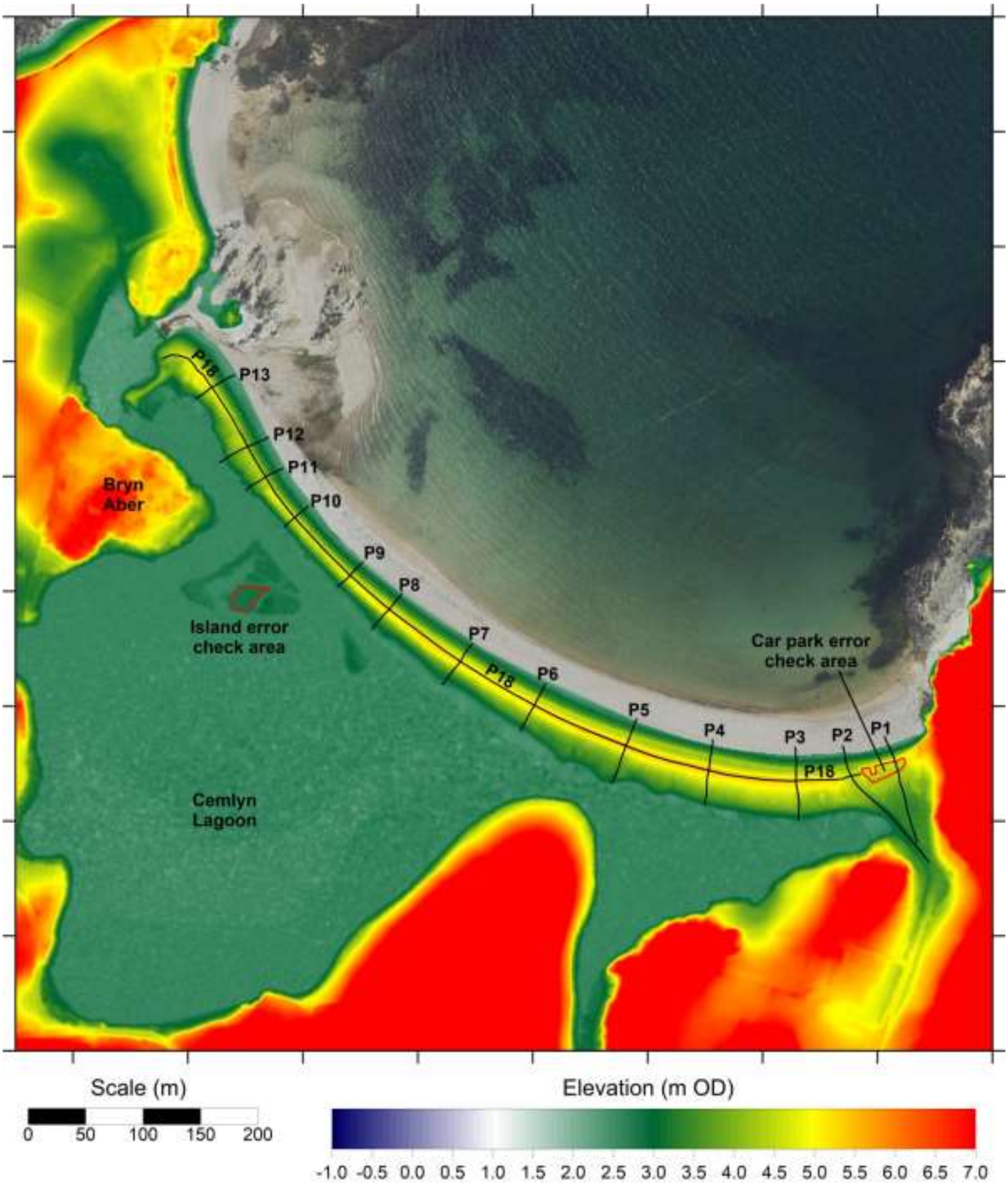


Figure 45. LiDAR survey flown on 27th November 2010. Cross profile numbers P1 to P13, and crest profile P18, are also shown.

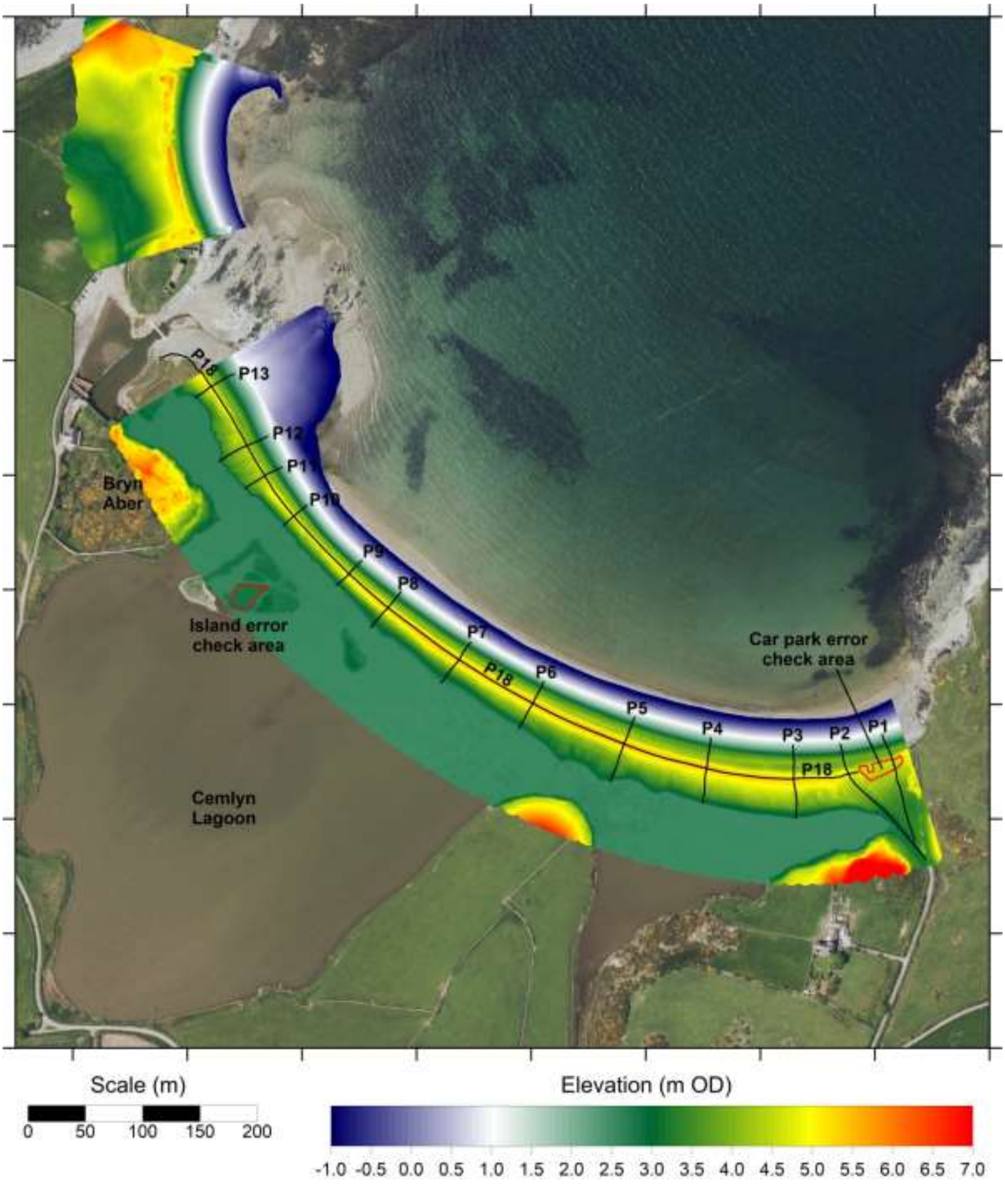


Figure 46. LiDAR survey flown in May 2017 by Horizon NP. Cross profile numbers P1 to P13, and crest profile P18, are also shown. Data have been lowered by 2 cm, following an error check with the previous 2010 LiDAR survey, and the ground RTK survey on 1st February 2016.

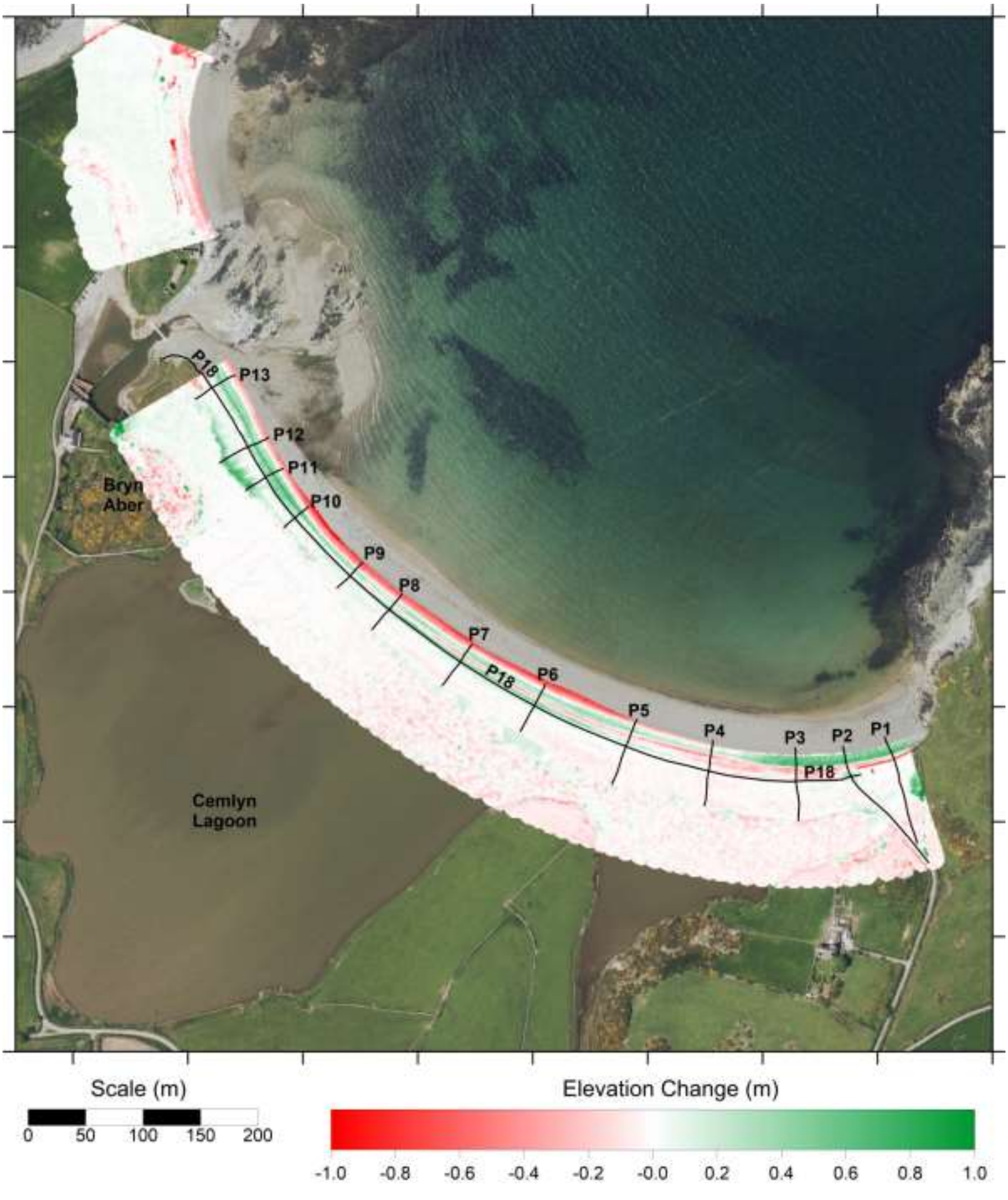


Figure 47. Elevation difference map between the 2010 and adjusted 2017 LiDAR surveys

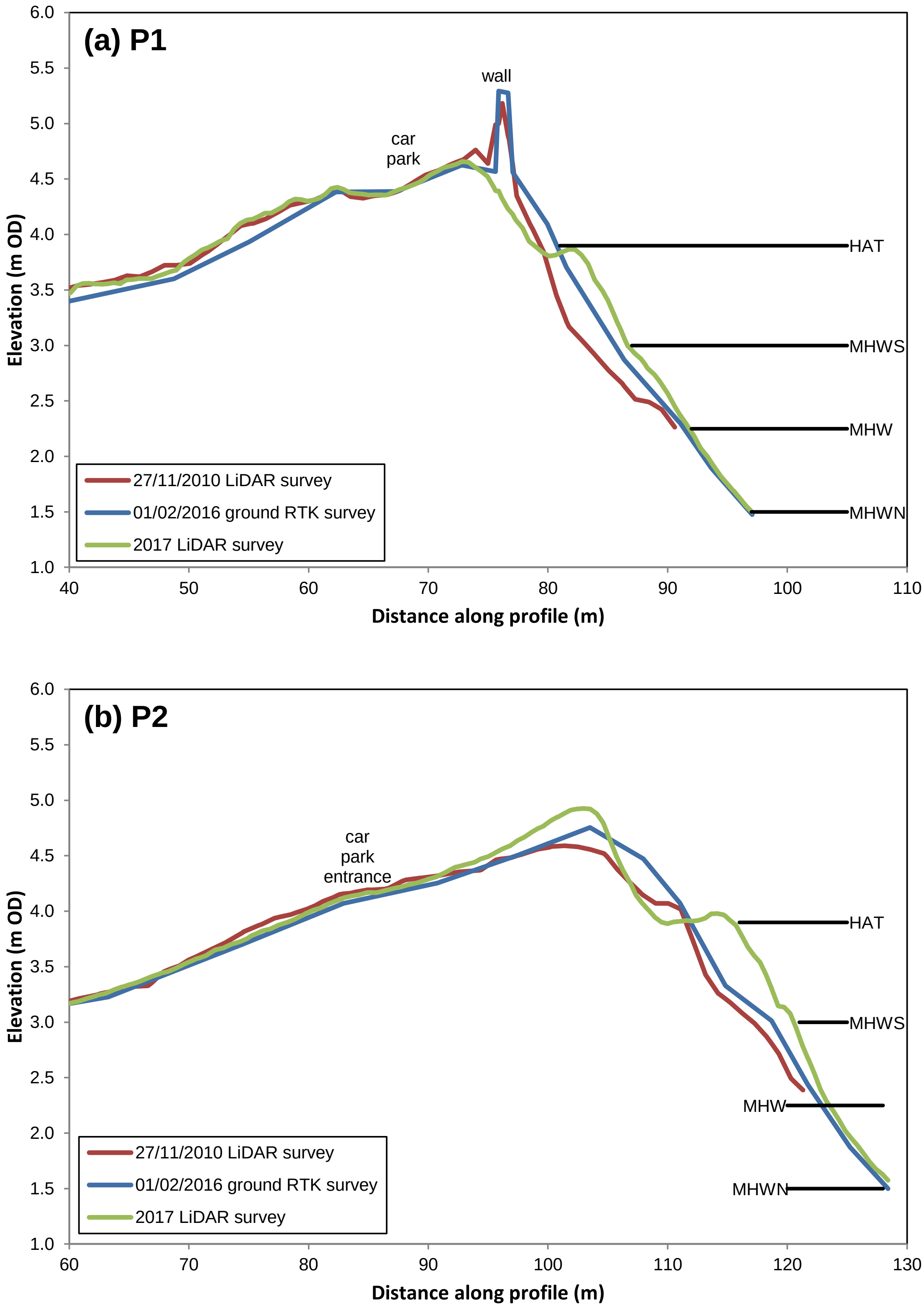


Figure 48. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016. NB. In (a) the filtering of the 2010 data failed to 'remove' the wall which remains in place

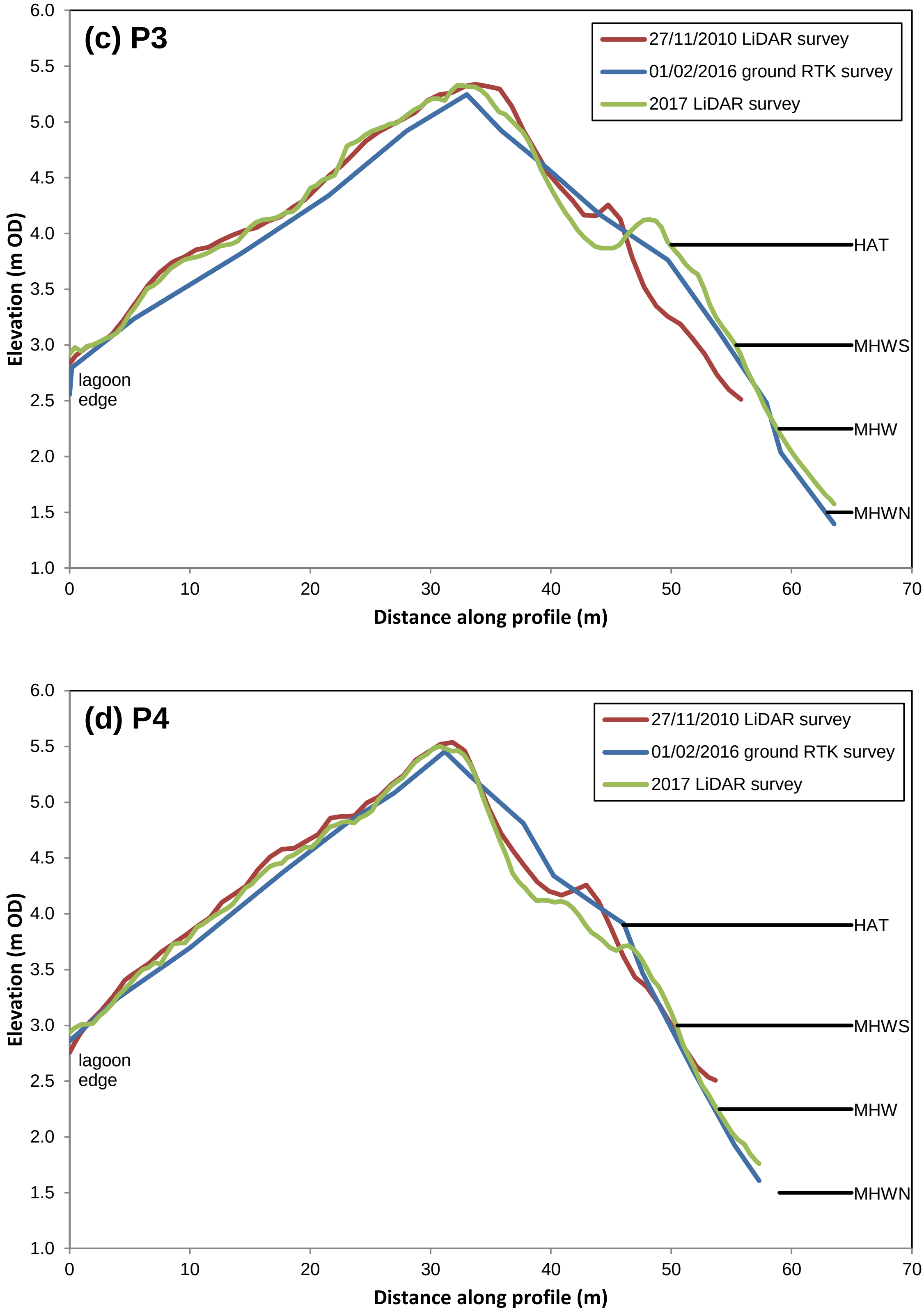
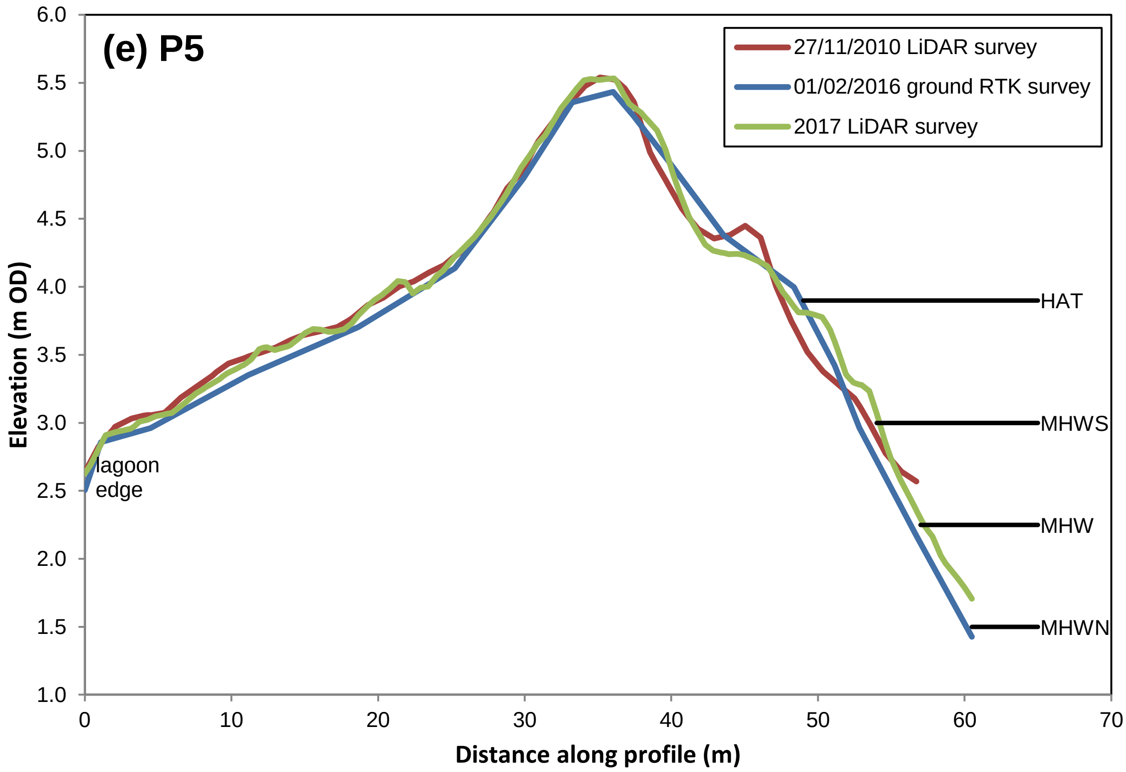


Figure 48 cont. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.



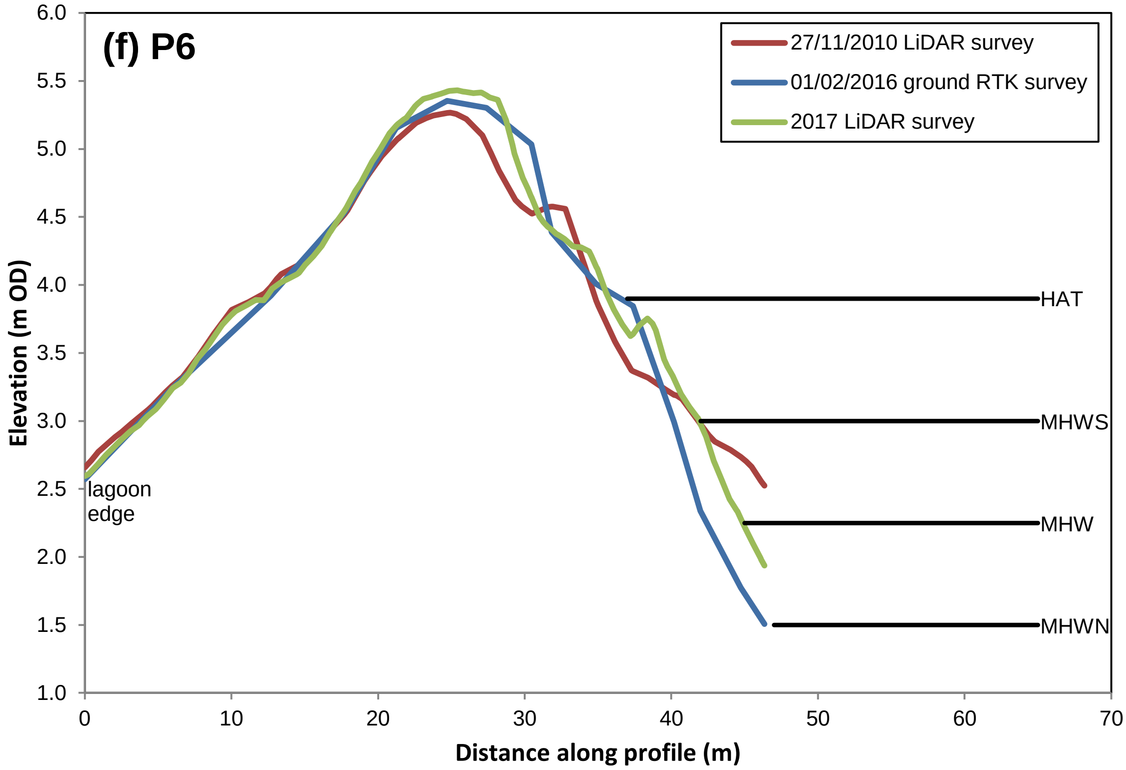
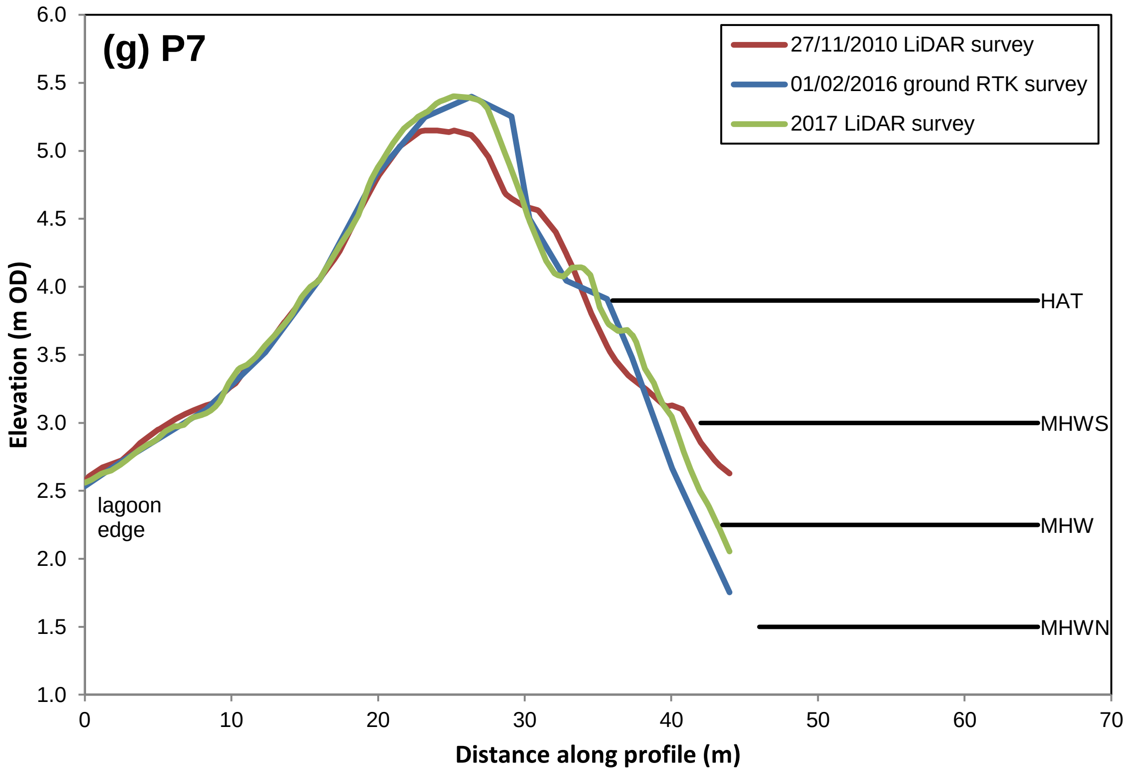


Figure 48 cont. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.



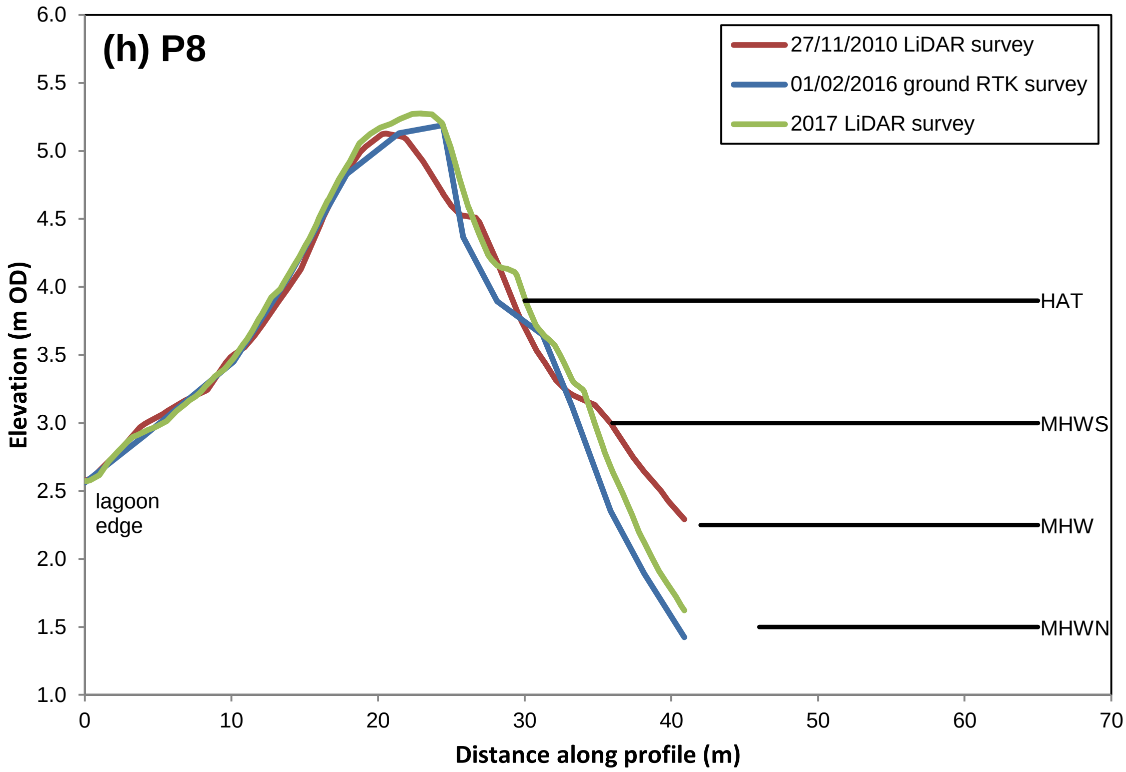
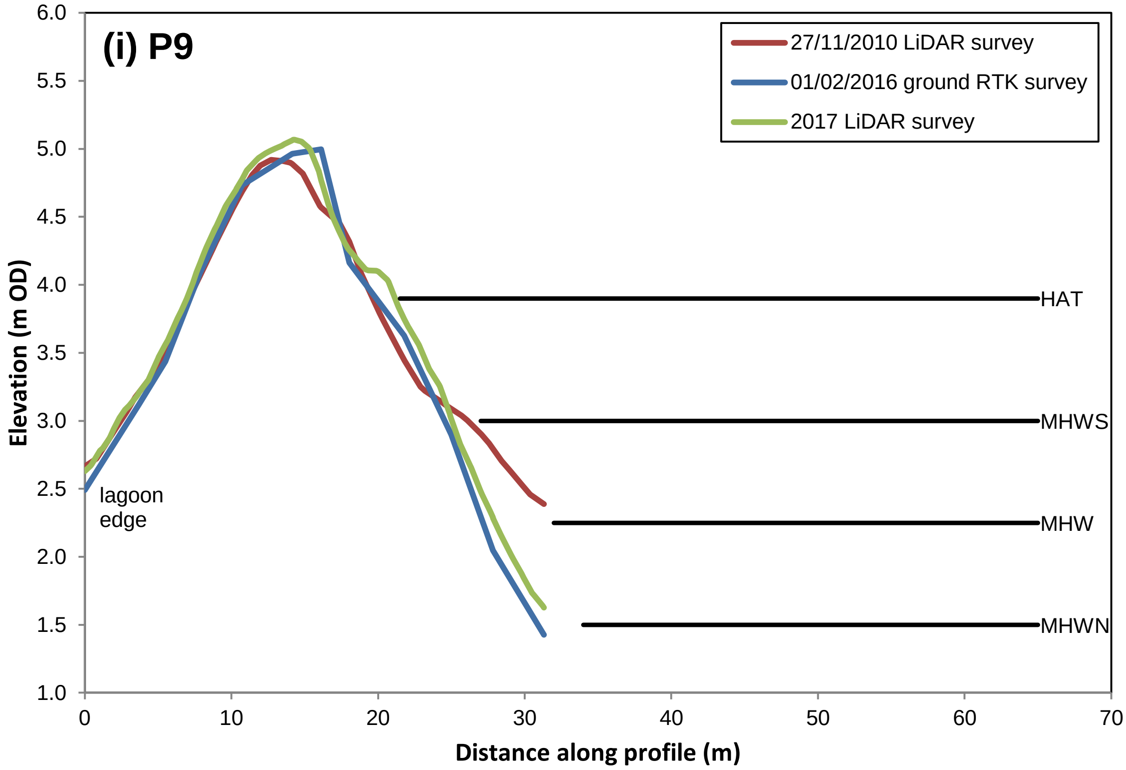


Figure 48 cont. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.



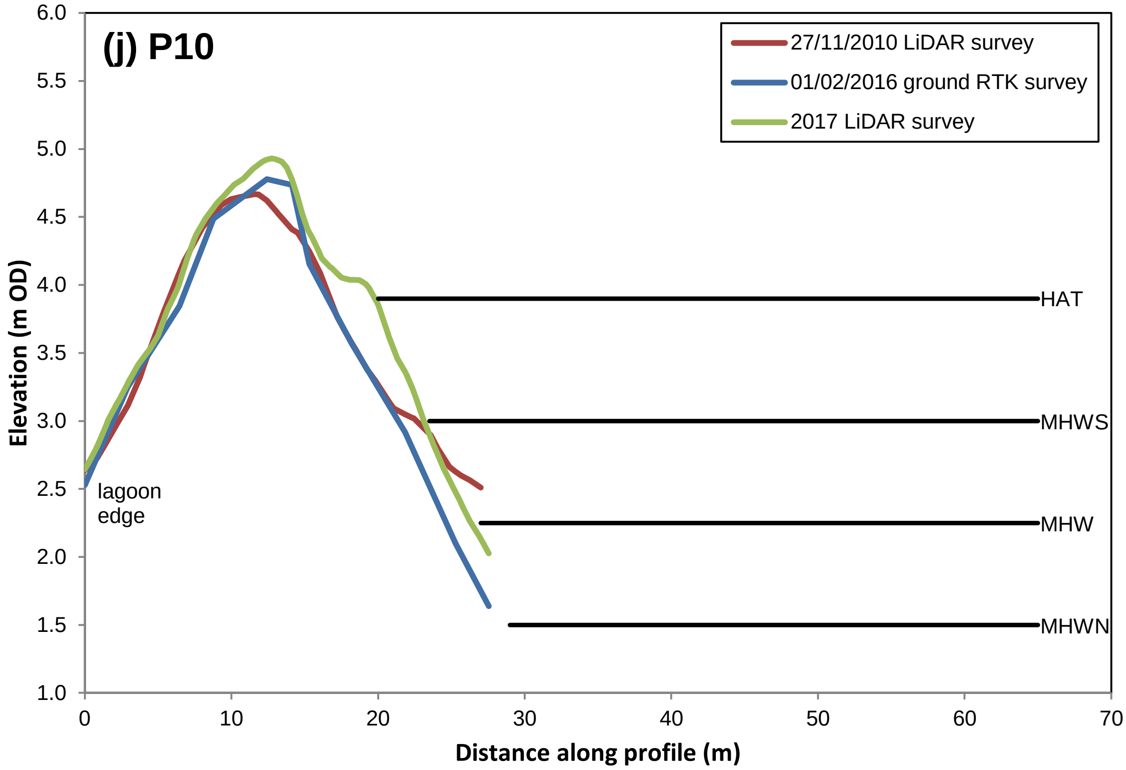
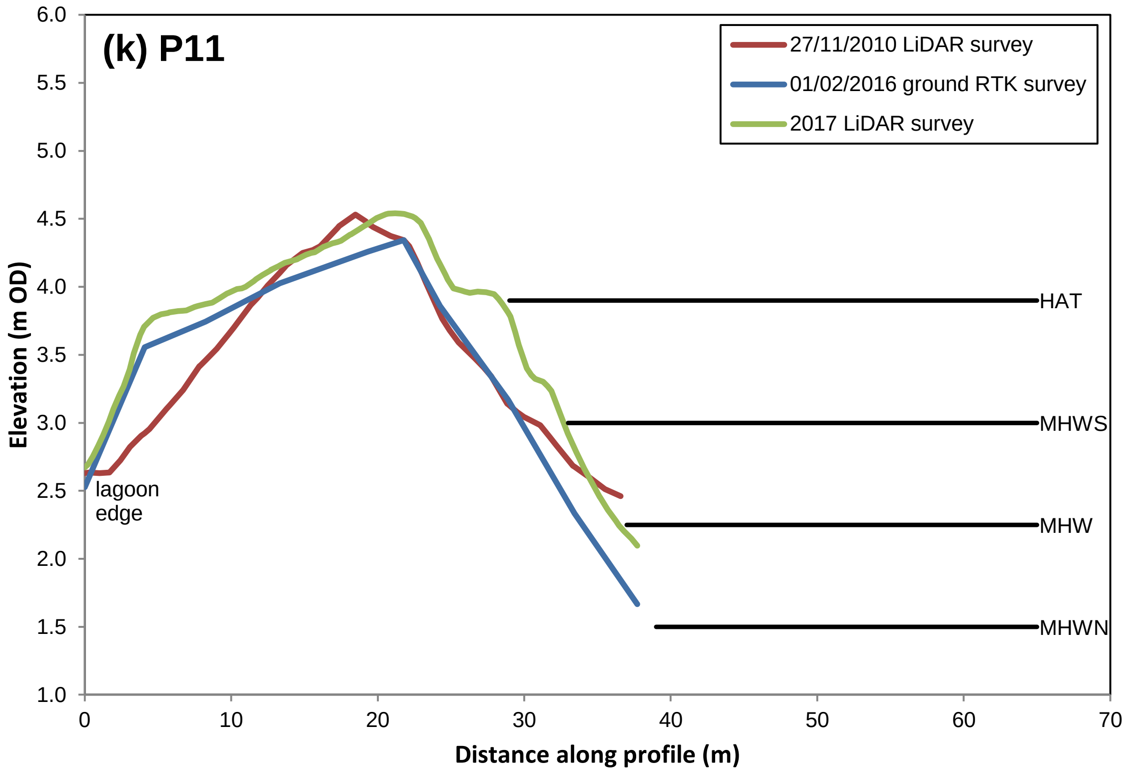


Figure 48 cont. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.



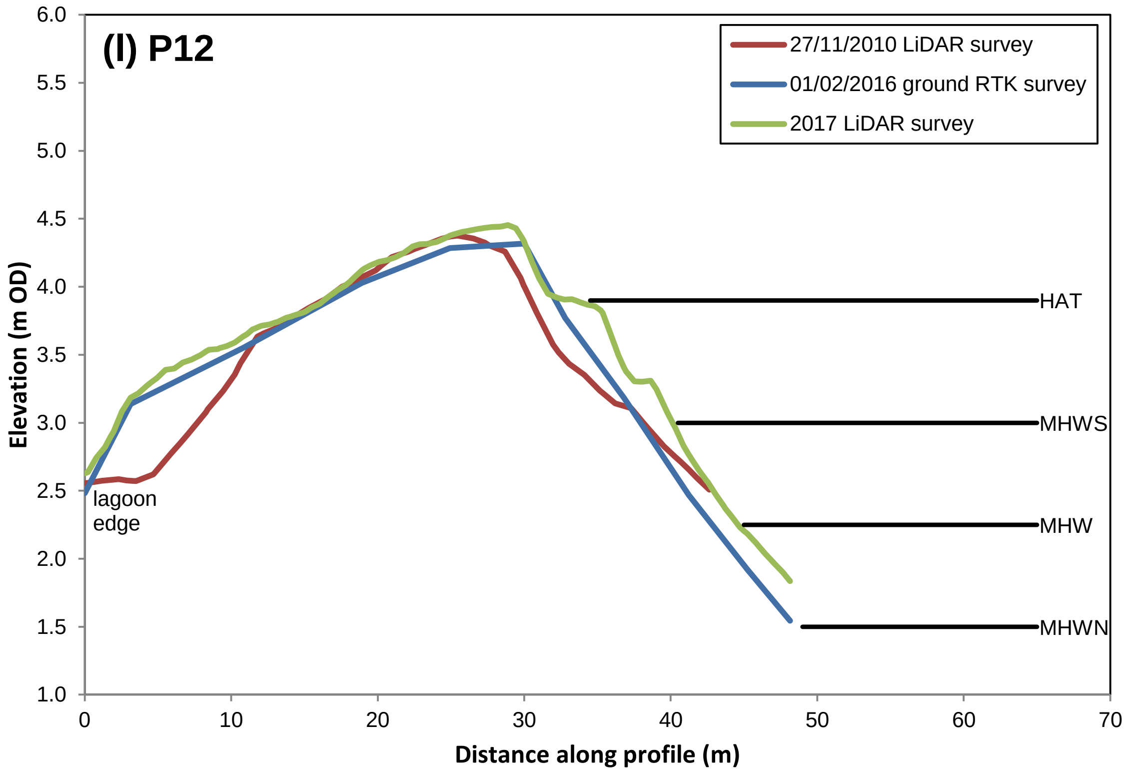
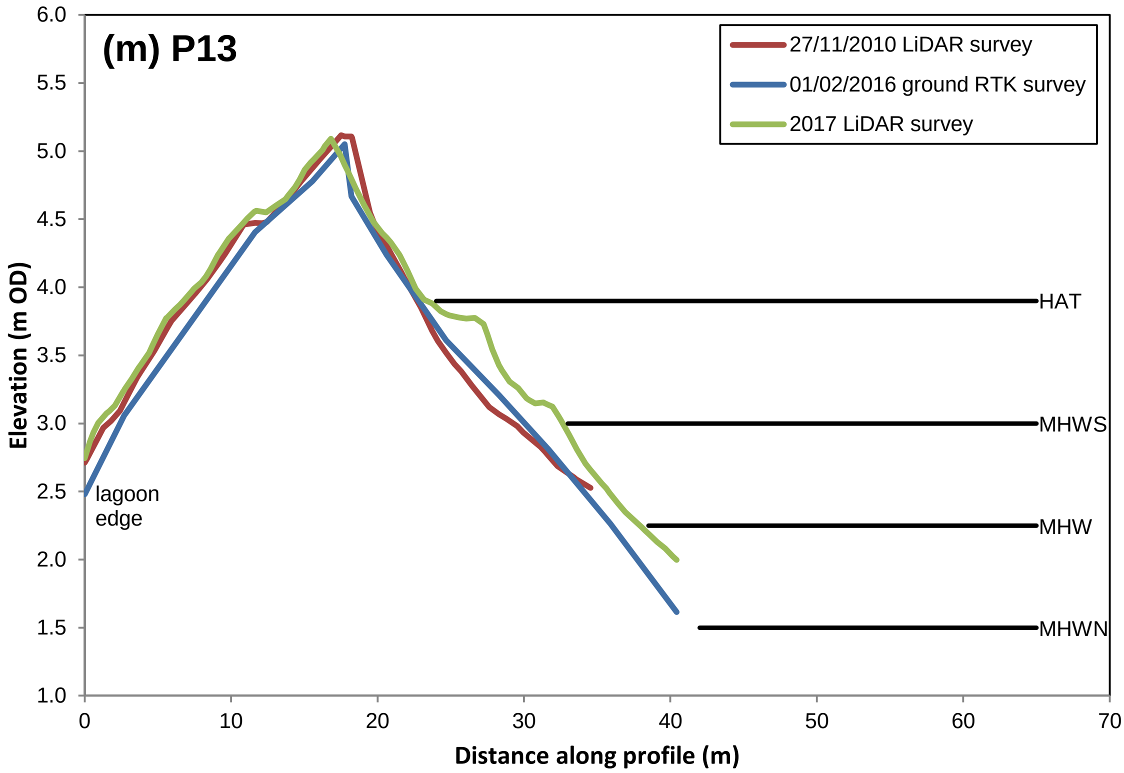


Figure 48 cont. Comparison of cross profiles of the barrier crest area taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.



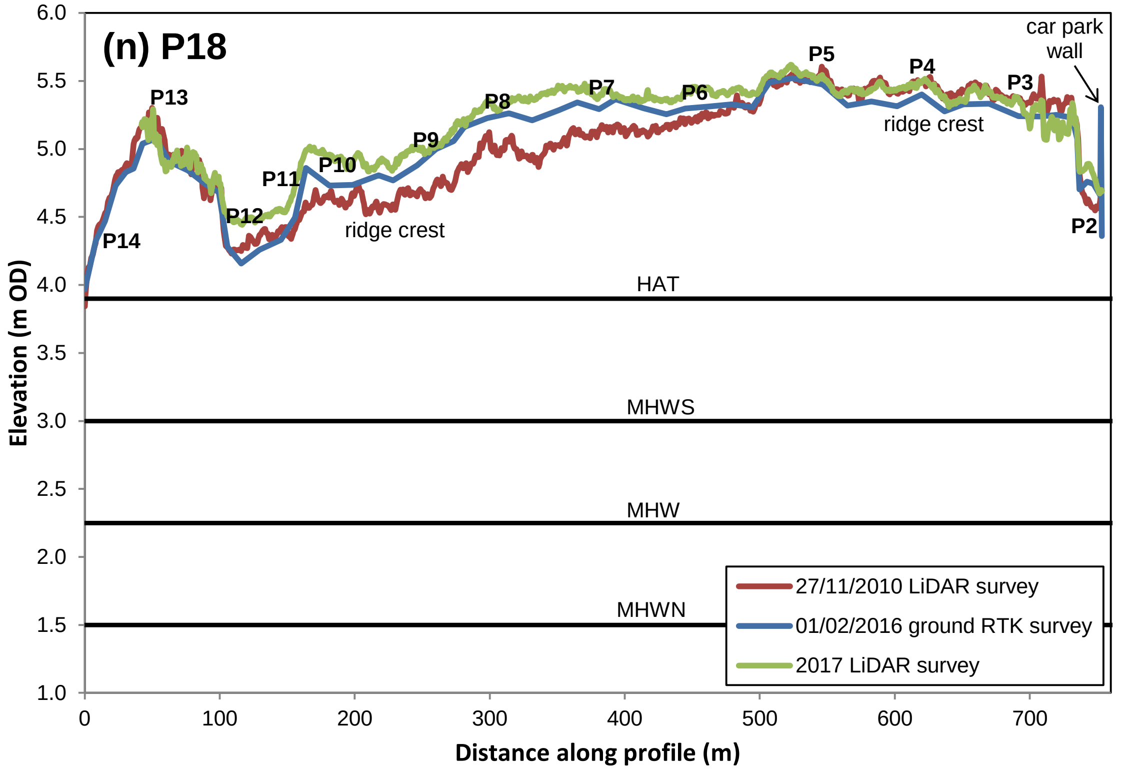


Figure 48 cont. Comparison of cross profiles of the barrier crest area and (n) crest profile along the length of the barrier taken from LiDAR surveys in 2010 and 2017, and a KPAL ground RTK survey in 2016.

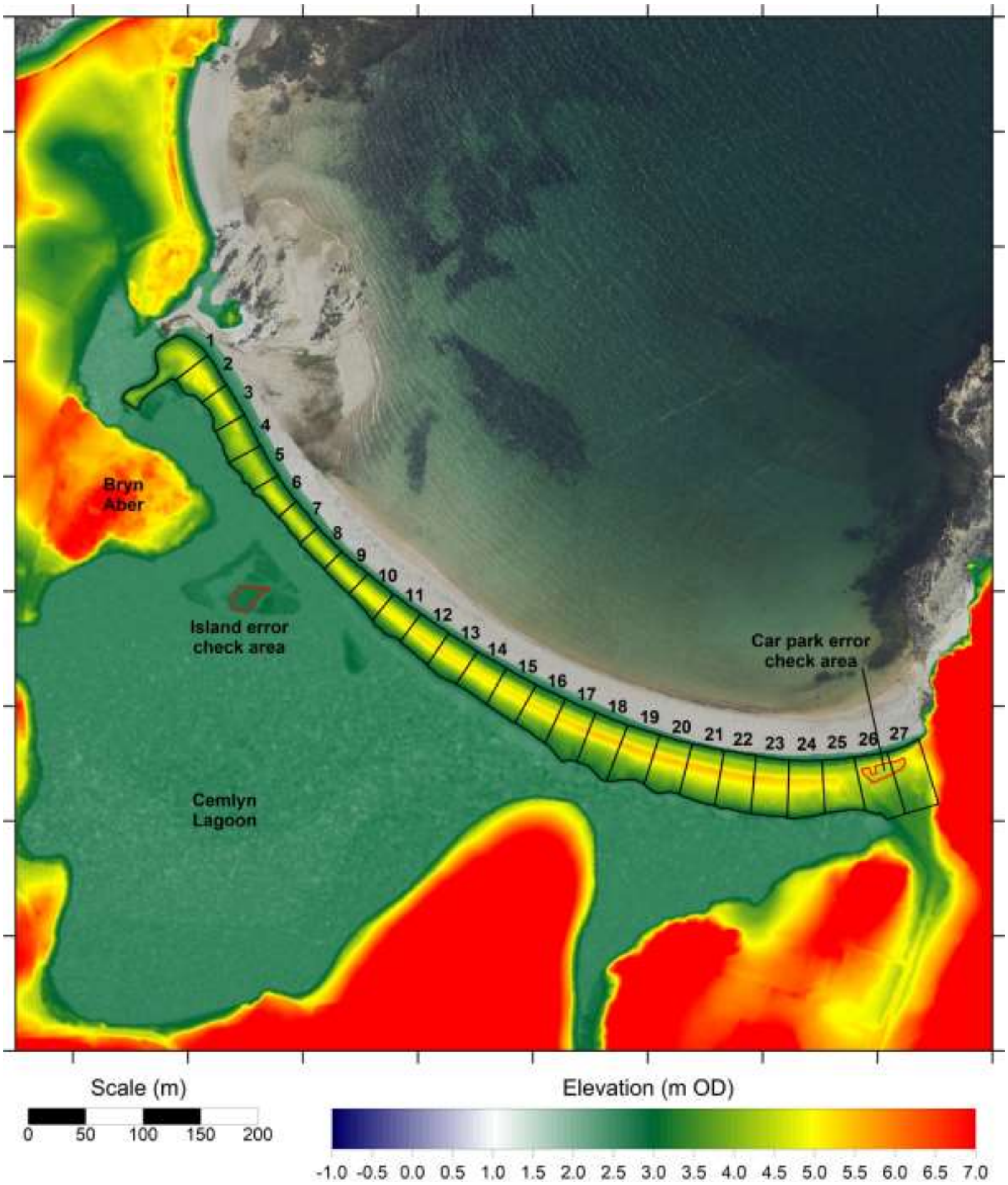


Figure 49. Defined cell numbers 1 to 27 (each 30 m wide at the seaward end) used for calculating barrier volumes and areas are also shown, superimposed on 2010 LiDAR DEM.

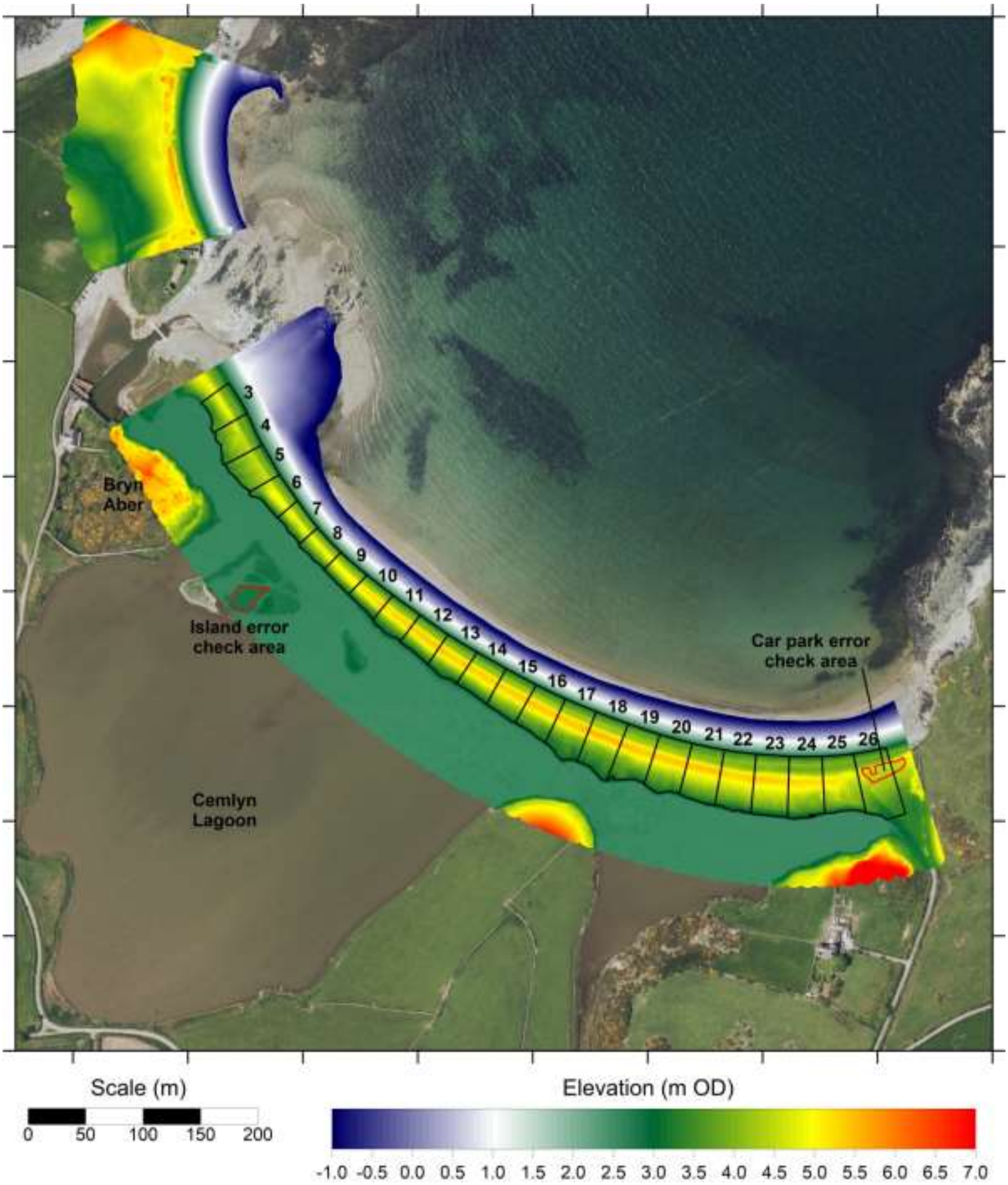


Figure 50. Defined cell numbers 1 to 27 (each 30 m wide at the seaward end) used for calculating barrier volumes and areas, superimposed on 2017 LiDAR DEM.

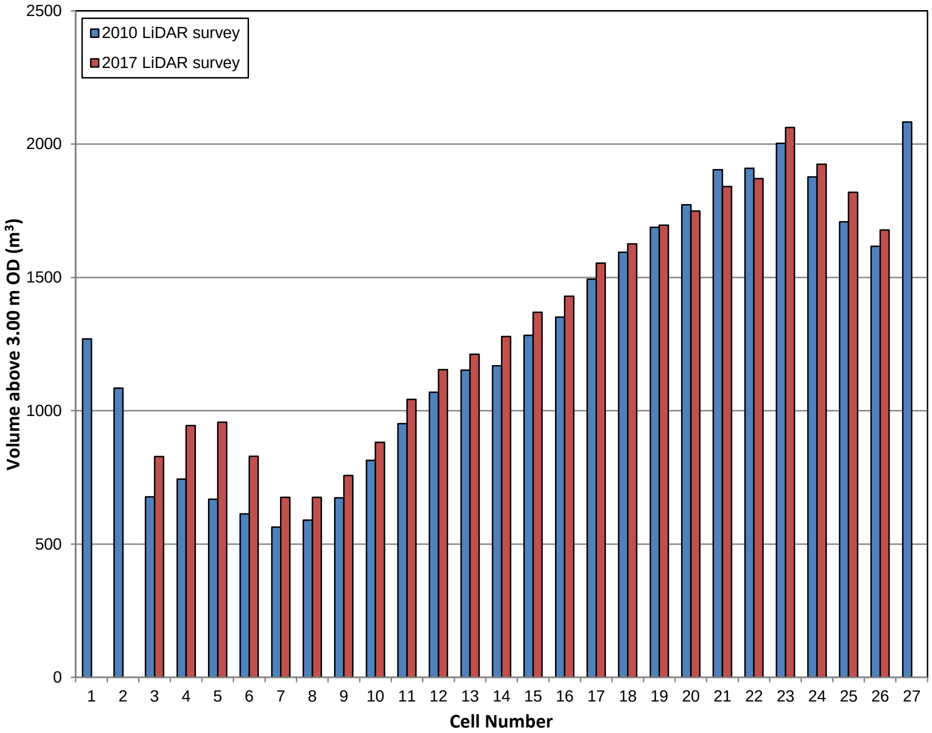


Figure 51. Comparison of sediment volumes above 3.00 m OD in cells 1-27, based on LiDAR surveys in 2010 and 2017.

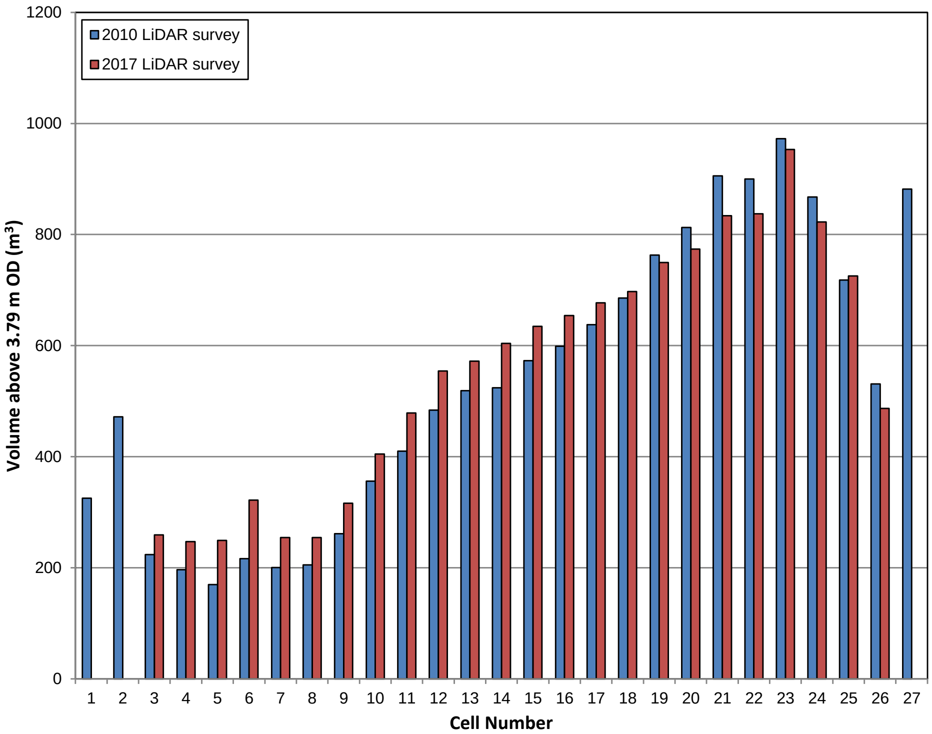


Figure 52. Comparison of sediment volumes above 3.79 m OD (HAT) in cells 1 – 27, based on LiDAR surveys in 2010 and 2017.

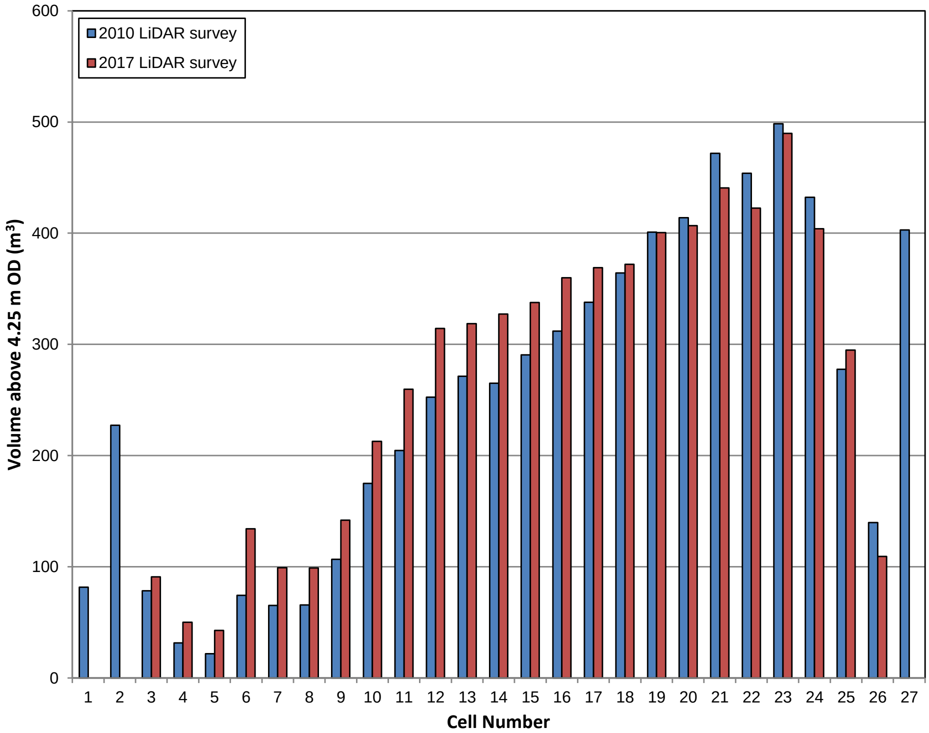


Figure 53. Comparison of sediment volumes above 4.25 m OD (1 in 200 year surge level) in cells 1 – 27, based on LiDAR surveys in 2010 and 2017.

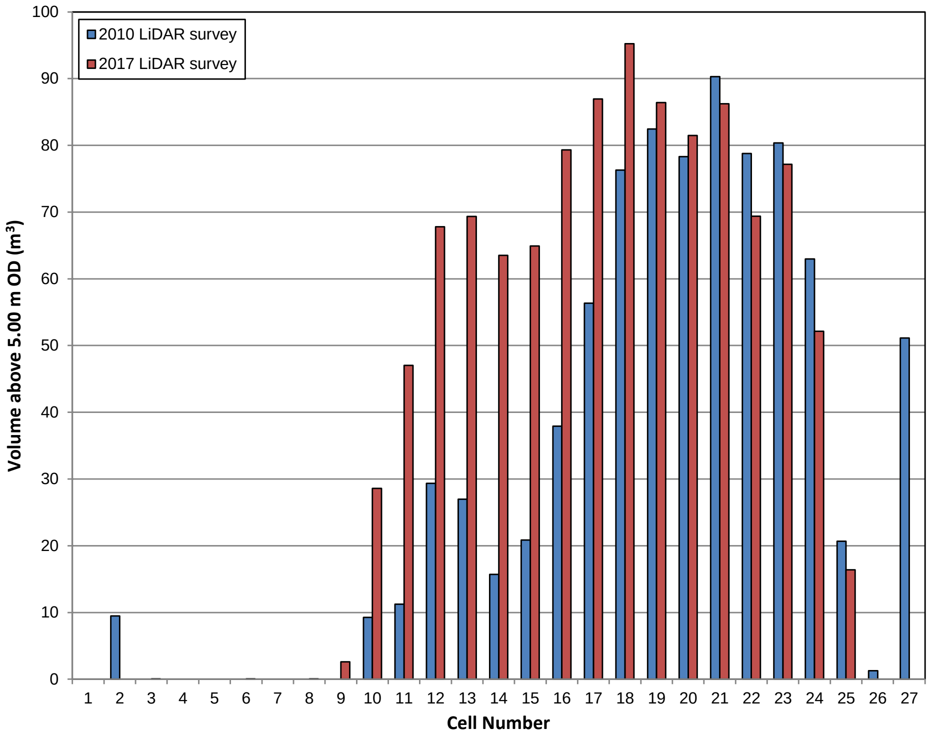


Figure 54. Comparison of sediment volumes above 5.00 m OD in cells 1 - 27, based on LiDAR surveys in 2010 and 2017.

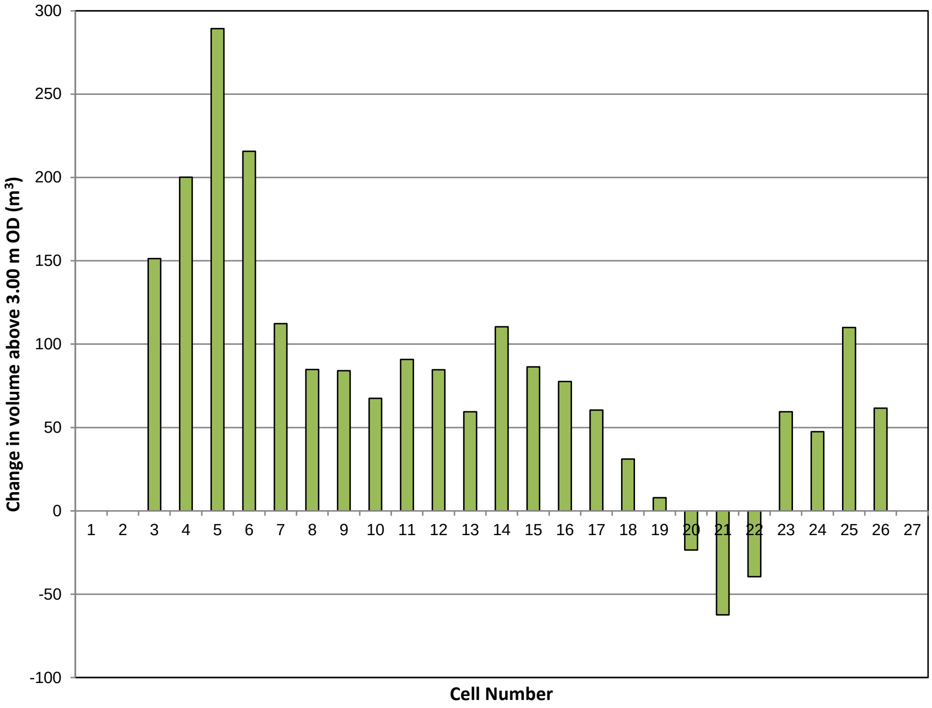


Figure 55. Change in sediment volume above 3.00 m OD in cells 1- 27 based on LiDAR surveys in 2010 and 2017.

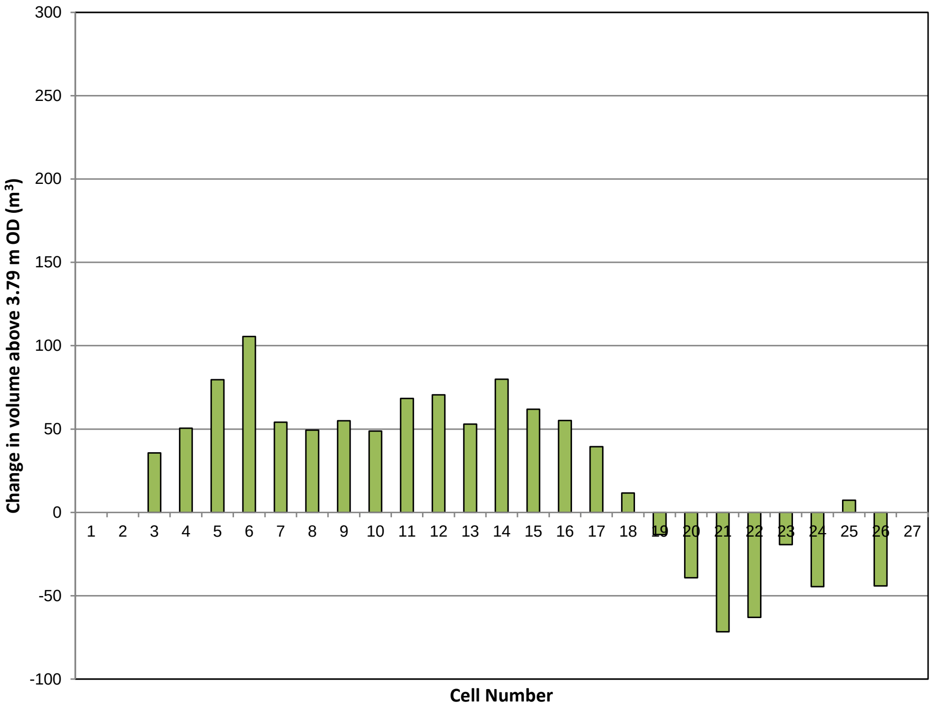


Figure 56. Change in sediment volume above 3.79 m OD (HAT) in cells 1 – 27, based on LiDAR surveys in 2010 and 2017.

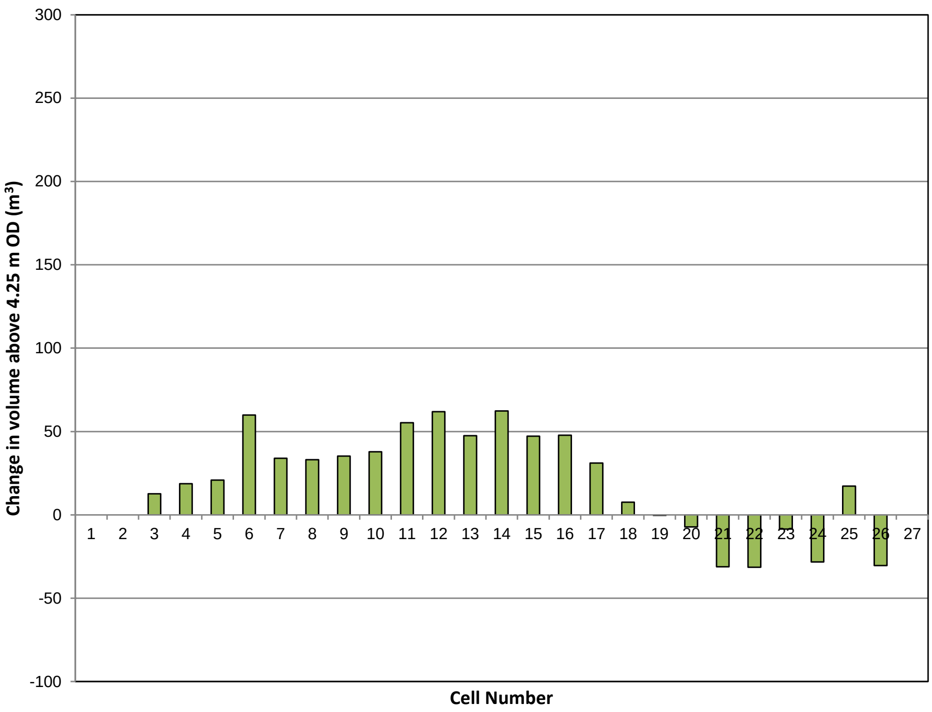


Figure 57. Change in sediment volume above 4.25 m OD (1 in 200 year surge level) in cells 1 - 27, based on LiDAR surveys in 2010 and 2017.

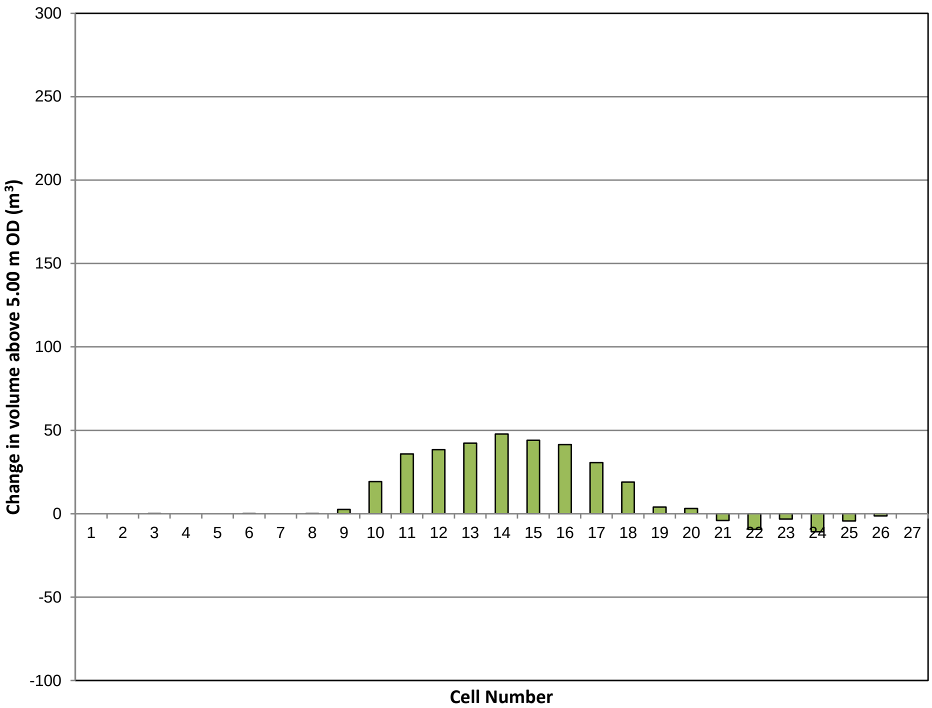


Figure 58. Change in sediment volume above 5.00 m OD in cells 1 – 27, based on LiDAR surveys in 2010 and 2017.

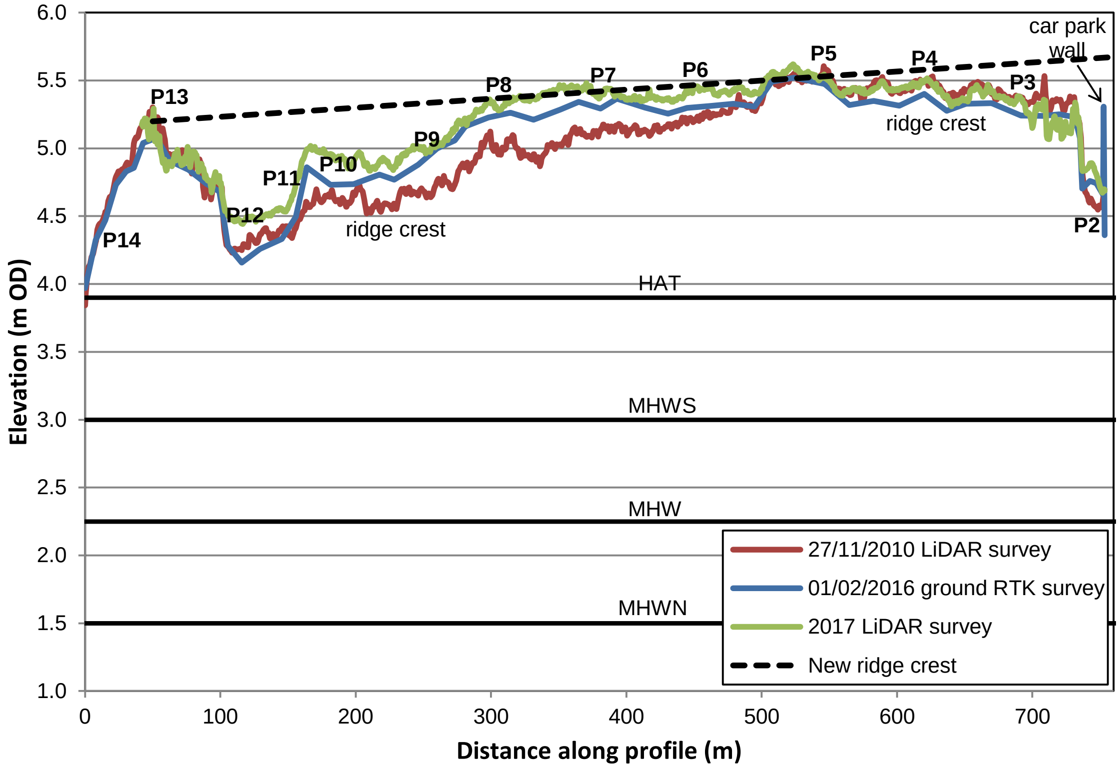


Figure 59. Cross-section along the crest of the barrier, showing the idealized new ridge crest sloping from 5.2 m OD at the NW end (profile P13) to 5.7 m OD at the SE end (profile P1).

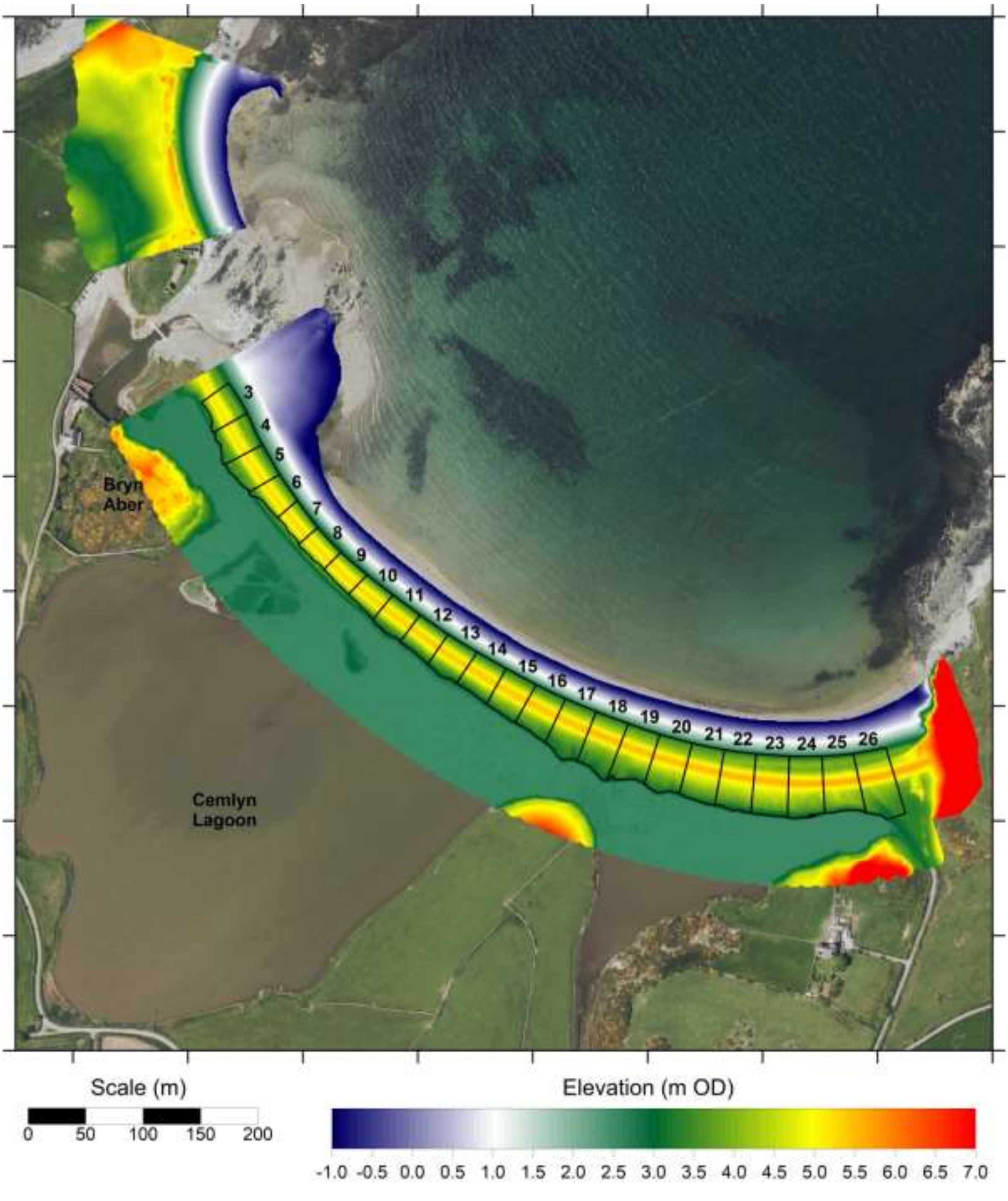


Figure 60. LiDAR survey flown in 2017, with the barrier increased in height and volume to match the barrier profile in Cell 12, with a crest elevation of 5.2 m OD at NW end and 5.7 m OD at SE end.

Figure 61. Enlargement of the NW half of the May 2017 DEM, showing interpolated 1 m contours

Figure 62. Enlargement of the SE half of the May 2017 DEM, showing interpolated 1 m contours

Figure 63. Enlargement of the NW section of a modified DEM, with superimposed hypothetical contours following the addition of gravel from an external source. The modified ridge slopes slightly from 5.2 m at the NW end to 5.7 m OD at the SE end. The modified barrier as shown has been graded into the existing 0 m OD seaward contour, and the 3 m OD landward contour, or the 2 m contour where the rear toe of the ridge extends into the existing lagoon.

Figure 64. Enlargement of the NW section of the Cemlyn Barrier showing the depth of gravel required (in cm) to raise and widen the barrier to that shown in Figure 62.

Figure 65. Enlargement of the SE section of a modified DEM, with superimposed hypothetical contours following the addition of gravel from an external source. The modified ridge slopes slightly from 5.2 m at the NW end to 5.7 m OD at the SE end. The modified barrier as shown has been graded into the existing 0 m OD seaward contour, and the 3 m OD landward contour.

Figure 66. Enlargement of the SE section of the Cemlyn Barrier showing the depth of gravel required (in cm) to raise and widen the barrier to that shown in Figure 21.

Figure 67. One possible enlargement to the tern islands in the lagoon, used in sediment demand calculations

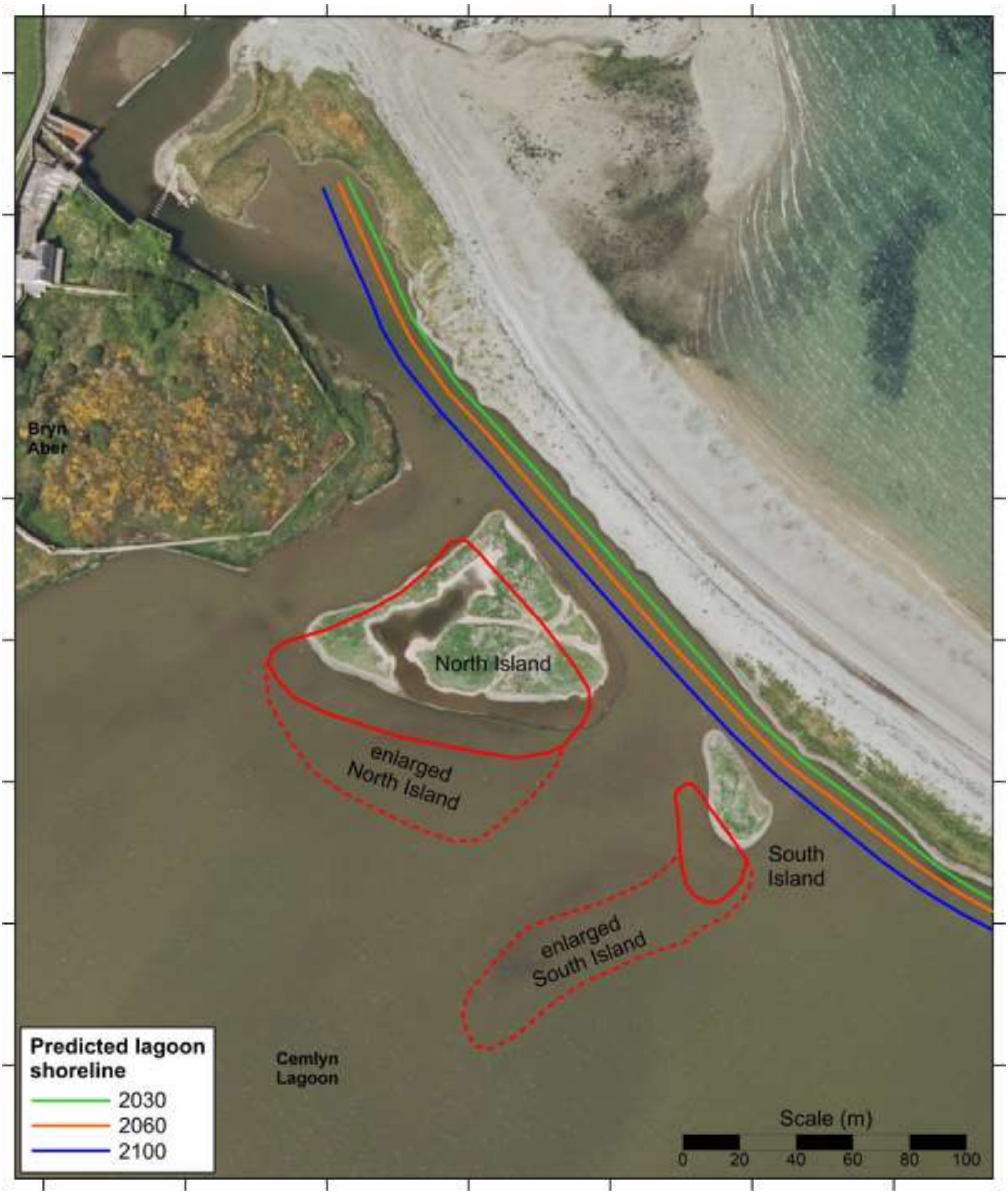


Figure 68. Projected positions of the lagoon shoreline in 2030, 2060 and 2100, based on historical trend analysis and increased future erosion rates calculated by Pye and Blott (2010). Also shown are possible positions for the tern to be relocated to allow space for the barrier to retreat landwards until 2100.

Appendix 1

Historical Maps and Aerial Photographs

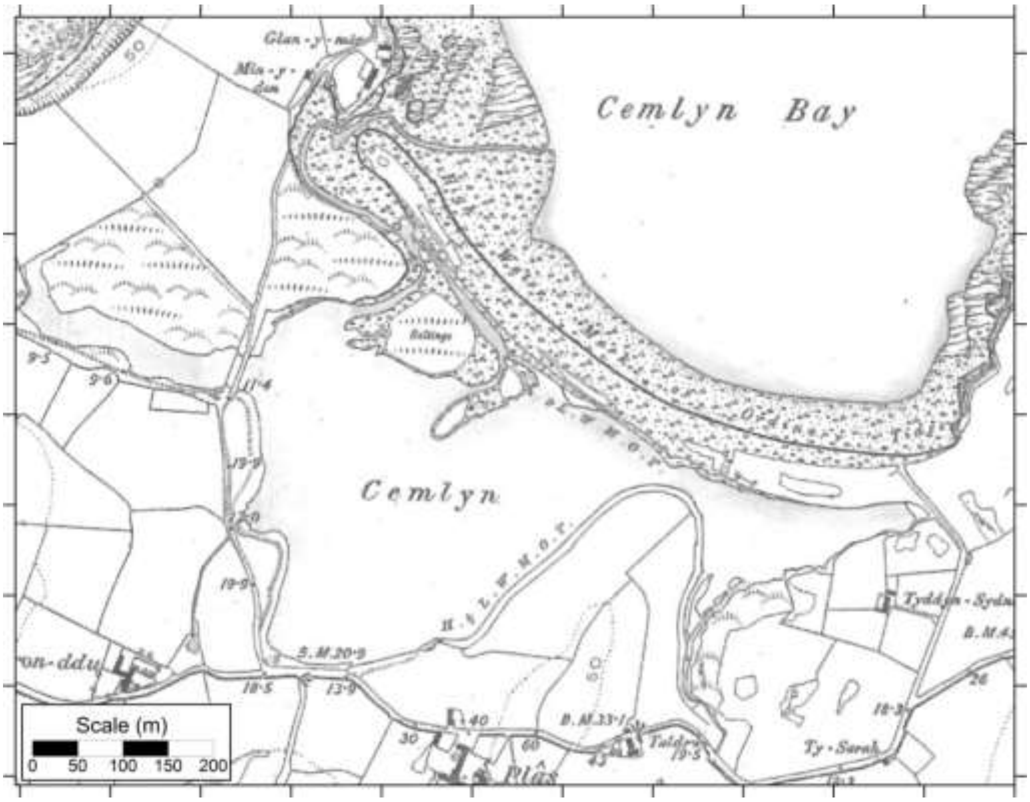


Figure A1.1 First Edition County Series Ordnance Survey Map, published in 1890, surveyed in 1887.

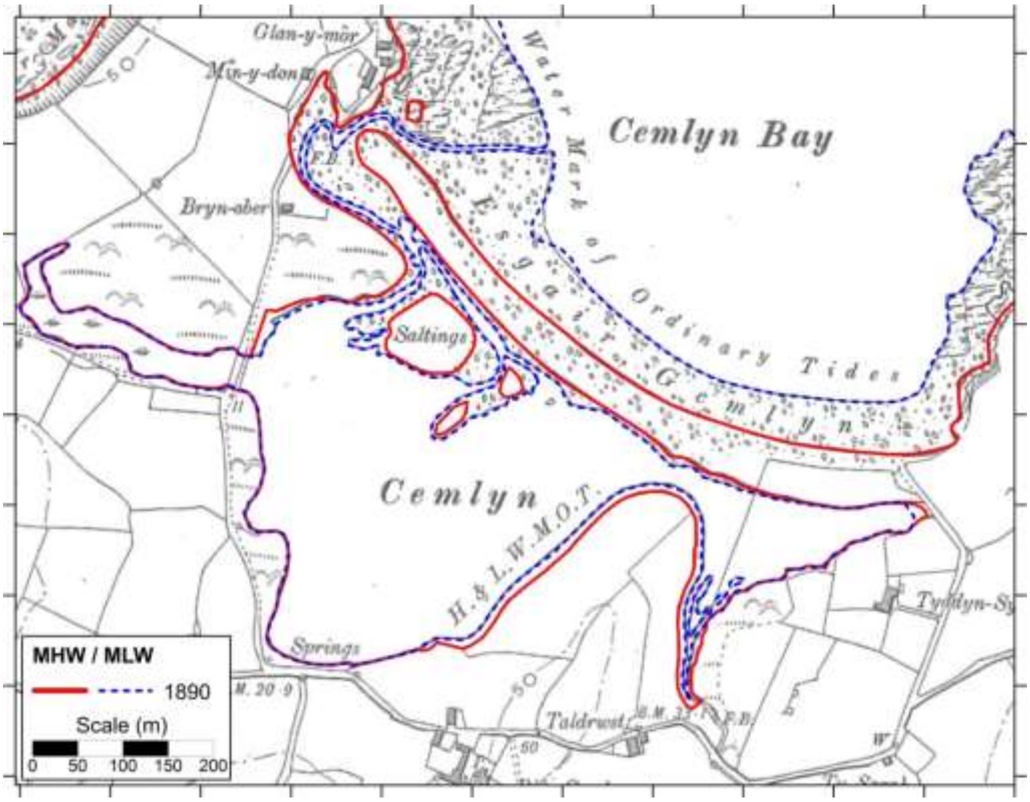


Figure A1.2 Second Edition County Series Ordnance Survey Map, published in 1901, revised in 1899. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

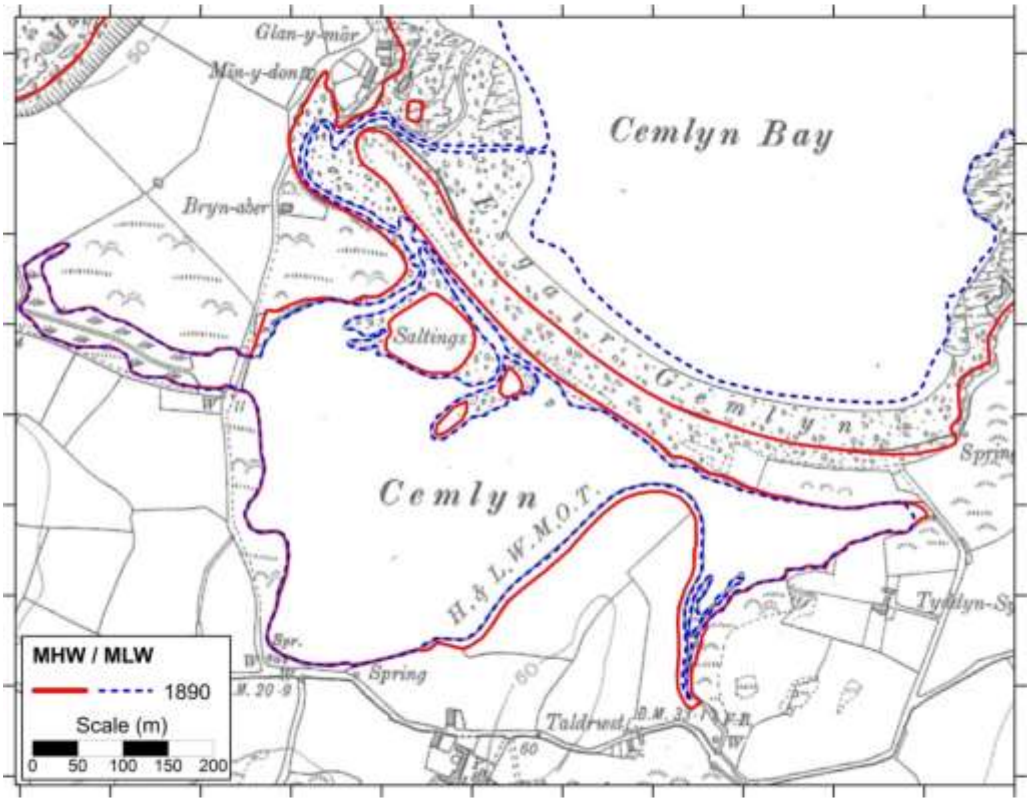


Figure A1.3 Third Edition County Series Ordnance Survey Map, published in 1926, revised in 1922. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

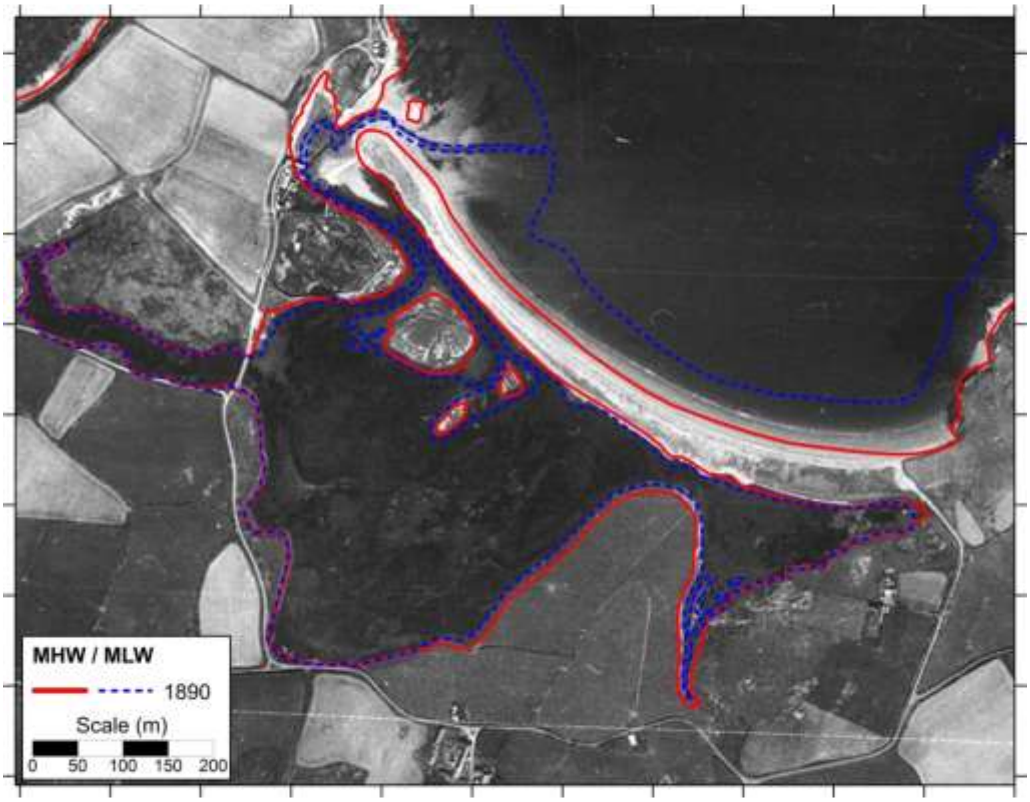


Figure A1.4 Air photograph flown 19th May 1948 by the RAF. MHW and MLW lines in 1887 overlaid in red and blue for comparison. Source: APU Wales

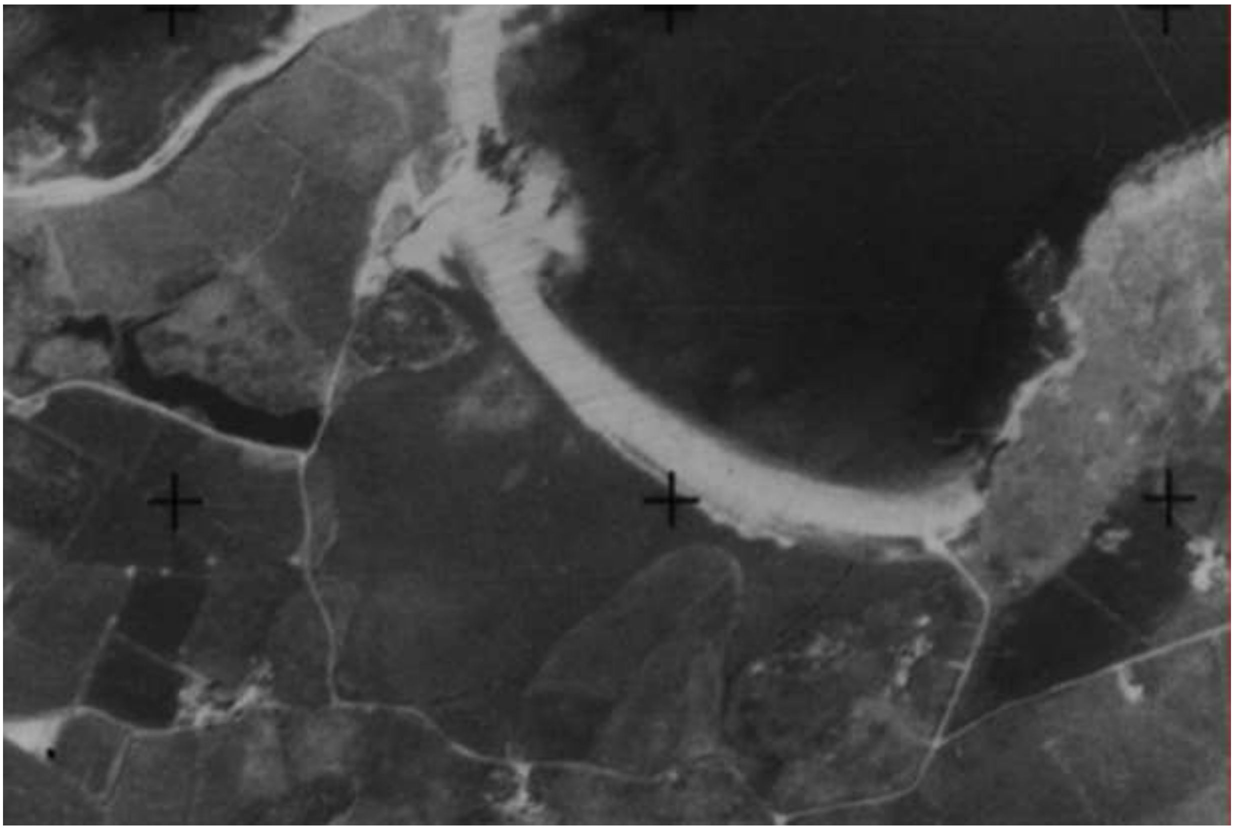


Figure A1.5 Aerial photograph flown on 10/06/1960 by the RAF. Source: APU Wales.

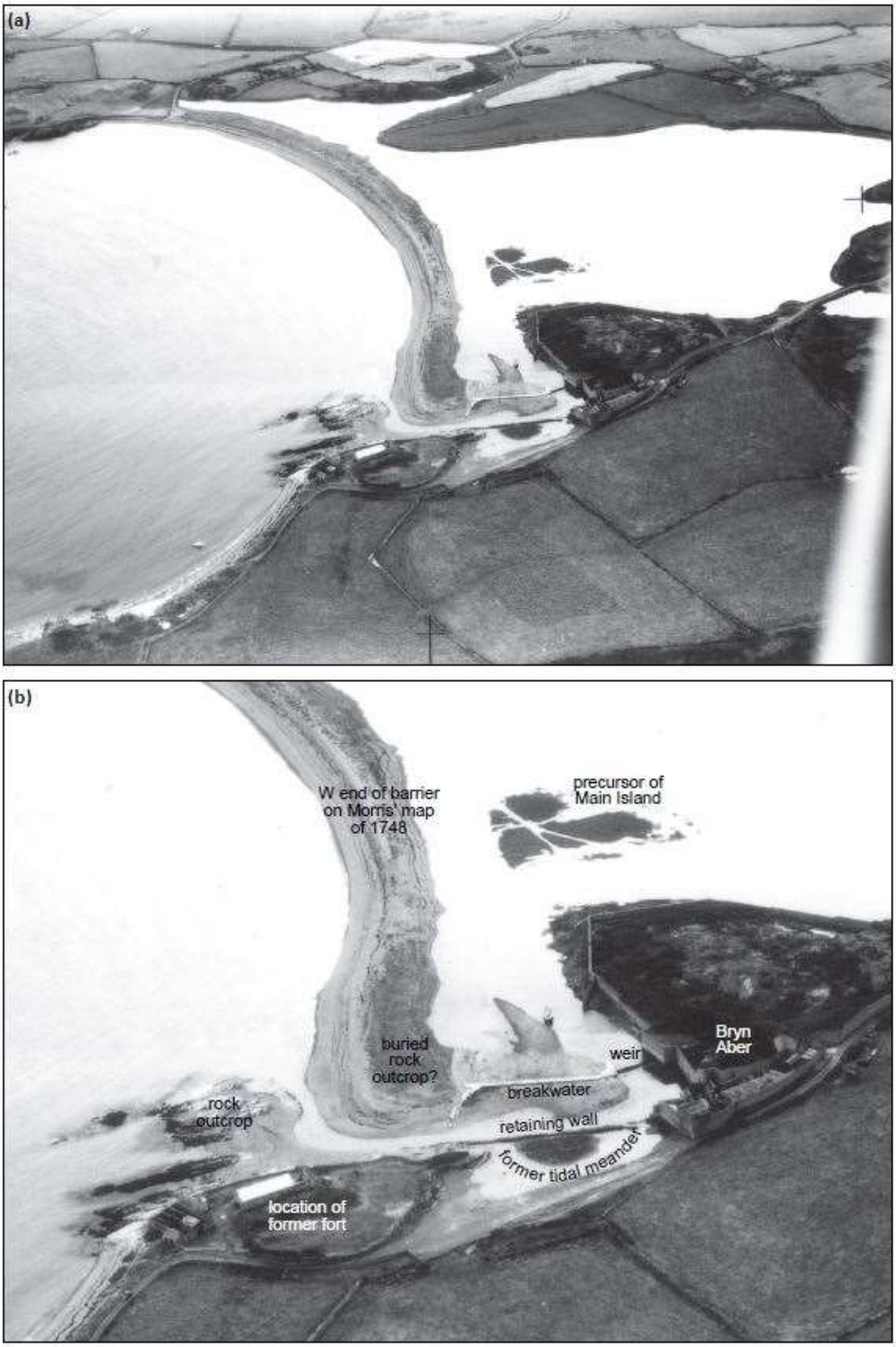


Figure A1.6 Oblique aerial photographs taken 24 August 1963 (Source: Cambridge Committee for Aerial Photography)

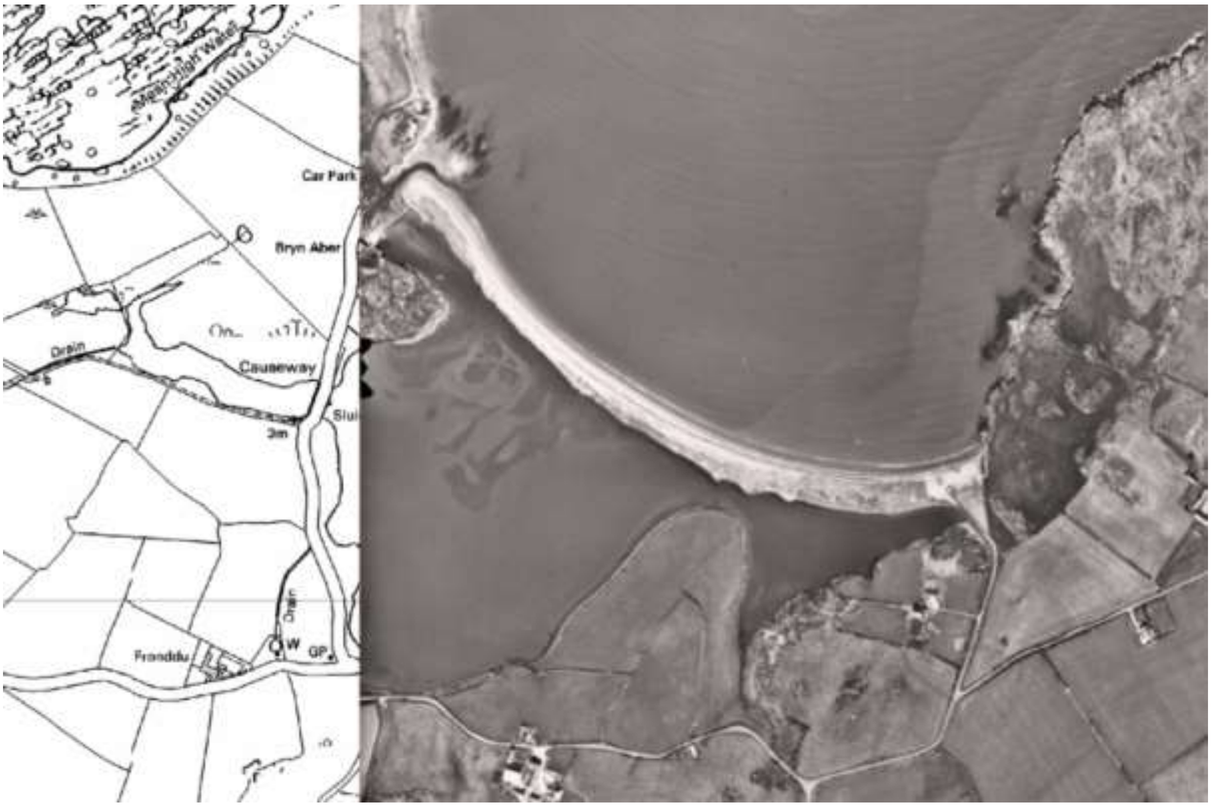


Figure A1.7. Aerial photograph flown in 1972 by the Ordnance Survey. Source: NRW

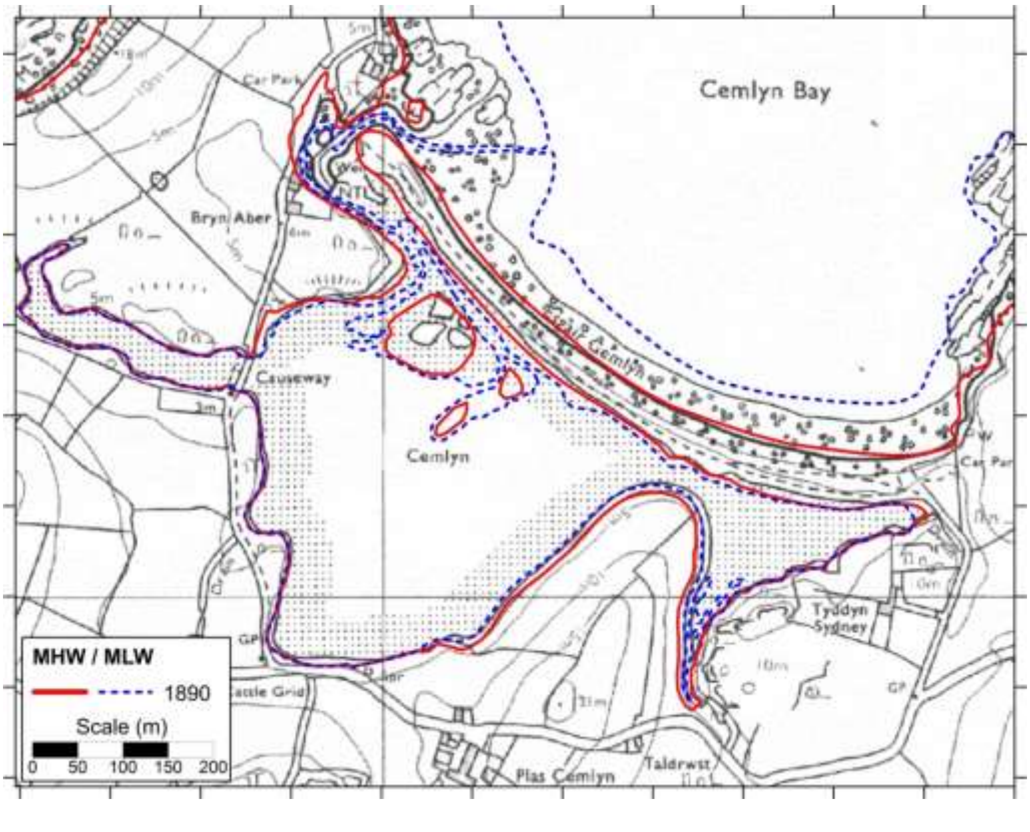


Figure A1.8 1:10,000 National Grid Ordnance Survey Map, published in 1978 (surveyed in 1973, revised for major changes in 1977, MHW surveyed in 1973, MLW surveyed in 1972). MHW and MLW lines in 1887 overlaid in red and blue for comparison.

Figure A1.9. Aerial photograph flown on 10/08/1982 by Cambridge University Centre for Air Photography. Source: CUCAP

Figure A1.10 Aerial photograph flown in 17/06/1992 by the Welsh Government. Source: APU Wales

Figure A1.11. Aerial photograph flown on 26/06/1993 by Geonex UK. Source: NRW.

Figure A1.12. Aerial photograph flown on 03/05/1996 by Cambridge University Centre for Air Photography. Source: NRW.

Figure A1.13. Aerial photograph flown in 2000 by GetMapping. Source: NRW

Figure A1.14. Aerial photograph flown on 16/05/2002 by Cambridge University Centre for Air Photography. Source: NRW

Figure A1.15. Aerial photograph flown in 2006 by COWI-Vexcel. Source: NRW.

Figure A1.16. Aerial photograph flown on 20/04/2009. Source: NRW.

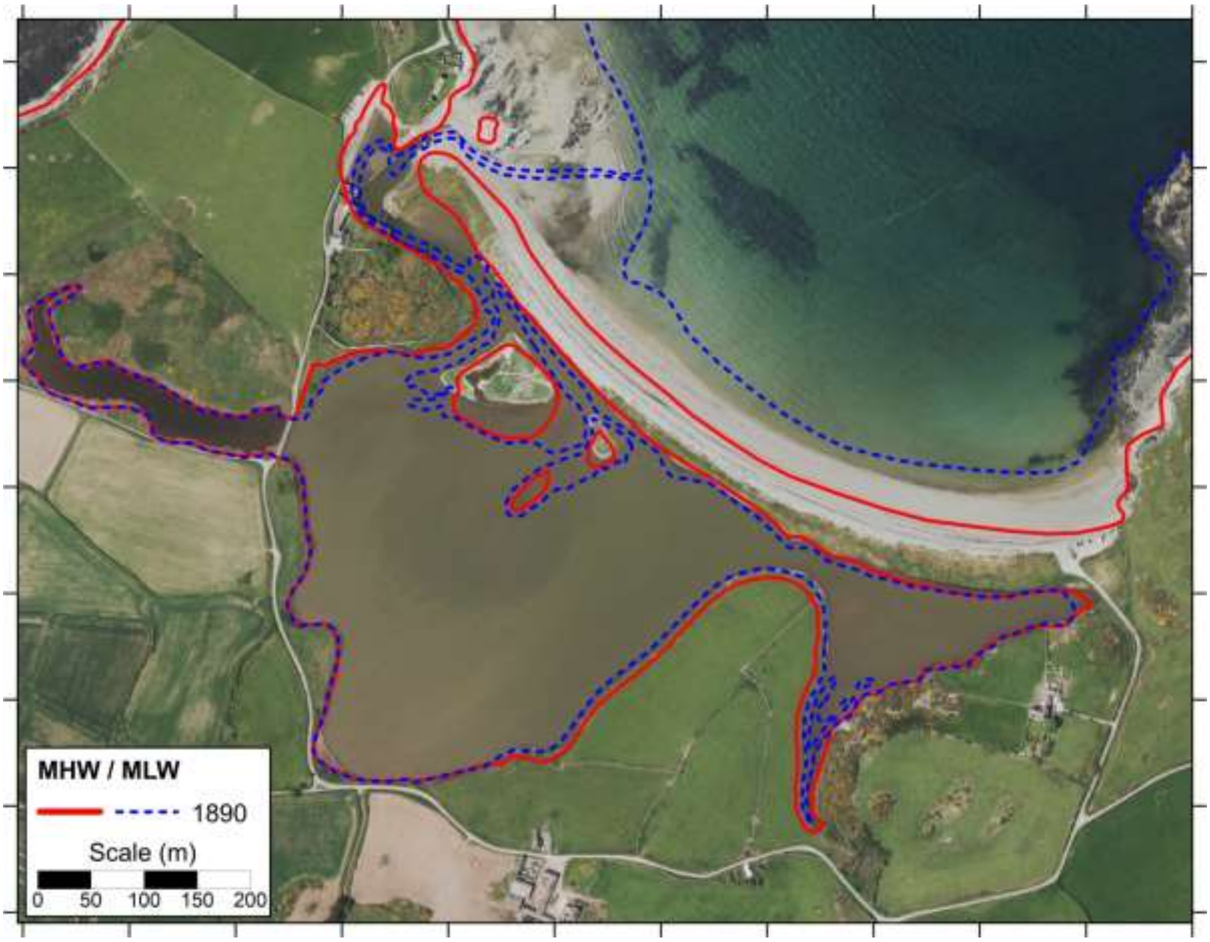


Figure A1.17 Aerial photograph flown March 2014 for NRW. MHW and MLW lines in 1887 overlaid in red and blue for comparison

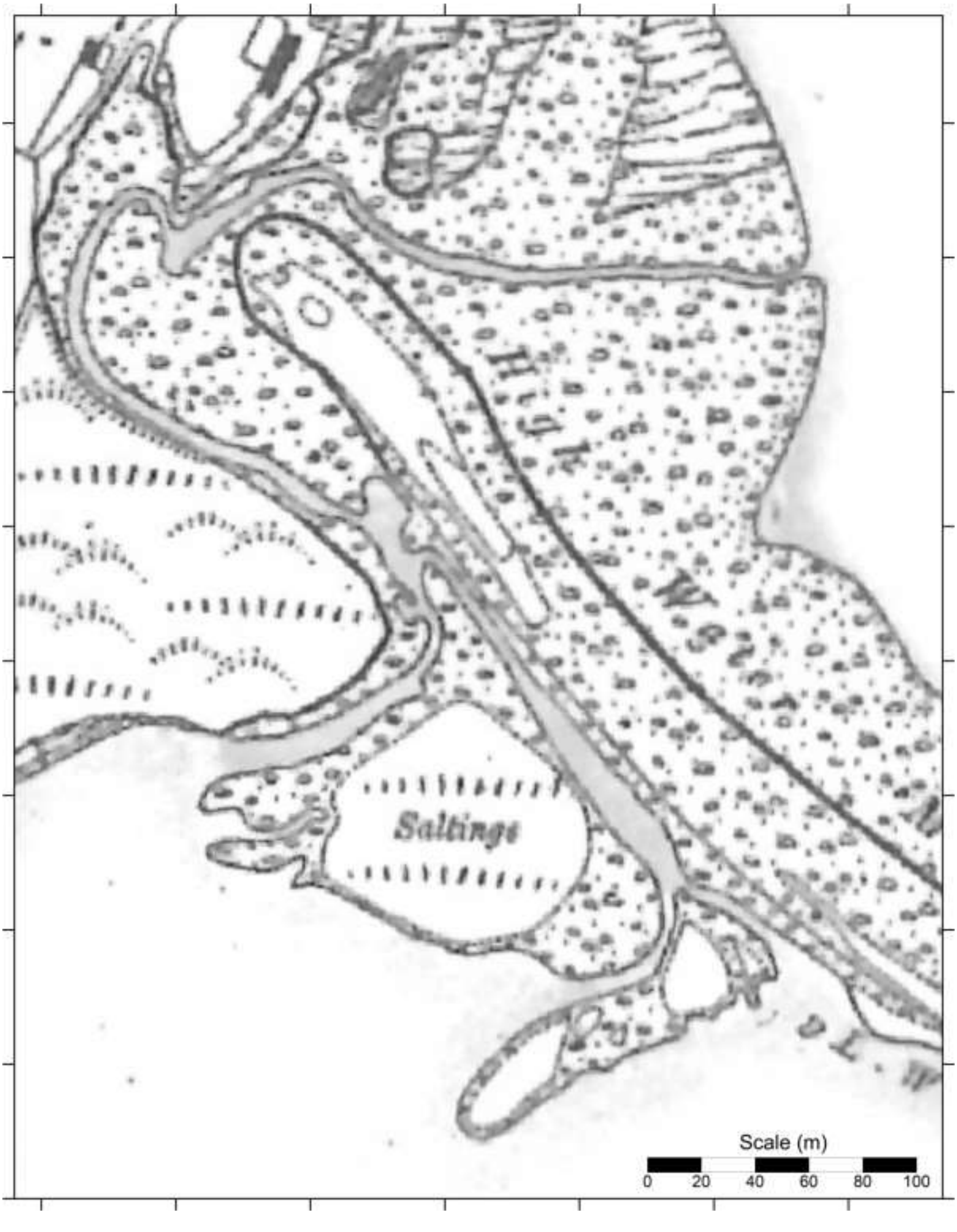


Figure A1.18 First Edition County Series Ordnance Survey Map, published in 1890, surveyed in 1887, enlargement of the NW section of Cemlyn Lagoon and barrier.

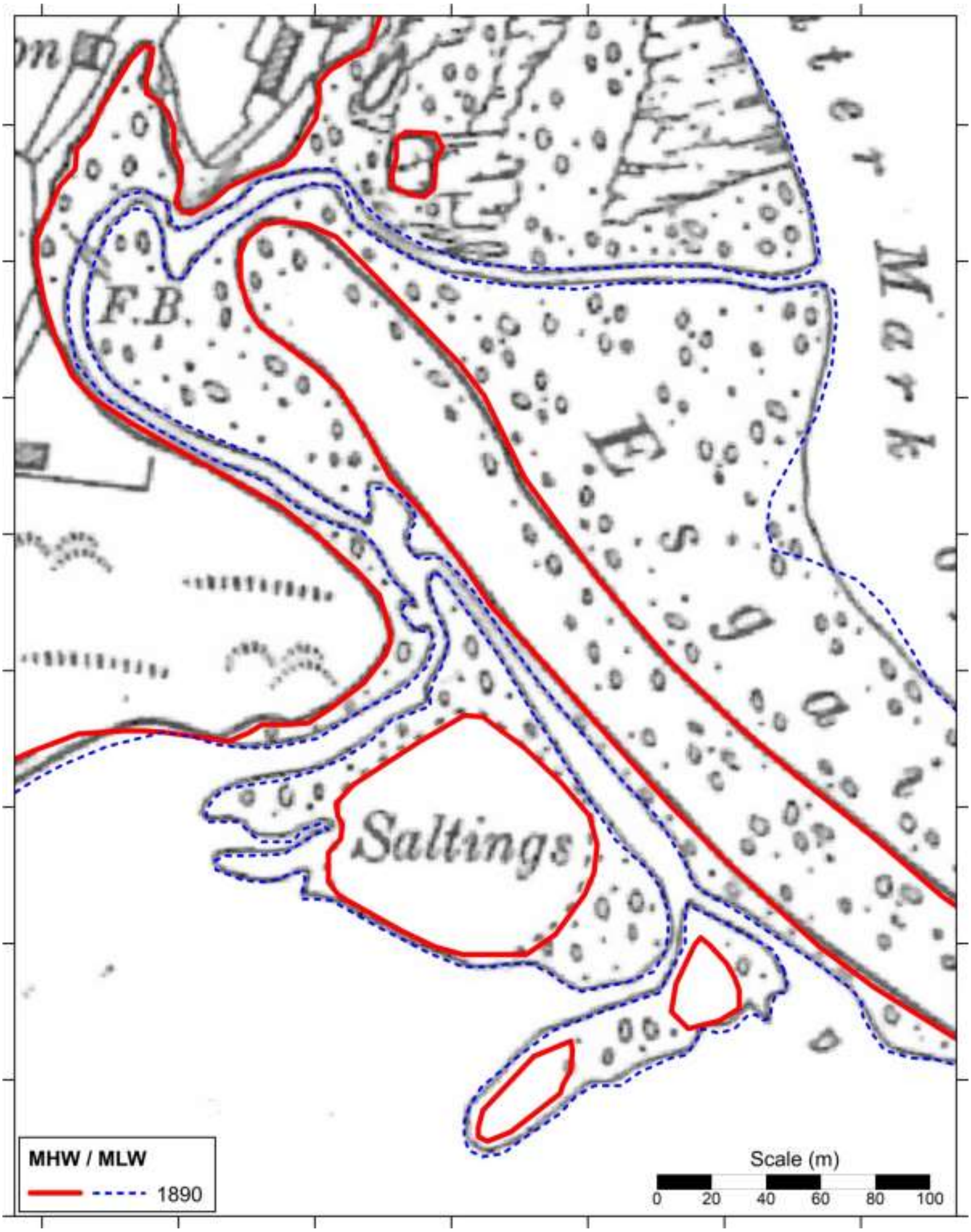


Figure A1.19 Second Edition County Series Ordnance Survey Map, published in 1901, revised in 1899, enlargement of the NW section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

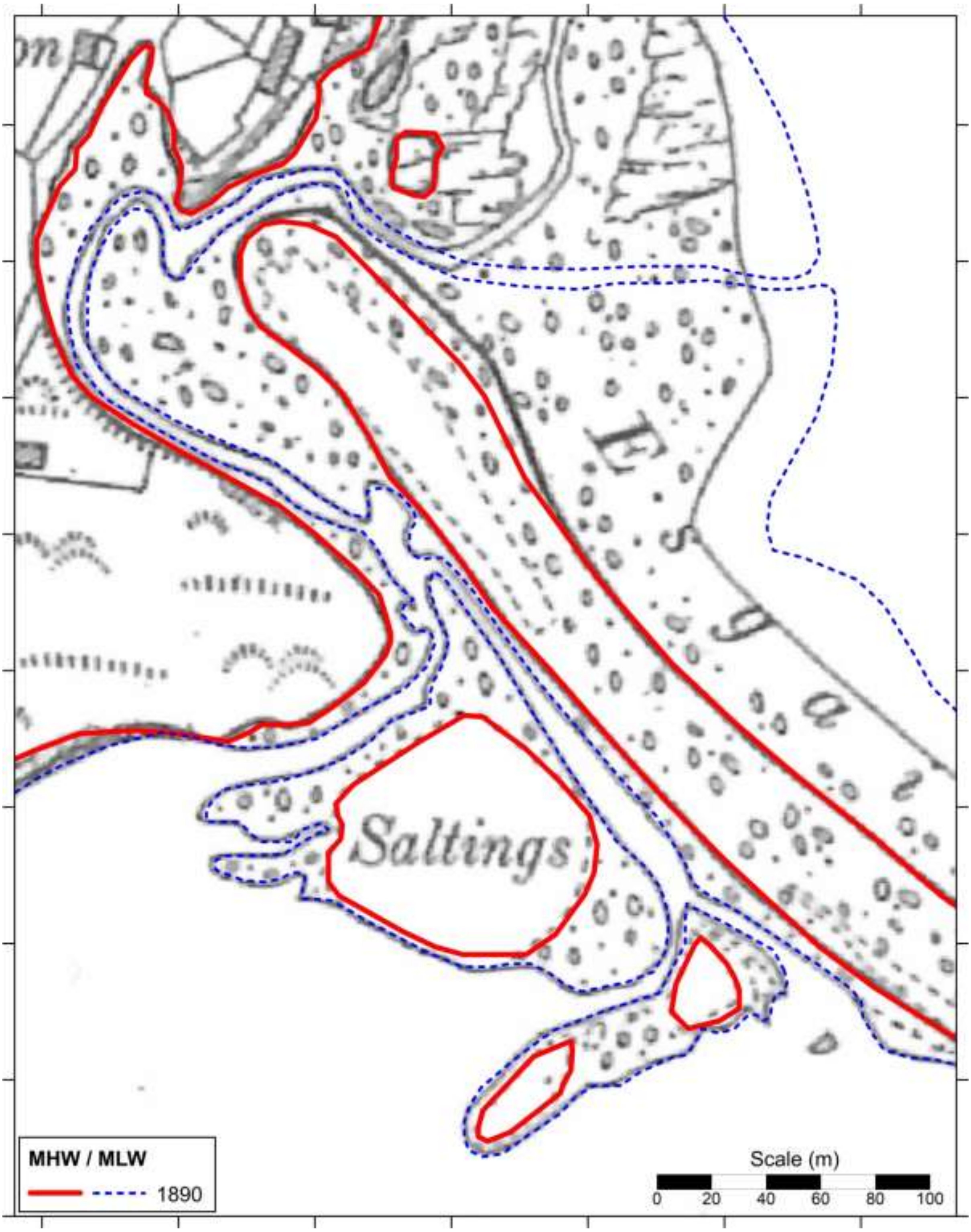


Figure A1.20 Third Edition County Series Ordnance Survey Map, published in 1926, revised in 1922, enlargement of the NW section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

Figure A1.21 Air photograph flown 19th May 1948 by the RAF, enlargement of the NW section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

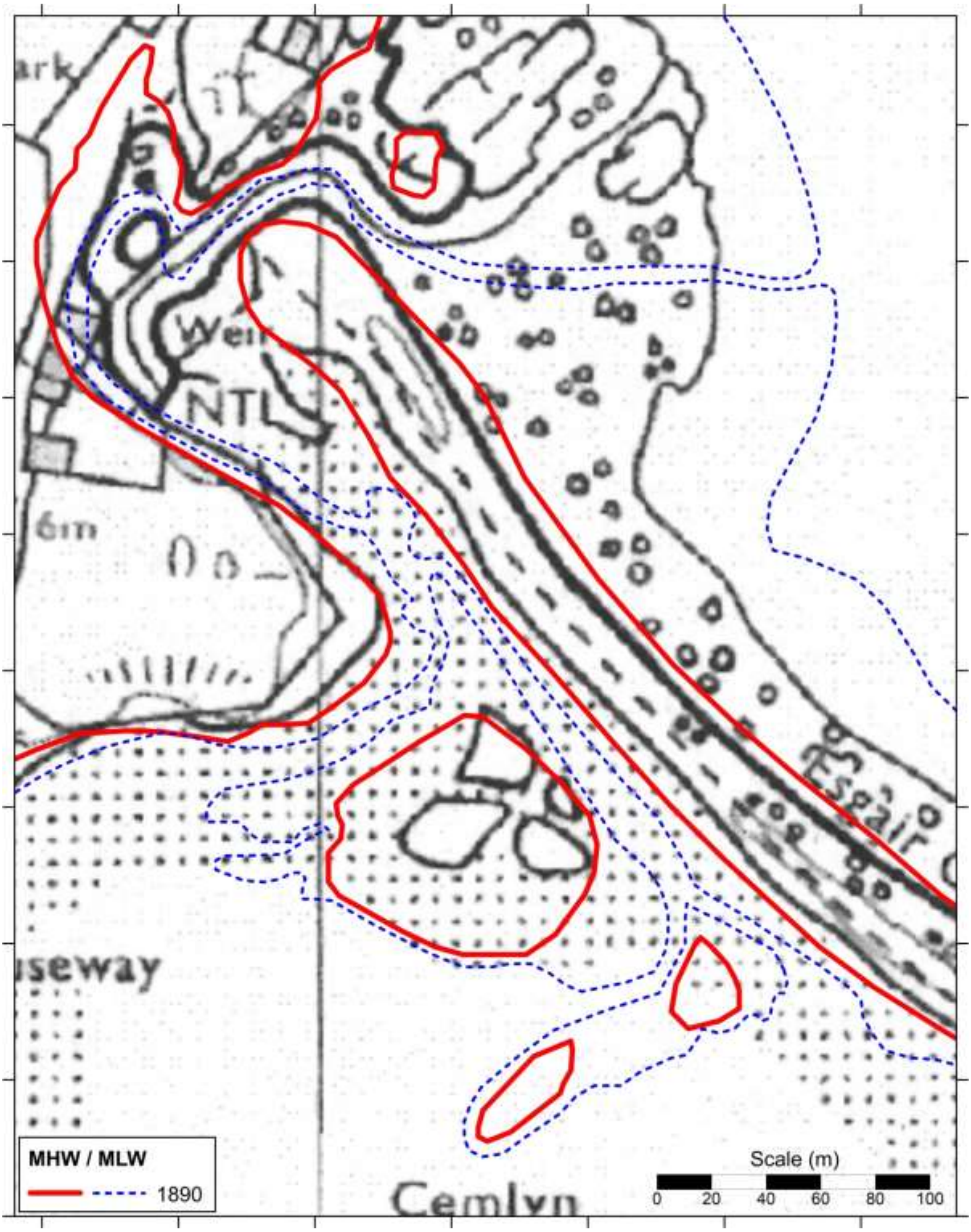


Figure A1.22 1:10,000 National Grid Ordnance Survey Map, published in 1978 (surveyed in 1973, revised for major changes in 1977, MHW surveyed in 1973, MLW surveyed in 1972), enlargement of the NW section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

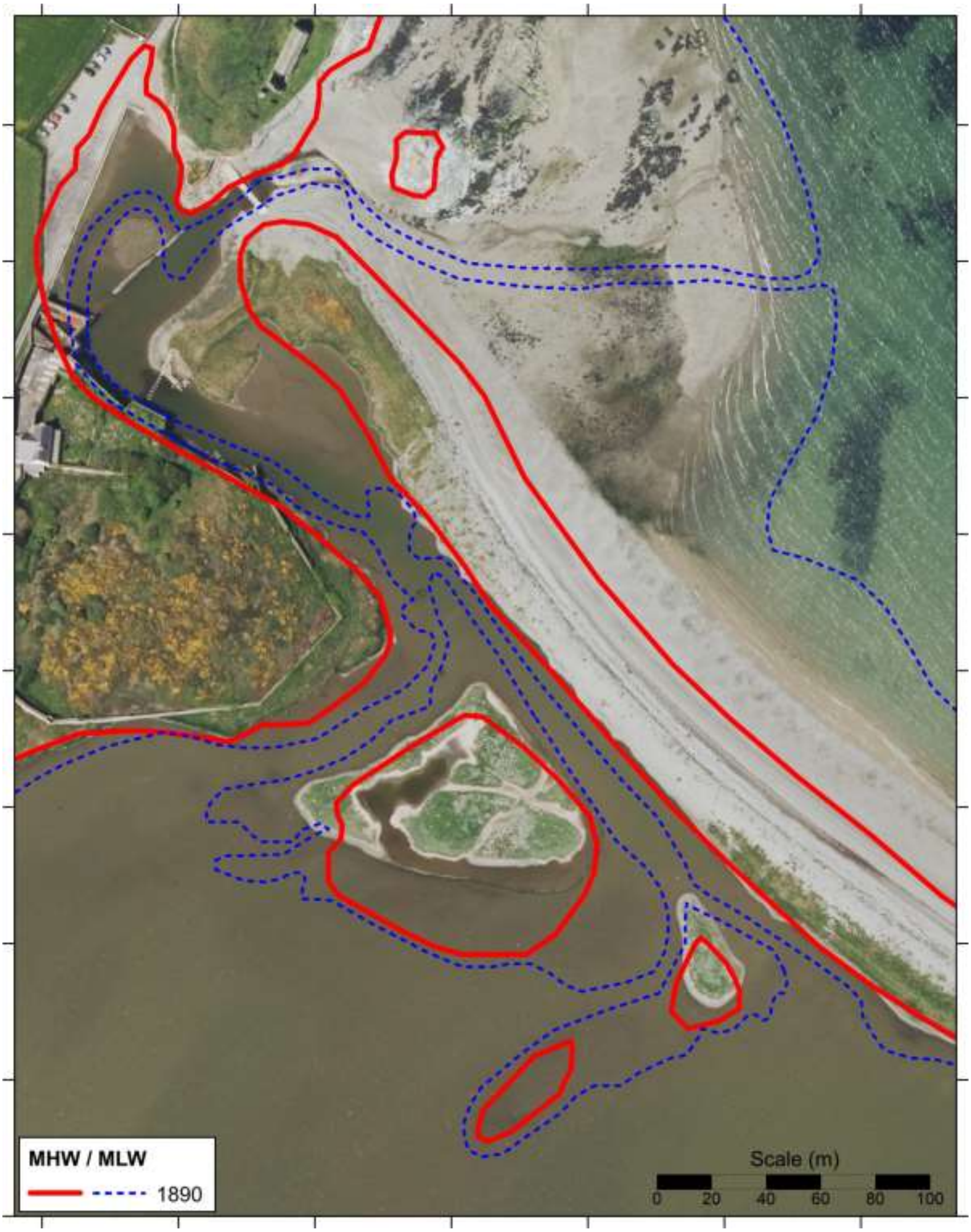


Figure A1.23 Air photograph flown 2013-14 for NRW, enlargement of the NW section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

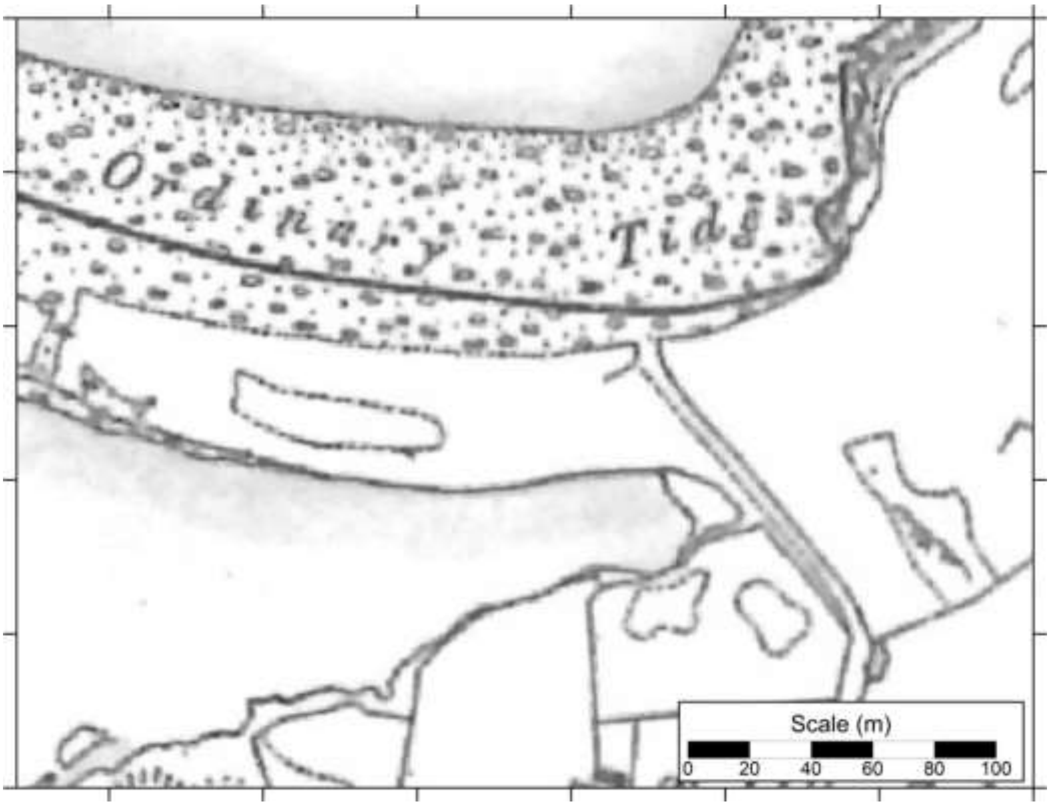


Figure A1.24 First Edition County Series Ordnance Survey Map, published in 1890, surveyed in 1887, enlargement of the SE section of Cemlyn Lagoon and barrier.

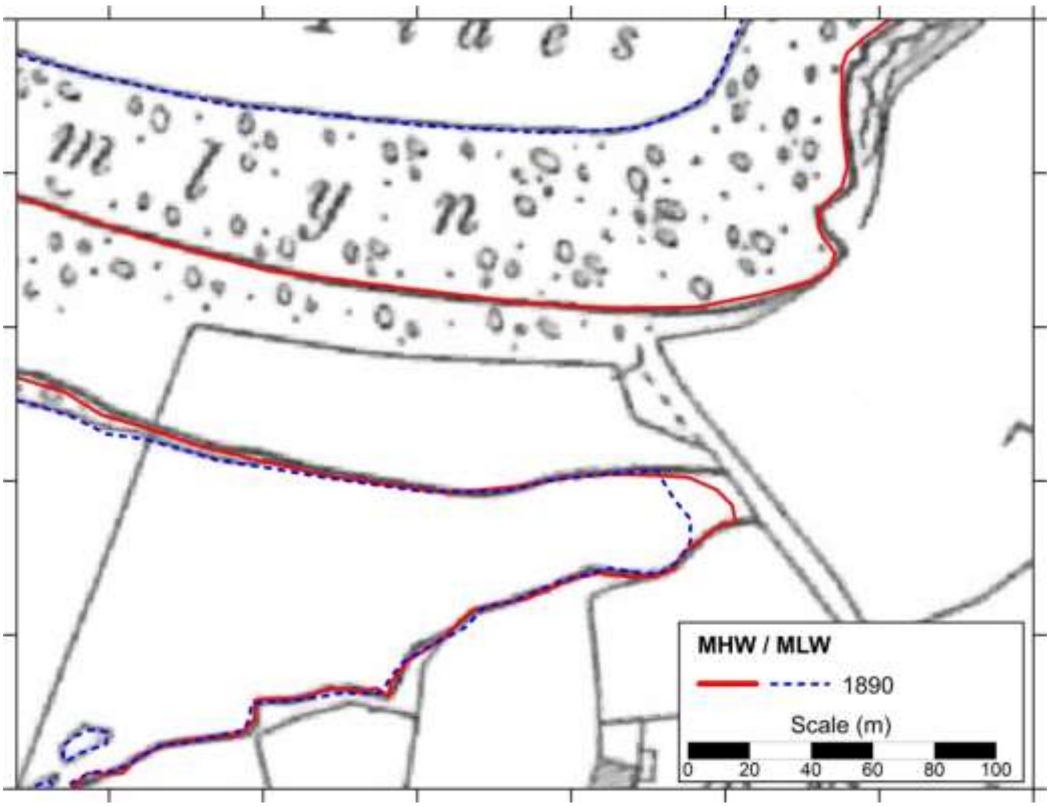


Figure A1.25 Second Edition County Series Ordnance Survey Map, published in 1901, revised in 1899, enlargement of the SE section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison

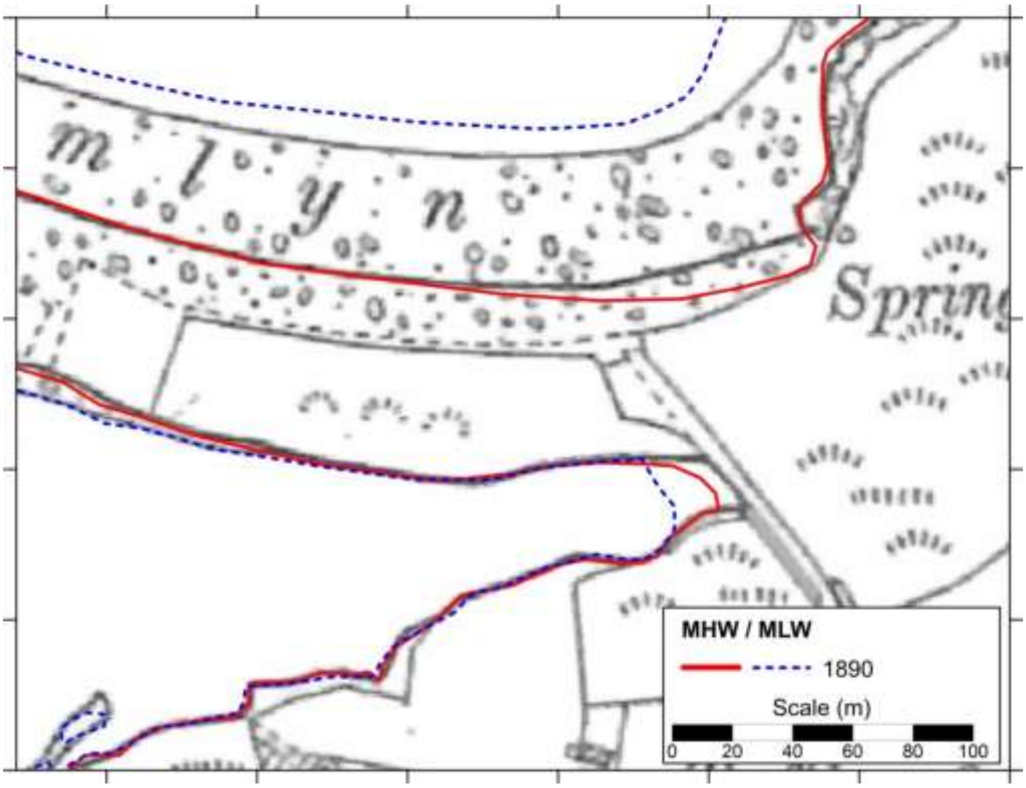


Figure A1.26 Third Edition County Series Ordnance Survey Map, published in 1926, revised in 1922, enlargement of the SE section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

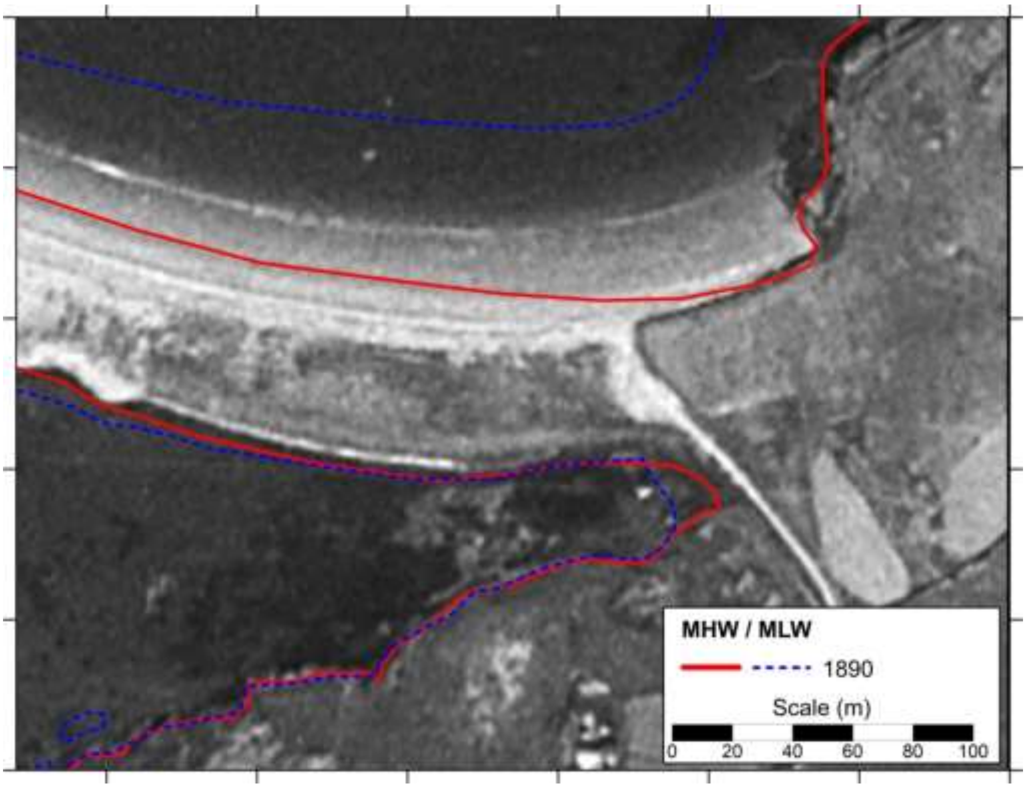


Figure A1.27 Air photograph flown 19th May 1948 by the RAF, enlargement of the SE section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

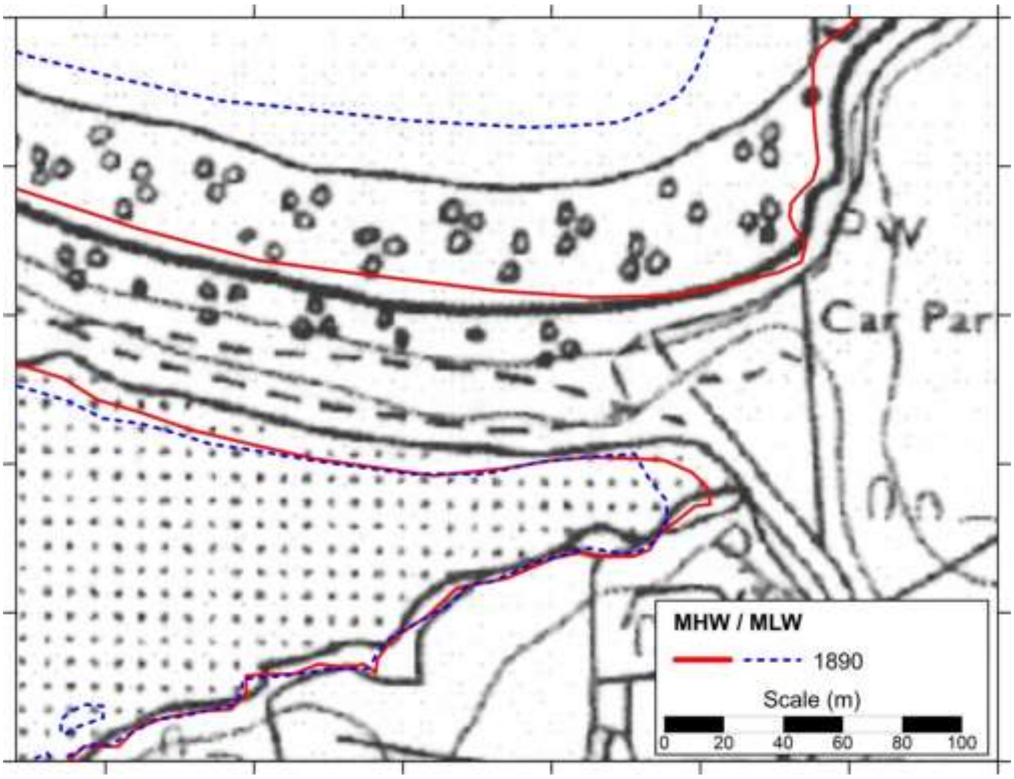


Figure A1.28 1:10,000 National Grid Ordnance Survey Map, published in 1978 (surveyed in 1973, revised for major changes in 1977, MHW surveyed in 1973, MLW surveyed in 1972), enlargement of the SE section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

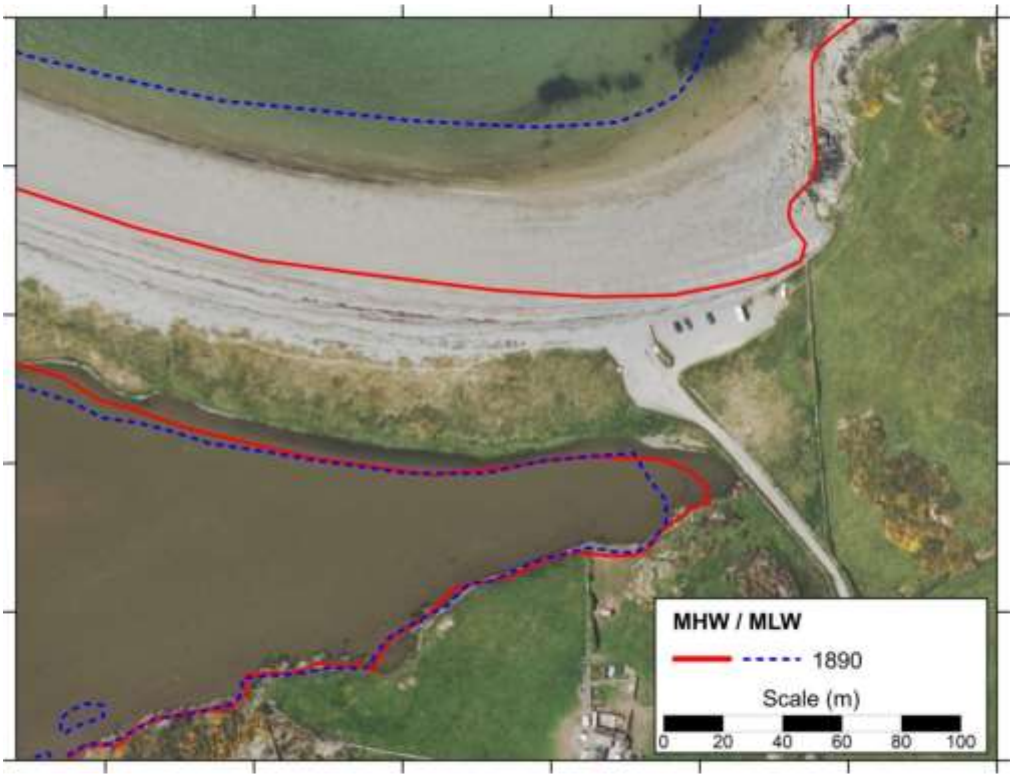


Figure A1.29 Air photograph flown 2013-14 for NRW, enlargement of the SE section of Cemlyn Lagoon and barrier. MHW and MLW lines in 1887 overlaid in red and blue for comparison.

ANNEX 2

Kenneth Pye Associates Ltd Report on Topographic Survey and Tidal Levels Investigation, August 2018

Cemlyn Bay, Anglesey: Topographic Survey and Tidal Level Investigation Summary Report

Kenneth Pye ScD PhD MA FGS CGeol
and
Simon J. Blott BSc MRes PhD

KPAL External Investigation Report No. EX 181118

Report history	
Version 1.0	19 November 2018

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Contents

1.0 Report scope and purpose

This report provides a summary of the results obtained from a field survey carried out at Cemlyn Bay between 13th and 15th August 2018. It builds on previous studies of the Cemlyn Bay area reported in Pye & Blott (2010, 2016 and 2018).

The main objectives of the work undertaken were:

(1) to provide better information about differences in tidal levels between Cemlyn Bay and the Class A tide gauge station at Holyhead, in part to provide better translation of historical tide gauge records for Holyhead to the Cemlyn Bay area
(2) to provide more information about the exchange of tidal waters between Cemlyn Bay and Cemlyn Lagoon, with a view to informing the design of a more detailed study at a later date
(3) to provide information about changes in the morphology of the beach and Esgair Gemlyn shingle ridge since previous field and LiDAR surveys in 2016 and 2017, respectively
(4) to provide further information about beach sediments on the seaward side of the shingle ridge.

The present weir was constructed in May 1978 following storm damage to an earlier structure built by Captain Vivian Hewett in the 1930s to control water levels and salinity in the lagoon. The weir has ten ‘gates’, the central four of which have one-directional flaps which were designed to release water to the sea during extreme rainfall events. One flap is currently broken and allows partial passage of water in each direction. The remaining six gates can be fitted with stop logs to limit the ingress of seawater during the tern breeding season. Over the past 10 years the stop logs have generally been put in place during the second half of March and removed in late August or early September, at the end of the tern breeding season. In 2018 the logs were installed in early April and removed in early August, prior to the field survey. When the logs are in place a gap of about 10 cm is left beneath the boards to permit some ingress of seawater. Prior to 2010 gaps were left beneath the boards in three or fewer of the gates, but since 2011 gaps have been left beneath the boards in all six gates. Outside the bird breeding season, when the logs are removed, the ingress of water to the lagoon remains partially restricted by the concrete piers between the gates and by the basal sill, but is considerably greater than during the summer months.

The main lagoon is separated from a subsidiary western lagoon (Tyn Llan) by a causeway. The two are linked by a culvert which at one time had a leaky simple flap-gate, and through which there is limited bi-directional tidal exchange.

2.0 Topographic survey error checking

A topographic survey was undertaken using a Leica GS16 SmartRover mounted on GS18 pole (2 m). The RTK GPS control station was located at Porth-y-felin, Holyhead Harbour, Leica Smartnet Station 0191: Easting: 224104.310 m, Northing: 383342.513 m, Height: 13.281 m above Ordnance Datum Newlyn (ODN).

Table 1 summarises the average estimated errors for all points surveyed. The average 1-D error (equivalent to height measurements) was 12.0 mm and the average 2-D error (equivalent to position measurements) was 8.0 mm. These values are consistent with the manufacturer's expected error range. An additional check on accuracy was made by comparison with a previously surveyed notch in a stone on the wall of the East Car Park. Observed differences were 13-14 mm in the position and 10 mm in the height (Table 2). These differences are on the upper side of those expected due to the limitations of the instrumentation and the survey technique.

3.0 Survey of tidal levels and physical feature levels

Two Valeport Tidemaster tide gauges were used to provide synchronous measurements of water levels in Cemlyn Bay and Cemlyn Lagoon. The Tidemaster tide-gauge in the bay was installed within the lower intertidal zone at Trwyn Pencarreg (OS grid reference 233775E 393553N, elevation -1.30 m ODN). The steep coastal slope at this location allowed the Tidemaster controller to be secured and installed well above the expected tide level. The second Tidemaster in the lagoon was installed at two locations on different tides, one just inside the weir at OS grid reference 232947E 393455N, elevation 2.33 m ODN, and the second on the southwest side of the lagoon close to the Tyn Llan culvert (232845E, 393236N, elevation 2.59 m ODN)**.** Spot measurements of water levels were also made at a number of locations inside and outside the lagoon using the RTK GPS equipment (Figure 1).

The elevations of a number of man-made and natural features were also determined during the survey, including different elements of the main weir, the Coastal Path footbridge, the shingle ridge crest, and the low water mark within the Bay (Table 3; Figure 1).

4.0 Comparison of water levels recorded at Cemlyn and at Holyhead

The tidal measurements were made just after the peak of a period of spring tides at a time when predicted astronomical levels were expected not to be significantly affected by meteorological surge effects (Figure 2). Winds were slight during the period of survey, and wave heights closed to the shore within Cemlyn Bay were observed to not to exceed 20 cm. The survey was undertaken following a dry weather and no rainfall occurred during the survey. Very little flow was observed in the streams leading into Cemlyn Lagoon; the recorded lagoon water levels were therefore not significantly affected by surface water

runoff. Groundwater seepage into the lagoon was not quantified but is unlikely to have been significant in relation to the tidal exchange. Some seepage of water from the lagoon, through the shingle ridge onto the lower beach, at low tide was observed but was qualitatively assessed as being small in relation to the tidal exchange.
Table 4 compares the measured high water levels at Cemlyn Bay with levels recorded at the Holyhead 'Class A' tide gauge. The maximum high water levels recorded in Cemlyn Bay were found to be 35 - 36 cm higher than those recorded at Holyhead. For the three tides recorded, high water in Cemlyn Bay was observed to occur approximately 14 minutes later than at Holyhead. The phase lag between the two locations for all three tides was greatest during the early stages of the flood tide (approximately 40 minutes later at Cemlyn) and was approximately 18 minutes later at Cemlyn on the ebb tide (Figure 3). Only one measured value for dead low water in Cemlyn Bay was obtained, approximately 32 minutes later and 30 cm lower than at Holyhead.

Since three tides with differing levels of high and low water were being considered, the actual tidal levels were converted to ratioed factors. Using the three average time differences at high water, mid tide, and low water, it was possible to derive polynomial relationships between the ratioed elevation values for the rising and falling tides (Figure 4). The derived polynomial relationships for the flood and ebb tides were then used to interpolate the time differences at all stages of the tide. The times for all points on the tidal stage curve at Holyhead were then adjusted to match those at Cemlyn Bay using the interpolated time differences. Having adjusted for the time differences, the adjusted water levels at Holyhead and the time-equivalent measured levels at Cemlyn were then plotted, and a simple linear relationship found (Figure 5). Having obtained this linear relationship, it was then used to adjust the Holyhead water level record to observed levels at Cemlyn. The time and elevation adjusted values at Holyhead were then compared with the observed values at Cemlyn (Figure 6). A high level of agreement was found for these three tides. Based on this high level of agreement, the linear relationship shown in Figure 5 was used to provide a first-order estimate of different average tidal levels at Cemlyn Bay (Table 5). The level of mean high water spring tides (MHWS) in Cemlyn Bay (2.92 m ODN) is estimated to be 37 cm higher than the MHWS level at Holyhead (2.55 m ODN) given in the Admiralty Tide Tables (UKHO, 2017). However, the differences in average tidal levels should be treated with a degree of caution since the preliminary relationship is based only on three spring tides; ideally the relationship would be based on a much longer period of record.

The relationship shown in Figure 5 has also been used to provide a first order estimation of extreme high water levels in Cemlyn Bay based on recorded levels at Holyhead since 1964 (Table 6). Two methods of estimation have been used, the first based on simple linear extrapolation of the observed elevation at Holyhead using the equation in Figure 5, assuming that the linear relationship holds both for the astronomical and meteorological (surge) components of the observed water levels, and the second based on linear extrapolation of the predicted (astronomical) component at Holyhead plus the magnitude of the skew surge observed at Holyhead. The difference in the predicted level at Cemlyn obtained using the two methods varies by 5 to 11 cm. While both methods are subject to limitations, the second method is likely to be more reliable for a majority of high tides since a linear growth relationship in the surge component has not been demonstrated, and might not be expected. The highest still water level recorded at Holyhead occurred on 1st February 2002 (3.81 m ODN, incorporating a skew surge component of 0.88 m) which, using extrapolation method 2, would be equivalent approximately to 4.22 m ODN at Cemlyn. The second highest still water level recorded at Holyhead (3.78 m ODN, incorporating a skew surge component of 0.64 m, on 3 January 2014), is also predicted using method 2 to have resulted in a still water level of approximately 4.22 m ODN at Cemlyn.

Figure 7 presents a graphical plot of all the predicted high waters at Cemlyn since 1964, based on the Holyhead record and preliminary relationship described above. An apparent increase in the occurrence of high water levels > 3.9 m ODN is evident, but should be viewed with caution since both the location and method of tidal measurement at Holyhead changed during the period, and notably following the break in the record between 1992 and 1995. However, the record demonstrates that extrapolated still water levels have exceeded 3.9 m ODN at Cemlyn on at least 13 occasions since 1995 (see also Table 6). A tide reaching 3.53 m ODN at Holyhead (approximately 3.96 m ODN at Cemlyn) which occurred on 4 January 2018 was associated significant wave over-topping of the lower parts of Esgair Gemlyn ridge (Figure 8; Table 6). A number of slightly lower tides reaching 3.2 to 3.3 m ODN at Holyhead on 4-5 March 2018 (Figure 8) also caused some wave over-topping of the lowest parts of the shingle ridge, resulting in further movement of shingle over-wash lobes towards the term nesting islands. Since the lowest parts of the crest had an elevation of c. 4.5 m ODN during the 2017-2018 winter, any tidal still water level exceeding 3.5 m ODN in Cemlyn can create conditions suitable for wave over-topping of the ridge crest under conditions of moderate or high storm wave activity, when storm-wave run-up may reach levels at least 1 m higher than the still water level.

5.0 Water levels close to the weir and within Cemlyn Lagoon

Although the tidal curves recorded in Cemlyn Bay on 13-15 August 2018 were broadly symmetrical (Figure 3), those recorded within Cemlyn Lagoon are markedly asymmetric (saw-toothed), characterized by a very steep flood limb and a much more gradual ebb limb (Figures 9, 10 & 11). The maximum high water level attained within the lagoon on the three tides monitored was 31 to 51 cm lower than that recorded near the entrance to Cemlyn Bay (Table 4). The high water level in the ‘pool’ between footbridge and the weir were found to be only slightly lower (5 cm for the one tide measured) than in the open Bay, indicating that, even for tides which to not overtop the footbridge, the structure has only a small effect in restricting the passage of the incoming tide towards the weir, but the weir structure has a major effect in restricted tidal flow into the lagoon, even with no stop-logs in place (Figure 9).

At the end of the ebb tide on 13 August the water level in the lagoon was only 2-3 cm higher than the sill of the weir, and a very small seaward discharge continued until the incoming tide around midnight exceeded the residual ebb flow level (c. 2.60 m ODN). The water level in the lagoon just inside the weir then rose sharply, although initially in an irregular, oscillating manner, followed by a period of relatively smooth rise until an elevation of 2.90 m ODN was attained, at which point the rate of rise slowed slightly and again became more irregular (Figure 10). A similar pattern of tidal rise behaviour inside the weir was also observed during the lower mid-day high tide on 14 August (Figure 11). By comparison, the rise and fall of the tide recorded on the western side of the lagoon near the Tyn Llan culvert was much more regular (Figures 10 & 11), suggesting that the apparent rate of tidal rise near the weir is influence by local effects, possibly associated with standing waves and turbulence linked to the weir itself (see also photographs in Appendix 1).

Observations during the midday tide on 14 August showed that ebb flow under the Coastal Path footbridge began more than 30 minutes before flow reversal started at the weir, and the water level in the lagoon continued to rise for approximately 20 minutes after the onset of flow reversal at the footbridge. This reflects the fact that water levels in the pool between the footbridge and the weir remained higher than in the lagoon, giving rise to a surface slope which drives inward flow into the lagoon. Reversal of flow over the weir begins when the water level in the pool drops below that in the lagoon (Figure 9). In the early stages of the ebb the eater level in the pool was observed to be very similar to that in the open bay, but over the course of the ebb the difference increased, resulting in a greater seaward water slope and greater head of water to drive strong and stronger ebb current flows through the lagoon inlet.

Over the course of the three tides monitored the ‘residual’ water level in the lagoon at the end of each ebb period showed a rising trend (Figure 10), indicating that each successive tide was acting to ‘top-up’ the lagoon. This reflects the effectiveness of the weir in restricting the seaward tidal flow; the rate of outward flow on the ebb is too low to evacuate all of the water which enters the lagoon on a spring tide. Falling low water levels within the lagoon are normally associated with periods of neap tides.

Owing to the relatively steep sides of the lagoon, the area of water increases only slightly with increasing water level; the increase in water volume in the lagoon is therefore dependent more on change in water level (tidal height) than on change in floodable area (Figure 12). With a water level within the lagoon of 3.00 m ODN the tidal prism of the lagoon would be approximately 65000 m^3; at a water level of 3.5 m ODN the potential tidal prism would be approximately 165,000 m^3. If significant wave action is combined with a still water level of 3.5m ODN or higher within Cemlyn Bay, seawater would be likely to enter the lagoon both as a result of wave over-wash and flow across the weir.

6.0 Analysis of water samples

A number of 1 litre water samples were collected during the field survey and returned to the KPAL laboratory for determination of pH, conductivity and suspended solids concentration (Table 7). The pH just inside the weir was determined to lie within the range 7.0 to 7.2, with little variation across the lagoon. However, a lower pH value of 6.6 was recorded within the Tyn Llan sub-lagoon.

The electrical conductivity of the main lagoon water was determined to lie within the range 49000 – 53000 µS, being highest (very close to open seawater values) just inside the weir close to the time of high water. A slightly lower value of 410 µS was recorded within the Tyn Llan sub-lagoon close to the culvert, reflecting the greater influence of freshwater within the western sub-lagoon.

Suspended solids concentrations were determined to lie within a relatively narrow range of 79 to 94 mg/l.

7.0 Survey of the shingle ridge

Thirteen cross-shore profiles were surveyed using the RTK GPS equipment on 14 August, extending from the low water mark on the seaward side of the shingle ridge to the lagoon shoreline on the landward side of the shingle ridge. The low water mark, the break in slope between the upper beach slope (gravel-dominated) and lower beach flat (sand-dominated), and the crest of the shingle ridge were also surveyed (see Figure 1). The full surveyed profiles are shown in Figure 12 and expanded plots of the upper parts of each profile are shown in Figure 13. Both sets of profile plots also make a comparison with levels determined during a previous KPAL ground survey in 2016, and from LIDAR surveys in 2010 and 2017 (the latter commissioned and provided by Horizon NP, exact flight date known).

The profile survey and lidar data show very little change in crest position or morphology at the southern end of the shingle ridge since 2010, with the exception of a short stretch adjacent to the eastern car park beach access point where there is a low point in the shingle ridge. At profiles P4, P5, P6 and P7 some cliffing of the upper part of the shingle ridge occurred between spring 2017 and August 2018, mostly during the high tides between January and March 2018. Most of the eroded sediment appears to have been moved seawards and deposited on the lower part of the upper beach slope. Upper beach face erosion also occurred between profiles P8 and P12, leading to breakthrough of the crest, over-washing and landward transgression of sand lobes towards the tern nesting islands. At profile P13, where the ridge crest has historically been higher and is well-vegetated, some cliffing of the seaward side of the ridge occurred but there was no breach or over-washing. Take together, the survey data obtained since 2010 indicate that there is a high risk both of over topping and ridge crest breaching between profiles P8 and P12 where the shingle ridge is lowest, narrowest and much of the upper beach slope is composed of relatively coarse sediment. Opposite profiles P11 and P12 the combination of a narrow upper beach and exposed rock platform in the mid and lower intertidal zone reduces the capacity to dissipate wave energy and increases the likelihood of high wave run-up.

8.0 Beach sediments

Beach sediments were collected from the upper, mid and lower beach along four shore-normal transects during the survey. The sampling positions are shown on Figure 1 and the sampling locations are described in Table 8. Samples were taken from three levels on each profile: (a) the upper beach berm just below the high water mark attained during the midnight on 13 / 14 August, (b) the lower part of the upper beach slope above the point where the water table outcropped on the beach at the time of sampling, and (c) the lower beach flat just above the low water mark at the time of survey. Each sample was taken with a shovel from a depth of 0 - 15 cm below the surface.

All of the high water mark samples consisted entirely of moderately sorted, moderately well sorted or well-sorted gravel (Tables 8 & 9; Figure 14). The samples from the lower part of the upper beach slope were also dominated by gravel (57 - 98%) but with a sub-component of sand (2 - 42%). The median size (D50) of the upper beach slope samples was largest in the central part of the bay (260 – 654 mm) and finest at the eastern end of the bay (c. 13 mm). All of the gravel and cobble-sized sediment present on the upper beach and mid beach is likely to be mobile during moderate to high wave events.

Although visual observations during several field visits to the site have shown there is considerable spatial and temporal variability in the particle size distribution of the surface beach sediments, reflecting variations in incident wave conditions and tidal levels, there is a long-term net tendency for accumulation of finer gravel and sand at the eastern end of Cemlyn Bay. The combined effect of wave-generated currents and tidal currents within the Bay has given rise to a long-term net anti-clockwise movement of sediment within the Bay, leaving a lag of coarser gravel at the northwestern end. The residual coarser material is less easily mobilized by waves, and constructive waves have been unable to build up the ridge crest to the same height as in the southeastern part of the Bay where the sediment is on average finer grained and more easily moved towards the ridge crest by constructive waves.

The samples taken from the lower beach flat were all composed of well-sorted or very-well-sorted fine sand with a D50 size of 0.170 – 0.180 mm. This material would be potentially mobile under quite low bed shear stresses induced by combined wave and current action.

The lower sand flat sediments contain a small proportion of mud (< 63 µm), determined to be 0.3% by dry sieving and up to 4.65% by laser diffraction.

The surface of the lower beach at the northwestern end of the shingle ridge is armoured by a layer of cobbles and very coarse gravel. The extensive development of algae and other marine vegetation of these clasts testifies to the fact that they are only rarely, if ever, moved by wave action. Bedrock is exposed at the surface in places in this area, and more notably on the northwest side of the ebb tidal delta to seaward of the lagoon inlet / outflow channel (see photographs in Appendix 1).

The small cobble and gravel-size clasts which form the major part of the upper beach and shingle ridge are predominantly rounded or well-rounded and are composed very largely of hard metamorphosed sedimentary and igneous rock types including quartzite, jasper, felsite, schist and vein quartz. The relative rarity of sandstone, granite and limestone clasts suggests that most of the gravel is derived from local cliff and intertidal platform sources rather than far-travelled glacial till.

The sand fraction is mainly composed of siliciclastic particles of similar composition to the gravel fraction, together with a subsidiary bioclastic calcium carbonate component (mainly shell fragments). The calcium carbonate content of the sand fractions of a number of the samples collected, estimated using the 10% HCl weight loss method, were determined to lie in the range 7 - 12% (Table 10). The vast majority of the marine bioclastic carbonate is likely to be locally sourced within, or close to, Cemlyn Bay.

9.0 Conclusions and recommendations

The preliminary field investigation described in this report has provided useful new information about still water levels, morphological change and sediment patterns within the Cemlyn Bay - Esgair Gemlyn - Cemlyn Lagoon system. However, further field investigations are required to provide representative long-term information about tidal levels, waves and currents in the nearshore zone, beach and nearshore sediment transport, the water, sediment and nutrient budgets of the lagoon and their relationship to the ecological features of the lagoon. The following recommendations are made for further studies:

- a water depth, conductivity and temperature sensor should be deployed within the nearshore area of Cemlyn Bay to provide long-term information about water levels, salinity and temperature to complement the monitoring currently undertaken by NRW within the lagoon close to the tern nesting islands
- the water level monitoring should be capable of recording short-term variations due to waves as well as longer interval changes due to tides
- in the absence of regular airborne LIDAR surveys, a programme of ground topographic monitoring should be put in place to identify change in the morphology and rate of recession of the shingle ridge feature
- a single beam or multi-beam bathymetric survey should be undertaken of the immediate nearshore area between mean low water spring tide level and the – 5m OD depth contour to cover the gap in existing data; accurate and up-to-date nearshore bathymetric data are required to inform further computer modelling of waves, sediment movement and the risk of over-washing / breach to the shingle ridge
- a sea bed sediment survey of the subtidal areas of Cemlyn Bay to inform assessment of sediment character and potential mobility
- a bathymetric survey of the lagoon to provide more accurate information relating to the total water holding capacity and tidal exchange capacity of the lagoon

- a survey to better characterize the bed sediments within the lagoon (this could be carried out as part of a future benthic ecology survey.

10. References

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Tables

Table 1. Average quality control for all 580 data points in the 14-15 August 2018 survey

	1-D (height) CQ	2-D (position) CQ	GDOP	VDOP
Average	12.0 mm	8.0 mm	1.68	1.07
StDev	2.9 mm	2.2 mm	0.26	0.16

Table 2. Comparison of position and elevation of benchmark surveyed at wall corner of the East Car Park, previously surveyed by RTK GPS on 1st February 2016

Survey date	Easting	Northing	Elevation (m)	1-D (height) CQ	2-D (position) CQ
01/02/2016	233582.920	393146.416	5.054	0.017	0.012
14/08/2018	233582.906	393146.429	5.064	0.009	0.006
Difference	14 mm	13 mm	10 mm	n/a	n/a

Table 3. Levels of selected features around Cemlyn Bay, surveyed by RTK GPS on 14-15 August 2018

Feature	Easting	Northing	Elevation (m ODN)	1-D CQ	Average elevation (m ODN) with error range
Weir – top of sill	232943.945	393456.930	2.571	0.009	2.57 ± 0.01
	232944.039	393457.296	2.571	0.010	
Weir – bottom of sill	232942.763	393457.767	2.237	0.090	2.24 ± 0.01
Weir – top of breakwater	232948.688	393465.220	3.398	0.010	3.41 ± 0.01
	232946.572	393462.961	3.409	0.008	
	232944.300	393459.226	3.419	0.009	
	232943.497	393457.795	3.412	0.009	
Weir – top of breakwater extension	232948.296	393455.434	3.194	0.08	3.19 ± 0.01
Footbridge – deck level	232971.303	393529.269	3.199	0.012	3.19 ± 0.01
	232976.869	393522.936	3.189	0.012	
	232981.231	393517.544	3.187	0.011	
Footbridge – main sill	232975.196	393523.414	2.044	0.011	2.04 ± 0.01
	232976.883	393524.582	2.044	0.011	
	232976.877	393524.587	2.049	0.009	
Footbridge – lower concrete foundation	232977.047	393524.732	1.889	0.009	1.83 ± 0.01
	232974.800	393529.372	1.777	0.010	
Footbridge – top of culvert	232977.422	393520.849	2.814	0.010	2.81 ± 0.01
Gravel barrier crest (min to max)	233046.795	393428.257	4.289	0.016	4.93 ± 1.28
	233363.487	393173.667	5.552	0.018	
Lagoon shoreline (min to max)	233028.009	393413.388	2.634	0.011	2.70 ± 0.29
	233444.771	393115.758	2.914	0.009	

Table 4. Summary of three successive high water levels recorded on 14-15 August 2018 at the Class A Station at Holyhead, in Cemlyn Bay, in the 'outer lagoon' between the Coastal Path footbridge and the weir, and within Cemlyn Lagoon above the weir. NB Data for Holyhead are recorded at15 minute intervals, those for Cemlyn at 1 minute intervals

Holyhead		Cemlyn Bay		Between footbridge and weir		Cemlyn Lagoon	
Date and time	Level (m ODN)	Date and time	Level (m ODN)	Date and time	Level (m ODN)	Date and time	Level (m ODN)
14/08/2018 01:00	3.09	14/08/2018 01:09	3.45	Not measured		14/08/2018 01:45	2.98
14/08/2018 13:30	2.74	14/08/2018 13:30	3.10	14/08/2018 13:50	3.05	14/08/2018 14:14	2.79
15/08/2018 01:45	2.97	15/08/2018 01:49	3.32	Not measured		15/08/2018 02:55	2.81

Table 5. Average tidal levels predicted at the nearby Standard Port of Holyhead (predictions by UKHO and NTSLF) and the Secondary Port at Cemaes Bay (UKHO), and the estimated levels at Cemlyn Bay on the basis of tidal measurements made using the TideMaster gauge mounted in the bay 13th to 15th August 2018, converted from Holyhead using the relationship shown in Figure 5. Values in brackets are averaged from the neap and spring tidal values

Tidal level	**Holyhead**		**Cemaes Bay**	**Cemlyn Bay**
	NTSLF predictions 2008-2026 (NTSLF website)	UKHO predictions 1988-2006 (2018 Admiralty Tide Tables)	UKHO predictions 1988-2006 (2018 Admiralty Tide Tables)	Estimate
HAT	3.28	3.25	3.90	3.71
MHWS	2.61	2.55	3.00	2.92
MHW	(2.11)	(1.95)	(2.25)	2.25
MHWN	1.46	1.35	1.50	1.57
MSL	(0.24)	0.22	0.07	0.31
MLWN	-1.03	-1.05	-1.30	-1.12
MLW	(-1.69)	(-1.70)	(-2.05)	-1.85
MLWS	-2.34	-2.35	-2.80	-2.58
LAT	-3.05	-3.05	(-3.61)	-3.36
MTR	(3.80)	(3.65)	(4.30)	4.09
MSR	4.95	4.90	5.80	5.50
MNR	2.49	2.40	2.80	2.69

Table 6. The highest 50 water levels recorded at Holyhead during the period January 1964 to August 2018, with the surge residual at the time of observed high water and the skew surge recorded at Holyhead. Levels at Cemlyn are estimated using two methods: (1) an extrapolation of observed levels at Holyhead using a linear relationship established on the basis of three tides on 14-15 August 2018: CEM = (1.1217 × HOL) + 0.0601, where CEM are observed levels at Cemlyn and HOL are observed levels at Holyhead; (2) an extrapolation of predicted levels at Holyhead using the same linear relationship as (1), plus the magnitude of the skew surge observed at Holyhead. Method (1) implies that surges are slightly amplified at Cemlyn compared to Holyhead, whereas (2) implies that skew surges are the same at Holyhead and Cemlyn. Original data source: NTSLF

Date and time	Observed level at Holyhead (m ODN	Estimated level at Cemlyn (M ODN[1]	Estimated level at Cemlyn (M ODN)[2]	Surge residual at HW (m)	Skew surge (m)
01/02/2002 12:45	3.81	4.33	4.22	0.88	0.88
03/01/2014 11:45	3.78	4.30	4.22	0.69	0.64
10/02/1997 12:15	3.63	4.13	4.08	0.46	0.46
12/12/2000 23:30	3.59	4.09	3.99	0.88	0.79
03/02/2014 12:30	3.56	4.05	3.99	0.50	0.49
23/12/1999 22:45	3.55	4.04	3.96	0.65	0.65
30/03/2006 10:45	3.54	4.03	3.98	0.44	0.44
04/01/2018 12:00	3.53	4.02	3.96	0.52	0.49
10/03/2008 12:00	3.53	4.02	3.94	0.59	0.59
06/01/2014 14:00	3.51	4.00	3.91	0.77	0.77
08/10/2006 23:00	3.50	3.99	3.95	0.29	0.29
05/12/2013 11:45	3.50	3.99	3.93	0.49	0.48
01/02/2014 11:30	3.49	3.97	3.94	0.35	0.30
26/02/1990 11:00	3.48	3.97	3.89	0.63	0.63
07/10/1987 22:00	3.44	3.91	3.86	0.43	0.43
10/03/2001 10:45	3.43	3.91	3.86	0.42	0.42
20/02/2007 12:00	3.42	3.90	3.86	0.33	0.33
09/03/1989 11:00	3.42	3.90	3.86	0.26	0.26
25/12/1999 00:00	3.41	3.89	3.81	0.63	0.58
17/10/2012 11:15	3.41	3.88	3.83	0.44	0.42
27/09/1988 23:00	3.40	3.87	3.84	0.21	0.21
28/10/2015 22:45	3.39	3.87	3.84	0.21	0.21
07/10/2006 22:15	3.39	3.86	3.84	0.18	0.18
01/01/1991 23:00	3.39	3.86	3.77	0.72	0.72
19/02/2007 11:30	3.39	3.86	3.82	0.34	0.34
29/01/1990 12:00	3.38	3.85	3.78	0.60	0.60
03/01/1998 13:15	3.38	3.85	3.76	0.75	0.74
13/12/1981 12:00	3.38	3.85	3.79	0.57	0.47
15/09/1989 22:00	3.38	3.85	3.80	0.38	0.38
26/11/1999 12:00	3.38	3.85	3.78	0.52	0.52
02/03/2014 10:45	3.38	3.85	3.82	0.24	0.24
27/10/2015 22:00	3.37	3.84	3.81	0.19	0.19
16/10/1997 22:15	3.37	3.84	3.82	0.16	0.16
08/09/1998 23:45	3.36	3.83	3.80	0.26	0.26
25/09/1988 22:00	3.36	3.83	3.80	0.29	0.29
19/03/1988 11:00	3.36	3.83	3.80	0.23	0.23
31/03/2006 11:30	3.35	3.82	3.78	0.29	0.29
26/01/2016 11:45	3.35	3.81	3.73	0.68	0.68
16/10/2016 22:15	3.35	3.81	3.80	0.16	0.16
06/11/2014 21:45	3.34	3.81	3.76	0.45	0.45
08/02/1966 12:00	3.34	3.81	3.77	0.30	0.30
07/02/1970 11:00	3.34	3.81	3.77	0.31	0.31
04/01/2014 12:15	3.34	3.80	3.78	0.21	0.21
07/03/1981 11:00	3.33	3.80	3.75	0.41	0.41
07/04/1985 11:00	3.33	3.79	3.75	0.32	0.32
01/02/1983 01:00	3.33	3.79	3.70	0.79	0.78
08/10/2010 22:30	3.32	3.79	3.77	0.17	0.17
16/10/1982 22:00	3.32	3.79	3.72	0.51	0.51
17/10/1997 23:00	3.32	3.79	3.77	0.13	0.13
24/10/1995 22:15	3.32	3.78	3.73	0.46	0.46

Table 7. pH, conductivity and suspended solids concentration of water samples collected on 14 August 2018

Sample	Location	Easting	Northing	Date	Time	pH	Conductivity uS/cm	SSC mg/l
CEM20	W side lagoon	232870	393266	14.08.18	09.00	7.2	49000	90
CEM21	W side lagoon	232857	393228	14.08.18	09.05	7.2	49000	89
CEM22	SE end lagoon by car park	233567	393108	14.08.18	09.10	7.2	49000	94
CEM23	Tyn Llan lagoon	232814	393232	14.08.18	09.15	6.6	41000	79
CEM24	Inside weir	232949	393452	14.08.18	09.30	7.2	49000	82
CEM25	Inside weir	232949	393452	14.08.18	12.00	7.1	49000	93
CEM26	Inside weir	232949	393452	14.08.18	12.30	7.0	51000	85
CEM27	Inside weir	232949	393452	14.08.18	13.30	7.0	53000	81

Table 8. Beach sediment samples collected on 14 August 2018, with location and percentages of gravel, sand and mud (UB = upper beach slope; LB = lower beach flat; HWM - high water mark; WT = water table)

Sample	Location	Easting	Northing	Folk (1954) Classification	Gravel (%)	Sand (%)	Mud (%)
CEM40	UB HWM berm	233582	393154	Gravel	100.0	0.0	0.0
CEM41	UB above WT	233576	393187	Sandy Gravel	57.6	42.4	0.0
CEM42	LB flat above LWM	233561	393232	Sand	0.0	99.7	0.3
CEM43	LB flat above LWM	233399	393245	Sand	0.0	99.7	0.3
CEM44	UB above WT	233398	393212	Gravel	91.9	8.1	0.0
CEM45	UB HWM berm	233387	393180	Gravel	100.0	0.0	0.0
CEM46	LB flat above LWM	233261	393306	Sand	0.0	99.7	0.3
CEM47	UB above WT	233239	393287	Gravel	98.5	1.5	0.0
CEM48	UB HWM berm	233216	393272	Gravel	100.0	0.0	0.0
CEM49	UB above WT	233098	393420	Gravel	94.6	5.4	0.0
CEM50	UB HWM berm	233075	393407	Gravel	100.0	0.0	0.0

Table 9. Mean, mode, median (D50), phi sorting and phi skewness parameters calculated using Folk & Ward (1957) formulae

Sample	Mean (µm)	Mode (µm)	D50 (µm)	Phi Sorting		Phi Skewness	
CEM40	13569	13600	13255	0.688	Moderately Well Sorted	-0.063	Symmetrical
CEM41	1437.6	4800	2718	2.137	Very Poorly Sorted	0.481	Very Fine Skewed
CEM42	179.57	152.5	179	0.414	Well Sorted	-0.175	Coarse Skewed
CEM43	173.12	152.5	170	0.331	Very Well Sorted	-0.112	Coarse Skewed
CEM44	25582	76500	44753	2.261	Very Poorly Sorted	0.681	Very Fine Skewed
CEM45	26894	26950	26017	0.588	Moderately Well Sorted	-0.122	Coarse Skewed
CEM46	179.45	215	180	0.368	Well Sorted	-0.058	Symmetrical
CEM47	60345	76500	65422	0.695	Moderately Well Sorted	0.540	Very Fine Skewed
CEM48	39524	54000	41686	0.483	Well Sorted	0.229	Fine Skewed
CEM49	27153	76500	39213	1.680	Poorly Sorted	0.540	Very Fine Skewed
CEM50	14797	9600	13285	0.797	Moderately Sorted	-0.258	Coarse Skewed

Table 10. Estimated calcium carbonate content of the sand (< 2 mm) fractions of selected beach samples from Cemlyn Bay (determined using the 10% HCl weight loss method)

Sample	% weight loss (10% HCl)
CEM41	10.18
CEM42	9.83
CEM43	9.81
CEM44	7.77
CEM46	11.66
CEM49	7.10

Figures

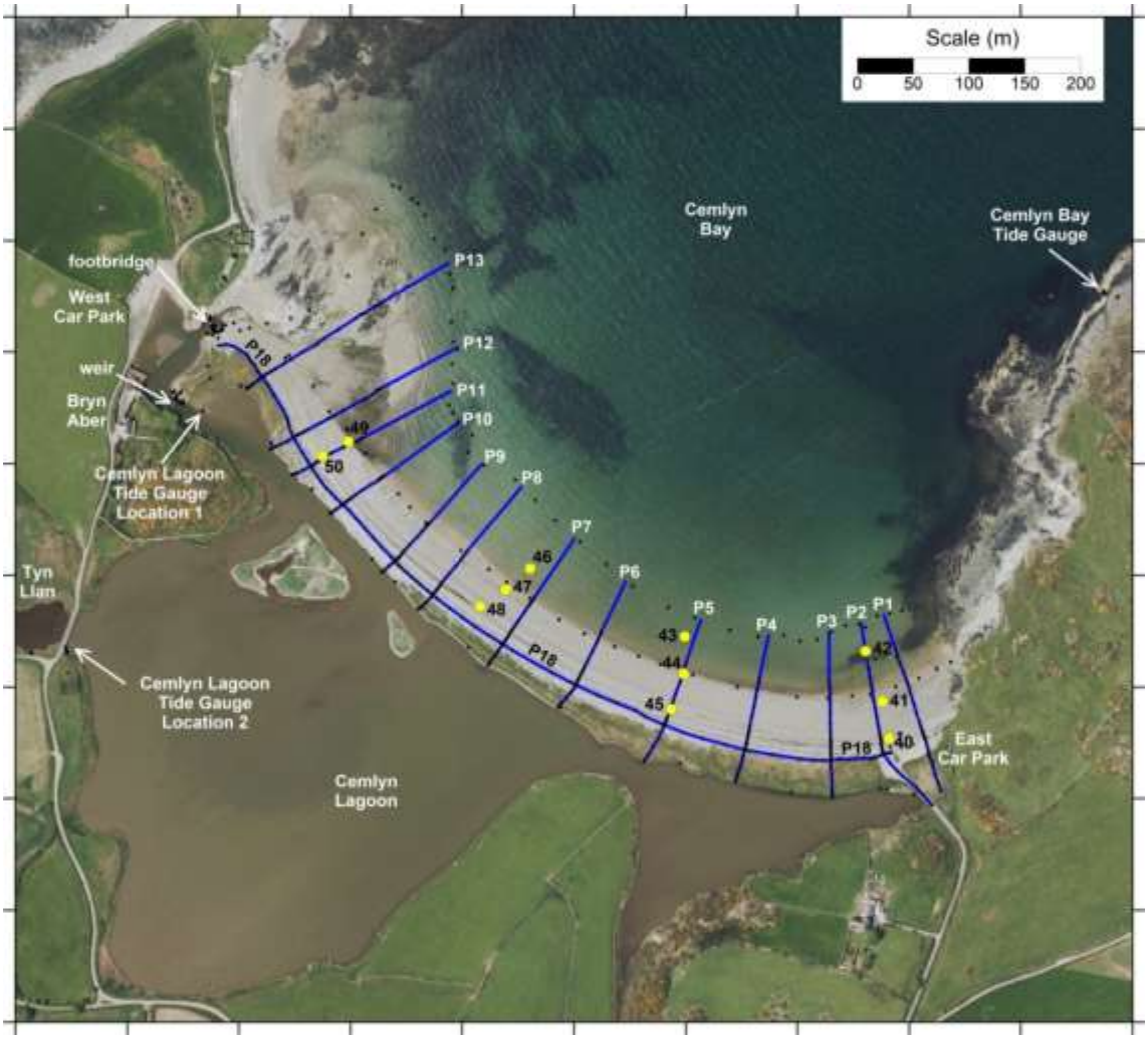


Figure 1. Locations of RTK GPS ground survey points (black dots) superimposed on base 2013-14 aerial photography; blue lines indicate cross-shore and alongshore ridge crest profiles. The locations of the tide gauges deployed 13-15 August 2018 are also indicated. Yellow dots indicate the positions of beach sediment samples collected on 14 August 2018.

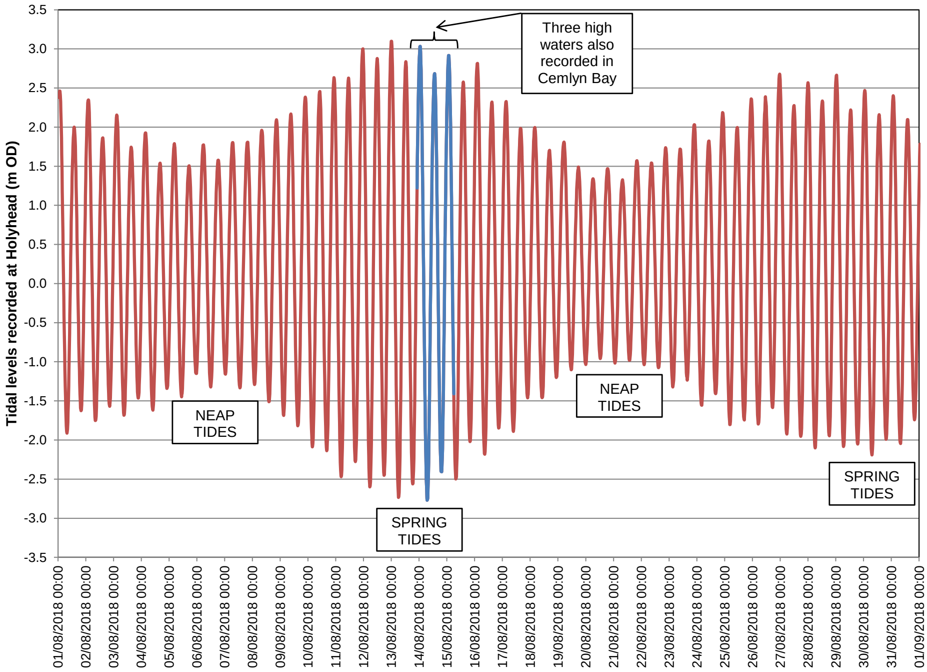


Figure 2. Tidal levels (relative to ODN) recorded at 15 minute intervals at Holyhead during August 2018, showing the differences in tidal range between spring and neap tides during the month. During the period between 13/08/2018 and 15/08/2018 (blue line) tidal levels were also recorded at 1 minute intervals using a Valeport TideMaster tide gauge mounted in Cemlyn Bay. Times are relative to British Summer Time

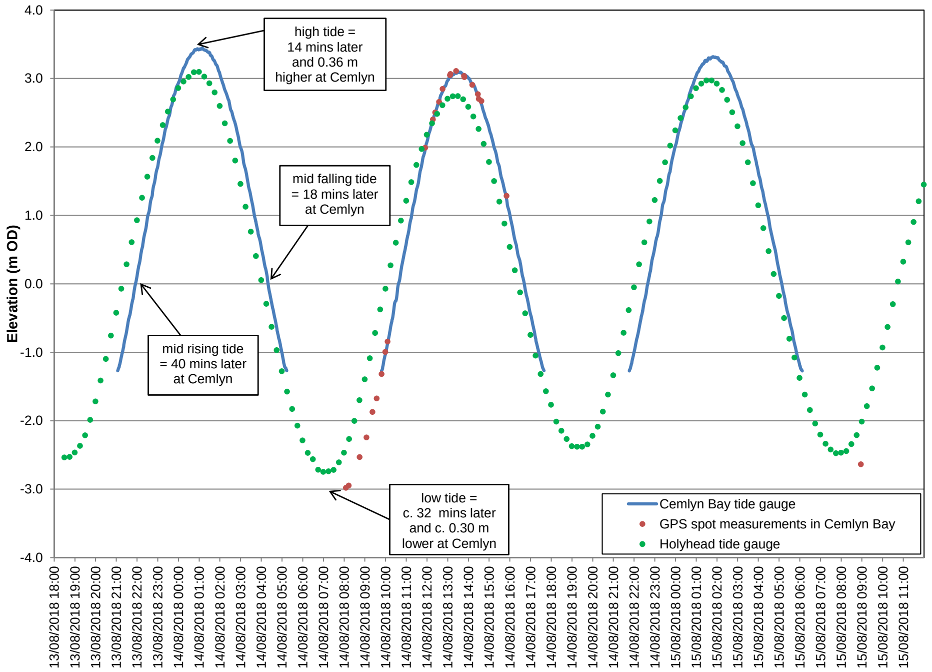


Figure 3. Tidal levels exactly as recorded in Cemlyn Bay and Holyhead. Blue line shows values recorded at 1 minute intervals using a Valeport TideMaster tide gauge mounted in Cemlyn Bay between 13/08/2018 and 15/08/2018 (at OS grid reference 233775E 393552N). Red dots show additional spot water level measurements recorded in Cemlyn Bay using a Leica SmartRover RTK GNSS System. The green dots show the water level recorded at 15 minute intervals Holyhead. All times are relative to British Summer Time, and levels relative to Ordnance Datum Newlyn.

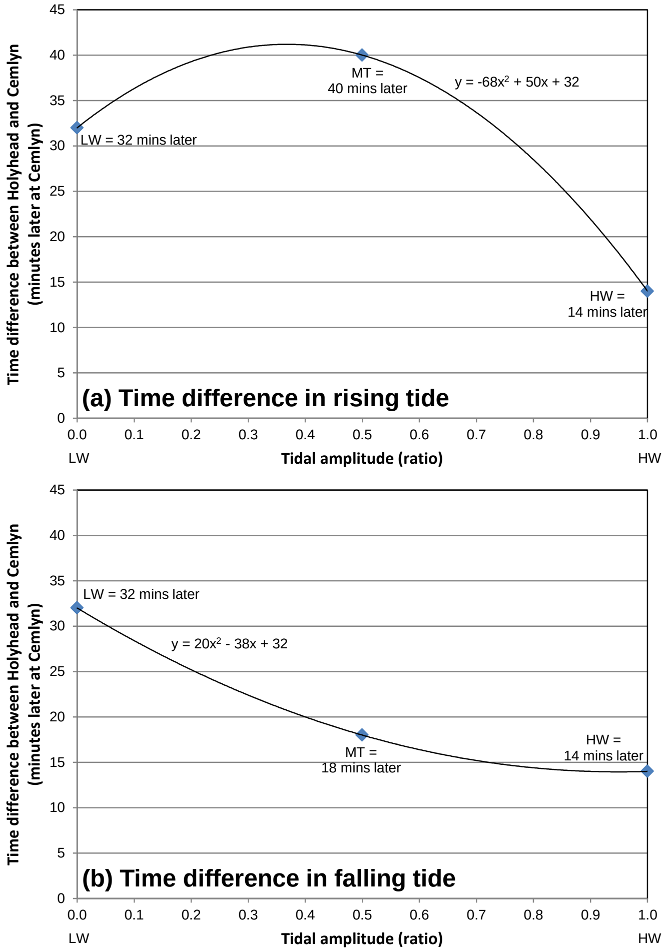


Figure 4. The average time difference between tidal levels recorded at Holyhead and Cemlyn Bay for three measured tides on 13-15 August 2018. Different relationships are observed for rising and falling tides due to tidal asymmetry. The curves show the difference between the two stations on the basis of polynomial relationships based on the time differences observed at high, mid and low waters at the two stations (blue diamonds, established from Figure 3)

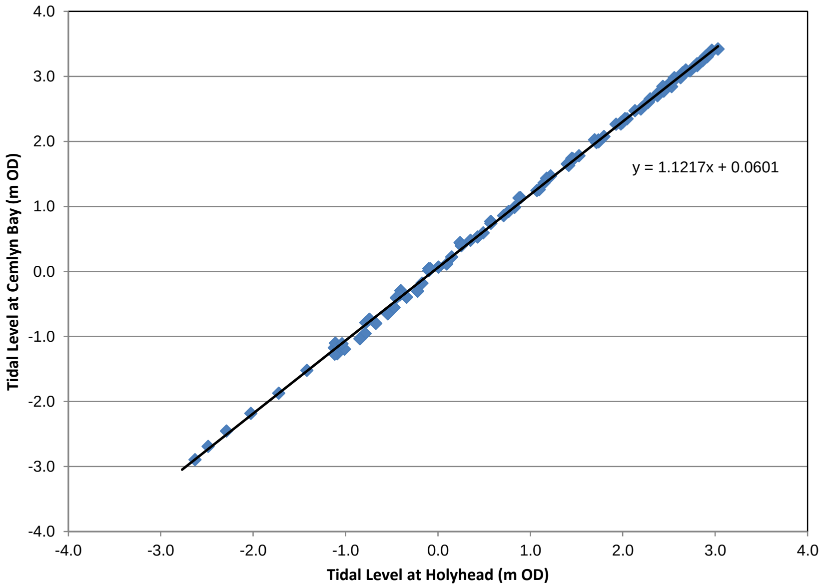


Figure 5. Comparison of tidal levels recorded for three tides at Cemlyn Bay and Holyhead (13th to 15 August 2018), after allowing for a time differences between the gauges as described in Figure 3a and 3

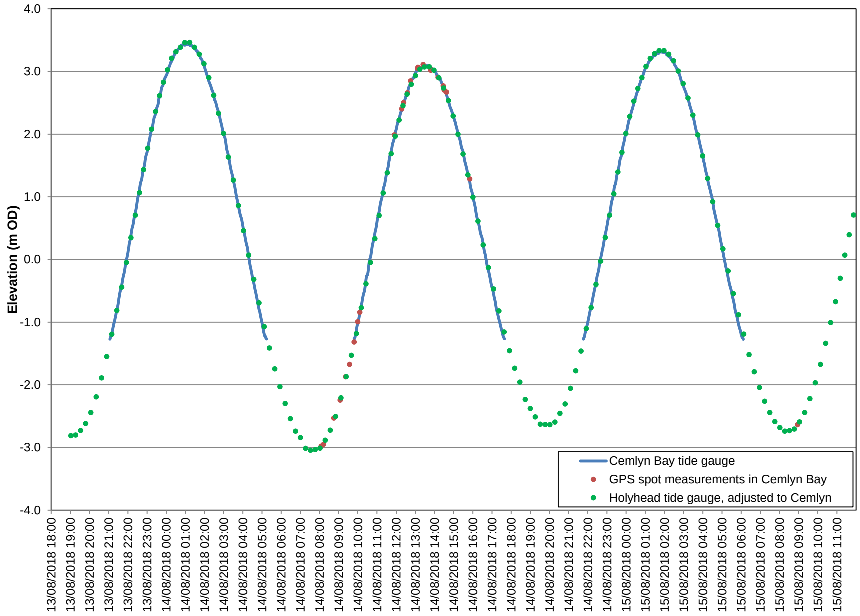


Figure 6. Tidal levels recorded in Cemlyn Bay and Holyhead, after values recorded at Holyhead every 15 minutes have been converted to values at Cemlyn on the basis of time differences (as described in Figures 3a and 3b) and elevation differences (as described in Figure 4). Times are in British Summer Time and levels are relative to Ordnance Datum Newlyn

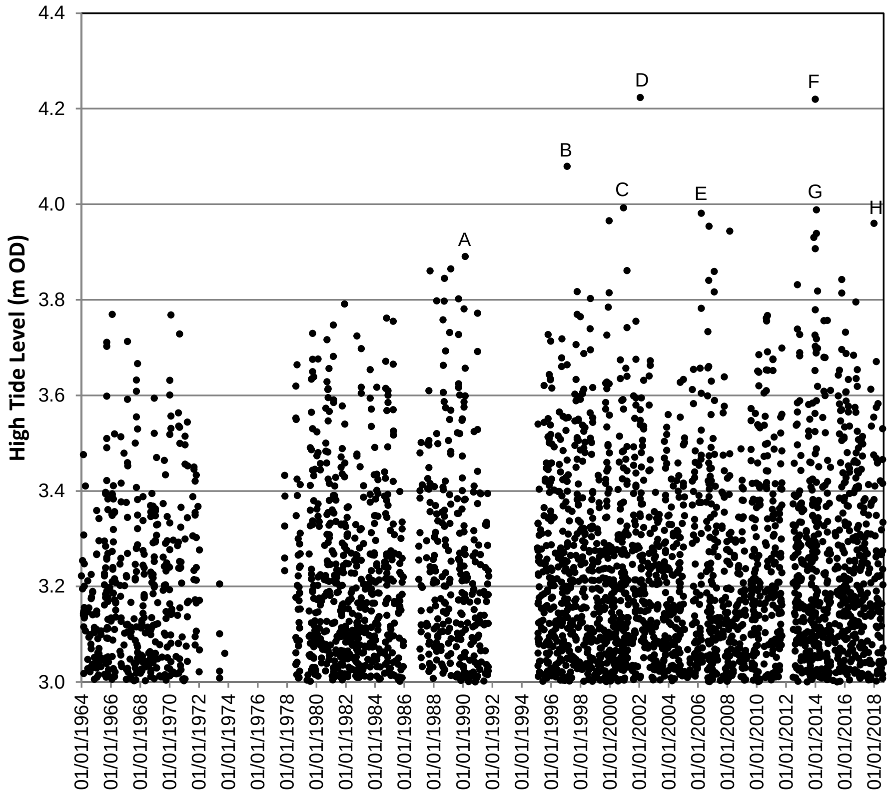


Figure 7. High water levels recorded at Holyhead during the period January 1964 to August 2018, converted to levels in Cemlyn Bay. Particularly high tides are annotated: (A) 26/02/1990; (B) 10/02/1997; (C) 12/12/2000; (D) 01/02/2002; (E) 30/03/2006; (F) 03/01/2014; (G) 03/02/2014; (H) 04/01/2018

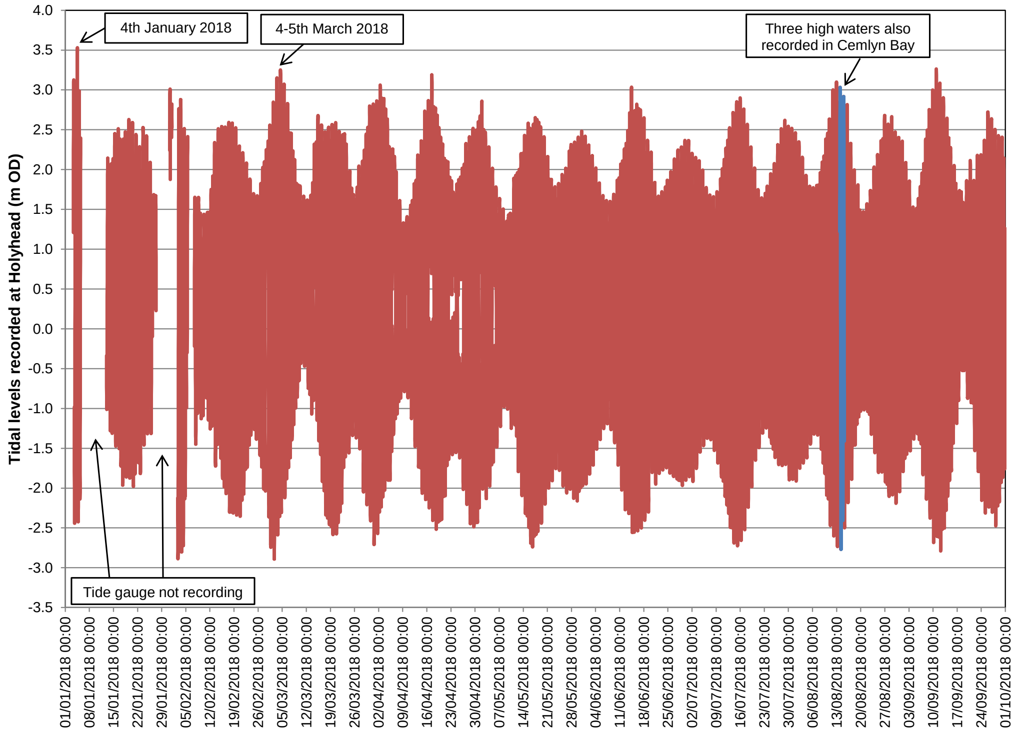


Figure 8. Recorded water levels at Holyhead between 1 January and 1 October 2018 (original data source; NTSLF)

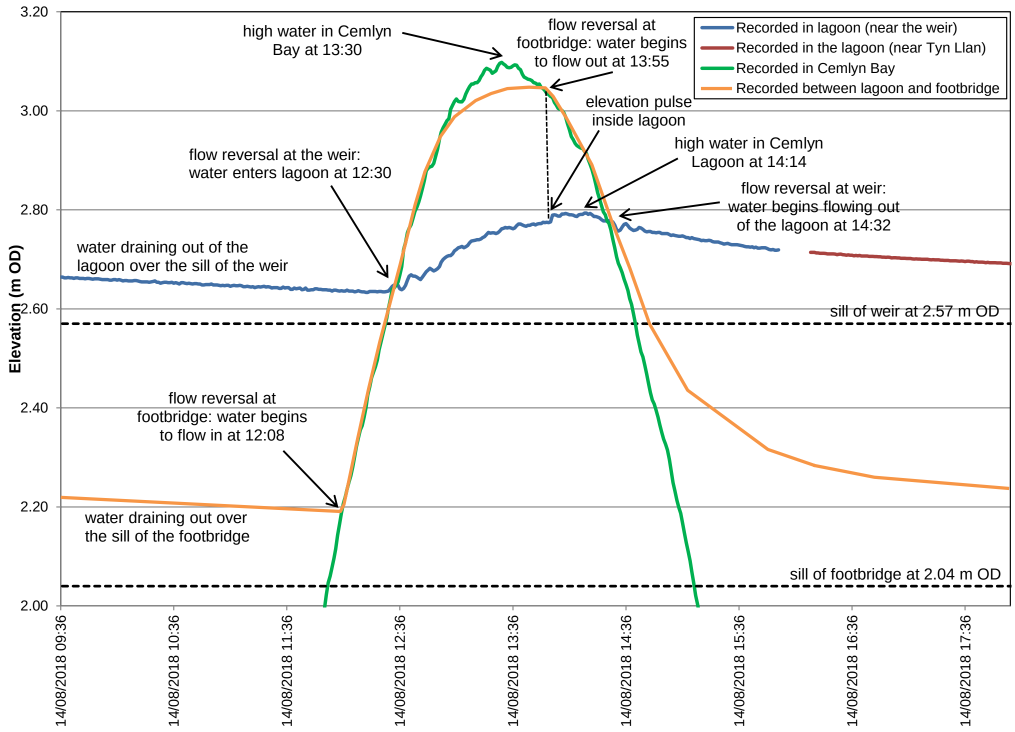


Figure 9. Tidal stage curves for the midday tide on 14th August 2018, comparing levels recorded in Cemlyn Bay, in the 'pool' between the footbridge and the weir, and within Cemlyn Lagoon

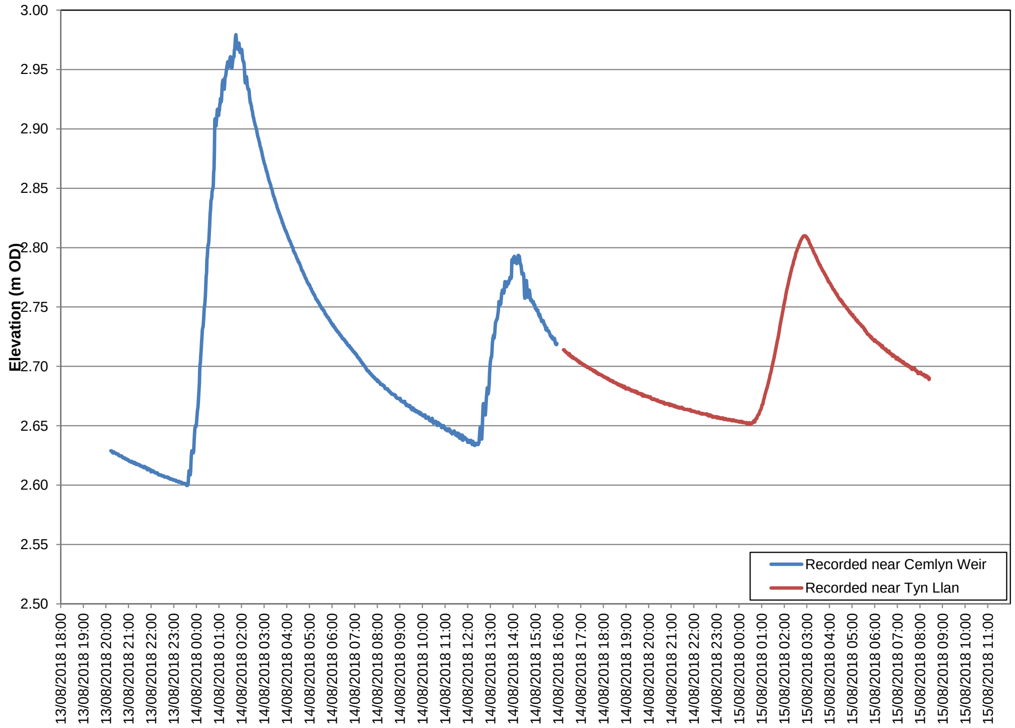


Figure 10. Tidal stage curves recorded in Cemlyn Lagoon near the weir and near the Tyn Llan culvert. Times are relative to British Summer Time, and levels are relative to Ordnance Datum Newlyn

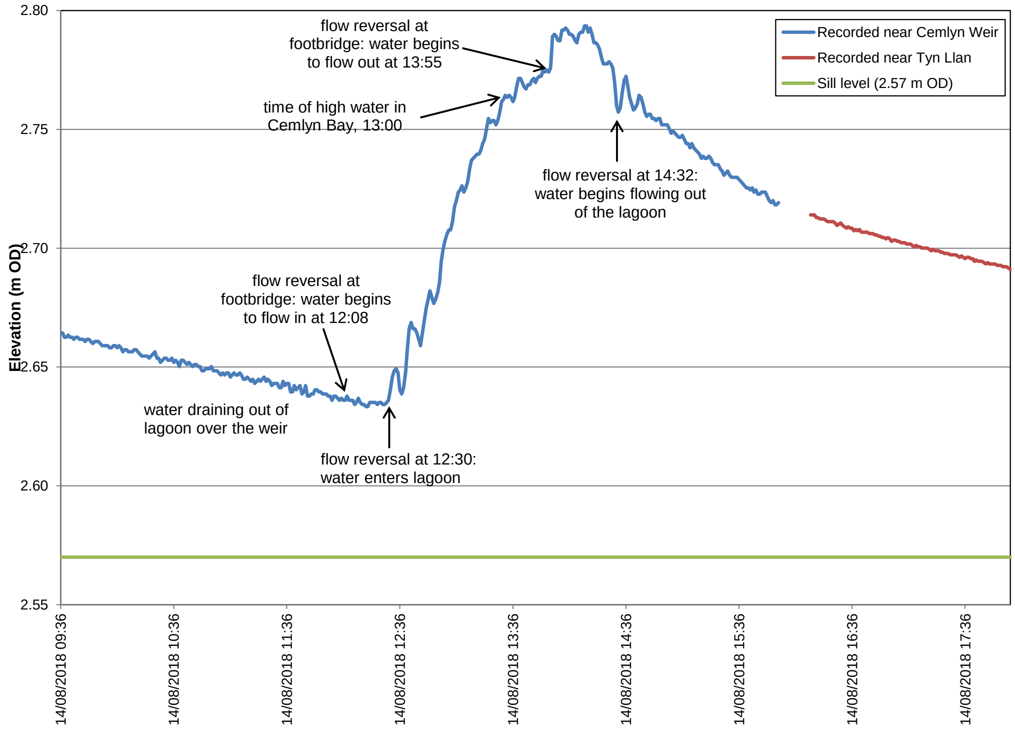


Figure 11. Enlargement of part of Figure 9 showing the midday tide on 14th August 2018, showing times of flow reversal and other features of interest

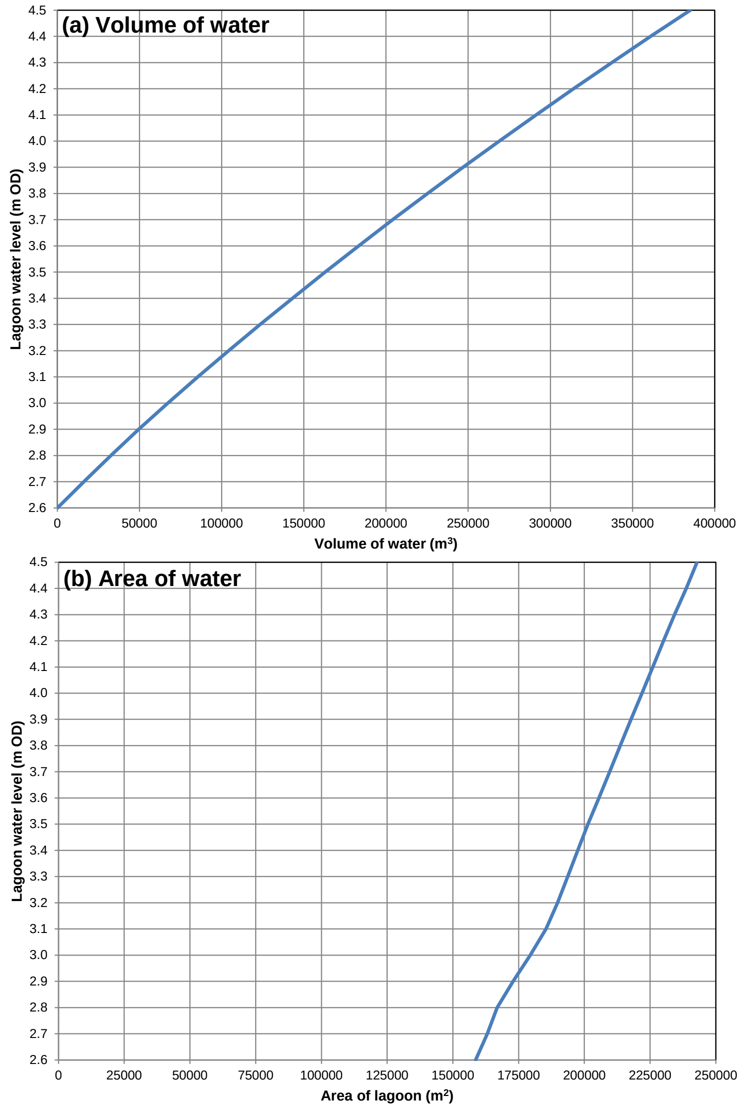


Figure 12. Potential volume and area of Cemlyn Lagoon (above 2.6 m OD, just above the level of the weir sill) as a function of water level, calculated from LiDAR surveys of the lagoon in 2010 and 2017

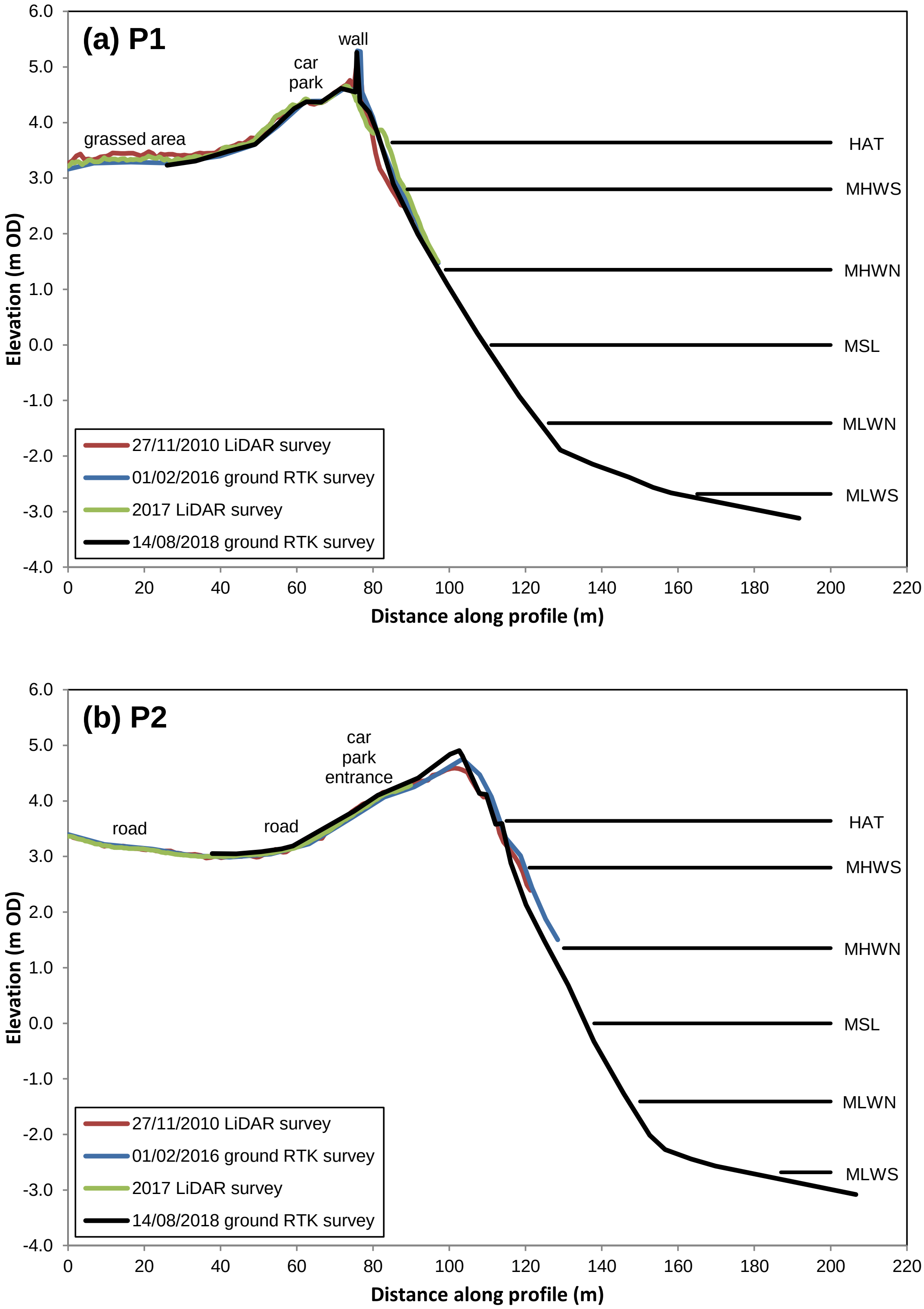
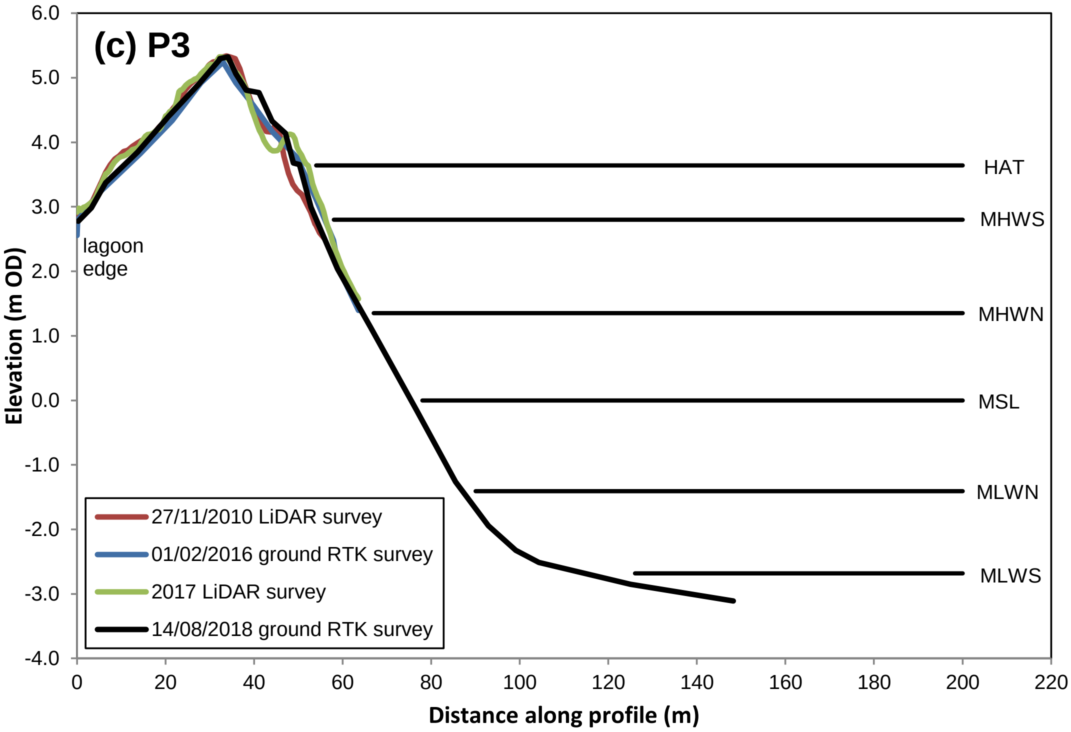


Figure 13. Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



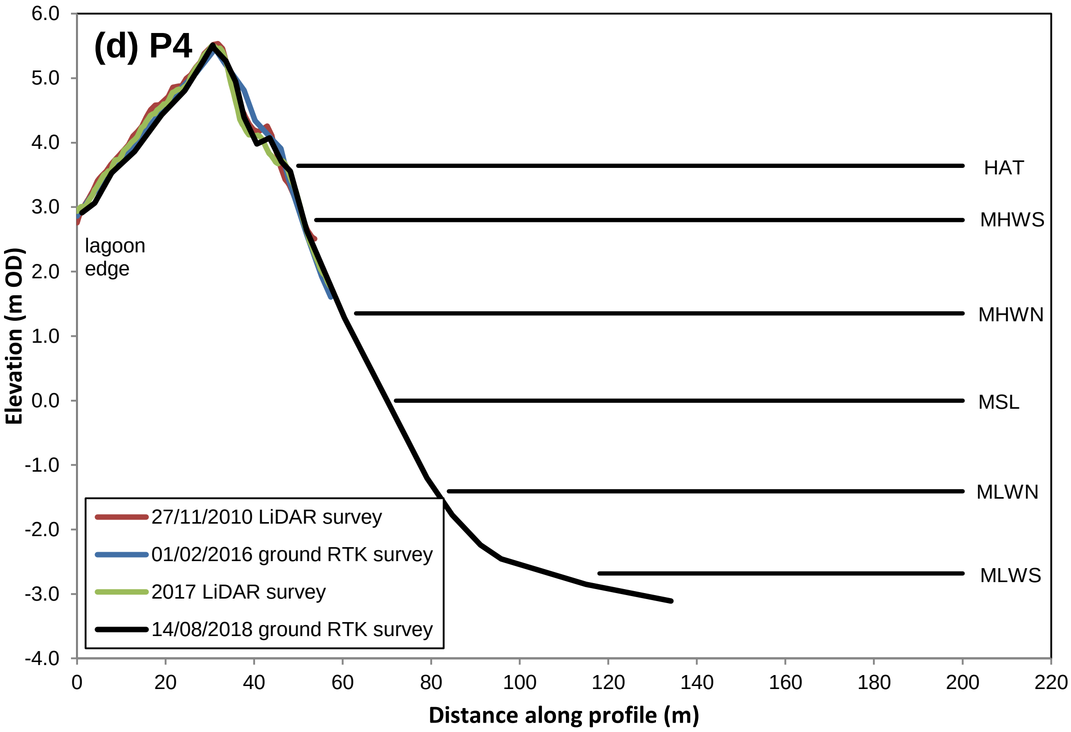
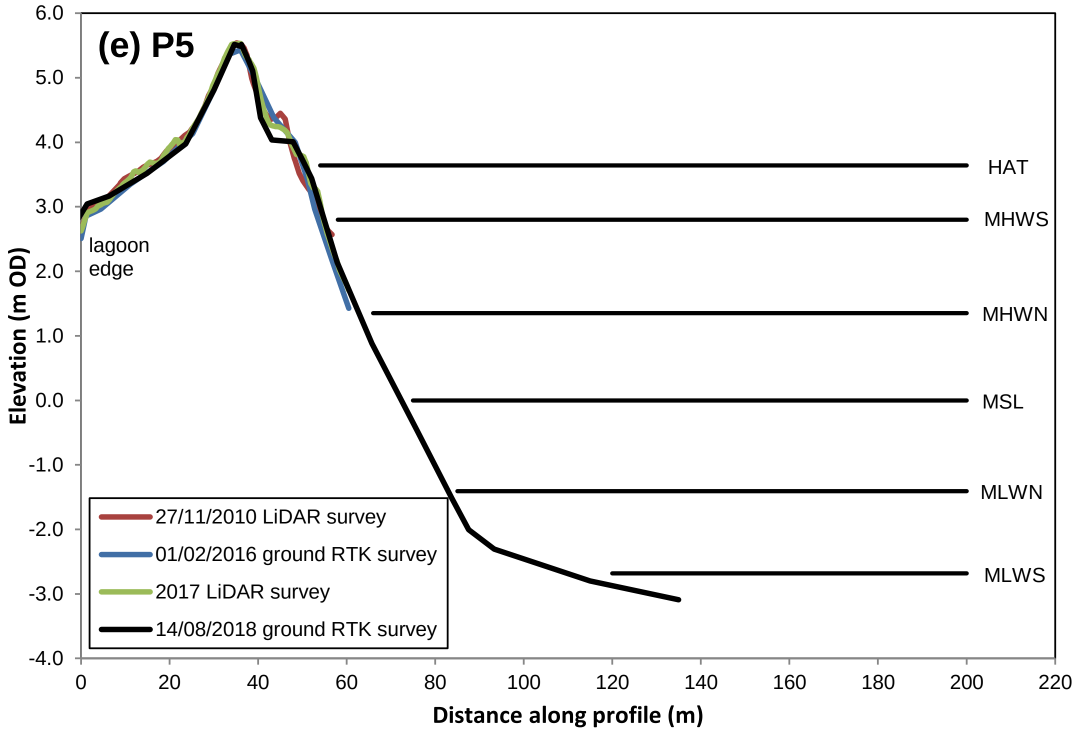


Figure 13 (continued). Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



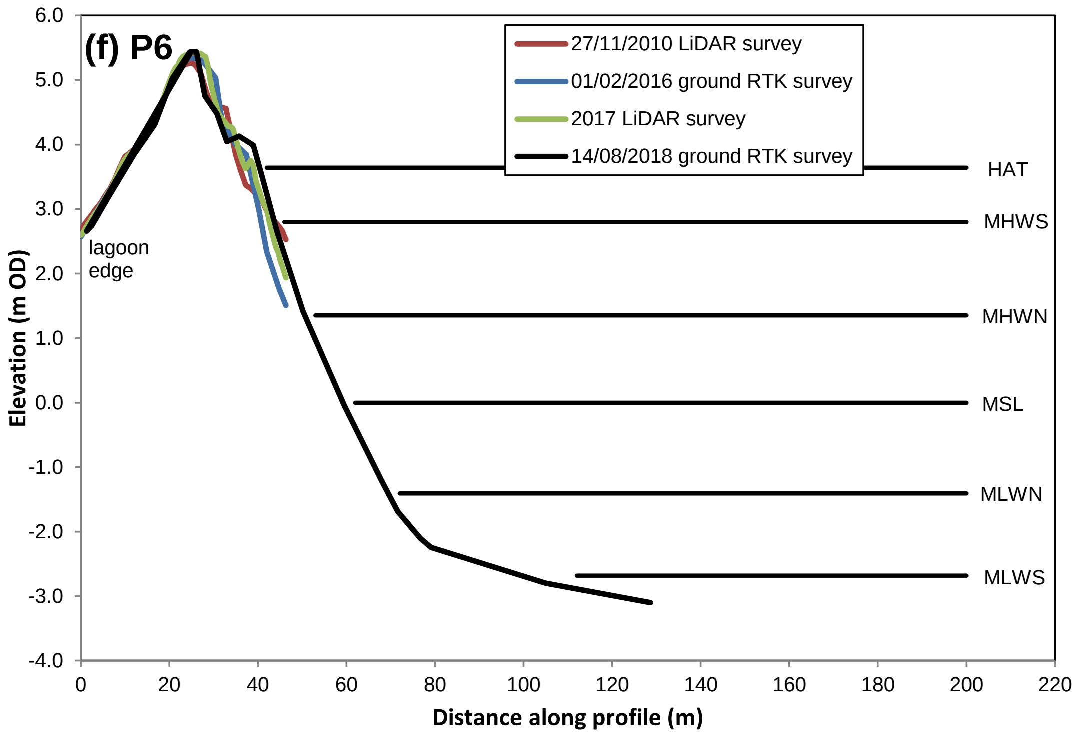
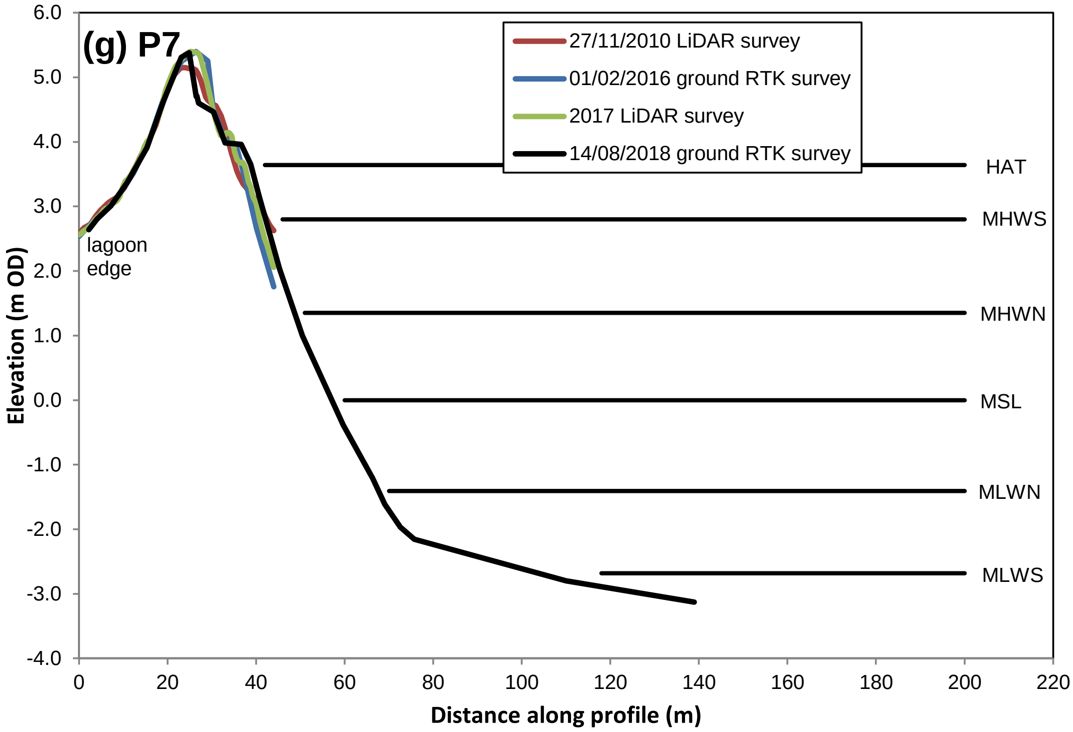


Figure 13 (continued). Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



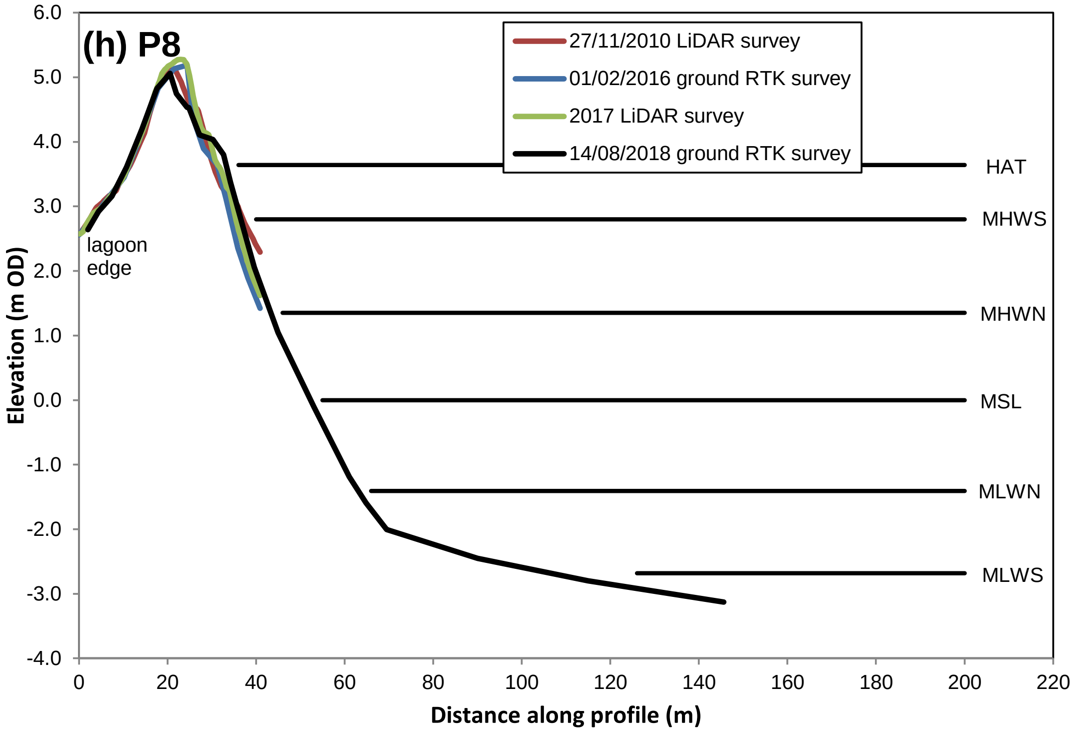
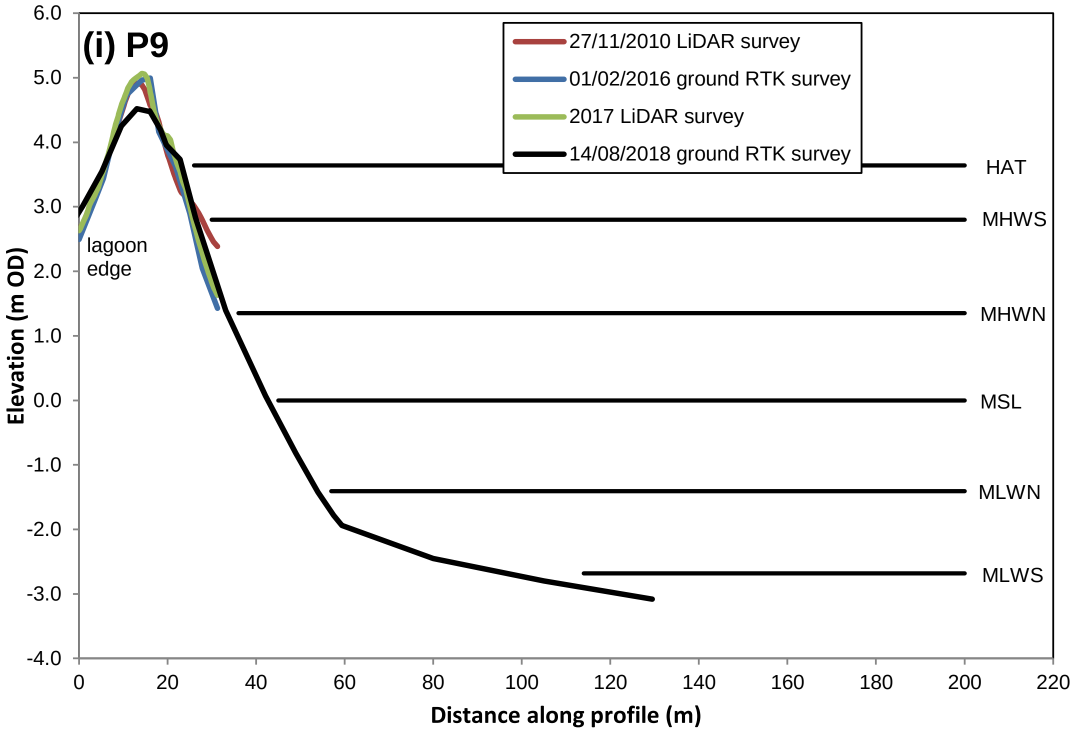


Figure 13 (continued). Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



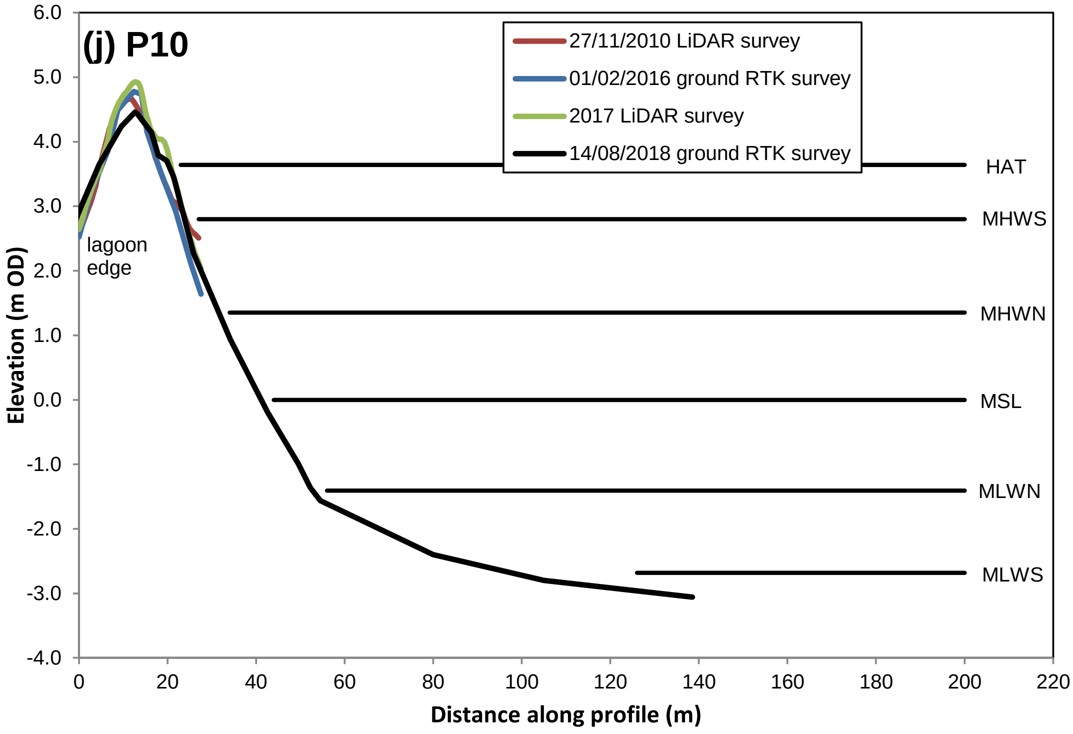
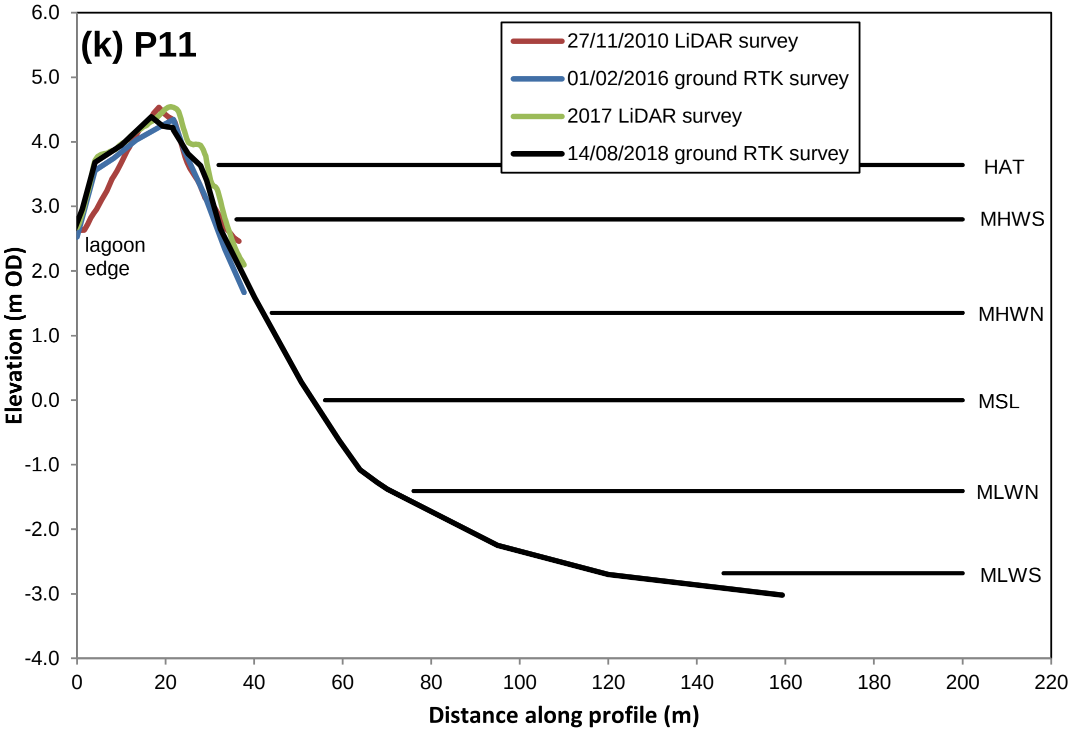


Figure 13 (continued). Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



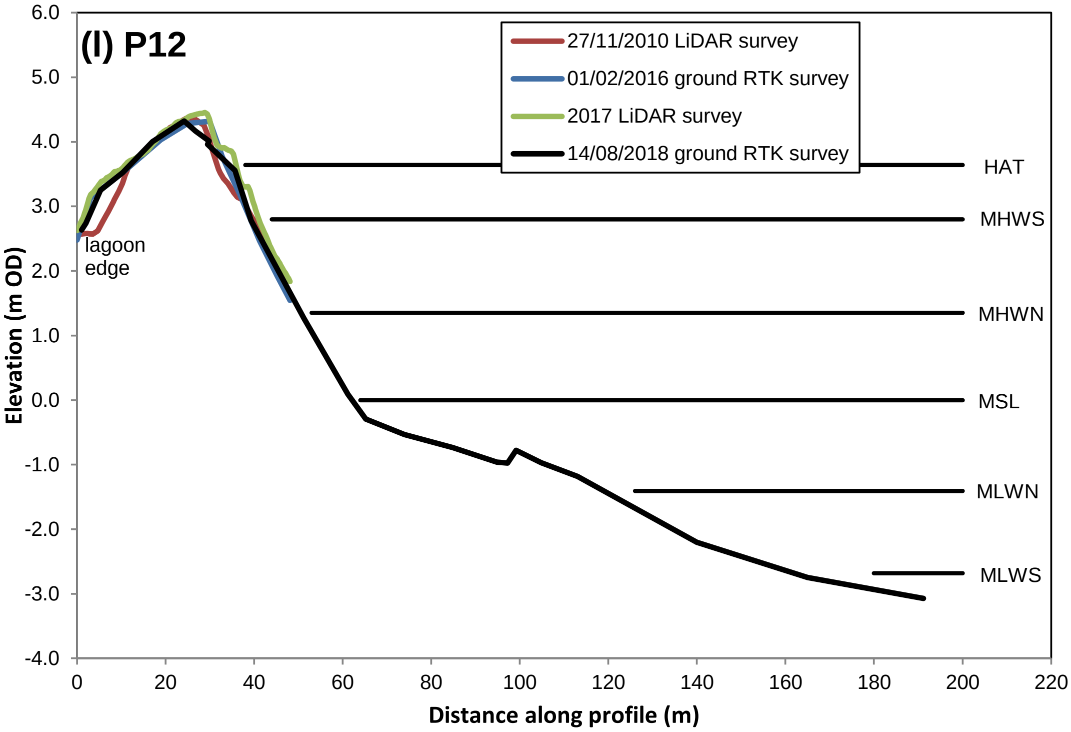
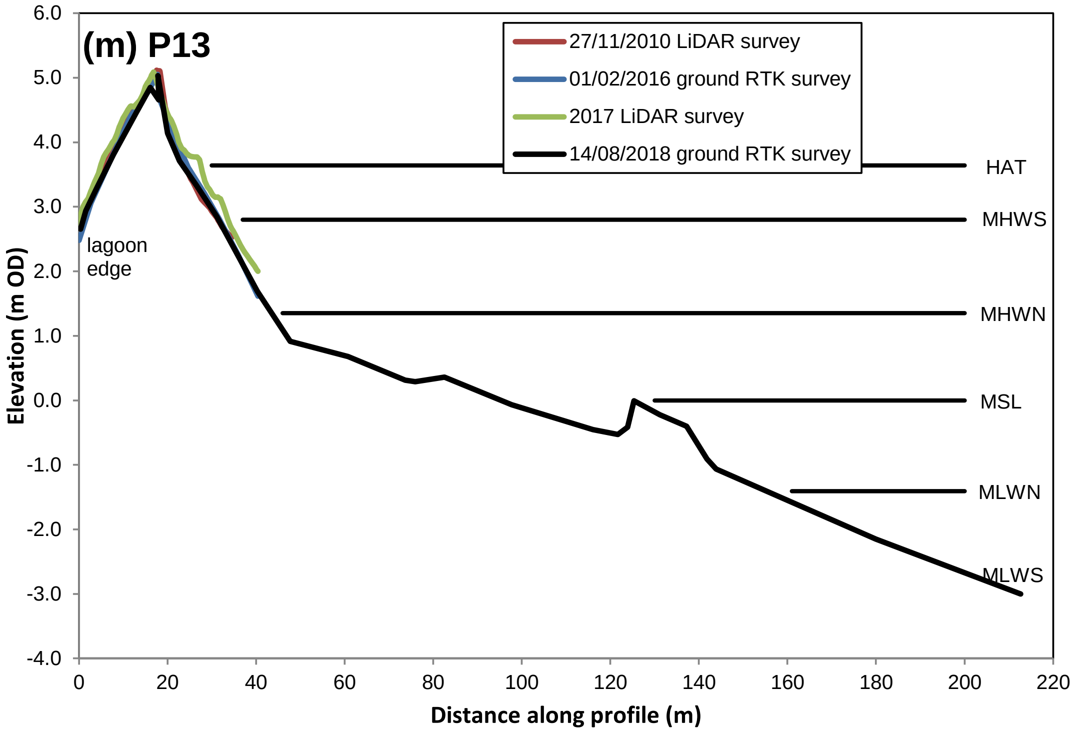


Figure 13 (continued). Cross-shore profiles of the beach surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys



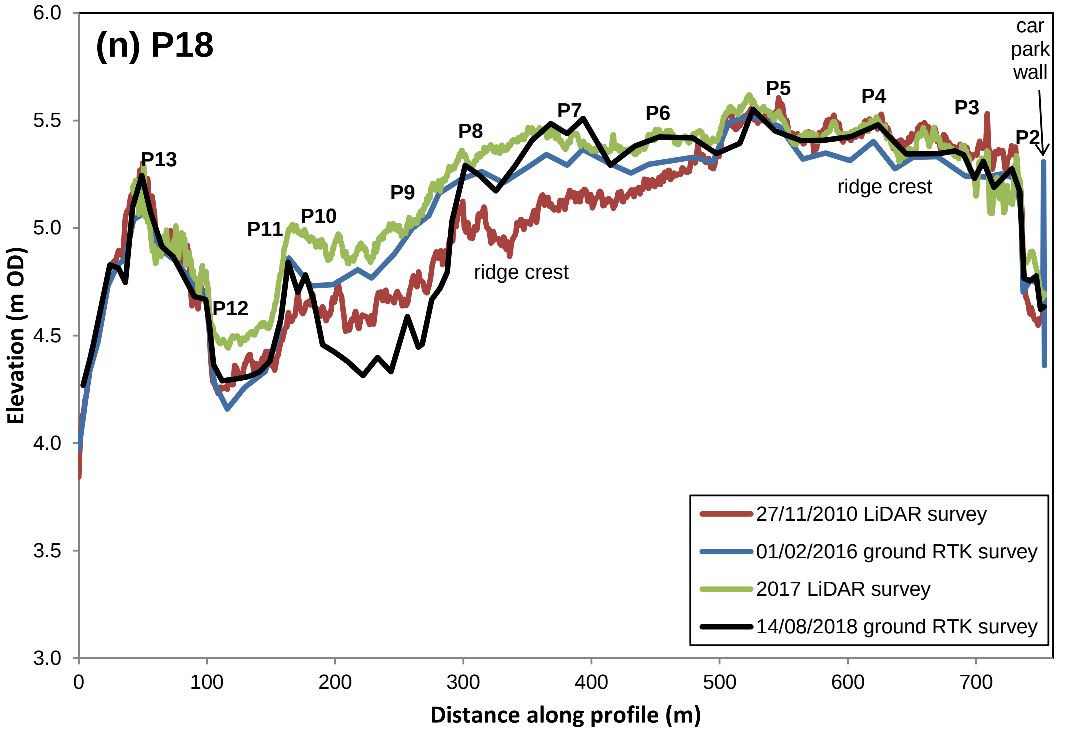


Figure 13 (continued). Cross-shore profile P13 (m) and alongshore ridge crest profile P18 (n) surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys

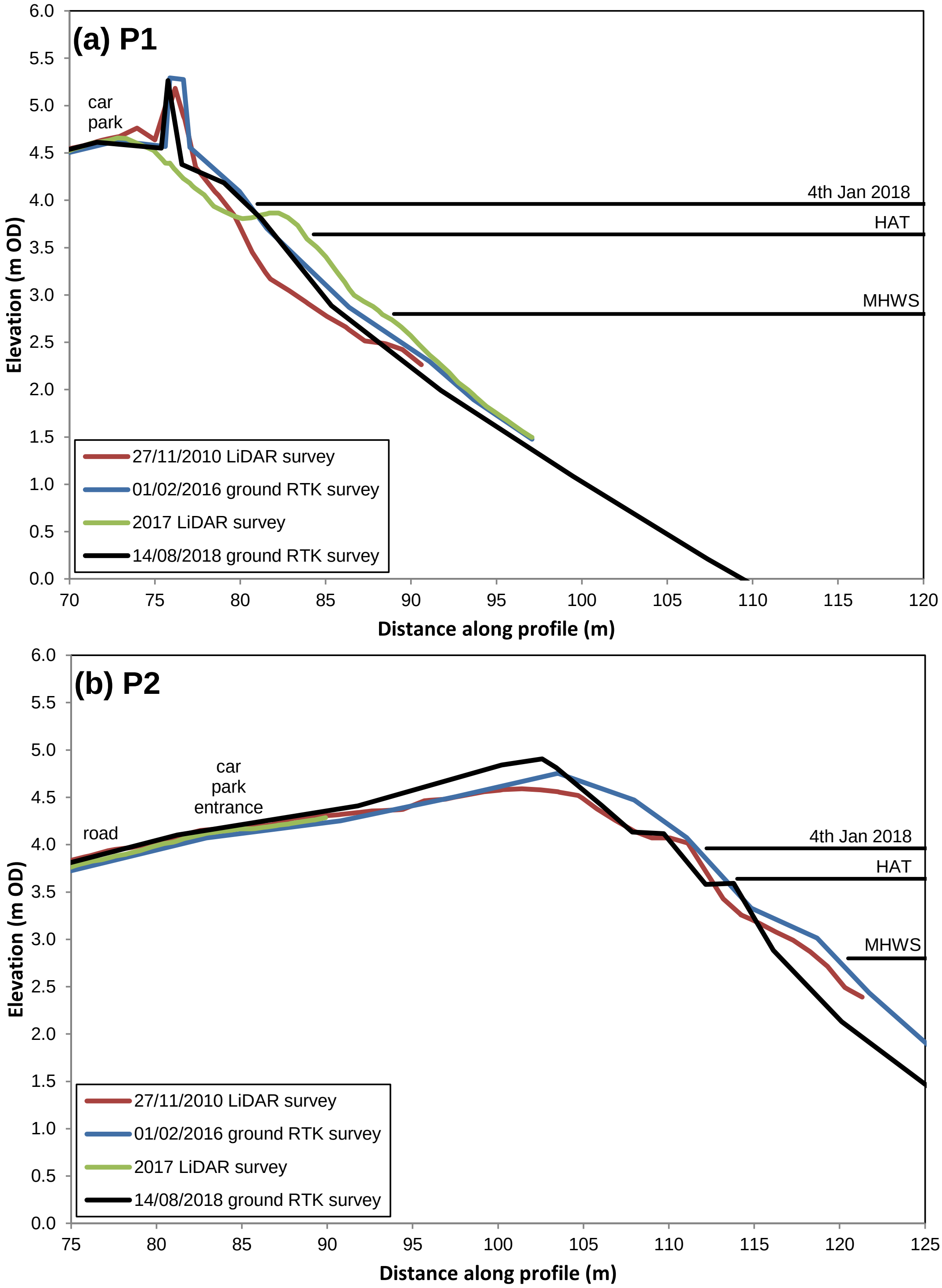


Figure 14. Enlargement of upper beach and ridge crest cross-shore profiles surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys. The level of the storm surge event on 4th January 2018 (estimated to have reached 3.96 m ODN at Cemlyn, using method 2 in Table 5) is also shown

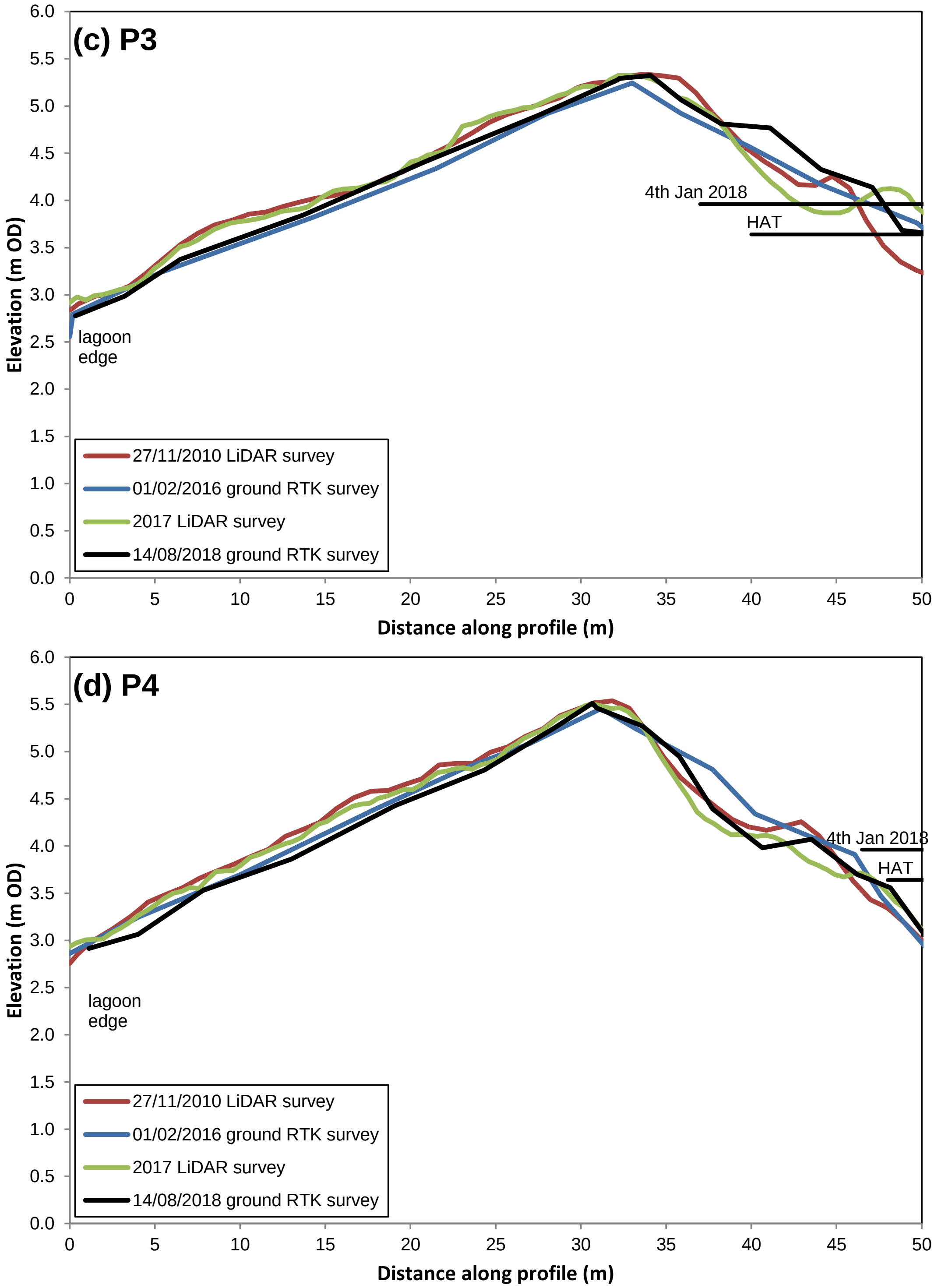


Figure 14 continued. Enlargement of upper beach and ridge crest cross-shore profiles surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys. The level of the storm surge event on 4th January 2018 (estimated to have reached 3.96 m ODN at Cemlyn, using method 2 in Table 5) is also shown

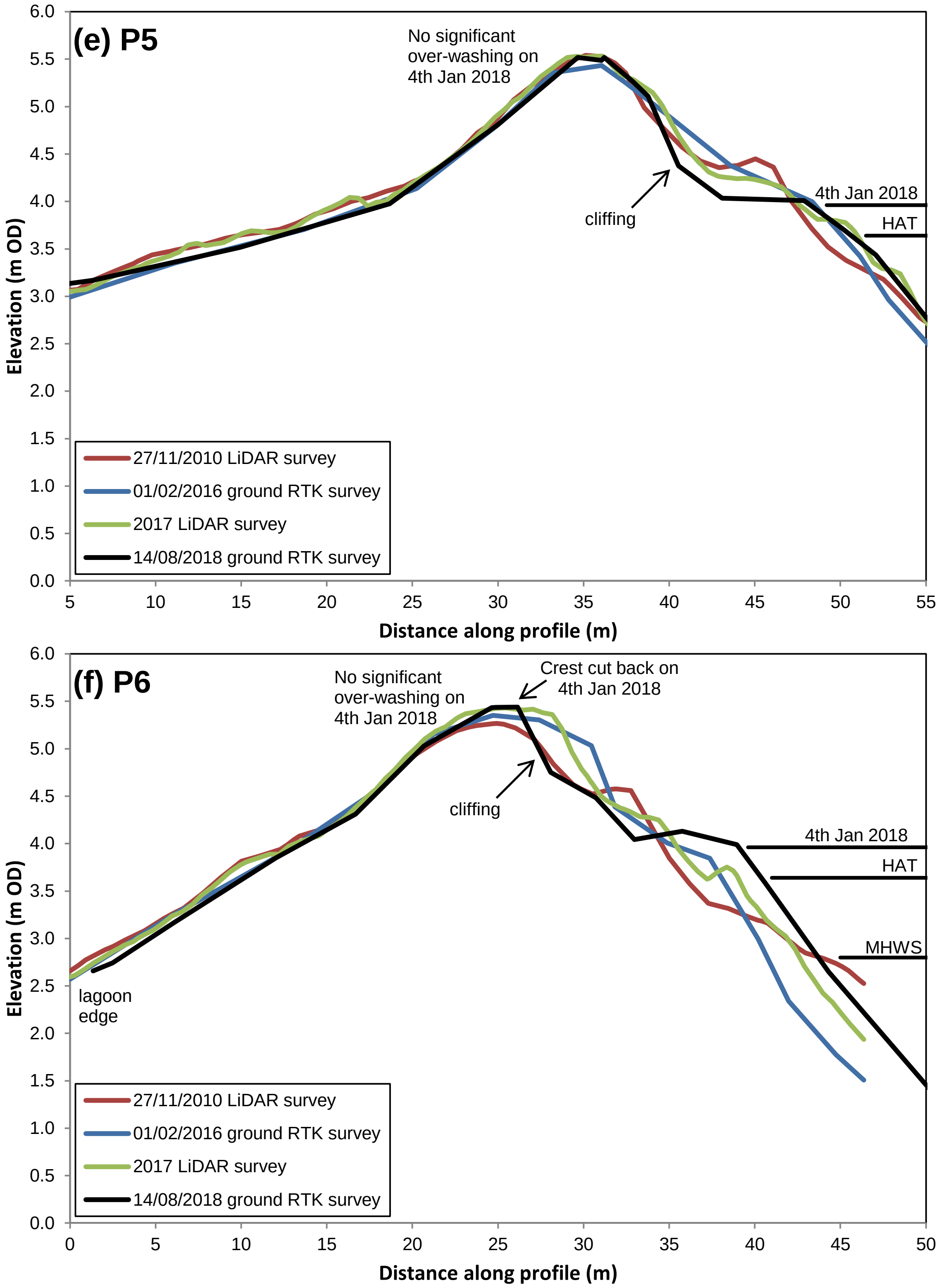


Figure 14 continued. Enlargement of upper beach and ridge crest cross-shore profiles surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys. The level of the storm surge event on 4th January 2018 (estimated to have reached 3.96 m ODN at Cemlyn, using method 2 in Table 5) is also shown

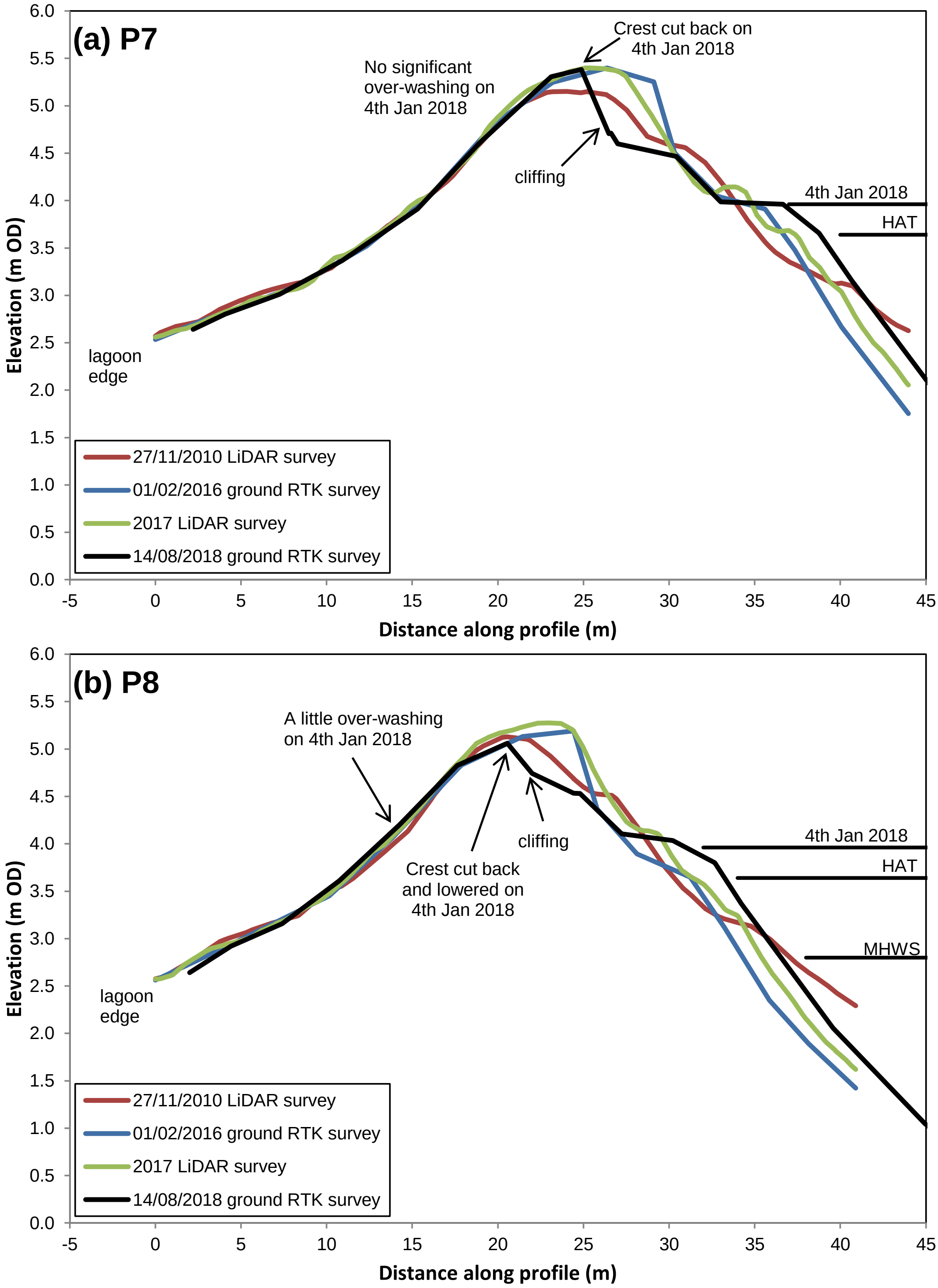
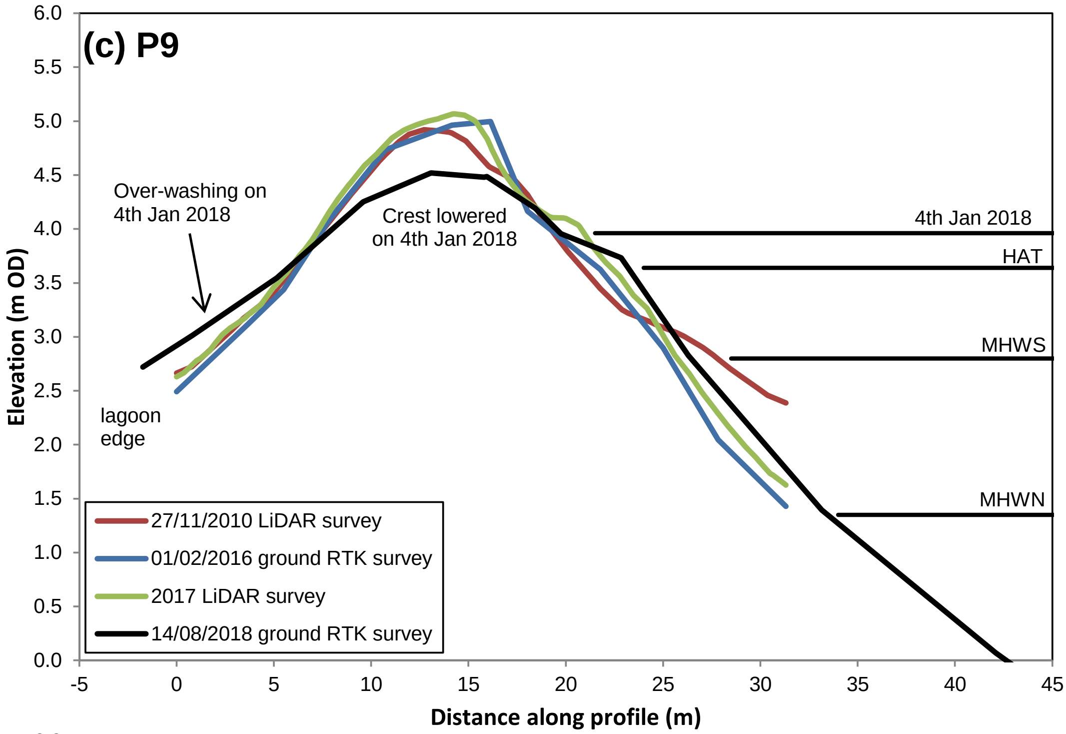
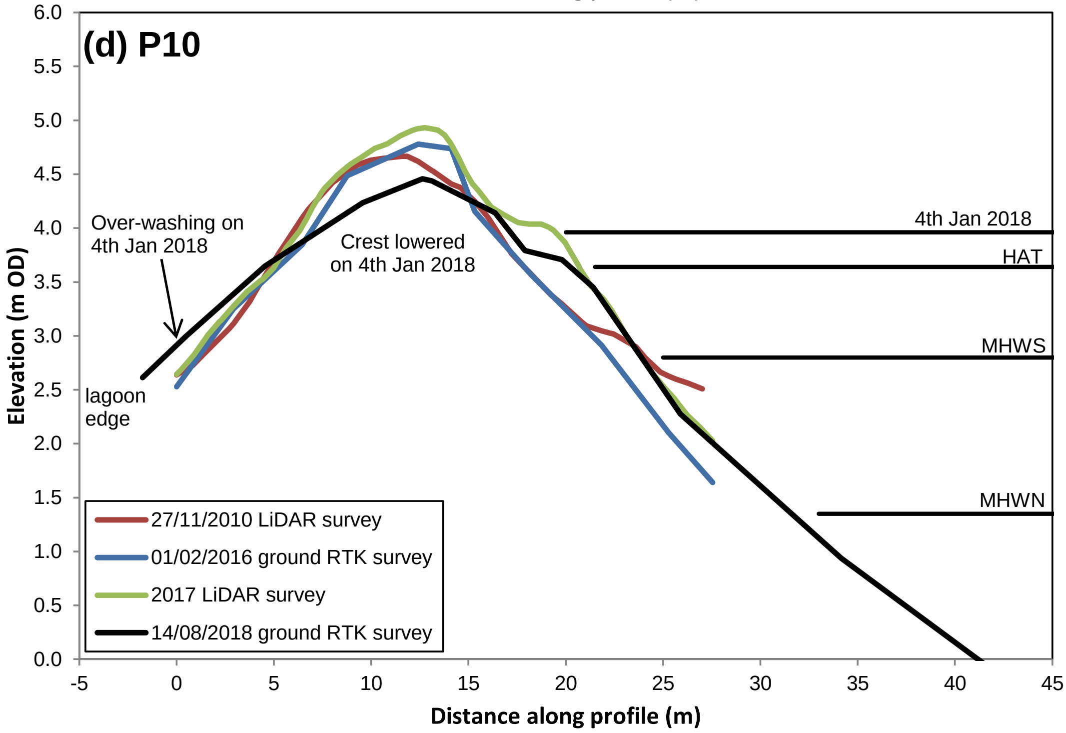


Figure 14 continued. Enlargement of upper beach and ridge crest cross-shore profiles surveyed on 14th August 2018 (black line) compared with previous RTK and LiDAR surveys. The level of the storm surge event on 4th January 2018 (estimated to have reached 3.96 m ODN at Cemlyn, using method 2 in Table 5) is also shown





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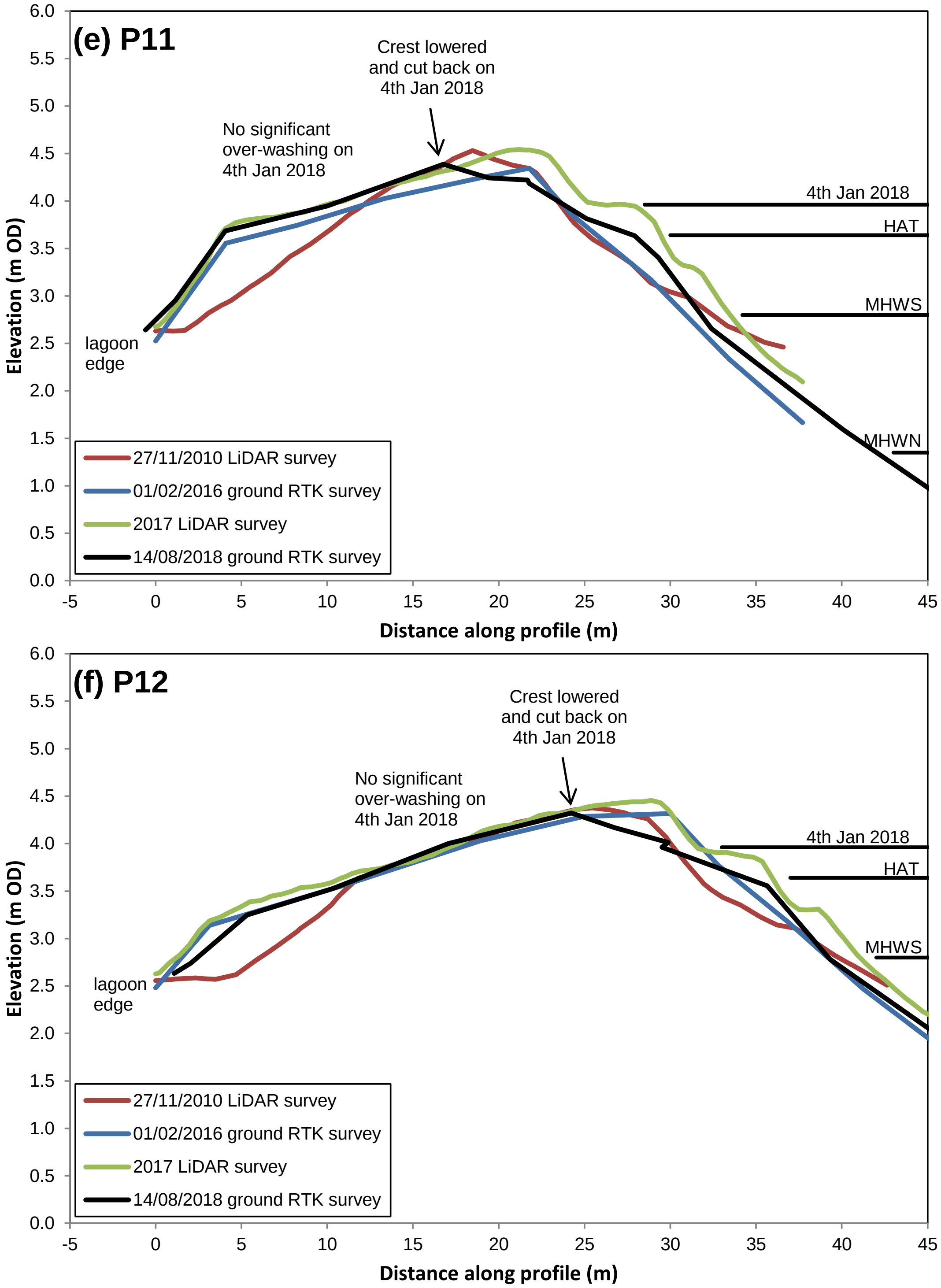

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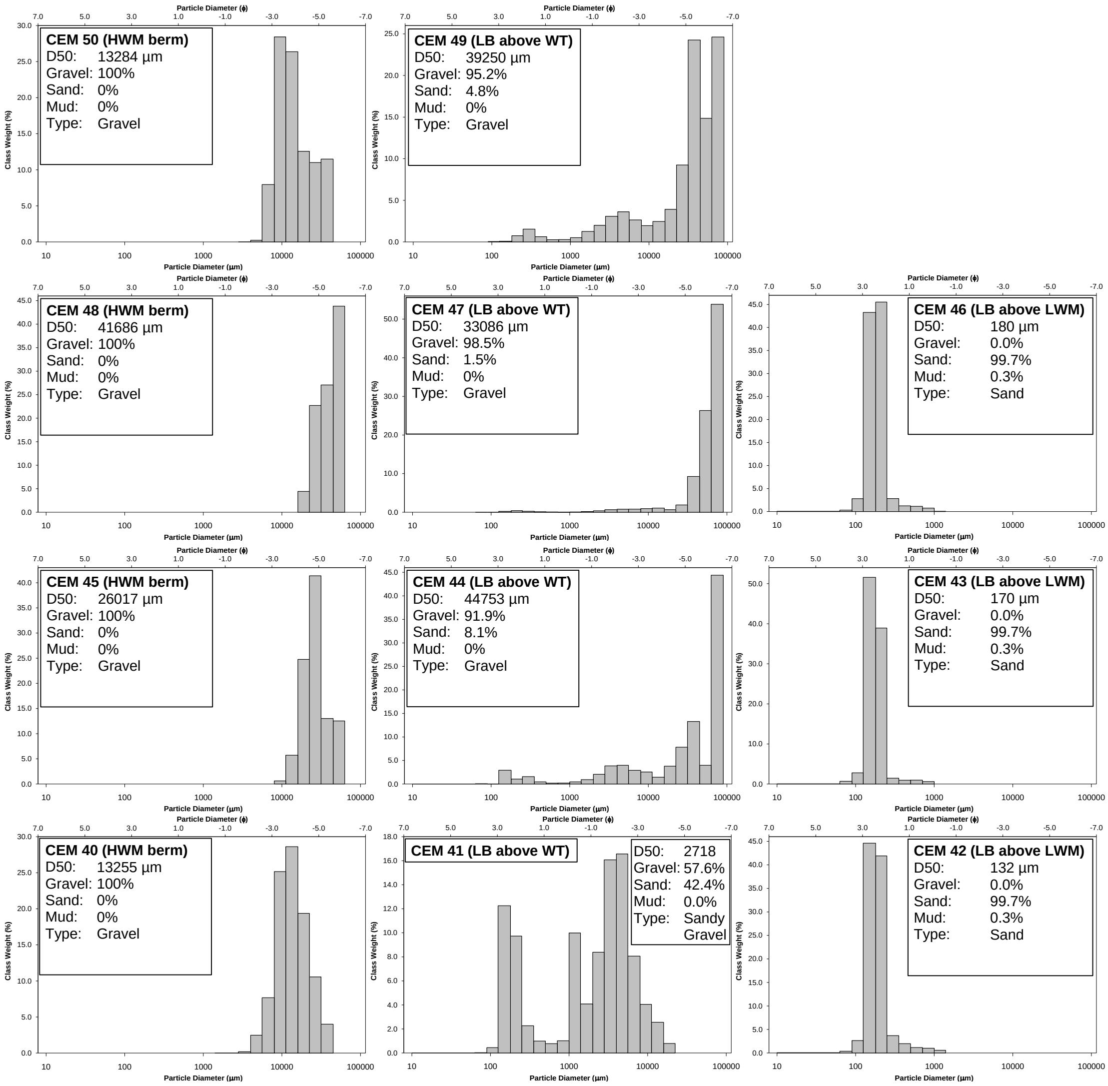

Figure 15. Particle size histograms of beach sediment samples collected on 14 August 2018. Histograms are plotted in approximate geographical position: high water to low water from left to right; and north-western to south-eastern part of the bay from top to bottom.

Appendix 1

Ground photographs taken during the field survey

Figure 1. View across Cemlyn Bay from Trwyn Pencarreg towards Trwyn Cemlyn

Figure 2. View along Esgair Cemlyn Bay from the east

Figure 3. View along the east-central part of Esgair Cemlyn Bay from the east

Figure 4. Sediment on the upper beach slope below MHW level, mid-central part of the barrier

Figure 5. Sediment on the lower part of the upper beach slope, mid-central part of the barrier

Figure 6. View east along the central part of the barrier

Figure 7. View towards the ride crest on the mid part of the barrier

Figure 8. View towards the smaller Tern island from the ridge crest

Figure 9. View along the ridge crest towards the larger Tern island and Bryn Aber

Figure 10. View along the western part of the barrier towards the lagoon inlet and old harbour office buildings

Figure 11. Fine to medium gravel- on the mid part of the upper beach slope, western end of the barrier

Figure 12. View across Cemlyn Bay from the western end of the barrier towards towards Wylfa A

Figure 13. Recent vegetation growth on shingle wash-over lobe, landward side of the west-central part of the barrier , view looking towards Bryn Aber

Figure 14. Recent vegetation growth on shingle wash-over lobe, landward side of the west-central part of the barrier , view looking towards the larger Tern island

Figure 15. View eastwards along the recent shingle wash-over lobes, landward side of the west-central part of the barrier

Figure 16. View eastwards along the western end of the barrier; wave eroded shingle-soil mixture on the right, with juvenile Sea Holly growing to seaward

Figure 17. Temporary tide gauge location adjacent to the Tyn Llan sluice, southern side of Cemlyn Lagoon

Figure 18. View north across the Tyn Llan lagoon towards Tyn Llan farm

Figure 19. View across Cemlyn lagoon from the southwest, looking towards Wylfa A power station

Figure 20. View across Cemlyn Bay from the shore in front of the old harbour office, looking towards Wylfa A

Figure 21. The inlet channel to Cemlyn lagoon, view seaward from near the old harbour office

Figure 22. The inlet channel to Cemlyn lagoon, view landward towards the Coastal Path footbridge and Bryn Aber from near the old harbour office

Figure 23. Ebb tidal flow under the Coastal Path footbridge

Figure 24. View eastwards across the Coastal Path footbridge on an ebbing tide

Figure 25. The outer lagoon between the Coastal Path footbridge and the weir, view towards Bryn Aber, late stage of an ebbing tide

Figure 26. Surveying the elevation of the footbridge using Leica GNSS RTK GPS equipment

Figure 27. Outward flow over the weir, just before the flood tide started to run, 09.00 14 August 2018

Figure 28. Time of zero flow across the weir, just before the flood tide started to run, 09.10 14 August 2018

Figure 29. Early inward flow across the weir, 09.30 on 14 August 2018

Figure 30. Inward flow over the weir, mid stage of the flood tide, 10.15 on14 August 2018

Figure 31. Onward flow across the weir at time of maximum flood tide stage rise, 11.00 on14 August 2018

Figure 32. The maximum water level attained in the lagoon, 12.00 on 14 August 2018, view towards the Tern island from the weir

Figure 33. The maximum water level attained in the 'outer lagoon', 12.00 on 14 August 2018, view towards the Coastal Path footbridge from the weir

Figure 34. The beginning of outward flow over the weir, just after the tide started to ebb, 13.00 on 14 August 2018

Figure 35. Peak outward flow over the weir, approximately 1 hour after the time of high water, 13.45 on 14 August 2018

HORIZON NUCLEAR POWER LIMITED DEVELOPMENT CONSENT ORDER

EN010007

RESPONSE BY NATIONAL TRUST (20010995), NORTH WALES WILDLIFE TRUST (20011639) AND THE RSPB (20011586).

ISSUE: POST HEARING NOTE RELATING TO THE ISSUE SPECIFIC HEARING ON 9/1/19 (SECOND ISSUE SPECIFIC HEARING ON THE DRAFT DEVELOPMENT CONSENT ORDER).

1. INTRODUCTION

1.1 This post hearing note is provided on behalf of the Environmental Non-Governmental Organisations (eNGO) comprising National Trust (NT); RSPB; and the North Wales Wildlife Trust (NWWT). However, where individual comments relate to the interests of a specific organisation(s) this is indicated in the text.

1.2 The note relates to Section 7 of the agenda (Section 106 Agreement).

1.3 The eNGO's have been seeking input and discussion on potential Section 106 issues for several years during pre-application for the Wylfa Newydd Development Consent Order (DCO). The draft Section 106 documentation submitted by Horizon to the Examination at Deadline 3 (REP3-042) is the first opportunity that the eNGO's have had to engage with the Section 106 process and the first time we have seen any of the proposed financial contributions.

1.4 We are concerned about the lack of consultation on this initial draft and the approach taken by Horizon to arrive at this point, particularly since the eNGO's are identified as potential recipients of financial contributions in Schedule 11. We remain concerned about the lack of substantive progress demonstrated within the draft, and lack of agreement between the key parties outlined within the Status update paper for key issues arising from the Section 106 agreement (REP3-043).

1.5 Given the importance of the issues to North Anglesey and its future environment, we are surprised and disappointed about the progress reported to the Issue Specific Hearing by Horizon. We are also surprised there has been no attempt to engage with the eNGO's on the proposed detail of the Section 106 agreement prior to its release, particularly in the light of the proposed financial contributions mentioned above.

1.6 The lack of progress clearly demonstrates an unsatisfactory approach taken by Horizon to engagement throughout the DCO process. We are concerned with the approach advocated by Horizon to move forward by Unilateral Undertaking, and await clarification on how funding will be provided for project mitigation.

1.7 It is surprising that Horizon has chosen to use the Issue Specific Hearings as its only engagement on Section 106 issues, and did not seek any input from the eNGOs' to the proposed Section 106 agreement before the ISH. We await any change in approach by Horizon to engagement but consider it very late in the Examination to consider detail.

1.8 **Our overarching comments are: a general disappointment in the ambition for the projects; the need for clarity on how financial contributions have been calculated and recognition that some of these items are core to mitigation and/or monitoring and should be separately identified with separate ring-fenced budgets if they are to be implemented by 3rd parties**.

1.9 The commentary below is provided on specific detail of the proposed Schedules to the draft Section 106 Agreement.

2. **SCHEDULE 3 (TOURISM)**

2.1 Schedule 3 Tourism paragraph 6 ∞ 6.1. This attempts to deal with issues relating to visitor experience and usage of the WNDA in the longer term.

2.2 NT and NWWT do not believe the commitment "to use reasonable endeavours" is strong enough to obtain planning permission for the Visitor and Media and Reception Centre in a timely fashion and considers that a commitment to use "best endeavours" would be appropriate here. We also consider that the drafting of paragraph 6 is unclear. It states the Developer will use reasonable endeavours "to obtain a planning permission for the development of a (Centre) to be available from the commencement of Operation Unit 2". It is not clear whether the planning permission or the Centre itself should be available from the commencement of Operation Unit 2. This needs to be clarified; moreover, if the intention is merely to obtain planning permission, further obligations should be included in paragraph 6 which confirm that the planning permission will be implemented by a specific date. In any event, even if the Centre is to be delivered by commencement of Operation Unit 2 this will do nothing to manage visitor behaviour impacts or expectations during construction. Horizon should confirm how it proposes to manage these impacts.

2.3 The Section 106 commitment should be viewed in conjunction with Horizon's response to NT's and the eNGO's written representations (REP3-028) ∞ 4.7.1 and (REP3-026) ∞ 2.3.4 respectively, relating to concerns about lack of management of the visitors "temporary viewing platform available around six months after the start of construction, dependent on availability of safe access and parking capacity." This has not changed between the Main Power Station sub-CoCP (APP-415) and the updated CoCP (REP2-031).

2.4 There remains uncertainty in how construction tourism will be managed on and around land in NT ownership, and how any mitigation will be secured. Further detail from Horizon is awaited.

2.5 Both of the proposals (visitor centre and viewing platform) represent heavily caveated commitments by Horizon and may not be implemented and/or be significantly delayed if planning permission or safe access and parking capacity (respectively) cannot be secured.

2.6 NT has developed a long term strategy for its land ownership in North Anglesey (Cemlyn Vision, 2017), and would wish to consider how elements of any tourism contribution (paragraph 2.2 of Schedule 3) or tourism contingency fund (paragraph 5.1) might achieve the outcomes identified within paras 2.2.1, 2.2.2 and 2.2.3 Schedule 3. We would very much welcome discussion on these issues with Isle of Anglesey County Council and Horizon.

3. SCHEDULE 10 (CONSTRUCTION NOISE MITIGATION).

3.1 NT raised issues in relation to construction noise in its Written Representation (REP2-323) ∞ 2.2.1, and seeks clarification as to why only two properties are identified within Schedule 10 to the Section 106. It is noted that Horizon intend to provide further detail on construction noise at Deadline 4, confirming within the Deadline 3 Submission - Horizon's Response to Written Representation - National Trust (REP3-028): "*In response to National Trust's concern about identifying specific construction noise levels at their properties, and similar comments from residents in Tregele, Horizon will bring greater clarity to Figures D6-3 to D6-10 in ES Volume D - WNDA Development Figure Booklet - Volume D (Part 1 of 2) (APP- 237). At Deadline 4 (17 January 2018), Horizon will provide these figures at a much larger scale to make it easier to identify the noise level band at each property*".

3.2 NT awaits this further detail and how Horizon will approach noise mitigation at NT tenanted properties, prior to any further comment.

4. SCHEDULE 11 (ENVIRONMENT AND HISTORIC ENVIRONMENT)

4.1 Section 1. *Environment Enhancement Fund (EEF).*

4.1.1 The eNGO's do not support the proposed approach to establish an EEF since we are unclear on how the proposed contributions have been calculated, consider the proposed amounts to be insufficient and there is uncertainty in how funding can be ring-fenced.

4.1.2 It is our considered opinion that the fund will only be able to resource a very small number of projects in any given year. These would need to be projects with relatively modest scale capital costs. The funds, therefore, need to be increased.

4.1.3 It is the eNGO's view that these schemes will have limited impact and reach over short time frames. We consider this fund could be expanded to deliver a legacy for the area, but in its current form, the proposal reflects the lack of ambition for the environment of North Anglesey.

4.1.4 We welcome the principle of including an agri-environment scheme in the proposed Section 106 agreement but consider a greater ambition should be brought forward given the scale of impact of the project and the need to connect the WNDA with its adjoining environment. We consider that the value of the fund needs to be increased significantly.

4.1.5 In relation to the works to improve the resilience of the Chough Network (paragraph 1.3.3), Horizon need to commit to providing a ring-fenced financial contribution that will allow these works to be delivered, not least since this necessary mitigation was put forward by Horizon and, therefore, should not be in competition with other applications for funding. See the NWWT presentation of our oral case ISH Biodiversity agenda item 5a vi.

4.2 Section 2. *Environment (Cemlyn Lagoon) Fund.*

4.2.1 In relation to the proposed Research & Monitoring Funding (paragraphs 2.3.2 and 2.3.3): the eNGO's do not consider that funding of schemes to investigate long-term population trends/monitoring of terns, or studies to improve understanding of Cemlyn Lagoon should be subject to applications for competitive funding. There is sufficient uncertainty over the impacts of the scheme to require monitoring details to be determined and agreed by all parties (NRW, IACC and input from the eNGO's). For example, we refer to industry standards MMO (2014 referred at 3.143 – 3.144 (REP2-348) eNGO Cemlyn Biodiversity submission) and to Professor Ken Pye's proposal for monitoring of the geomorphological and chemical condition of Esgair Gemlyn and Cemlyn Lagoon (REP2-316). We also refer to the accompanying Post Hearing Note in relation to Coastal Processes and an appropriate monitoring response to the acceptance of impact on Esgair Gemlyn and need to resolve how this can be secured. Again, Horizon need to commit to providing a ring-fenced financial contribution that will allow these programmes to be delivered.

4.2.2 The eNGOs recognise that a clearly scoped monitoring project could be delivered by a third party such as Bangor University or other independent specialist research organisation that has the best expertise for the task. Third party funding for monitoring should be identified and costed separately.

4.3 Section 3. *Tern Warden.*

4.3.1 NWWT has considered the proposed funding for a tern warden at Cemlyn Bay. It is considered by NWWT that the proposed scheme will not provide sufficient funding and would result in additional costs to NWWT. The proposed scheme would only provide part funding of additional staffing resulting in additional costs to NWWT which, without the development of Wylfa Newydd, the charity is not forecasting would be necessary.

4.3.2 The tabled Section 106 is unclear what the proposal contains (eg additional post on current contract length or additional post on contract over whole of the breeding season). Nor is it clear how the sum proposed was calculated.

4.3.3 Using current costings for a warden post, the proposed sum of £45,000 over a 12 year implementation period (SPC through to start of operation) would result in a significant cost to the Wildlife Trust. This is an additional expenditure and is not a cost that can be borne by the Wildlife Trust's budgetary arrangements.

4.3.4 NWWT welcome further consideration of costings by Horizon, and further detail can be provided if required. NWWT estimate a salary increase of 3% per annum with a start date of 2019: 1 warden on current timing over 12 years £99,986; 1 warden for cost of whole breeding season £118,930 (Figures provided by Frances Cattenach CEO NWWT, an excel spreadsheet can be provided if detail is required. NWWT are happy that this information can enter the public domain). Horizon's contribution will only provide 45% or 38% (respectively) of the costs. The use of 12 years within the data analysis is on the basis of an implementation period, which as a result of the call-in of the Town and Country Planning application (for Site Preparation and Clearance), the SPC and the DCO works (especially marine) may now overlap.

4.3.5 A caveat is required to indicate that the role of the additional Tern Warden is entirely based at Cemlyn Nature Reserve and does not encompass any works under the on-site behavioural monitoring as identified in the sHRA (APP-050).

4.3.6 There is a need for clarification of the wider monitoring role being proposed and since there is a lack of clarity in Horizon's response to eNGO's written representation (REP3-026) ∞2.3.1.

4.3.7 Horizon identifies that they "will support this (Workforce Management Strategy) by employing or providing the funding for a warden to monitor these sensitive areas and support landowners…" This is to be submitted at deadline 4 (17th January).

4.3.8 The additional wardening of other sensitive sites should be entirely separate from that provided at Cemlyn Nature Reserve and should not fall within the role of the Tern Warden as identified in Schedule 11. If Horizon decides that this matter should be implemented via funding to a 3rd party it should be identified separately within Schedule 11. We await further consideration of this issue post deadline 4.

4.4 Section 4. *Environmental Fund Officer.*

4.4.1 Clarity is required on the role of the proposed Environmental Fund Officer. The definitions at the start of Schedule 11 state "Environmental Fund Officer means 0.5FTE wetland project officer". Is it envisaged that this role will oversee the SSSI compensation measures? If so then this needs to be identified in perpetuity or an alternative period to be agreed with NRW/IACC as the creation, establishment and management of fen habitats will be required for longer than 12 years

4.4.2 Paragraph 4 of Schedule 11 indicates that the EFO will monitor the implementation of the scheme and contractor compliance. It does not mention the wetland project officer role.

4.4.3 It appears that two officer functions are identified – Wetland Project Officer and Compliance Monitoring of Implementation. These posts would require two different skill sets and would represent more than a 0.5 equivalent post. The posts should, therefore, be identified as two separate items and contributions.

4.5 Section 5. *Cestyll Gardens Payment.*

4.5.1 NT and NWWT are not satisfied with the terminology to "use reasonable endeavours" to enter into a Deed of Covenant before the Operational Period and consider that a commitment to use "best endeavours" would be appropriate.

4.5.2 The inclusion of a funding mechanism for Cestyll Gardens is welcomed, but NT and NWWT seek clarification on how the proposed figure has been calculated and what it is proposed to achieve. We note that, at present, Horizon commit to use reasonable endeavours to enter into a Deed of Covenant before the Operational Period. It is not clear what will happen to the Cestyll Garden Payment if the Deed is not entered into "prior to the Operational Period" and this should be confirmed.

4.5.3 Paragraph 6.4.203 of the Planning Statement states: "….Horizon will agree with National Trust, CADW and Gwynedd Archaeological Planning Service, the designs of appropriate landscape measures to restore and/or enhance the former location of the Cestyll Garden kitchen garden. This will be secured through a planning obligation".

4.5.4 However, the draft Section 106 Agreement does not provide for this; instead the agreement is between Horizon, the Welsh Government and Isle of Anglesey Council, and NT is not mentioned in paragraph 5 of Schedule 11.

4.5.5 NT are unclear whether Horizon still intend to enter into a Section 106 Agreement with them and despite raising the matter on a number of occasions, no answer has been provided. The position needs to be confirmed as soon as possible.

4.5.6 NT and NWWT await further discussion on heritage matters in the forthcoming ISH. NT and NWWT support the response by IACC to the Examination Authority Question 6.0.7 (REP2-153) in which they recognise the substantial harm to heritage assets and advocate that the "Conservation Management Plan needs to be for the entire garden including Felin Gafnan which is to be included in the statutory area". NT and NWWT also support the response by IACC to the Examination Authority Question 6.0.21 (REP2-153) in terms of the need for funding to bring forward heritage outreach.

5. **SCHEDULE 12 (COMMUNITY FUND).**

5.1 The eNGO's support the establishment of an off-site landscaping fund and endorse the proposed Section 106 Agreement detail identified by IACC in the Local Impact Report Chapter 17 - Wylfa Newydd Development Area (REP2-077) and schemes identified in paragraph 2.6.1. We welcome clarification of how this will be secured in the absence of a Section 106 Agreement.

6. DEED OF COVENANT

6.1 We note the clause 7 of the Section 106 Agreement provides that third parties who are due to receive payments directly under the agreement (such as the eNGO's under paragraph 2.2 of Schedule 11) must enter into a Deed of Covenant with Horizon. Under clause 7.1.1, the Developer and Council covenant that they will "use reasonable endeavours to enter into a Deed of Covenant….as soon as reasonably practicable following the date of (the Section 106 Agreement).

6.2 To ensure this can be achieved, we request that a draft Deed of Covenant is provided to the eNGO's as soon as possible so that any comments can be provided to Horizon in good time. The eNGO's also assume that the Deed of Covenant will contain a provision similar to clause 20 of the Section 106 Agreement which, in the usual way, will require Horizon to pay the eNGO legal costs in negotiating the deed. The eNGO's would be grateful if this could be confirmed.

eNGO & NWWT presentation of Oral Case by Teresa Hughes (Biodiversity Planning Consultant)
Wylfa Newydd Nuclear Power Station – DCO (EN010007)

North Wales Wildlife Trust - 20011639

National Trust - 20010995

The Royal Society for the Protection of Birds - 20011586

Introduction to the eNGO consortium

On each day when Teresa Hughes (Biodiversity Planning consultant) presented an oral case she introduced herself and the 3 hats that she was wearing in the Issue Specific Hearings.

The environmental NGOs (eNGOs) of North Wales Wildlife Trust (NWWT), National Trust (NT) and the Royal Society for the Protection of Birds (RSPB) came together more formally in early 2016 and submitted their first joint eNGO note to Horizon in May 2016 as part of the public consultation process.

The Written Representation (WR) submitted for Cemlyn Nature Reserve by the eNGOs [REP2-348 NWWT, REP2-318 National Trust and REP2-360 the RSPB] is a truly collaborative piece of work, which whilst written and presented by Ms Hughes, has been peer reviewed at a local and national level (UK – the RSPB and Wales – NWWT and NT) by specialist scientists, HRA advisors and legal personnel.

As in the ISH this written statement of the oral case will indicate which parties are being represented in an introductory sentence for each agenda item.

Day 1 First Issue Specific Hearing – Socio-economic, 7th January 2019

Agenda item 3d – Accommodation

NWWT attended this session on their own behalf and did not have a seat at the Hearing Table. Comments were delivered from the floor on two occasions: -

1. In response to comments from Mr Humphries (Horizon) regarding the policy position: - NWWT pointed to their evidence [REP2-349 ∞3.20 et seq.] in particular NWWT read from the WR [∞ 3.21], which quotes the EN-1 National Planning Statement (2011, paras 5.3.7, 5.3.8 and 5.3.11). These paragraphs indicate the need to consider reasonable alternatives and the avoidance of adverse impacts to SSSIs, either individually or in combination.

   NWWT do not agree with the arguments presented by Horizon in relation to their interpretation of the NPS EN-6 policy and feel that this approach is contrary to The Well Being of Future Generations Act (2015). In addition, the recently published Planning Policy Wales 10th ed (December 2018), re-emphasises the importance of a Resilient Wales at paragraph 1.2 of the new guidance.

2. NWWT approached the table to provide an overview of their position: -

   Following the Deadline 3 representations and the ISH, NWWT have not materially changed their view as stated in their representation [REP2-349 ∞ 1.6] maintaining the objection to the location of the TWA (Temporary Workers Accommodation) due to its adverse impacts on the SSSI and biodiversity hotspot. It was not the intention to address biodiversity issues in this oral representation as this was to be covered on Thursday/Friday ISH.

   NWWT do not wish to unduly emphasise one particular location over any other. However, we would point to the Land & Lakes (L&L) scheme as it provides an indication of what a robust approach can achieve. NWWT agree with IACC (Isle of Anglesey

County Council) that the L&L scheme benefits from an appropriate planning permission. NWWT responded to the original L&L application and were fully involved in the various consultations. NWWT belief that the biodiversity matters were fully resolved during determination of the TCPA and that the securing of the L&L Section 106 [REP-247] provides not only for a housing legacy, but also an environmental legacy (Visitor Centre and nature reserve). The view of NWWT's ecological planning advisor has been endorsed by the CEO of NWWT.

The TWA does not have these benefits and will try to recreate complex habitats on a virgin landform.

Agenda Item 6c - Recreation & Tourism

Ms Hughes presented her oral case from the floor of the ISH. NWWT (also representing the views of National Trust) pointed to their evidence [REP2-348 ∞ 3.146 et seq.] and the importance of wildlife tourism and recreation to this part of Anglesey, particularly Cemlyn Nature Reserve.

NWWT pointed to IACC's Local Impact Report (LIR) [REP2-065] and its Annex [REP2-110 section 6.1], which specifically identifies Cemlyn Nature Reserve as a "jewel in the crown" of the island's wildlife visitor attractions and that this section of IACC's LIR provides figures of visitor demographics and spend in this sector in particular.

NWWT/National Trust following the submission of additional information and the ISH indicates that their opinion has not changed on this matter and stays the same as at D2 due to the lack of clarity on 4 items: -

The temporary viewing platform this will only become available around 6 months and is contingent on safe access and parking capacity – there appears to be no change in Horizon's position since the DCO submission. This approach takes no account of any of the existing arrangements in the area (wider WNDA) and whether these have safe access or capacity.

The Visitor Centre needs to seek additional permission outside the DCO, although Horizon indicated orally that this may now come forward earlier in construction and may obviate the need for the temporary facility[1].

Workforce Management Strategy (WMS) NWWT noted the change to the WMS [REP3-026 ∞ 2.3.1], and that this would be published at D4. NWWT whilst indicating that this may be positive, still have concerns regarding the funding for additional wardening of 'sensitive sites' as this does not currently appear to be identified in Schedule 11 of the draft s.106 [REP3-042] or the draft DCO Requirements.

Tern Warden NWWT's concerns regarding the WMS are reinforced by Horizon's commitment in Item 3 of Schedule 11 of the draft s.106 [REP3-042], which will result in NWWT having to foot the bill for more than 50% of the proposed new Tern Warden post. This is unacceptable, see D4 submission by eNGO on the Section 106 and costings.

During the ISH roundtable discussion NWWT indicated having listened to the roundtable discussions there was a mounting concern regarding the unquantified impacts that loss/reduction in size of the breeding colony of birds may have on visitor faithfulness/loyalty[2] to the Cemlyn Nature Reserve and the wider offer and/or brand identity of both NWWT and the National Trust. It should be noted, that the wider tourism case has not been presented by the National Trust or NWWT.

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[1] On Day 4 ISH – Biodiversity the ExA asked Horizon what weight should be placed on the Visitor Centre commitment, given that its delivery relied on a permission outside the DCO submission. It was concluded that the weight was limited.

[2] Visitor loyalty to Anglesey as a whole was presented by IACC

Day 3 – Second Issue Specific Hearing draft DCO & Section 106, 9th January 2019

Due to a family bereavement over the Christmas holiday period, NWWT were unable to attend this ISH. National Trust attended and they have issued a joint statement on the draft s.106 at Deadline 4, which NWWT and the RSPB endorse.

Day 4 – First Issue Specific Hearing on Biodiversity, 10th January 2018

Habitats Regulation Assessment

Ms Hughes indicated that for this part of the agenda she would be representing the views of all 3 eNGOs (NWWT, National Trust and the RSPB).

Agenda Item 3a – Seabird survey data

The eNGOs confirmed that they agreed with NRW's view regarding the appropriateness of the gathering of seabird data, but that the issue remained in terms of its interpretation and evaluation.

The eNGOs indicated that their position was still the same following the review post D2 and D3 that: -

- Matters relating to the Anglesey Terns SPA have not been demonstrated by Horizon beyond reasonable scientific doubt.
- The eNGOs agree with NRW that they also are of the opinion that there will be an adverse effect on integrity (AEOI).
- The eNGOs agree with NRW that the matter should be taken to stage 3 and 4 of the Habitats Regulations Assessment.

The eNGOs pointed to the EU definition & guidance on the Precautionary Principle[3] (PP), which is enshrined in the UK's Habitats Regulations (2017). This definition's stated purpose is: -

> *"Ensuring a higher level of environmental protection through preventative decision-taking in the case of risk."*

So far in the last 3 years and in the representations, most parties have concentrated on the first part of the 3 parts of the PP process, which is: -

- Scientific evaluation and degree of certainty of conclusions, on which there is still stated differences between the main parties (Horizon and NRW and the eNGOs).

However, the next stages of PP evaluation are: -

- Evaluation of risk and more importantly the consequences of inaction. In the case of the Anglesey Terns SPA breeding colony the risk of inaction (or inappropriate action) could be sequential over a number of years of colony collapse/decline in productivity, which may act either cumulatively or synergistically with other sources of disturbance. This could potentially ultimately lead to colony abandonment during construction. Any of these outcomes is of detriment to the wider populations of breeding terns in other SPAs, as well as failure to meet the conservation objectives of the Anglesey Terns SPA.
- The third part of the PP is the involvement of all parties in the development of precautionary measures. As landowner (National Trust), tenant (NWWT) and recognised UK authority on bird ecology (the RSPB) it is the eNGOs' view that they have considerable local knowledge and expertise and should be involved in all stages of the development of precautionary measures.

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[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l32042 a copy of the EU summary attached as Annex to this oral case submission.

The EU guidance document goes on to consider the key principles of risk management which include: -

- Proportionality of measures in relation to the necessary level of protection.
- Consistency with measures taken elsewhere (i.e. use of industry standards or BAT - Best Available Technology).
- Benefits and costs of action vs inaction.

The eNGOs indicated that this is the manner in which they have approached their preparation for the ISH and suggested that the ExA may wish to consider these the tests of risk management in their determination of the appropriateness of Horizon's response to matters.

Agenda item 3b i – To explore impacts on interest features of Anglesey Terns SPA, including blasting effects on tern (species)

The ISH discussion was led through a number of questions by the ExA and the salient features of the ISH oral representation of the eNGOs is laid out below, but the Post-hearing note in response to the ExA specific requests is presented separately.

Blasting noise levels – The eNGOs' agreed with NRW assessment that the identified noise level (during establishment) was appropriate.

However, in relation to NRW's response to the changes in the terns' soundscape between the current and construction environment, the eNGO's sought to clarify the matter by pointing to their WR [REP2-348 ∞ 3.7 which refers directly to Horizon's own work APP-225]. It was explained that the difference between the current agricultural environment and the construction blasting soundscape is related not just to the volume of the sound, but more importantly to the rise time of that sound. Horizon's evidence on the comparison of similar rise time profiles is based on 3 events in 2017, which is too small a sample to base conclusions. Hence, the eNGOs do not agree with the criticism levelled at them on this matter by Horizon [REP3-026 ∞ 2.1.7].

4 week establishment period and its date range This is a key point for the eNGOs and they pointed to the WR [REP2-348 fig. 1 and text ∞3.43 - 3.53], which is a calendar of when the different tern species return to the SPA and when each might be considered to start its own 4 week establishment period. The date range is important not just for Sandwich tern but the other tern species of the SPA (common, Arctic and roseate) for which the SPA is designated.

The eNGOs were very concerned to hear the views at the ISH of Sian John (on behalf of Horizon) and explore this further in the eNGO Post-hearing note.

Fly-up responses and its applicability to mitigation red/amber approach On this matter the ExA directed specific questions to Horizon, NRW & the RSPB, in terms of physiological and psychological responses of the birds and their energy budgets.

In response to Horizon's assertions that the resilience of the colony was demonstrated by its recovery in 2018, the eNGOs indicated that this pattern has been observed during the previous colony collapse (2007) and elsewhere. It was added that the numbers of pairs and breeding successes in 2018 were recovering - not recovered - and that if perturbations of a similar kind, involving partial or total colony collapse, occurred over several breeding seasons throughout the 10 years construction of the scheme, the likelihood of total recovery would be eroded with each year the colony failed to thrive.

Energy budgets The eNGOs had noted the small amount of additional literature-based analysis presented by Horizon in their D3 response [REP3-026 ∞ 2.2.5] and indicated that it was similar to that presented in the DCO application and consequently it did not alter the eNGO WR's conclusions or the scientific uncertainty surrounding this matter. At the request of the ExA this is explored further in the Post-hearing Note.

The eNGOs' indicated that the D2 and D3 submissions and the roundtable discussion heard in this ISH agenda item had not altered their position and that there is grave concern regarding the lack of movement on the limited mitigation that has been proposed in Horizon's updated technical note on how they will meet committed noise levels [REP3-048]. This is addressed in full in the ExA requested Post-hearing note.

Agenda item 3b ii – Cemlyn Bay SAC, including Mound E drainage

Ms Hughes at this section of the ISH agenda represented the views of NWWT and the National Trust, as the RSPB has indicated that they will defer to their colleagues on this matter [REP2-348 ∞ 2.4].

Ms Hughes agreed with the statement made by NRW and acknowledgement that further information was to be presented by Horizon at D5 on drainage. Agreed with NRW that there was a need for additional baseline gathering over 2 full seasons (i.e. 2 years) in order to set realistic sediment thresholds of drainage discharges.

Ms Hughes went on to indicate that National Trust's and NWWT's view as presented in the WR [REP2-348, Chapter 4] was that the difference between favourable and unfavourable conservation status of the SAC was in-part reliant on the presence or absence of one of a very small number of specialist species, many of which both plants and animals, would be susceptible to the effects of sedimentation. Therefore, sufficient detail should be available to provide not just 'comfort' (in planning terms) but to demonstrate with confidence that this matter could be controlled effectively prior to a decision on the DCO and the report to the Secretary of State on the HRA (RIES).

Ms Hughes took the opportunity to indicate that although not an HRA issue, the cross-cutting nature of Mound E drainage with other topic areas including the WRs on landscape [REP2-317 ∞ 3.2.1- 3.2.12] and Landscape Habitat Management Strategy [REP2-319 ∞ 17 – 19], as Mound E falls within the AONB and the site's habitat restoration under the LHMS was a matter of difference of opinion with Horizon, especially relating to any need to rework Mound E and phasing of this work.

The ExA asked what detail the National Trust and NWWT would require to help alleviate concerns and this is presented in the Post-hearing note.

Agenda item 3c – Coastal processes and geomorphological monitoring

This oral presentation was provided on behalf of all 3 eNGOs by Professor Kenneth Pye who has provided a separate note.

Ms Hughes for the eNGOs provided a correction to Horizon's rebuttal [REP3-026 ∞ 2.5.7] by stating that **<u>no</u>** works have been undertaken by NWWT/National Trust to repair the shingle ridge. Both examples presented in the eNGO WR [REP2-348 ∞ 3.2.16] were positive actions to increase the area of bird breeding habitat on the SPA islands.

<u>Marine Works and the Marine Environment</u>

Agenda item 4b iii – Cumulative effects in relation to benthic ecology

This oral presentation was provided on behalf of National Trust and NWWT by Dr David Parker who whilst providing verbal context to the issues, will await the further information before making any full comments.

Terrestrial Ecology and Birds

In this part of the ISH Ms Hughes presented the NWWT case in relation to the matters discussed, except for chough, which also represents the RSPB's views.

Agenda item 5a i - Tre'r Gof SSSI baseline surveys

NWWT had no further comment to add than that presented by NRW.
NWWT noted the comments from NRW in relation to the TWA (Temporary Workers Accommodation), hydrology and its preference on the TWA's location.
NWWT reiterated the comments made at the ISH on socio-economic matters (see above) on the appropriateness of the location of the TWA. It additionally, pointed to IACC's Local Impact Report and WR [REP2-078 ∞ 1.4.13 and REP2-219 ∞ 14.0.1 – 14.0.8] relating to discussions between IACC and Horizon of alternative designs to the TWA within the current proposed footprint. The premise of this discussion could reduce the footprint of the proposal and concentrate the built development to the north western part of the TWA site near to the existing Magnox plant. NWWT indicated that they would be interested to follow discussions on this matter as it may provide a satisfactory alternative to the objections raised by NWWT in their WR.
NWWT emphasised that they agreed with the comments raised by IACC in relation to recreation and that they had presented their views on this matter in the first ISH on socio-economic roundtable discussions (see above).

Agenda item 5a ii - SSSI compensation sites

NWWT supported the views of NRW and had nothing to add. NWWT will consider the additional information due to be submitted by Horizon.

Agenda item 5a iii – Air Quality Cae Gwyn SSSI

NWWT acknowledged that they have not presented any WR on this matter, but agreed with NRW on the sensitivity of the SSSI to even small changes in air quality. They went on to indicate that the mitigation measures suggested in the NWWT WR [REP2-349 Chptr 4 ∞ 7 item 6] of berth-side electric hook-ups, would be appropriate in this case and would further reduce marine vessel emissions.
NWWT acknowledged and welcomed the introduction of Tier III marine vessels, but had been unaware of the land-based construction emission controls that Horizon had indicated will be adopted. These too were welcomed but they indicated that the point raised was still of relevance.

Agenda item 5a iv – Air Quality Trwyn Pencarreg (Wildlife Site)

NWWT acknowledged that this site does not receive the same degree of statutory protection as the SSSIs, however it was indicated that the lichen and moss rich coastal heath habitat has similar sensitivities to small changes in nitrogen deposition as the habitats on the SSSIs.
NWWT presented the APIS (Air Pollution Information Service) figures 5 – 8 kgN/ha/year for lichen and moss assemblages respectively. They went on to point to figure D5-9 [APP-238] which shows very high increases of nitrogen albeit using the human receptor figures.
NWWT acknowledged that they used 'bad maths' to try to extrapolate to the relevant approach to habitats and also that they had not been aware of the D3 [REP3-052] update on the modelling of this aspect of the scheme.
Directly following the ISH NWWT approached Stephen Byrne (acting on behalf of Horizon). The Post-hearing note provides an update on NWWT's position, but in summary the point in relation to reducing marine vessel emissions are still relevant.

Agenda item 5a v – Reptiles and Bat roosts

NWWT indicated that they agreed with IACC in relation to the baseline and mitigation in respect of reptiles.

NWWT had considered the Horizon technical note on light spillage [REP3-047], but noted that this did not consider the light spillage from the MUGA onto the bat commuting corridor away from the compensatory bat barn, which has been demonstrated to be successful with 54 individuals of 4 species [REP3-027 ∞ 2.4.7].

NWWT will await the further information on light issues to be presented by Horizon.

Agenda item 5a vi – Chough

Due to this item being passed into the second ISH on Biodiversity, the RSPB had indicated that they could not attend, but Ms Hughes confirmed that the views expressed on this item had been discussed with the RSPB prior to them being presented. A jointly compiled response is presented in the Post-hearing note.

Ms Hughes indicated that the concerns of RSPB have not been addressed by the D3 submission [REP3-046], which the eNGOs received in draft form prior to D2 and discussed in the NWWT WR [REP2-349 summary ∞ 1.18 and the RSPB's response to the ExA questions [REP2-358 ∞ ExQ1 Q2.0.21].

Two points of additional concern were presented: -

– In response to NRW Horizon have indicated [REP3-035 ∞ 9.7.2] that "*phasing plans (detailed) are not necessary because all landscape is to be undertaken cohesively at completion of construction*". This is particularly relevant to providing reinstated chough foraging as early as possible in the construction timeline. It was emphasised that this is also of relevance more widely and will be returned to by the eNGOs in the ISH to be held on landscape, particularly in relation to Mound E. Further NWWT made comparison with Mineral Planning Applications, which are often of a similar scale to the earthworks proposed in this DCO, where detailed phasing of landscape restoration would be required as a matter of course.
– Given the remaining concerns at D3 and the roundtable ISH that the contribution to the chough network outside the WNDA, as proposed in the s.106 [REP3-042 Schedule 11 item 1.3.3], should be identified separately within the Environmental Enhancement Fund with a specified ring-fenced budget. This item is not a nice to have, but is integral to chough mitigation. Later in the ISH, Ms Hughes also went on to demonstrate that there was a conflict between the chough mitigation and the measures necessary to improve Cemaes Bay Bathing Water Quality as discussed by NRW (Agenda Item 6 – Consents).

Day 5 – Second Issue Specific Hearing – Biodiversity

<u>Coastal Change</u>

Agenda item 3c i – Sediments

Ms Hughes noted and agreed with the comments from NRW (Dr Emmer Litt) that Cemlyn Lagoon SAC could benefit from the introduction of more shingle and took the opportunity to point to adaptive management options as presented in the eNGO WR [REP2-348 ∞ 5.24 – 5.34].

As the majority of matters under this agenda item were largely addressed by Professor Kenneth Pye these are discussed more fully in his Post-hearing note submitted on behalf of National Trust (NWWT and the RSPB defer to Professor Pye's expertise on this matter).

ANNEX 1 – EU Summary Note on the Precautionary Principle

‘Communication (COM92000) 1final) on the precautionary principle’
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l32042
(last updated 30.11.2016)

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The precautionary principle

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The precautionary principle

SUMMARY OF:

Communication (COM(2000) 1final) on the precautionary principle

WHAT IS THE AIM OF THE COMMUNICATION?

- It explains the precautionary principle which enables a rapid response to be given in the face of a possible danger to human, animal or plant health, or to protect the environment.
- In particular, where scientific data do not permit a complete evaluation of the risk, recourse to this principle may, for example, be used to stop distribution or order withdrawal from the market of products likely to be hazardous.
- It establishes **common guidelines** on the application of the precautionary principle.

KEY POINTS

The precautionary principle is detailed in Article 191 of the Treaty on the Functioning of the European Union. It aims at ensuring a higher level of environmental protection through preventative decision-taking in the case of risk. However, in practice, the scope of this principle is far wider and also covers consumer policy, European Union (EU) legislation concerning food and human, animal and plant health.

The definition of the principle shall also have a positive impact at international level, so as to ensure an appropriate level of environmental and health protection in international negotiations. It has been recognised by various international agreements, notably in the Sanitary and Phytosanitary Agreement (SPS) concluded in the framework of the World Trade Organisation (WTO).

Recourse to the precautionary principle

According to the European Commission the precautionary principle may be invoked when a phenomenon, product or process may have a dangerous effect, identified by a scientific and objective evaluation, if this evaluation does not allow the risk to be determined with sufficient certainty.

Recourse to the principle belongs in the general framework of **risk analysis** (which, besides risk evaluation, includes risk management and risk communication), and more particularly in the context of **risk management** which corresponds to the decision-making phase.

The Commission stresses that the precautionary principle may only be invoked in the event of a potential risk and that it can never justify arbitrary decisions.

The precautionary principle may only be invoked when the **three preliminary conditions** are met:

- identification of potentially adverse effects;
- evaluation of the scientific data available;
- the extent of scientific uncertainty.

Precautionary measures

The authorities responsible for risk management may decide to act or not to act, depending on the level of risk. If the risk is high, several categories of measures can be adopted. This may involve proportionate legal acts, financing of research programmes, public information measures, etc.

Common guidelines

The precautionary principle shall be informed by **three specific principles**:

- the fullest possible scientific evaluation, the determination, as far as possible, of the degree of scientific uncertainty;
- a risk evaluation and an evaluation of the potential consequences of inaction;
- the participation of all interested parties in the study of precautionary measures, once the results of the scientific evaluation and/or the risk evaluation are available.

In addition, the **general principles** of risk management remain applicable when the precautionary principle is invoked. These are the following five principles:

- proportionality between the measures taken and the chosen level of protection;

- non-discrimination in application of the measures;
- consistency of the measures with similar measures already taken in similar situations or using similar approaches;
- examination of the benefits and costs of action or lack of action;
- review of the measures in the light of scientific developments.

The burden of proof

In most cases, European consumers and the associations which represent them must demonstrate the danger associated with a procedure or a product placed on the market, except for medicines, pesticides and food additives.

However, in the case of an action being taken under the precautionary principle, the producer, manufacturer or importer may be required to prove the absence of danger. This possibility must be examined on a case-by-case basis. It cannot be extended generally to all products and processes placed on the market.

BACKGROUND

For more information, see:

- Press release on the European Commission's website.

MAIN DOCUMENT

Communication from the Commission on the precautionary principle (COM(2000) 1 final of 2 February 2000)

last update 30.11.2016

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Post Hearing Notes at the request of the Examining Authority

Wylfa Newydd Development Consent Order - EN010007

North Wales Wildlife Trust id 20011639
National Trust id 20010995
Royal Society for the Protection of Birds id 20011586

Introduction

This Post-hearing note has been prepared by Ms Hughes, in collaboration with the other eNGOs (environmental non-governmental organisations – North Wales Wildlife Trust, National Trust and RSPB – local & UK). It should be read in conjunction with the written record of the eNGOs' and NWWT's (North Wales Wildlife Trusts) oral presentations at the Issue Specific Hearings (ISH) on Biodiversity, but represents the views of the individual parties (National Trust, RSPB and NWWT) where identified in the oral case record.

Much of the information presented by way of rebuttal of the eNGOs' WR [Horizon REP3-026 rebuttal of REP2-348] and NWWT WR [Horizon REP3-028] sought simply to re-justify Horizon's position as supplied in the DCO application. Following review of these documents, the eNGOs feel that they have provided sufficient clarification of their position and/or any necessary correction at the oral examination, such that there is little merit in addressing any remaining matters point-by-point, and the eNGOs are content to let these WRs stand.

It has become abundantly clear during the proceedings of the 4 days of the ISH that the eNGOs attended, that unfortunately a significant amounts of new information are required from Horizon to update and/or provide more detail on a vast array of topics. Therefore, this Post-hearing note seeks to summarise the eNGOs' conclusions following the ISH, and set out what the eNGOs feel could helpfully be presented by Horizon during the relevant updates in order to progress outstanding concerns.

ExA 1 Response in a post-hearing note to the D3 evidence from HNP

Draft Section 106

The views of the eNGOs are presented in a separate paper prepared by the National Trust.

Cemlyn Nature Reserve

The eNGOs agree with the conclusions of NRW that the Anglesey Terns SPA should be taken to HRA stages 3 & 4 and a compensation package should be submitted as soon as possible.

The eNGOs agree with NRW on Esgair Gemlyn that it has not been demonstrated, beyond reasonable scientific doubt, that there will be no adverse effect on integrity (AEOI).

In relation to the mitigation elements of the scheme: -

<u>Anglesey Terns SPA</u> This is subject to a separate ExA question in this paper.

<u>Esgair Gemlyn</u> Presented in Professor Kenneth Pye's Post-hearing report, which in summary provides: -

- Information that he considers necessary to fully and adequately assess the risk to the shingle ridge.
- His Annex 1 and Annex 2 provide details of what he considers may be included in a monitoring strategy
- The Annex 1 also provides a summary of the beneficial re-use of dredged materials [REP2-348 ∞ 5.24 – 5.34]

<u>Mound E drainage</u> The ExA asked for information on what would might be needed to progress resolution of concerns on this matter. These are in summary: -

- Detail of how the drainage system will work: - drawings showing by-pass fluming system, hydraulic calculations of its capability and capacity along with emergency operating procedures
- Of particular importance is reconsideration of the location of the silt busters at the road junction on the north-western corner of Mound E, which is the gateway to Cemlyn Nature Reserve for visitors.
- No reworking of Mound E at later phases of the construction timetable, with a once only restoration scheme implemented when the Mound is first formed.
- Submission and understanding of the phasing of LHMS (Landscape Habitat Management Strategy) restoration. This also represents a wider eNGO point.
- Detail of flood risk on the Nant Cemlyn and Afon Cafnan, which has not been addressed during the licence applications. This has correlation with the design of the drainage scheme both in construction and operation. The National Trust and NWWT wish to be kept informed of progress on this matter and be consulted on any additional information that may be submitted to the consenting body.

Recreation & Tourism There seems to be little clarity as yet on this issue and Horizon still appear to adopt a piecemeal approach, but key points: -

- Workforce Management Strategy – not enough movement yet and unclear how it will operate or be delivered.
- Delivery mechanism needs to be identified for 'sensitive sites warden', either s.106 or a Requirement.
- Tern Warden the significant shortfall in s.106 funding allocations should be addressed.
- Visitor Centre – won't solve all the identified problems and ExA state little weight can be placed on this commitment due to needing permission outside the DCO. Horizon have indicated that more detail will be forthcoming on this element later in the DCO Examination and clarity would be welcomed.
- Temporary Viewing Platform – given the above on the Visitor Centre, if it cannot be given any weight, it is considered that a significant upgrade/thought to the temporary viewing area would be necessary. Ultimately, this should demonstrate that the DCO can overcome safe access and parking capacity not just at the viewing platform, but more widely across the WNDA and its immediate environs (i.e. National Trust land eastern car park and Trwyn Pencarreg, Wylfa Head and Coastal Path).

Predator and undesirable species monitoring and management protocol The stance presented by Horizon at D3 [REP3-026 ∞ 2.4] reiterates the points made in the DCO application. This matter was not discussed in ISHs, but the eNGO WR [REP2-348 ∞ 3.209] is that a predator/undesirable risk management strategy should be secured via a Requirement in addition to opportunities to secure predator protection measures as Cemlyn Nature Reserve via the Environment Funds.

Marine Mitigation for loss of seabed

This matter was provided on behalf of National Trust and NWWT by Dr David Parker. The additional information at D4 is awaited with interest. Key points: -

- Measures should be sought to demonstrate protection of the National Trust owned coastline in Porth-y-Pistyll, particularly from the removal of the temporary causeway.
- The new information should seek to compensate for all the additionally D3 identified habitat losses.

Tre'r Gof SSSI - TWA (Temporary Workers Accommodation)

NWWT's position objecting to the current TWA proposal, has not altered and the RSPB's concerns relating to chough have not yet been addressed.

Alternative locations of the TWA There would be considerable merit for investigation of alternatives for TWA which could be pursued: -

- It appears that IACC have similar problems with the TWA, its scale and location. However, discussions on the IACC alternative approach for a smaller campus to north of current TWA on-site boundary seems to have stalled. Consideration of an amendment of the DCO application – dependant on detail – may provide a solution to this matter in terms of biodiversity.
- NWWT recognise that the Land & Lakes scheme is out with the DCO, but this was not the case until PAC3 when it was removed. The L&L scheme has significant merits in NWWT's view and any adjustment to the DCO application via an amendment to the scheme would be a solution to this matter in terms of biodiversity.

Chough the RSPB's concerns are still extant, which can be summarised from their response to the ExA questions [REP2-358 ∞ ExQ1 Q2.0.21]: -

"To be considered "sufficient", chough habitat provision needs to:
*• be of sufficient **quality***
*• be of sufficient **extent** and*
*• have **continuity** through the construction phase"*

It is our view (the RSPB and NWWT) that the D3 representations and the ISH leave critical features, which could achieve this, unresolved: -

- There is a need to understand and secure the phasing of the LHMS restoration in relation to seeding of Mound A.
- There is a need for clear separation of contributions to secure the protection of the chough network outside of the Environmental Enhancement Fund in the s.106, as the delivery of these measures are necessary as mitigation to protect this Schedule 1 and Annex 1 species, and their funding should therefore be identified as a separate costed item.

Drainage schemes around Tre'r Gof SSSI – it is recognised that a new drainage package is to come forward at D5.

The D5 drainage proposals should demonstrate the feasibility of the proposals at the TWA, which NWWT feel are novel, untested and damaging in their own right. This relates both to the operation of the TWA and its restoration (restoration not discussed at ISHs).

SSSI compensation sites – NWWT agreed with NRW's points on this matter, the summary points from NWWT perspective are: -

- It is recognised that 2 full seasons hydrological assessment will be necessary to understand the extent and likely quality of habitats that can be created.
- Dependant on the results of hydrological assessment there may be a need for additional sites - from the original long list – to be reconsidered.
- Clarification of the details of long-term funding for management and the Bond to be secured on the work.
- Details of topsoil stripping, management and/or disposal on or off site.

Recreation and Tourism see the eNGO section above.

Air Quality

Immediately after the ISH NWWT approached Stephen Byrne (Horizon) and acknowledged their 'bad maths'. Mr Byrne took NWWT to Horizon's analysis in REP3-052. Table 2-12 shows a 13% change in nitrogen deposition at Year 2. Additionally, there is a 2% change in nitrogen at Year 5 (Table 2-17).

NWWT accept these figures and recognise the reduction in deposition rates over the DCO application figures. The introduction of the new D3 measures to control construction and marine vessel emissions are welcomed.

However, the points discussed at the ISH about the sensitivity of critical elements of the Trwyn Pencarreg and Cae Gwyn habitats (eg lichen-rich coastal heath and mire habitats respectively – APIS figures) to very small changes in nitrogen deposition still stand.

Additional improvements in air quality could be achieved by adopting electric hook-ups for marine vessels moored in the harbour [REP2-349 ∞ Chapter 4, section 7 item 6].

ExA 2 Post-hearing note on tern energetic budgets in response to Horizon REP3-026 ∞ 2.2.5 (directed initially to the RSPB)

In response to the ExA question at the ISH Ms Hughes, on behalf of the eNGOs, indicated that their position had not changed by the addition of the calculations provided by Horizon at D3 [REP3-026 ∞ 2.2.5]. To assist the ExA further on this matter the following pulls together the threads of the eNGO case: -

- The most salient feature of the energy budget debate is Horizon's acknowledgement as stated in the sHRA [eNGO REP2-348 ∞ 3.74 and 3.97] that construction disturbance and flight deviations are likely within the Zone of Influence (ZOI) resulting from noise (and visual[1]) disturbance and that this will result in additive energy expenditure. The eNGOs' WR concludes that this objectively increases energy requirements over and above 'normal' breeding conditions.
- The remainder of the discussion between both parties is based in the interpretation of the baseline data and available scientific literature. In the eNGOs' view; this is the need for an energetically efficient provisioning strategy for terns and the observed extent/degree of deviation on the commuting routes (particularly vertically) [REP2-348 ∞ 3.90, 3.97 and 3.115 – 3.122].
- This is contrasted with Horizon's position and the "suggested" energetic costs that may occur at Cemlyn extrapolated from deviations of avoidance in windfarm studies and their relevance to this proposal [REP3-026 ∞ 2.2.5].
- The crux of the issue here relates to the significant percentage - 75%[2] - of birds **commuting** through the ZOI (zone of influence) recorded by Horizon in their baseline studies, not as suggested by Horizon the level of foraging within the WNDA ZOI [REP3-026 ∞ 2.2.5 - rebuttal of eNGO WR], which is essentially a red herring in this discussion.
- The acknowledged cumulative effects on energy expenditure during commuting trips will combine with other factors relating to disturbance from construction (e.g. ExA physiological and psychological questions at ISH) and 'normal' site pressures, potentially causing adverse effects on the breeding success of the terns[3]. From the ISH and D3 it is evident that neither party has been able to accurately quantify this with any degree of scientific certainty or clarity, and therefore it is the eNGOs' view that the Precautionary Principle[4] must apply.

ExA 3 Post-hearing update on grave concerns in relation to the amber/red warning system methodology for Anglesey Terns

This is in response to the D3 Horizon Technical Note REP3-048. The eNGOs maintain the same conclusion as set out in their WR [REP2-348 summary 1.12 – 1.17].

The D3 approach does not represent effective risk management and is not proportionate to the level of risk. Elements of the methodology are not (Best Available technology/technique) BAT and many aspects of it are novel and untested in the industry. All elements are contrary to EU guidance on the Precautionary Principle and the eNGOs still believe that the proposed mitigation is inoperable.

The eNGOs' position is that the adjustments made at D3 add little to what was tabled previously. They do not go far enough to protect the terns either at the breeding colony or as Sandwich terns commute to and from the colony, passing over the new harbour construction/operational area.

Noise thresholds It was generally agreed that the proposed thresholds were in right area. However, there is still no definition of what constitutes the breeding colony ambient noise levels. As indicated in the eNGO WR [REP2-348 ∞ 3.58], the proposed approach could result

[1] Visual disturbance was not specifically addressed at the ISH, but is of relevance to the debate.
[2] The eNGO WR [REP2 -348 ∞ 3.90] reporting sHRA [APP-05 figs 10-8 & 10-9]
[3] Breeding success evaluated by number of breeding pairs or productivity in chick rearing
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l32042 a copy of the EU summary is attached as Annex 2 to the eNGO oral case report

in blast sizes used that are at a level where the breeding colony is already in a distressed/disturbed state, as Horizon acknowledge that the birds are noisiest in response to predators or threat species/events. This is not considered to be precautionary risk management.

4 week establishment period This has not been adjusted, which is not acceptable to the eNGOs. This is not BAT; which indicates that the bird breeding season is 1st March to 31st August (British Standard BS42020:2013 - model conditions).

Dates for the 4 week establishment period There was confusion in the ISH from Horizon (Sian John on behalf of Horizon) who appeared to indicate that 'NWWT can have whatever dates they want earlier in season'. Horizon's approach however, did not appear to indicate that the length of the establishment period would be extended to encompass the establishment period of all tern species (Sandwich, common, Arctic and roseate) for which the SPA is designated. Nor did Horizon make any comment on the collated tern establishment data of over 20 years, as presented in the eNGOs' WR [REP2-348 ∞ Fig. 1 and eNGO oral case]. The eNGOs' data provides an evidential basis for the vulnerable establishment period, and could be used to provide a more accurate definition of the establishment period for the breeding colony against its conservation objectives for each tern species. In this respect, the risk management has not responded or reviewed the most relevant scientific understanding (see Precautionary Principle - risk management 5th bullet point).

Responsive monitoring What has been presented [REP3-048] does not overcome the eNGOs' concerns. Responsive monitoring remains a novel technique with no track record of operation elsewhere. It is not considered by the eNGOs to represent effective risk management as it only responds once impacts have occurred (see Precautionary Principle eNGO oral case).

Furthermore, it is very concerning that Horizon (Sian John) feels that works would only need to stop for short periods (i.e. "*minutes not hours-and-hours*"). This places no recognition on the fact that disturbance impacts on the terns act cumulatively/synergistically over a period of time throughout the season, which could lead to either decline in productivity or colony collapse.

Other normal disturbance factors would also need to be well controlled (i.e. predation and visitors) as the construction noise disturbance will add to these.

From the ISH round table discussions there is no further clarity or confidence on how this part of the system will operate and the discussion on the 'walk through' of Eco Clerk of Works was very unclear from Horizon. Crucially, this matter relates to how does "*the big red button get pushed"* by whom and when. Specific issues still remaining: -

- Mechanism to identify the machinery actually responsible (not just the loudest one)
- Lines of communication within construction site
- Position of EcoCoW in corporate/contract hierarchy
- Authority to instigate shut down
- Conflict with H&S of machine operation
- Responsiveness of the system (ie how quickly can it be implemented)
- Monitoring and oversight by regulators (IACC/NRW)

References

BS42020:2013 'British Standard BS42020:2013 Biodiversity – Code of Practice for Planning and Development', BSI Standards Publication, August 2013