Wylfa Newydd Development Consent Order

Written Representation on Coastal Processes and Geomorphology

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27 November 2018

Kenneth Pye Associates Ltd

Scientific Research, Consultancy and Investigations

Wylfa Newydd Development Consent Order

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Summary

S1 This written representation relating to coastal processes and geomorphology has been prepared on behalf of the National Trust in response to the Examining Authority's request for Deadline 2 (4th December 2018). It is based on assessment of the relevant documentation submitted by Horizon Nuclear Power in support of the Wylfa Newydd DCO application, and on field surveys and environmental data analysis undertaken since 2010.

S2 In view of the geomorphological and ecological importance of the Cemlyn Bay – Esgair Gemlyn – Cemlyn Lagoon system there is a requirement for critical scrutiny of the potential impacts on these features of the Wylfa Newydd proposals. Any adverse impact on the shingle ridge arising from changes to physical processes and sediment transport within Cemlyn Bay could have significant effects on the functional integrity of the entire system, including the tern and other breeding bird populations.

S3 The DCO and Marine Licence (ML) applications for the proposed Wylfa Newydd nuclear power station, and notably the marine works, submitted by Horizon rely heavily on assessments of coastal geomorphology and coastal / marine processes undertaken between 2010 and 2016. The results and conclusions of these assessments, summarised in the Environmental Statement and the shadow Habitats Regulations Assessment, give rise to a number of concerns which, as summarised in the most recent Statement of Common Ground (dated 21/11/18) between HNP and the NT, remain outstanding.

S4 The assessments of the potential impacts of the proposed development, including the marine works, have relied heavily on the results of hydrodynamic modelling and wave modelling. Only very limited use has been made of other assessment approaches including analysis of field data, historical survey and background environmental information; no apparent use has been made of physical modelling. The scale and scope of geomorphological field data collection and analysis is limited compared with other comparable large-scale projects.

S5 The frequency of high tides exceeding c. 3.9 m ODN at Cemlyn has increased since the early 1990s, in part due to a rise in mean sea level and in part to a higher frequency of positive storm surge events. Estimates made by the UK Climate Programme suggest high water levels in the North Anglesey area may increase by between 7.1 cm and 31.8 cm by 2050, and by 18.6 cm to 84 cm by 2100, under a medium emissions scenario. The shingle ridge is therefore likely to experience increasing pressure from extreme high water levels and waves, leading to more frequent over-topping and a higher rate of landward movement. Any increase in wave heights resulting from the marine works would exacerbate these changes, increasing the risks of wave overtopping, barrier breaching, occlusion of the open water channel

between the shingle ridge and the tern nesting islands, and potentially blocking the tidal entrance channel on the lagoon side of the weir.

S6 The possibility that construction of the harbour structures, particularly the western breakwater, could cause a significant increase in nearshore wave heights within Cemlyn Bay due to wave reflection, refraction and greater focussing within Cemlyn Bay has been considered in the ES but has been judged not to be significant based largely on the results of the wave and hydrodynamic modelling. However, as advised to HNP throughout the consultation processes, there are dangers in placing over-reliance on the results of numerical modelling.

S7 The main focus of the hydrodynamic modelling and wave modelling undertaken to support the ES, sHRA and Marine Licence applications has been on possible changes in significant wave height and bed shear stress. No specific modelling or other form of assessment has been undertaken to consider the potential implications of changes in these parameters on coastal and seabed morphology, including the future evolution of Esgair Gemlyn and its importance for the functioning of Cemlyn Lagoon and its associated ecological features.

S8 An increase in significant wave height of up to 20 cm has been demonstrated by the HNP modelling, but the implications of this in terms of wave run-up, overtopping and possible erosion of the shingle ridge have not been appropriately considered in the ES or in additional work undertaken since DCO submission.

S9 Combined tide and wave modelling work undertaken for HNP has also demonstrated that there is likely to be a significant increase in bed shear stress within the western part of Cemlyn Bay following construction of the marine works. The lower intertidal zone in Cemlyn Bay is composed largely of fine to medium sand, while the surface layers of the mid- and upper-beach face of the shingle ridge typically consist of medium to coarse gravel and sandy gravel. The potential for mobilization of the fine sediment in the lower intertidal and shallow sub-tidal zones, and within the lower parts of the upper beach slope, is clear. The modelling results have indicated the existence of an anticlockwise circulation gyre within Cemlyn Bay which would encourage net movement of sediment from the northwestern part of the bay towards the southeast, or possibly out of the bay altogether. The effect of this, over time, would be to reduce sea bed levels in the northwestern part of Cemlyn Bay, increasing the exposure of rock and reducing the dissipation of wave energy before it impacts on the shingle ridge. In these circumstances the likelihood of upper beach face erosion and over-washing of the ridge crest would increase.

S10 Given the limited nature of the geomorphological information baseline provided in the DCO documents and the high level of uncertainty regarding the possible effects of the proposed marine structures on the shingle ridge, lagoon and adjoining sea bed, it is of critical importance that further work is undertaken, before any construction begins, to develop the following:

- an adequate morphological, sediment and water quality baseline, against which future changes can be measured

- a ‘fit for purpose’ monitoring programme, agreed Between HNP, NRW and NGOs; as a minimum this should include water levels (both tides and waves) topography / bathymetry, surface sediments and suspended sediments

- a suitable package of remediation and/or compensation measures in the event that any potentially negative impacts on the ridge / lagoon / bay are identified following the commencement of construction. These could include beneficial use of suitable sand and shingle materials arising from the harbour development works.

A Scope and purpose of the of this written representation

1 This written representation relating to coastal processes and geomorphology has been prepared on behalf of the National Trust (NT) in response to the Examining Authority's request for Deadline 2 (4th December 2018).

2 I am a specialist in coastal and marine processes, coastal geomorphology and sedimentology, with applications to environmental management, coastal engineering and habitat conservation. I have provided advice to the NT in relation to the Cemlyn property since 2010, including written contributions to inform the NT's response to PAC1, PAC2 PAC3. The advice provided has been based both on an assessment of HNP documents and independent field surveys and analysis of environmental data relating to the Cemlyn - Wylfa area. The results of these independent studies are summarised in a number of Kenneth Pye Associates Ltd (KPAL) technical reports (Pye & Blott, 2010, 2016, 2018a, 2018b; Blott & Pye, 2018).

3 The NT owns a significant area of land immediately to the west of the Wylfa Newydd Nuclear Development Area (WNDA) in north Anglesey (Figure 1). The NT land, together with the northwestern part of the WNDA, falls within the Anglesey Area of Outstanding Natural Beauty (AONB) and North Anglesey Heritage Coast HC). The NT estate includes Cemlyn Lagoon and most of the the Esgair Gemlyn shingle ridge which form part of the Cemlyn Bay Site of Special Scientific Interest (SSSI), the Cemlyn Bay Special Area of Conservation (SAC), and the Anglesey Terns Special Protection Area (SPA) which also includes the marine area adjacent to the WNDA. Since 1971 the Lagoon has been leased to the North Wales Wildlife Trust (NWWT) and managed as a nature reserve (Figure 2).

4 The primary features of scientific interest within the Cemlyn SSSI / SAC include the saline lagoon and its associated fauna, the shingle barrier and shingle vegetation, areas of fringing saltmarsh, and breeding birds which include Artic, Common, Sandwich and Roseate Terns. The Cemlyn Bay SAC is notified under the Habitats Directive for its Annex 1 "Coastal lagoons" priority habitat, with "Perennial vegetation of stony banks" being a qualifying feature. A Core Management Plan for the SAC and adjoining SPA, including the associated SSSIs, identifies the core management objectives relating to the feature interests (Lewis & Ratcliffe, 2008). The most recent NRW Indicative Condition Assessment of the Cemlyn Bay SAC judged to the site to have "Favourable" status in terms of Distribution and Extent, Structure and Function, Typical Species and Overall Indicative Condition (NRW, 2018).

5 A key feature of the NWWT reserve and the SPA is the population of breeding terns which nest on two artificial islands within Cemlyn lagoon. The success of this breeding population is critically dependent on the maintenance of the islands, the surrounding lagoon, and the protective shingle ridge. The Anglesey Terms SPA

encompasses the entire marine area adjacent to Cemlyn Bay and the WNDA, and is important for foraging during the breeding season.

6 Although not listed as a Geological Conservation Review (GCR) site, Esgair Gemlyn ridge and Cemlyn Lagoon represent one of the best examples of a shingle barrier and back-barrier lagoon system in Wales (Pye & Blott, 2018c).

7 **In view of the above, there is a requirement for critical scrutiny of the potential impacts on these features of the Wylfa Newydd proposals. Any adverse impact on the Esgair Cemlyn shingle ridge arising from changes to physical processes and sediment transport within Cemlyn Bay could have serious effects on the functional integrity of the entire system, including the tern and other bird populations.**

8 Several aspects of the Horizon Nuclear Power (HNP) proposals, as described in the Development Consent Order (DCO) application and shown on plan drawings APP-014 and AP-015, could impact on coastal and marine processes, geomorphology, habitats and species. These include:

- site preparation and clearance, excavations and the creation of earth mounds associated with construction (Figure 3), changes to ground cover affecting surface runoff, sediment transport into water courses and hence into nearshore waters; increase in airborne dust flux to coastal waters, Cemlyn Lagoon and adjoining terrestrial coastal habitats

- construction activities associated with building of the new harbour - including installation of temporary coffer dams, access causeway, dewatering, dredging of soft sediment and excavation of solid rock, directly affecting the sea bed and shoreline geomorphology, subtidal and intertidal habitats and seawater quality in Porth-y-pistyll and adjoining areas (Figures 4 & 5)

- permanent loss of sea bed features and natural biotopes beneath the footprint of the permanent marine structures in and around Porth-y-pistyll (Figures 6 & 7)

- short, medium and long-term effects of the completed harbour structures on waves, currents, sediment transport and coastal morphology in Porth-y-pistyll and Cemlyn Bay

- effects of continuing (post-construction) discharges from the power station and harbour on water quality and sedimentation in the surrounding area.

9 The DCO and Marine Licence (ML) applications for the proposed nuclear power station, and notably the marine works, rely in part on assessments of coastal geomorphology and / coastal marine processes undertaken in the period 2010 - June 2016. The nature and results of these assessments, summarised in the Environmental Statement (ES) (APP-077, APP-078, APP-131,APP-132, APP-216, APP-217 and APP-218) and the shadow Habitats Regulations Assessment (sHRA) (APP-050 & APP-051), give rise to a number of concerns which, as stated in the most recent Statement of Common Ground (SoCG) dated 21/11/18 between HNP and the NT, remain outstanding.

B General comments on the assessments undertaken by HNP in relation to coastal processes and geomorphology

10 The EIA process followed by HNP included (a) identification of coastal geomorphology receptors, (b) characterization of baseline conditions, and (c) assessment of potential risks of change from the baseline arising from the Project. These objectives have been addressed by:

(1) primary data acquisition through surveys relating to

- waves
- tidal currents
- bathymetry
- sediments

(2) computer modelling relating to

- significant wave height (SWAN model)
- tidal currents (DELFT 3D model)
- bed shear stress induced by tidal currents and tidal currents plus waves (combined DELFT3D and SWAN)
- dispersion of sediment released by dredging and from land discharge points (DELFT 3D)

(3) assessment of coastal geomorphology and potential changes arising from the Project, involving:

- desk study review of existing reports and environmental data
- Geomorphology field walkover survey
- assessment of data from marine field surveys undertaken 2014-2017
- examination of LIDAR survey data commissioned by NRW (2010) and Jacobs (2017)
- assessment of SWAN wave modelling data (significant wave height), with and without the Project

- assessment of combined tidal currents and waves in terms of bed shear stress, with and without the Project
- development of a conceptual sediment regime model.

11 The collection of 'long-term' metocean data (i.e. relating to periods of several months) to inform the EIA has been restricted largely to three locations, identified as S4, S9 and S11 shown on Figure D12-2 in APP-238. No long-term monitoring of water levels, waves, salinity, temperature or suspended sediment concentrations has been undertaken within, or close to, the sensitive receptors within Cemlyn Bay.

12 Only a 'high-level' geomorphological appraisal of the shoreline, including Cemlyn Bay, Esgair Cemlyn and Cemlyn Lagoon, has been undertaken, largely as part of a geomorphological walkover survey (limits shown in D12-2 in APP-238), supported by a desk study evaluation of existing reports and readily available information sources. No new onshore ground surveys or process measurements have been made, and no detailed data analysis undertaken.

13 A partial bathymetric survey, covering the marine area around the proposed development area, including the outer part of Cemlyn Bay, was undertaken by Titan Surveys but did not extend to the low water mark. A LiDAR survey was commissioned by Jacobs in the spring of 2017 to supplement an earlier survey by the Environment Agency's Geomatics Group in 2010, but neither survey was undertaken on a spring low tide, with the result that there is a gap in bathymetric data coverage between the marine and terrestrial surveys. Only a very simple comparison of topographic change on the shingle barrier between the two LiDAR surveys is reported in the Coastal Processes and Geomorphology chapter of the ES (APP-131).

14 Characterization and interpretation of the sea bed within Cemlyn Bay has relied almost entirely on a marine geophysical survey, with only a single sediment sample collected for particle size and benthic faunal analysis from a location near the bay entrance (location WS3, shown on Figure D12-7 in APP-238). No geophysical or other investigations have been undertaken to characterise the internal structure and potential mobility of the shingle ridge, or the sea bed immediately to seaward of it. No sediment samples have been collected from the shingle ridge, the adjoining beach, or Cemlyn Lagoon to determine their particle size and other properties.

15 **The assessments of the potential impacts of the proposed development, including the marine works, as summarised in Chapters 6.4.12 (APP-131) and 6.4.13 (APP-132) of the ES, have relied heavily on the results of hydrodynamic modelling and wave modelling. Only very limited use has been made of other assessment approaches including analysis of field data, historical survey and background environmental information; no apparent use has been made of physical modelling. The scale and scope of geomorphological field data collection and analysis, as**

reported in APP-131, APP-216 and APP-217), is very limited compared with those undertaken for other recent nuclear projects (e.g. Hinkley Point and Sizewell C).

16 The computer modelling relating to the proposed construction area has been undertaken in a number of phases:

Waves
Phase 1 – Baseline: typical and worst case events for present day, foreseeable future and long-term future with climate change effects

Phase 2 – project scenarios: partially and fully built conditions over typical and worst case events

Further modelling – sensitivity testing of Phase 2 results

Hydrodynamics
Phase 1: Baseline: typical and worst case events over spring-neap tidal cycles

Phase 2: Project scenarios: typical and worst case events for fully built conditions

Further modelling: Coupled hydrodynamics and waves for fully built conditions (including work undertaken post DCO-submission)

Sediments
Sediment plume study

17 The main focus of the hydrodynamic modelling and wave modelling as related to coastal and processes and geomorphology has been on possible changes in significant wave height and bed shear stress. **No specific modelling or other form of assessment has been undertaken to consider the potential implications of changes in these parameters on coastal and seabed morphology, including the future evolution of Esgair Gemlyn and its importance for the functioning of Cemlyn lagoon and its associated ecological features**.

18 The shingle ridge (Esgair Gemlyn) and Cemlyn Lagoon were identified as receptors early on in the EIA scoping process, but ssessment of the potential impact of the proposed development on these receptors has from the outset focused mainly on possible disturbance to the breeding bird populations (notably terns) caused by factors such as noise, lighting, vessel movements and increased visitor numbers. **The potential risk of indirect impact on the bird populations, and to the wider functional integrity of the shingle ridge and lagoon system, posed by possible changes in wave conditions and sediment movement due to construction of the marine works, has not been given adequate consideration.**

19 **The possibility that construction of the harbour structures, particularly the western breakwater (Figure 7), could cause a significant increase in nearshore wave heights within Cemlyn Bay due to wave reflection, refraction and greater focussing within the Bay has been considered in the ES (APP-131) but judged not to be significant based largely on the results of the wave and hydrodynamic modelling. However, as advised to Horizon during the audit of the hydrodynamic model by ABPmer in 2015 and 2016, bed shear stress in itself is not sufficient to characterize the potential for sediment movement and morphological change. Similarly, significant wave height alone does not fully characterize wave conditions or the potential for wave-induced sediment transport and morphological change. There are dangers in placing over-reliance on the results of numerical modelling, the outputs from which depend heavily of the model assumptions and input parameters, and especially in drawing broad conclusions about likely medium and long-term morphological change from short term results which consider only a small number of model output parameters. The HNP assessments make only limited attempt to integrate the modelling results with other information, and do not provide sufficient consideration of how changes in modelled significant wave height and bed shear stress may affect sediment erosion and longer term evolution of coastal morphology.**

20 The interaction of waves and high tidal levels is the critical factor leading to over-topping and landward movement of the Esgair Gemlyn shingle ridge. Based on short-term measurements of tidal levels at Cemlyn and comparison with synoptic records at the Holyhead Class A tide gauge (Pye & Blott, 208b), the level of mean high water spring tides (MHWS) in Cemlyn Bay is estimated to be 3.71 m ODN, approximately 37 cm higher than the MHWS tide level for Holyhead given in Admiralty tide Tables (UKHO, 2017) (Table 1). The Environment Agency Coastal Boundary Study for England and Wales (McMillan *et al*., 2011) estimated the 1 in 1 year still water level in the Cemlyn Bay area to be 3.70 +/- 0.1 m ODN, and the 1 in 200 storm surge level to be 4.25 +/- 0.2 m ODN. Based on the available tide gauge record for Holyhead, the frequency of high tides exceeding c. 3.9 m ODN at Cemlyn appears to have increased since the early 1990s (Figure 8), in part due to a rise in mean sea level and predicted high water levels, and in part to a higher frequency of high magnitude positive storm surge events. Estimates made by the UK Climate Programme (UKCP09) suggest high water levels in the North Anglesey area may increase by between 7.1 and 31.8 cm by 2050, and by 18.6 to 84 cm by 2100, under a medium emissions scenario. The ridge is therefore likely to experience increasing pressure from extreme high water levels and waves in the coming decades, leading to more frequent over-topping and a higher rate of landward movement (Pye & Blott, 2010, 2016). **Any increase in wave heights arising as a result of the marine works would therefore exacerbate these changes, increasing the risks of wave overtopping, barrier breaching, occlusion of the open water channel between the shingle ridge and the tern islands, and potentially blocking the tidal entrance channel on the lagoon side of the weir.**

21 The offshore wave climate near the north Anglesey coast is dominated by waves from the southwest and west, but waves from the northwest and from east-northeast are also important (Figure 9). At offshore point 1464, approximately 5.3 km NNE of Cemlyn Bay, the 99th percentile hind-cast significant wave height (H_s) in the period 1980-2016 was 2.96 m and the 99th percentile hind-cast wave period (T_z) was 5.67 seconds (Pye & Blott, 2018a).Waves from the west northwest, north and northeast are particularly important in terms of their impact on the Cemlyn Bay shoreline. Under northwesterly wave conditions, waves impact directly on Traeth Pencarreg and Cerrig Brith. Westerly waves are also refracted around Trywn Cemlyn and impact significantly on the eastern Cemlyn Bay shoreline (Figure 10). Waves from a northerly direction also have an important impact on these sections of the shore, also extending further to the northwest along Esgair Cemlyn (Figure 11). Waves from the northeast, which travel directly down the axis of Cemlyn Bay, impact on most of the Esgair Gemlyn shoreline (Figure 12).

22 The proposed marine works include the construction of a breakwater, approximately 400 m in length, which will be emergent at high tide. The southern two-thirds of the breakwater will have an approximate SSW-NNE orientation while the northern third will have an approximate S-N orientation (Figure 7). Consequently, refracted westerly and northwesterly waves will experience reflection off the breakwater, with the reflected waves being directed towards Cemlyn Bay. **The combination of reflected waves and refracted incident waves is likely to lead to increased wave focussing and greater significant wave heights within Cemlyn Bay.**

23 The Coastal Processes and Geomorphology chapter of the ES (APP-131), and the associated Figures contained in APP-238, present only a limited selection of modelling results. Figure D12-13 in APP-238 shows the difference in significant wave height between the present (2023) fully built minus baseline scenario for a 99th percentile winter wave from the NW sector. Differences are apparent only in the area immediately to the west of the Western Breakwater. A similar comparison for a 2087 'realistically forseeable' climate change scenario shows a slightly greater effect in the same area, and also a small impact (increase in significant wave height of up to 10 cm) in the western part of Cemlyn Bay. Additional results presented in the Main Site Wave Modelling report (APP-218) provide a more detailed picture. Sensitivity testing using different offshore wave approach angles showed than an effect on significant wave height in Cemlyn Bay is observed for wave approach angles of 176^o to 295^o, with maximum effect observed for approach angles of 241^o-251^o, i.e. from the west (Figure 4.22 in APP-218). An increase in significant wave height of up to 20 cm is indicated by the modelling in western Cemlyn Bay (Point 6) for the 2087 99th percentile winter wave scenario. Tables 4.17 and 4.18 in APP-238 show relatively little change in wave period for the 2087 99th winter wave scenario but a significant change in wave approach direction at the shoreline which could alter patterns of littoral sediment drift, resulting in greater transport towards the northwest (the tidal inlet entrance).

24. Figure D12-15 in APP-238 provides an illustration of the difference in maximum bed shear stress between baseline and fully-built scenario for spring tide ‘typical wave’ and ‘high north wave’ scenarios. An increase to the west of the harbour structures is indicated, but no increase is suggested within inner Cemlyn Bay. No comparable results for NW winter waves, or from refracted westerly waves, are presented.

25 Further coupled NW 99%ile wave and tidal modelling undertaken after DCO-submission, summarized in Jacobs Technical Memorandum 60PO80AGGE0TM002 (dated 4th October 2018) and presented to the NT and other NGOs at an ecological and marine issues consultation meeting on 11 October 2018, shows that for the 2023 fully built scenario there could be an increase in significant wave height of 10 - 20 cm in the inner part of Cemlyn Bay, close to the lowest and most vulnerable part of the shingle ridge, located between the tern islands and the inlet entrance (Figure 13). For the 2087 fully built ‘with climate change’ scenario the predicted increase in significant wave height in this area is even larger (Figure 14).

26 **The implications of an increase in wave run-up and overtopping of the shingle ridge associated with an increase in significant wave height of up to 20 cm are not considered in the Horizon documents referred to above. The risk of breaching of the ridge crest due to erosion of the upper beach face and seaward side of the crest also has not been considered.**

27 Preliminary wave modelling undertaken by Pye & Blott (2018a) examined changes in nearshore wave height, wave period, wave direction and wave power within Cemlyn Bay as a function of varying offshore wave approach direction. The results showed that at Point 1, opposite the tern nesting islands (see Figures 10-12), the largest significant wave height occurs with an offshore wave direction of N40^{o} - 50^{o}E, while the lowest peak wave periods were also associated with this offshore direction (Table 2). The combination of relatively large wave height and short period (related to small wave length) is likely to create waves with a relatively high steepness and strong backwash which moves sediment in a seaward direction, leading to erosion of the upper beach slope. Observations at Cemlyn and elsewhere have shown that under such conditions a small ‘cliff’ is cut into the ridge crest, and if the ridge crest is narrow waves may cut through to the landward side. If waves approach the beach at an oblique angle, sediment may be moved in an alongshore as well as an offshore direction. The height and width of the ridge, which are related to the volume of sediment present above critical tidal levels at any given point along the shore, are therefore important in determining the resilience of the ridge during storms. The interaction between these factors has not been considered in the Horizon assessment.

28 The additional combined SWAN wave and DELFT-3D tidal modelling results reported by Jacobs (20180 indicate that for a 99%ile NW wave, in the presence of marine structures there could be an increase of +0.5 N/m^2 to +5 N/m^2 in the bed shear stress in the western part of Cemlyn Bay when compared with the baseline. This would result in

bed shear stresses ranging from 3.7 to 6.7 N/m^2. These values compare with critical bed shear stress values for sediment mobilization quoted by Horizon (2018) of 0.1 – 0.5 N/m^2 for 'featureless sand' (D50 size = 0.1 to 1 mm) and 2.7 – 5.7 N/m^2 for 'irregular sandy gravel' (D50 size = 4 - 8 mm). **Although no sediment sampling or particle size analysis has been undertaken by Horizon within Cemlyn Bay, surveys by KPAL (Pye & Blott, 2010, 2018b) have demonstrated that the lower intertidal zone is composed largely of fine to medium sand, while the surface layers of the mid- and upper-beach face of the shingle ridge typically consist of medium to coarse gravel and sandy gravel. The potential for mobilization of the finer sandy sediment in the lower intertidal and shallow sub-tidal zones, and areas of finer sandy gravel on lower parts of the upper beach slope, is clear.**

29 The combined wave and tidal modelling undertaken for Horizon has demonstrated that under the most energetic spring tide ebb tide conditions, with waves from the northwest and north, net transport vectors would be directed from the northwest towards the south-eastern part of the Bay. Movement of sand and fine-gravel in this direction is therefore likely. The Horizon modelling has also shown that under these ambient conditions seaward-directed transport vectors occur in the eastern part of the Bay. Consequently, mobilized sediment of sand size could be moved into deeper water, or even removed from the bay altogether.

30 The results of the Horizon modelling have shown that the most energetic conditions in Cemlyn Bay are associated with storm waves approaching from the north and northeast which are unimpeded by the adjacent headlands and transmitted directly into the bay. This has been confirmed by KPAL assessments (Pye & Blott, 2018a). Such waves are unlikely to be affected significantly by construction of the breakwaters. **However, the effect of moving sediment from the northwestern part of the bay towards the southeast, or out of the bay altogether, would be to reduce sea bed levels in this inner part of Cemlyn Bay and to reduce the dissipation of wave energy from any direction before it impacts on the shingle ridge. In these circumstances the likelihood of upper beach face erosion and over-washing of the ridge crest would increase.**

31 The Horizon assessment also has not considered potential changes in sea bed levels and/or the morphology of the shingle ridge which might arise from the cumulative effect of increased wave heights and bed shear stresses associated with less extreme (50th - 99th percentile) waves from the north-west, and other directions.

C Additional comments on the Main Site Wave Modelling Report (APP-218)

32 The Main Site Wave Modelling Report summarises the results of the Phase 2 study undertaken by HR Wallingford Ltd which takes account of the Wylfa Newydd marine structures and possible future climate change. Predictions are made for additional nearshore points over and above those considered in the Phase 1 Baseline modelling. The same results are used to support the ES, sHRA, Flood Consequence Assessment (FCA), Marine Licence applications and Environmental Permit applications.

33 The modelling used the SWAN model to represent wave propagation from offshore towards the shoreline. Four nested grids were used, the largest covering an area of 29 km x 53 km at 500m grid resolution, the innermost covering the area near the development site with a grid resolution of 20 m. Model bathymetry was based on Seazone digital chart data supplemented by local survey data for parts of the inshore area. The model was run applying data for offshore waves generated by the 35 year WaveWatch III Met Office wind and wave model along the seaward boundary, and forced with coincident wind conditions applied uniformly across the whole model domain. Model runs were undertaken both for a constant high water level and realistically varying tidal levels. **The reliability of the outputs from this modelling will inevitably be dependent on the quality of bathymetric data and hind-cast modelled wave and wind data used as input to the SWAN model.**

34 The June 2018 report (APP-218) takes account of revised harbour layout to update results for the baseline assessment, a part-built harbour layout and a fully-built layout. This includes a 400 m Western Breakwater with crest height varying between + 10.7 m OD and +11.6 m ODN and a 150 m long Eastern Breakwater with crest elevation of + 11.1 m ODN. Side slopes of both breakwaters were been assumed to be 1:4/3. A wave reflection coefficient of 0.45 was assumed for the breakwaters, while reflection coefficients of 0.4, 0.2, 0.95 and 0.35 were assumed for sections of rocky coastline, beach coastline, vertical quays and the cofferdam (1:1.5 slope), respectively. **Any changes to the design of the marine works, particularly the orientation, slope angle and roughness of the seaward side of the western breakwater, could lead to a different magnitude and spatial pattern of effects to those indicated by the modelling carried out.**

35 The SWAN model was calibrated and validated against measured wave data obtained at four locations within the two inner model grids during the Phase 1 wave modelling study. **However, no measured nearshore wave data have been collected within Cemlyn Bay and the accuracy of the wave model predictions for this area is uncertain.**

36 Measured and modelled storm peak wave conditions were compared for 18 storms ranging from an estimated 1 in 1 year return period to 10 - 20 times a year conditions. **However, the period of wave data collection was relatively calm and no severe storms are represented in the record used to calibrate and validate the model.**

37 For the Phase 2 studies the validation process was repeated with the marine structures in place, using the same parameters for the same 18 storms. Calculated validation statistics for wave measurement site S2 included a root mean square model error (RMSE) of 0.31 for significant wave height and 0.56 for wave period. Respective values for measurement site S4 were 0.40 and 1.04, those for site S9 were 0.35 and 0.90, while those for site S11 were 0.28 and 1.52. **No validation statistics are presented in the report for station S6 in the inner part of Cemlyn Bay since no useable measured data were available for this area.**

38 Nearshore wave time series were generated for each of the ten 'inshore' sites using an 'emulation approach' whereby the SWAN model was run for a selected sub-set of events which were then combined using interpolation techniques. Using this approach a 35 year (3 hourly) time series was generated at varying water levels and for a series of layout / scenario conditions:

- Baseline 2023 'present day' conditions
- Baseline 2087 'reasonably foreseeable' conditions
- Part built layout, 2023 'present day' conditions
- Fully built layout, 2023 'present day' conditions
- Fully built 2087, 'reasonably foreseeable' conditions
- Fully built 2187, 'reasonably foreseeable' conditions
- Fully built 2087, 'credible maximum' conditions

The reliability of the emulation approach is not discussed or demonstrated in the report, and the degree of resulting uncertainty is not specified.

D Additional comments on marine modelling of the construction discharge (APP-232)

39 The Delft 3D hydrodynamic model has been used to simulate dispersion of drainage discharges, including suspended solids and dissolved contaminants (this application also was not covered in detail by the 2016 model audit by ABPmer). The inputs to the model for 1 in 2 and 1 in 30 year storm flows were provided by the InfoWorks ICM (4Rs) coupled surface water and groundwater flow model. The assumptions made during the Delft modelling include exclusion of wind and waves to represent a worst case scenario with minimal dispersion. The project discharges were assumed to consist of clay size material (<2 um) with a very low settling velocity. Further model

simulations were undertaken assuming that the clay grade material would experience flocculation and a higher settling velocity of 0.2 mm/s. A critical shear stress of 0.1 N/m^2 was used in the modelling study as the threshold for fine sediment re-suspension. Discharges were modelled as point sources at the proposed discharge outlet points. The assumed worst case suspended solids concentration for the 1 in 2 and 1 in 30 year storm events was 0.106 mg/l which is above the lower limit of the WFD classification of turbid waters. **No evidence has been provided to support the unrealistic assumption that all of the suspended material in the construction discharge will be of clay grade (it would be expected that a range of sizes will be present ranging from fine sand to clay), and no sensitivity test results have been reported for larger sizes (e.g. 31 µm medium silt).**

40 The maximum suspended sediment concentrations were predicted by the modelling to occur close to Cerrig Brith. Under a scenario with no wind and no waves, maximum short-term deposition in the inner part of Cemlyn Bay was predicted to be <0.2 cm, but up to 6.3 cm was predicted near Cerrig Brith. In practice these rates would probably be reduced by wave-induced turbulence and combined wave-current shear stress, and much of the sediment deposited in the short term would be expected to be re-suspended during high wave events. **However no modelling has been reported, or other assessment made, of the longer term dispersion and deposition pattern of sediment arising from construction discharges, or from harbour dredging. There has been no assessment of additive effects during the several years of construction on suspended sediment concentrations within Cemlyn Bay and the waters which enter Cemlyn Lagoon.**

E Comments on the Sediment Regime Report (APP-217)

41 Partrac Ltd were commissioned by Jacobs, on behalf of HNP, to undertake a synthesis of the baseline information relating to coastal processes and sediment regime in the Wylfa Newydd area. The review included a desk study of earlier reports, empirical evaluation of background environmental data, analysis of modelling results and application of professional judgement. **No field data relating to processes, sediments or geomorphological features were collected as part of the assessment. Similarly, no detailed analysis of historical time series of environmental data (tides, hind-cast waves, meteorological data) was undertaken.**

42 Section 4.2 of the report (APP-217) summarises available information relating to tidal water levels, including National Tide and Sea Level Facility (NTSLF) data for the Holyhead Tide Gauge 2008-2016, and a very brief summary of the maximum and minimum water levels recorded at a temporary tide gauge deployed at the Wylfa Magnox jetty between March 2010 and 2011. However, no comparison between the Wylfa and Holyhead records is presented.

43 A summary of the ten highest recorded levels at Holyhead up to November 2017’, including the height above HAT relative to Chart Datum, is presented (Table 6) and estimates of extreme tidal levels at Cemaes Bay and Wylfa made by Halcrow in 2012 are reproduced in Table 7 of APP-217. However, the basis and likely reliability of these estimates is not discussed. No new analysis of the frequency of observed water level elevations at Holyhead has been undertaken, and no assessment made of potential differences in extreme water levels between Holyhead, Cemlyn Bay, Wylfa and Cemaes Bay.

44 A summary of the minimum, mean and maximum current velocity at each of the four oceanographic monitoring stations (S2, S4, S9 and S11) is presented in Table 8, although the depths and tidal levels to which the values relate are not stated. Wave conditions at the time of recorded velocity also are not stated.

45 Figures 15-18 in APP-217 illustrate (a) depth-averaged flow directions and current speeds produced by the Delft 3D model and (b) inferred bed shear stress calculated from the depth-averaged current velocity, at mid-ebb and mid-flood during neap and spring tides. As would be expected, the figures show a general reduction in current velocities and bed shear stresses from the offshore region towards the inner part of Cemlyn Bay and Cemaes Bay. It is stated (p24 of the report) that “the distribution of (modelled) current velocities corresponds well quantitatively with velocities recorded at the (four) fixed monitoring stations”, but no statistical data are presented to support this statement.

46 Wave data were obtained at three four oceanographic monitoring stations using bottom-mounted Automated Wave and Current meters (AWACS), each with directional wave measurement capability, between July 2010 and November 2011. However, as previously noted in this review, the period of instrument deployment was relatively calm and no severe storms / wave events were recorded.

47 Outputs from the modelling of bed shear stress using the coupled DELFT-3D hydrodynamic and SWAN wave models are illustrated in Figures 30 and 31 of the Partrac report. The results show that wave action (in winter) has a major effect on the magnitude and distribution of bed shear stresses. During winter wave scenarios high bed shear stresses (>2 N m^{-2}) move closer inshore, affecting the relatively exposed rocky shore between Porth-y-pistyll and Cemlyn Bay which is likely to be swept clear of loose sediment. Within the outer and mid parts of Cemlyn and Cemaes Bay, wave-induced bed shear stress is considered likely to operate primarily in a landward direction, but closer to the shoreline a more complex situation is considered likely to exist, influenced by both landward and seaward wave-induced current motions. The details of the nearshore sediment transport processes, and their potential implications for the fate of suspended and sea bed sediment, are not discussed in detail within the report.

48 A geophysical survey by Titan Surveys in 2009 provided information about the general character of the sea bed, including the distribution of major sediment bodies and rock outcrops. A number of boreholes made in the marine area close to the proposed harbour works by Fugro Ltd in 2016 provided additional information about the sub-surface sea bed, but none were drilled within Cemlyn Bay. The principal sediment categories identified were 'Veneer' (consisting mainly of sand and gravel), 'Sandy Channel Fill' (also composed mostly of sand and gravel), 'Boulder Clay' and 'Bedrock'. **A map of the surficial sediment types inferred from the geophysical surveys is included in the Partrac report. However, the map has not been comprehensively ground truthed by sea bed grab sampling and laboratory analysis. Only a relatively small number of subtidal and intertidal sediment samples hae been collected as part of the baseline assessments, and there is a lack of clarity about the exact number, sampling positions and dates of sampling.**

49 The Partrac report (APP-217) states that 28 samples were collected from the Project area during a benthic sampling campaign by Jacobs in 2011; Figure 31 in the Partrac report shows particle size histograms for 25 samples reported collected by Jacobs in 2011, Figure 32 is a map showing 15 locations which were sediment samples were collected by Jacobs in 2015, and Figure 33 is a map showing 23 benthic and sediment sampling locations attributed to "Jacobs 2017". However, the Benthic Ecology report prepared by Jacobs in December 2017 (APP-220, appendix A4) presents particle size histograms for 24 samples collected in 2011, 24 collected in 2011 and 15 collected in 2015. Only one subtidal benthic and sediment sampling location (WS3) was located in Cemlyn Bay, and that very close to entrance. **No tables of particle size results with the expected location / timing metadata are presented in either report, and no estimates of the critical bed shear stress have been made by Partrac for any of the samples**.

50 Additional borehole samples were analysed for particle size following the FUGRO ground investigations in 2010, but the summary data presented in Table 23 of the Partrac report only state the relative percentages of clay, silt, sand, gravel and cobbles. Only four of the samples are sea bed surface samples.

51 **No sediment samples from the shingle ridge, nearshore sea bed or Cemlyn Lagoon have been analysed for particle size distribution. Consequently there is great uncertainty in estimating the critical bead shear stresses which would be required to initiate movement of bed sediment in these areas.**

52 Suspended sediment concentrations (SSC) were reportedly measured (using optical backscatter instruments) at six marine locations off the development area and along the wider North Anglesey coast (shown in Figure 33 of the Partrac report). None of the stations was located within Cemlyn Bay. The samples were collected using Lund tubes which provide an integrated water sample from the surface to 10 m below the surface. The average SSC ranged from 5.6 mg / l at station WQ1 to 8.2 mg/l at site

WQ3.The minimum concentration at all sites was c. 3 mg/l and the maximum recorded was 46.8 mg/l. Near-bed SSC were also inferred from turbidity data collected by Titan Surveys in 2010-11 at the four oceanographic monitoring stations. Average concentrations were generally found to be low (< 20 mg/l) but with occasional higher spikes (up to 217 mg/l). In general, near bed SSC were found to increase over spring tides and decrease over neap ties, in parallel with the pattern of current velocities. N**o measured SSC data were obtained for the inner part of Cemlyn Bay, presenting a significant gap in the baseline information.**

53 Monitoring of streams within the five identified fluvial catchments (Tre'r Gof, Afon Cafnan, Nant Cemlyn, Nant Cemas and Power Station Catchment) also included monitoring of total suspended solids (TSS). A summary of the average, maximum and minimum values recorded in each catchment is provided in Table 26 of the Partrac report. **Only six samples were obtained from the Nant Cemlyn which flows into Cemlyn Lagoon, the minimum concentration being 7 mg/l and the maximum 2750 mg/ l (average 1053 mg/l). This number of samples is too small to provide a representative picture of temporal variation or 'average' baseline conditions.**

54 Section 6.3 of the Partrac report contains an assessment of the potential mobility of the sea bed sediments in relation to the bed shear stress values predicted by the hydrodynamic and coupled hydrodynamic and wave modelling. The sea bed sediment at each model grid point was characterized either as entirely sand (< 2 mm) or gravel (< 8 mm) with sand. Mud was not considered in the analysis. The assessment focused on spring tide ebb conditions as these were considered to represent the 'worst case' in terms of potential sea bed mobility. Table 27 of the report provides a summary of the critical shear stress and percentage time exceedance for different size categories of sand and gravel. The results suggest that gravel is stable at all four oceanographic monitoring locations when subject to tidally-induced shear stresses alone, but that fine and medium sand could potentially be mobilized for 48.7% and 36.3 % of the time, respectively, at station S9 (entrance to Cemlyn Bay).

55 Table 28 in the report summarises the limiting significant wave height required for waves to 'feel' the sea bed (where the water depth is less than ten times the significant wave height), and the percentage of time when wave exceed this threshold at each of the monitoring stations. The critical value of significant wave height at station S9 (near the entrance to Cemlyn Bay) is identified as 1.6 m, which has a modelled exceedance of 10.7% of the time, generally associated with waves form a northwest or north-northwest direction. Similar values were indicated for station S11 at the entrance to Cemaes Bay, but the data for the offshore stations S2 and S4 suggest very little sediment resuspension occurs due to wave action, except during severe storms. The worst storm during the monitoring period (estimated to be almost a 1 in 10 year event on 13-15 November 2010) resulted in a measured maximum SSC concentration of 289 mg/ l at station S4 (Table 29 of the report). The report concludes that, owing to the relatively low tidal current speeds within the bays, any sandy sediment re-

suspended by winter wave storm) conditions is unlikely to move far and will be trapped within the current gyres generated by the headlands, rather than being exported by ebb currents to the open sea. **However, there is also no discussion in the report of the likely net transport behaviour of mobilized fine sand on the sea bed close to the shore within Cemlyn Bay and Cemaes Bay, or of the likely behaviour of different sand and gravel fractions within the Esgair Gemlyn ridge.**

56 Table 30 of the report summarises the extreme significant wave heights calculated by HR Wallingford for five offshore model points and 1, 10, 20, 50, 100 and 200 year return periods. **However, no comparable estimates are presented for the inner part of Cemlyn Bay which would assist assessment of the potential impacts on the shingle ridge.**

57 **Given the poor quality of the information Baseline for Cemlyn Bay, and the high level of uncertainty regarding the possible effects of the proposed marine structures on the integrity of the shingle ridge, lagoon and adjoining sea bed in Cemlyn Bay, it is of critical importance that further work is undertaken to develop the following:**

- **an adequate morphological, sediment and water quality baseline, before any construction or preparatory work is started, against which any potential future changes can be monitored**

- **a 'fit for purpose' monitoring programme, agreed with NRW and NGOs; as a minimum this should include water levels (both tides and waves) topography / bathymetry, surface sediments and suspended sediments**

- **a suitable package of remediation and/or compensation measures in the event that any potentially negative impacts on the ridge / lagoon / bay are identified following the commencement of construction. These could include beneficial use of suitable sand and shingle materials arising from the harbour development works.**

F Recommendations regarding requirements for future monitoring and consideration of mitigation / remediation / compensation options

58 **It is recommended that a monitoring programme should be established with the purpose of detecting possible negative changes in the morphology and sediment volume of the barrier before they might become a significant problem, and to allow remediation or compensation options to be considered in good time.**

59 **Pye & Blott (2016) initiated RTK GPS topographic surveys of 13 profiles across the Esgair Gemlyn shingle ridge in 2016 (Figure 15). A further survey at low water spring tide was carried out in August 2018. It is recommended that similar surveys should be undertaken twice a year, in spring and autumn, in line with strategic coastal monitoring practice.**

60 **Both HNP and KPAL have undertaken comparisons of airborne LIDAR surveys undertaken in 2010 and 2017 to determine changes in the cross-sectional morphology of the barrier. An elevation difference map between these two surveys is illustrated in Figure 16 and a comparison of levels along the ridge crest between 2010 and 2018, determined from the LiDAR and ground survey data, is shown in Figure 17. KPAL have also used the LiDAR data to undertake detailed analysis of changes in sediment volume above different elevation levels and within 27 defined 'cells' along the barrier (Figure 18). This approach has been used to identify 'weak' points in the ridge where overtopping and/ or breaching is most likely (Table 3; Figures 19 & 20). It is recommended that a future monitoring strategy should include similar methodology, in conjunction with monitoring of water levels (including waves) and water quality parameters in Cemlyn Bay and Cemlyn Lagoon.**

61 **It is recommended that a list of potential intervention options should be developed through discussions and agreement between HNP, NRW, the NT, NWWT and RSPB. The options for consideration, which might provide the basis for a formal beach management plan, should conclude:**

- **'Do nothing'**
- **intensify monitoring and defer decision on further intervention**
- **re-profiling of the ridge**
- **recycling of existing shingle within the bay**
- **beneficial use of shingle removed from the littoral zone of Porth-y pistyll during the marine construction works, or from other sources, either to improve the resilience of the shingle ridge and nesting islands, to extend the islands, or to create new islands.**

62 **A clear system of 'governance' should be established for the management of the monitoring programme, including commissioning of surveys, reporting, assessment of results and procedures for determining change threshold levels for further action. This might incorporate a 'traffic light' system for staged responsive action.**

63 The capacity of Esgair Cemlyn to retain similar morphology and crest height relative to the tidal frame in the face of future sea level rise will be limited by low rates of natural sediment supply and the low level of the lagoon floor over which it must migrate. As a result, the risk of over-washing, breaching, and/ or blockage of the lagoon inlet / outlet is likely to increase over time. **One option to address this problem would be to increase the volume of the shingle ridge using suitable imported sediment. Marine shingle from a proximal source would be preferable, on several grounds, to the use of imported rock or sediment of a different composition from a distant source. It is recommended that detailed consideration should be given to the possibility of using shingle 'dredged' from the proposed marine works in and around Porth-y-pistyll for this purpose. This possibility has been raised by the NGOs during consultation meetings with HNP's consultants, but has not so far been progressed.**

64 Pye & Blott (2018a) undertook a preliminary exercise to estimate the volume of shingle which would be required to improve the resilience of the shingle ridge to overtopping under present day conditions, and with allowances for future sea level rise. In this indicative 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 21). 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. For this indicative exercise, the crest line of the ridge was realigned by up to 3 m 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. It was calculated that c. 5100 m^3 of shingle would be required to achieve the idealised 'target' barrier morphology under present day conditions. The estimated volumes of shingle required to maintain the shingle ridge under different sea level rise scenarios are summarised in Table 4.

65 A preliminary assessment was also made by Pye & Blott (2018a) of the volume additional shingle that might be required to enlarge the existing tern nesting islands. Several options exist and further discussion is required involving relevant parties:

- 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 retaining walls, maintaining the present level (some infilling work has already been undertaken as part of the Roseate Tern *Life* project during the 2017-18 winter)

- as above but also raising the levels of the existing retaining walls and 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 the 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 involving removal and re-use of shingle from the barrier side of the islands in order to widen the channel and create space for the barrier to move westwards

- as above, but raising the islands to allow for sea level rise

- abandonment of the existing islands and creation of new islands further back in the lagoon.

66 By way of example, Figure 22 illustrates the option for landward extension of the two existing islands without removal of sediment from their eastern sides. Table 5 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.

G References

APP-014 Horizon Nuclear Power *Wylfa Newydd Development Area and Power Station Site Plans (1 of 2)*

APP-015 Horizon Nuclear Power *Wylfa Newydd Development Area and Power Station Site Plans (2 of 2)*

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APP-131Horizon Nuclear Power 6.4.12 ES Volume B – D12 – Coastal processes and coastal geomorphology

APP-132 Horizon Nuclear Power 6.4.13. ES Volume B – D13 – The marine environment

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Tables

Table 1. Average tidal levels predicted at the Standard Port of Holyhead (predictions by UKHO and NTSLF) and the Secondary Port at Cemaes Bay (UKHO), and levels at Cemlyn Bay estimated by Pye & Blott (2018b) on the basis of short-term tidal measurements. Values in brackets are averaged from the neap and spring tidal values. All elevations expressed in metres relative to Ordnance Datum Newlyn (ODN)

Tidal level	**Holyhead**		**Cemaes Bay**	**Cemlyn Bay**
	NTSLF predictions (NTSLF website)	UKHO predictions (2018 Admiralty Tide Tables)	UKHO predictions (2018 Admiralty Tide Tables)	Pye & Blott (2018)
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
MSTR	4.95	4.90	5.80	5.50
MNTR	2.49	2.40	2.80	2.69

Table 2. 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 3. Sediment volumes (m^3) above 5.00 m ODN (the approximate limit of extreme wave run-up) within defined cells on Esgair Gemlyn, seaward and landward of the barrier crest and for the whole barrier, calculated from LiDAR surveys in 2010 and 2017 (profile 1 at the northwestern end, profile 27 at the southeastern end). The net change between 2010 and 2017 is also shown (data from Pye & Blott, 2018a)

	Sediment volume seaward of crest m^3			**Sediment volume landward of crest m^3**			**Sediment volume of whole barrier m^3**		
	2010	**2017**	**Change 2010- 2017**	**2010**	**2017**	**Change 2010-2017**	**2010**	**2017**	**Change 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 4. Estimates of additional volumes of gravel required (in m^3) along the length of the shingle ridge, 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 95th percentile medium emissions scenario), 26 cm (Welsh Government (2016) allowance), 31.8 cm (UKCP09 95th 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 (from Pye & Blott, 2018a)

	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 5. Estimates of additional volumes of sediment required (in m^3) to enlarge the two tern islands,: the northern (Main) 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 ('New') island to the saltmarsh island limits similar to those shown on the Six-inch Ordnance Survey map surveyed in 1926. Surface levels are assumed to be 2.80 m ODN (approximate present maximum level), and assumed higher levels to allow for future sea level rise (from Pye & Blott, 2018a)

	Approximate 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

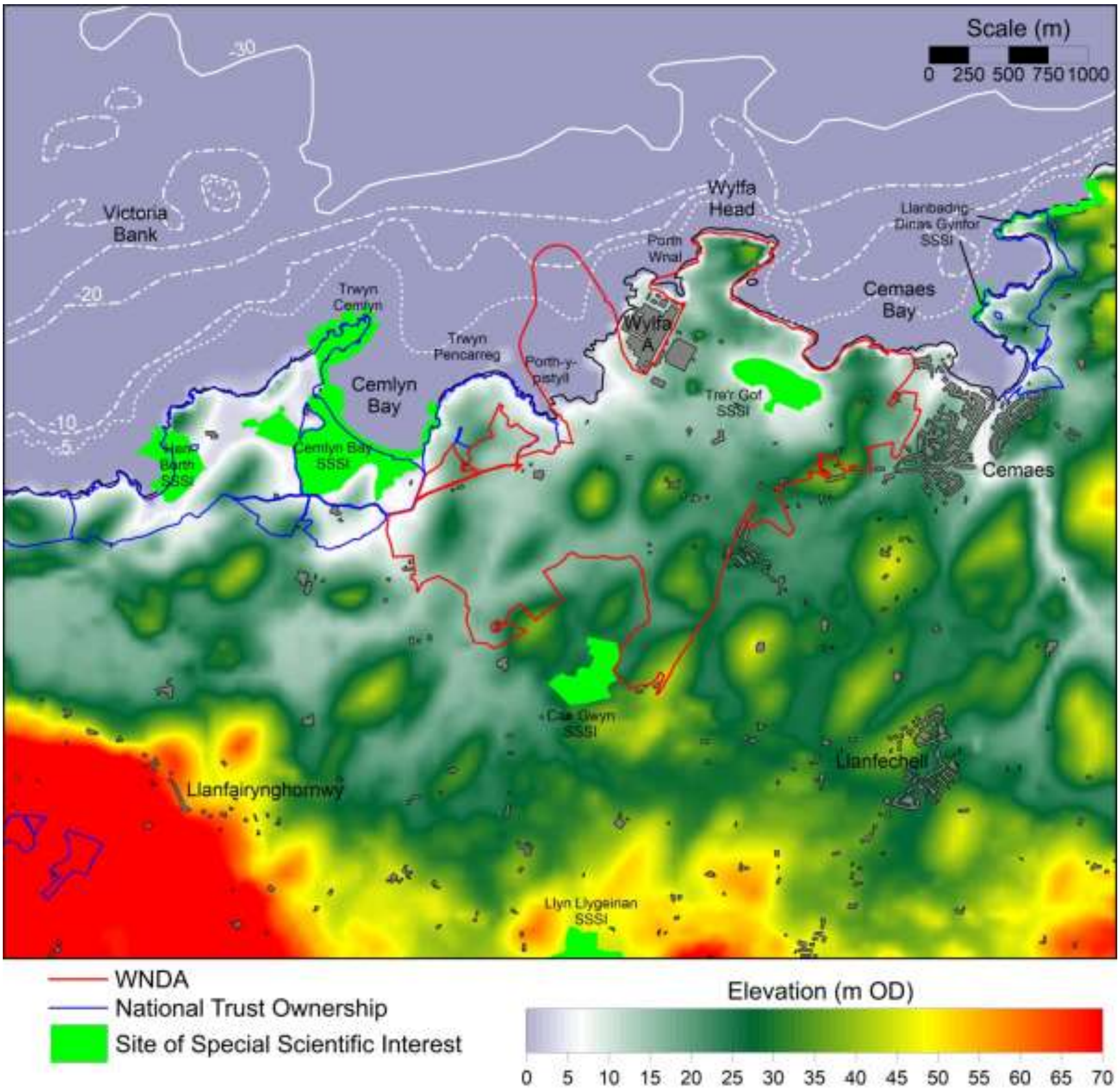

Figure 1. Boundaries of the Wylfa Newydd Nuclear development Area in relation to National Trust interests and Sites of Special Scientific Interest (SSSIs) on the North Anglesey coast. The topography is based on open source 5 m Ordnance Survey digital data

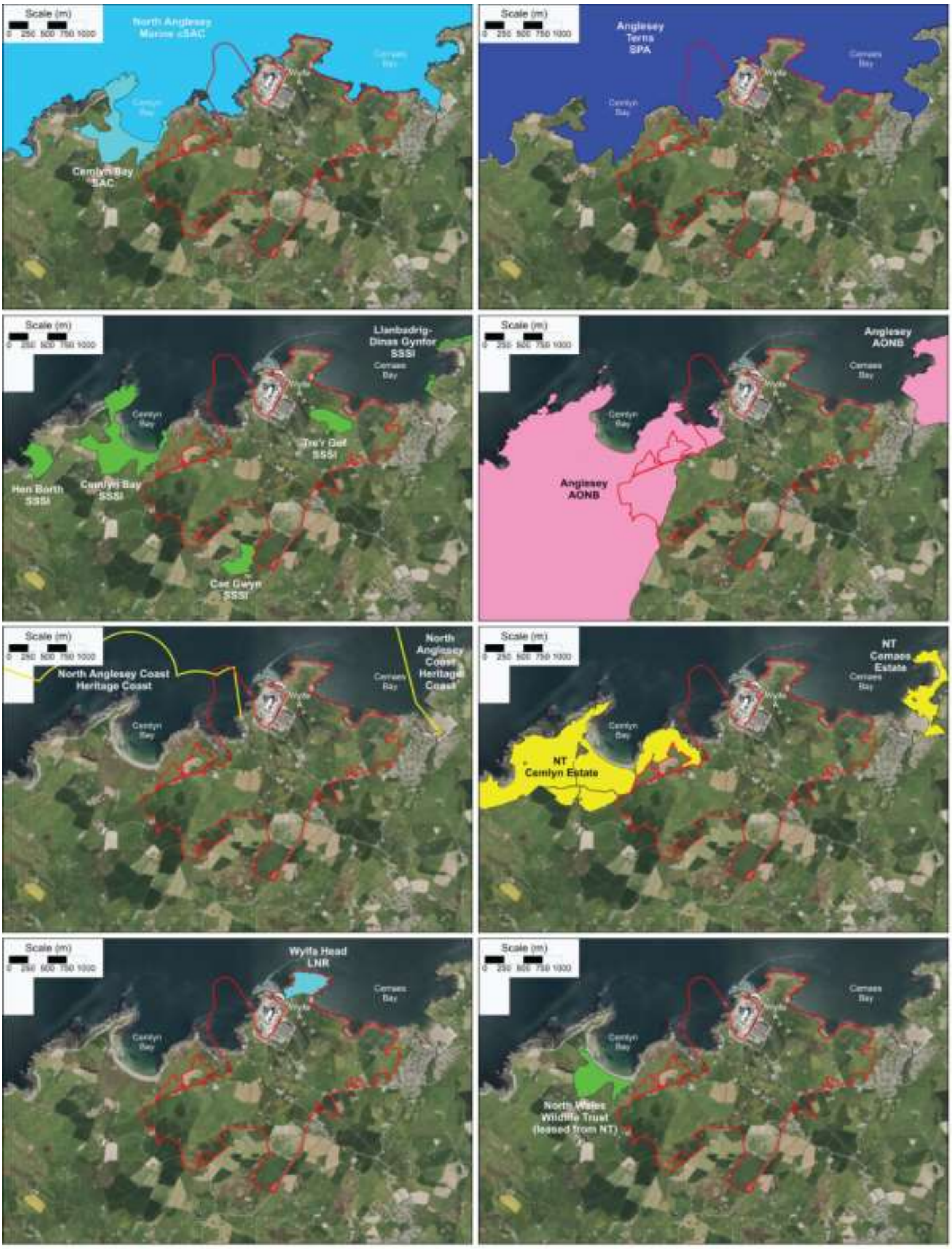

Figure 2. Internationally and nationally designated conservation areas in proximity to the WNDA

Figure 3. Proposed location of earth mounds, drainage routes and discharge points within the WNDA, also showing extent of proposed harbour works (indicative boundary of statutory harbour limits shown by the white dotted line); Project information taken from DCO documents and superimposed on base 2014 aerial photography

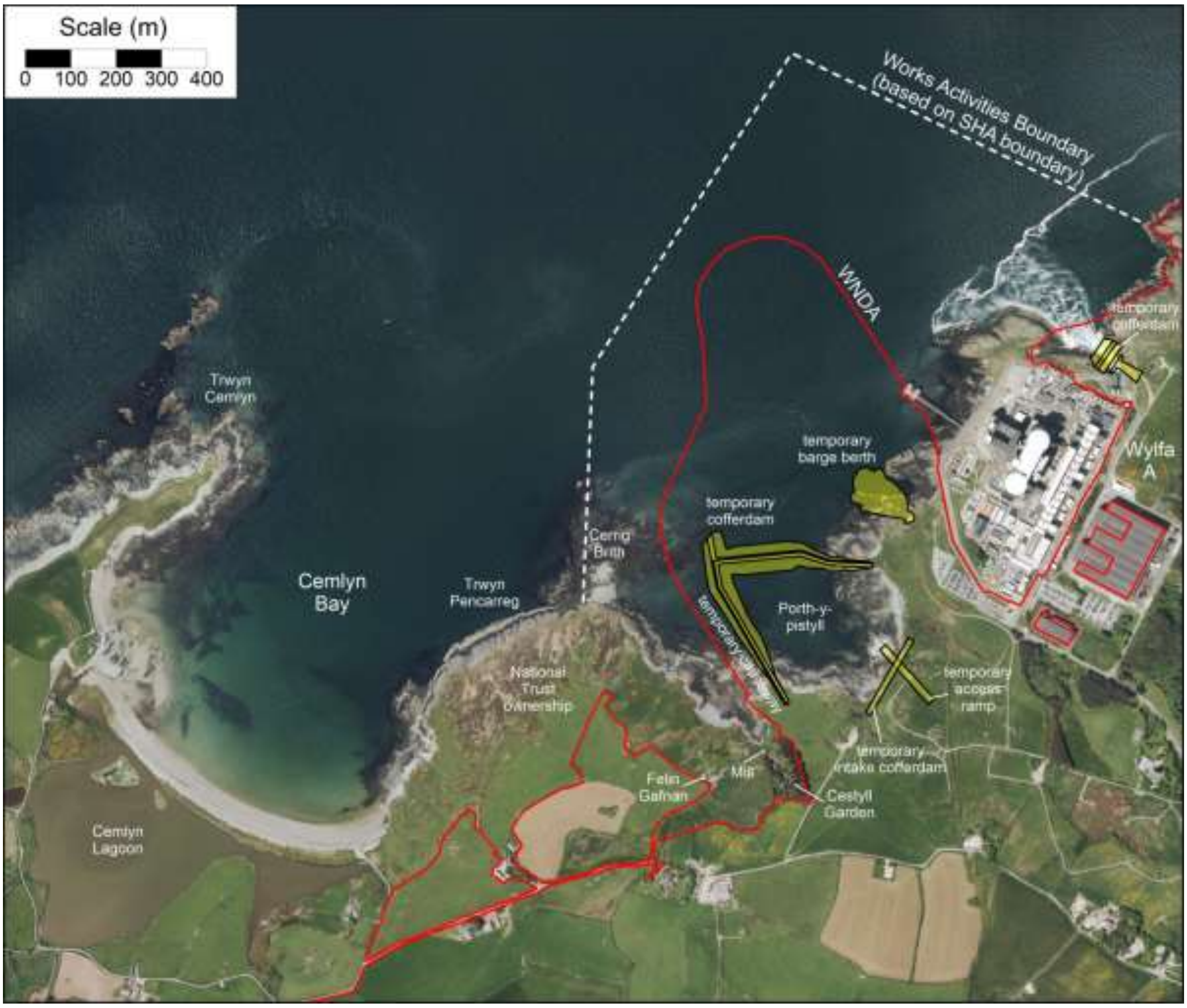

Figure 4. Location and extent of features associated with the construction phase of the proposed marine works (construction information from App. Ref No. 2.6.3, PINS No. EN10007, Wylfa Newydd project Volume 2: Plans, Sections and Drawings (Part 8/19, Rev. 1.0, June 2018; based aerial photography dated spring 2014). SHA = Statutory Harbour Authority

Figure 5. Enlargement of part of Figure 3 (Porth y-pistyll area)

Figure 6. Location and extent of features on completion of the proposed marine works (construction information from App. Ref No. 2.6.3, PINS No. EN10007, Wylfa Newydd project Volume 2: Plans, Sections and Drawings (Part 8/19, Rev. 1.0, June 2018; base aerial photography dated spring 2014)

Figure 7. Enlargement of part of Figure 5 (Porth-y-pistyll area)

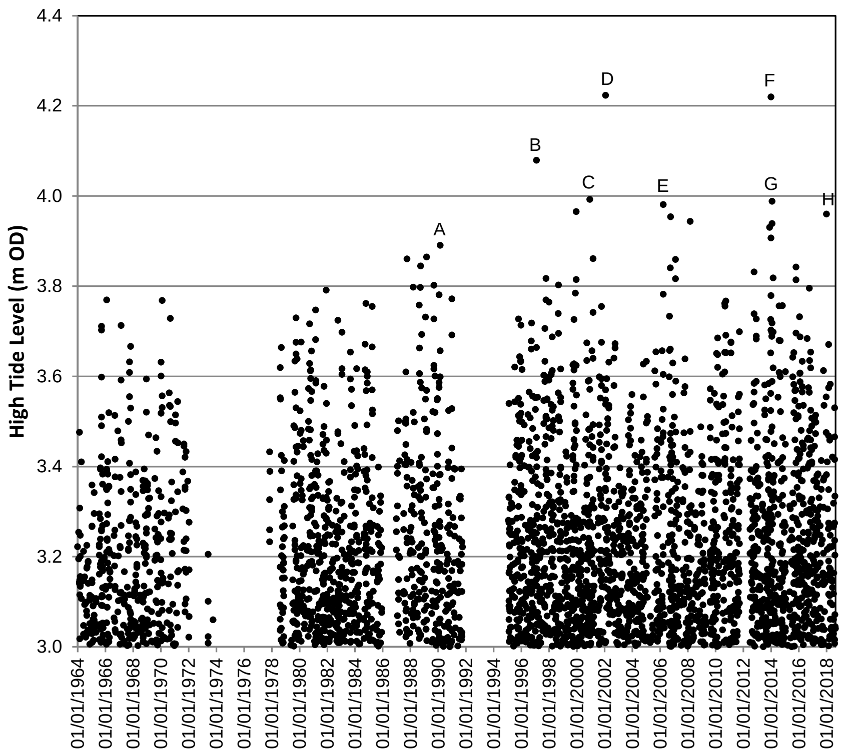

Figure 8. High water levels recorded at Holyhead during the period January 1964 to August 2018, converted to levels in Cemlyn Bay. Particularly high tides are annotated: (A) 26/02/1990; (B) 10/02/1997; (C) 12/12/2000; (D) 01/02/2002; (E) 30/03/2006; (F) 03/01/2014; (G) 03/02/2014; (H) 04/01/2018 (from Pye &Blott, 2018b)

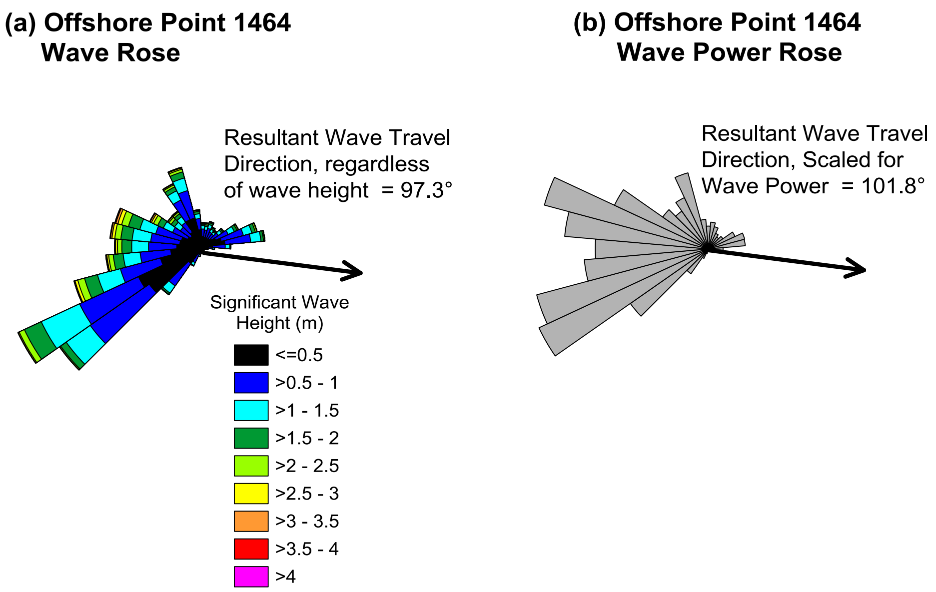

Figure 9. Wave roses for hind-cast offshore point 1464, 5.3 km NNE of Cemlyn Bay (at 236426E 398086N), for the period 1980-2016 inclusive: (a) approach direction and resultant travel direction scaled for all waves, with colours showing distribution of wave heights; (b) wave approach direction and result travel direction direction scaled for wave power (raw data from Cefas Wavenet website, figure reproduced from Pye & Blott 2018a)

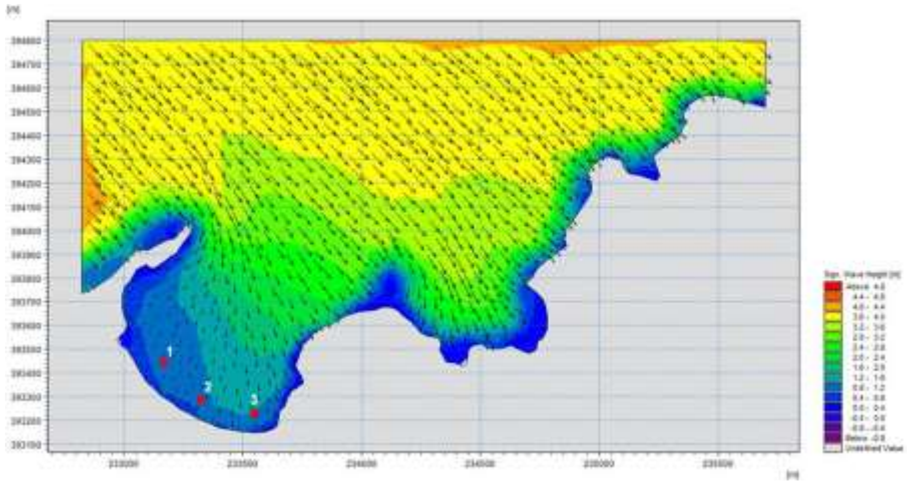

Figure 10. Significant wave height and wave direction with assumed model boundary input conditions of H_s = 4.0 m, T_p = 8 s, and Wdir N310^{o}E (northwest) , indicated by MIKE 21 modelling. Red dots indicate points are which numerical values of predicted inshore H_s were extracted from the model (from Pye & Blott, 2018a)

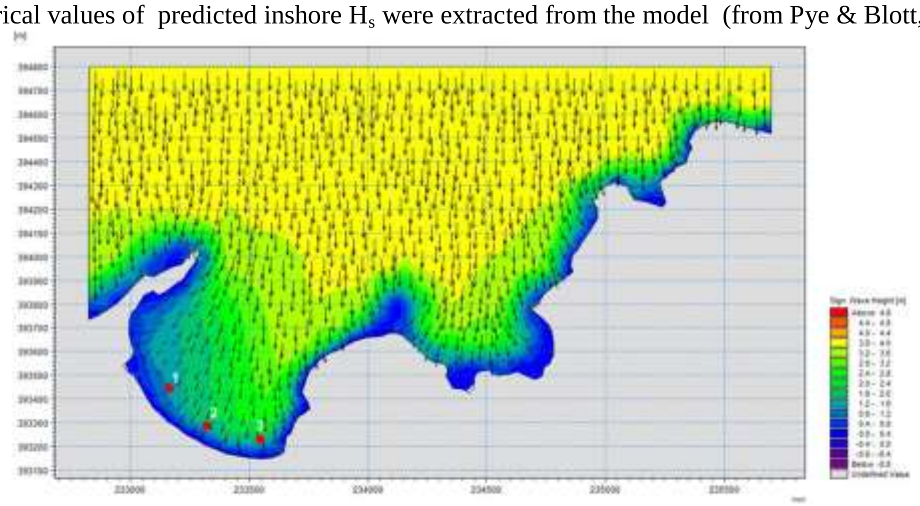

Figure 11. Significant wave height and wave direction with assumed model boundary input conditions of H_s = 4.0 m, T_p = 8 s, and Wdir N360^{o}E (north), indicated by MIKE 21 modelling. (from Pye & Blott, 2018a)

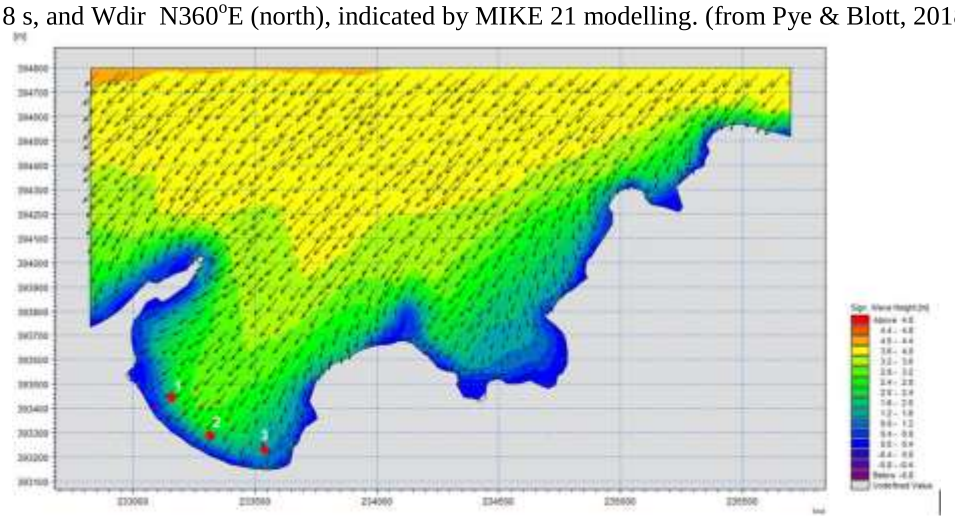

Figure 12. Significant wave height and wave direction with assumed model boundary input conditions of H_s = 4.0 m, T_p = 8 s, and Wdir N360^{o}E (northeast), indicated by MIKE 21 modelling. (from Pye & Blott, 2018a)

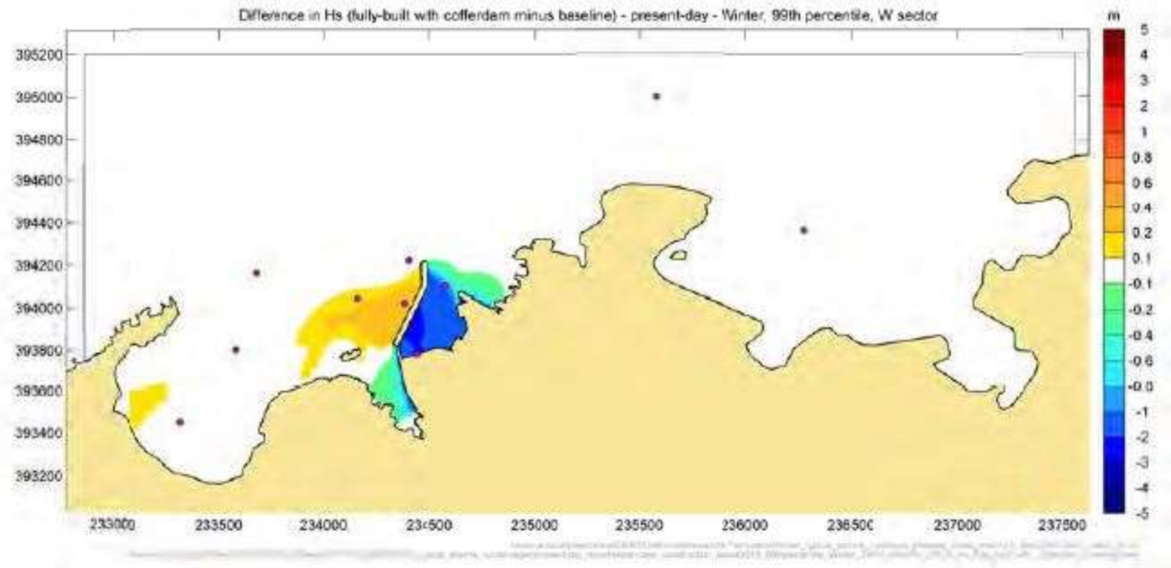

Figure 13. Difference in H_s for the fully-built (with cofferdam) 2023 scenario minus baseline, Winter 99th % wave from the NW (300°) (from Jacobs 2018)

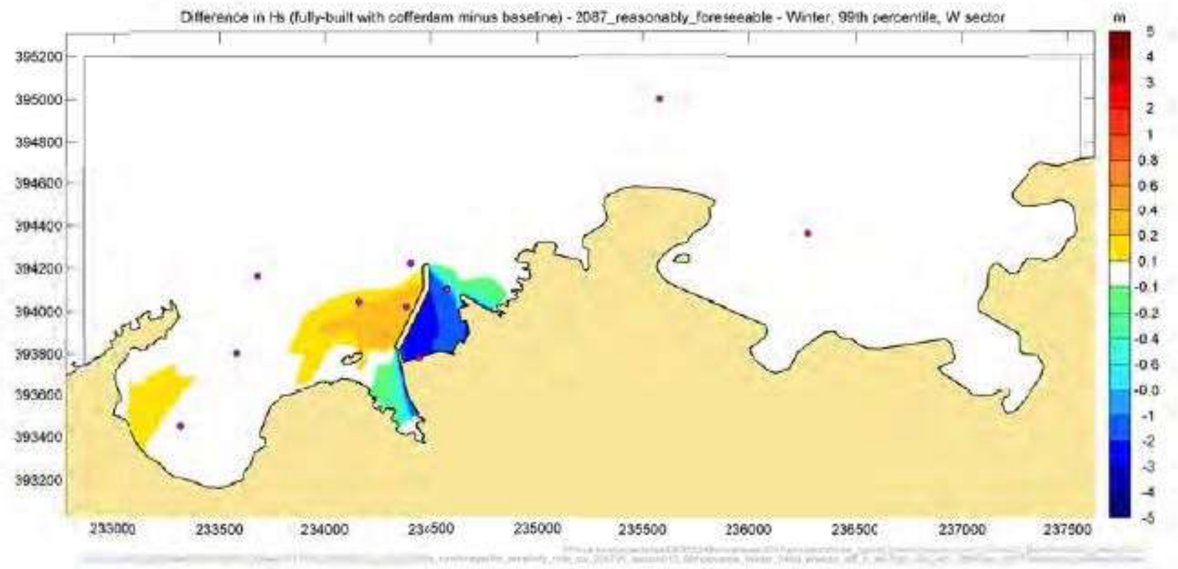

Figure 14. Difference in H_s for the fully-built (with cofferdam,) 2087 scenario minus baseline, Winter 99th % wave from the NW (300°) (from Jacobs 2018)

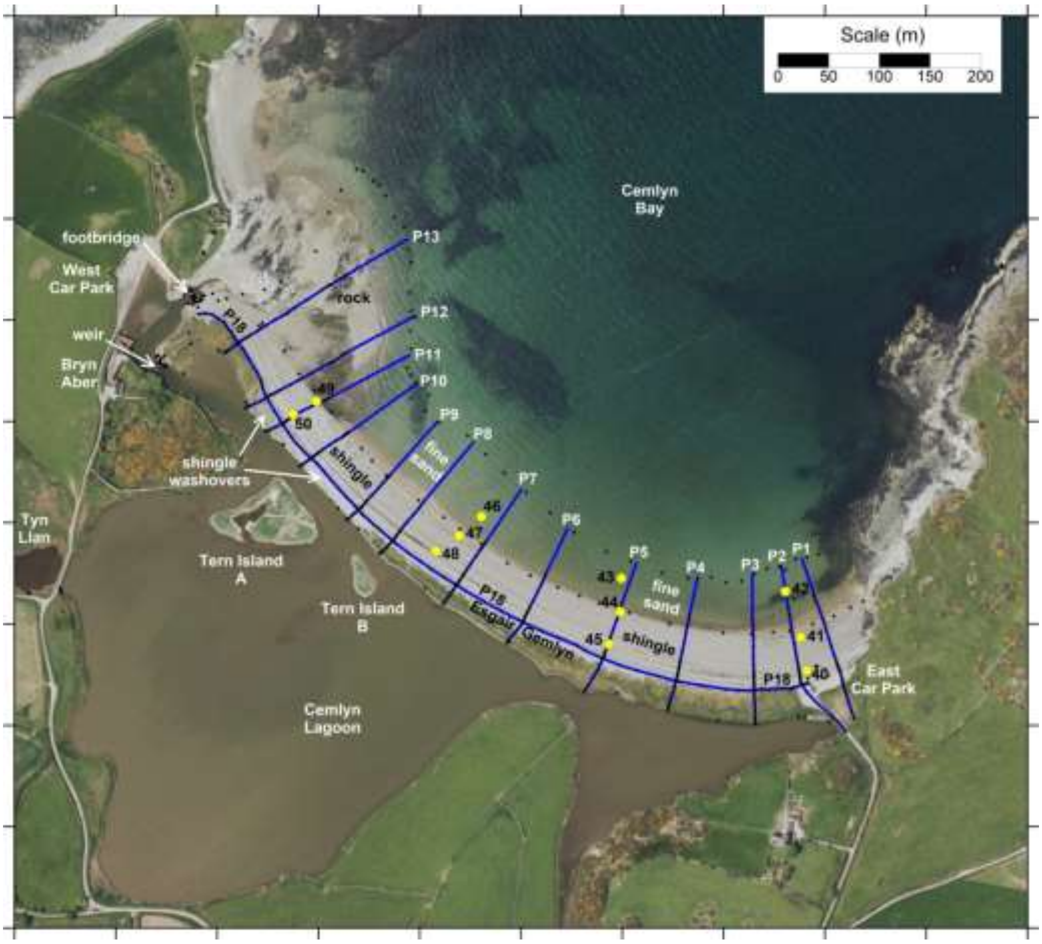

Figure 15. Locations of KPAL RTK GPS topographic survey profiles P1 - P18 (blue) and survey points in August 2018 (black dots). Yellow dots indicate the positions of beach sediment sampling. A and B are the tern nesting islands. Base aerial photography flow spring 2014 after the stormy winter of 2013-14

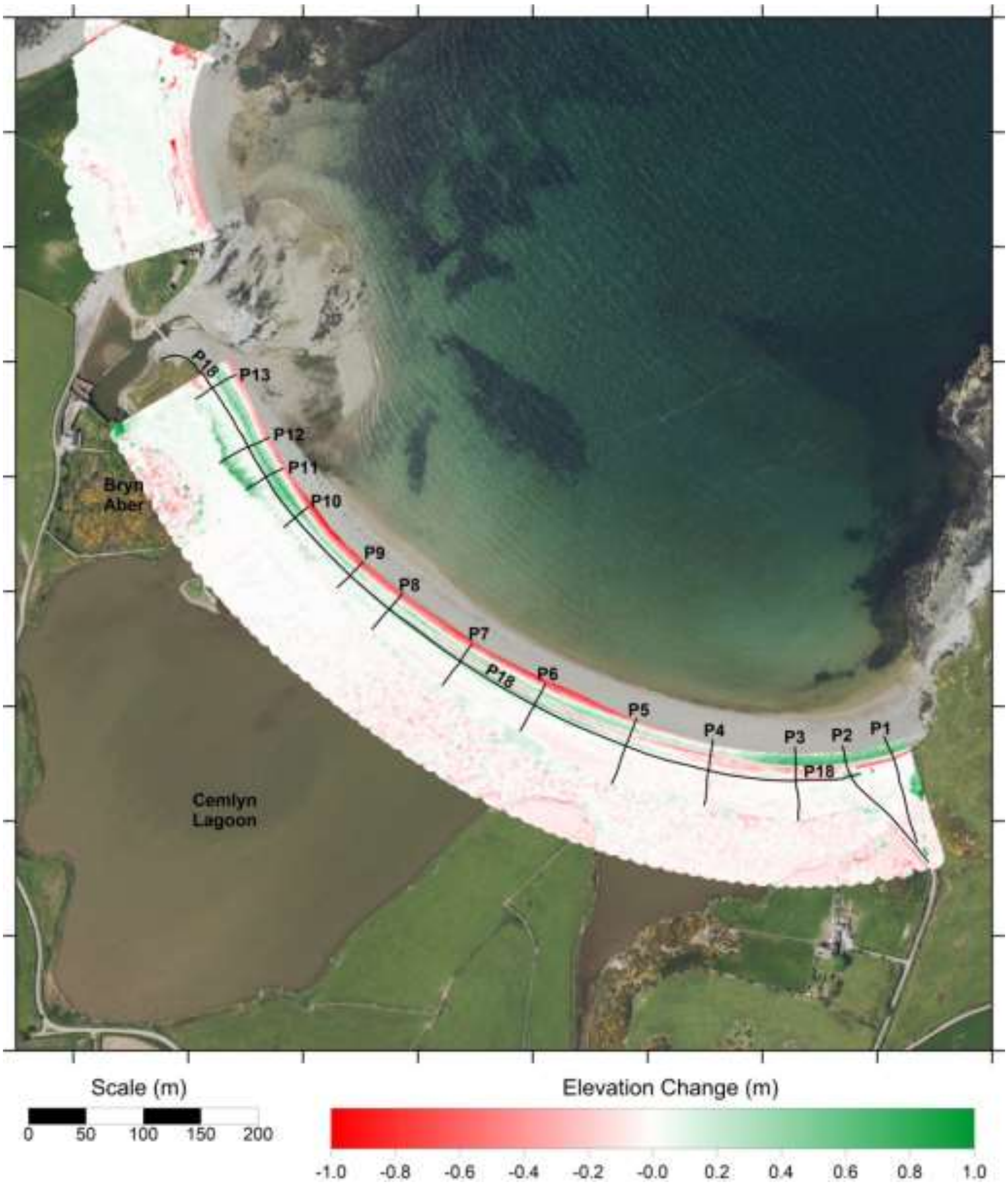

Figure 16. Elevation difference between LiDAR surveys in 2010 and 2017 (from Pye & Blott, 2018a)

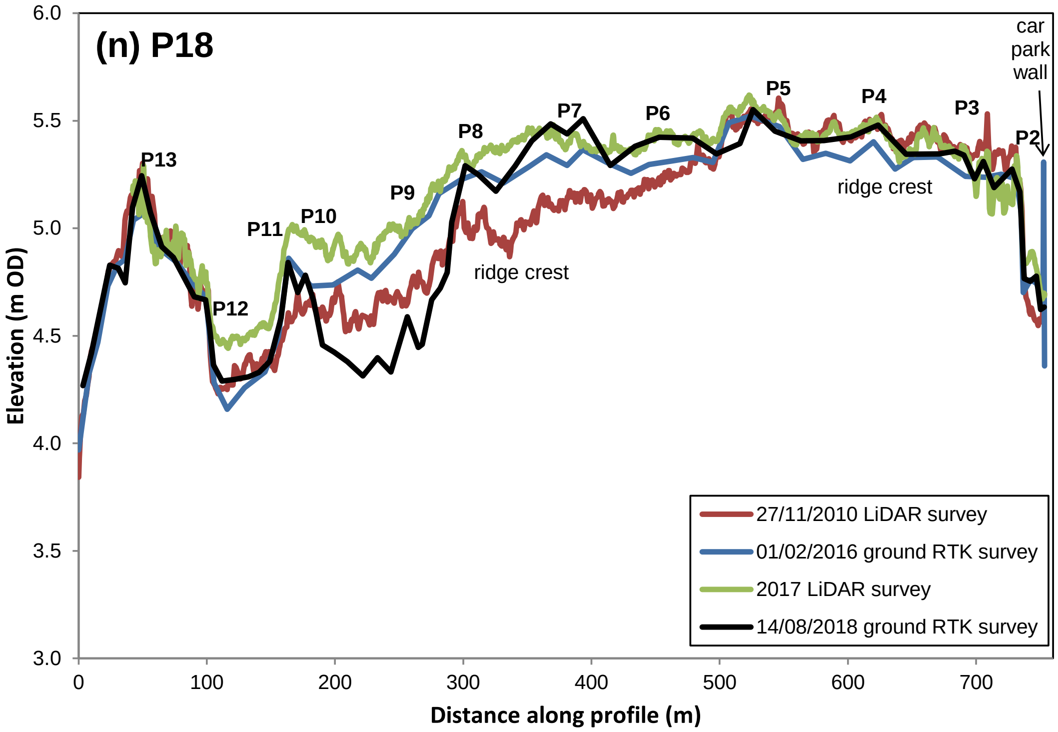

Figure 17. Profiles along the shingle ridge crest determined from LIDAR surveys and ground surveys between November 2010 and August 2018. The positions of the cross-shore profile P1 - P13 are shown on Figure1 & 16. The ridge crest between profiles P1-P2 and P7 - P12 is susceptible to over-washing during storm events (from Pye & Blott, 2018b)

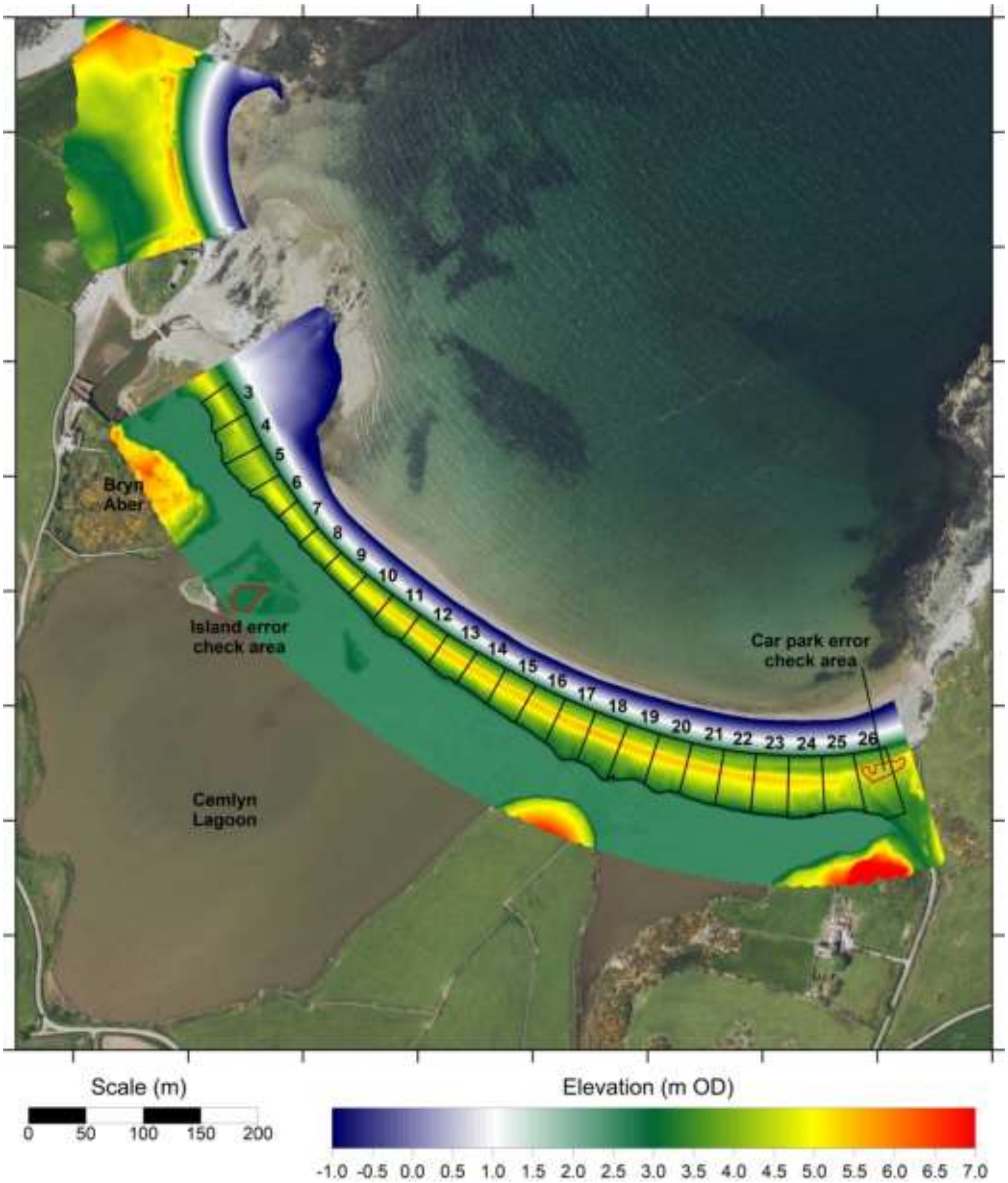

Figure 18. Location of defined sediment cells used to calculate sediment volumes, superimposed on spring 2017 LiDAR DTM (survey commissioned by Jacobs); data for cells 1 and 2 are only available for the 2010 Geomatics LiDAR survey (from Pye & Blott, 2018a)

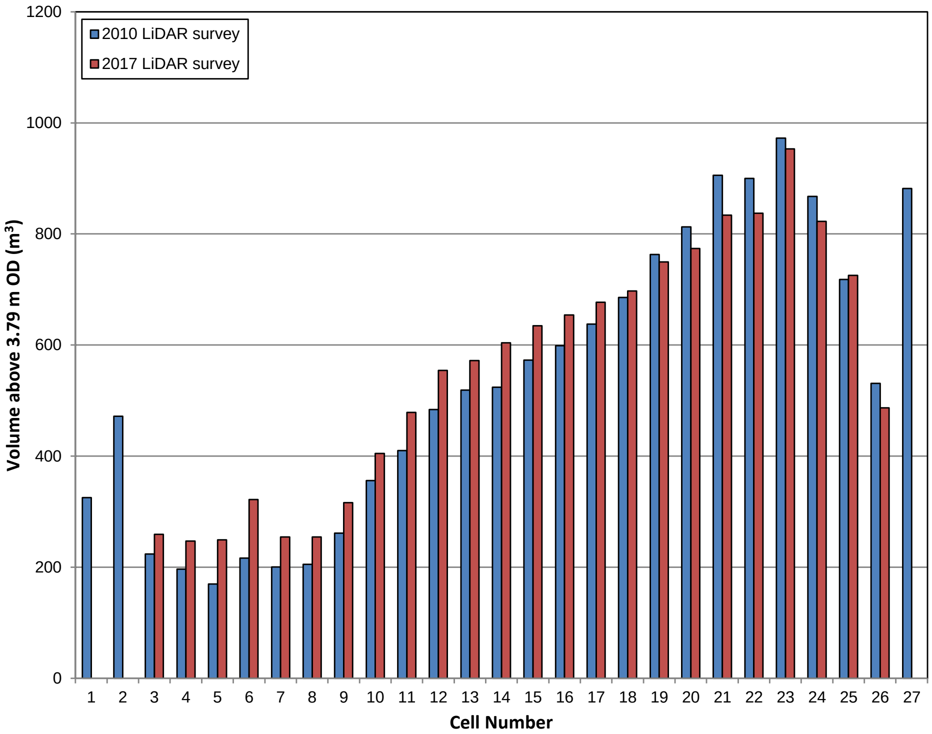

Figure 19. Comparison of sediment volumes of the shingle ridge above 3.79 m OD (HAT) in cells 1 – 27, based on LiDAR surveys in 2010 and 2017

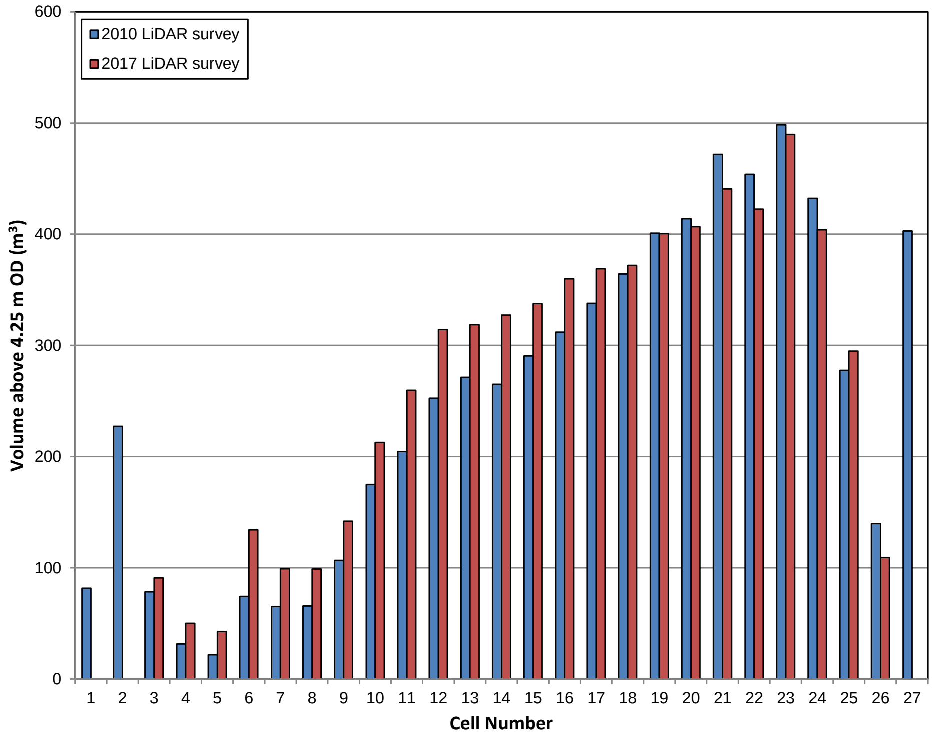

Figure 20. Comparison of sediment volumes of the shingle ridge above 4.25 m OD (1 in 200 year surge level) in cells 1 – 27, based on LiDAR surveys in 2010 and 2017 (from Pye & Blott, 2018a)

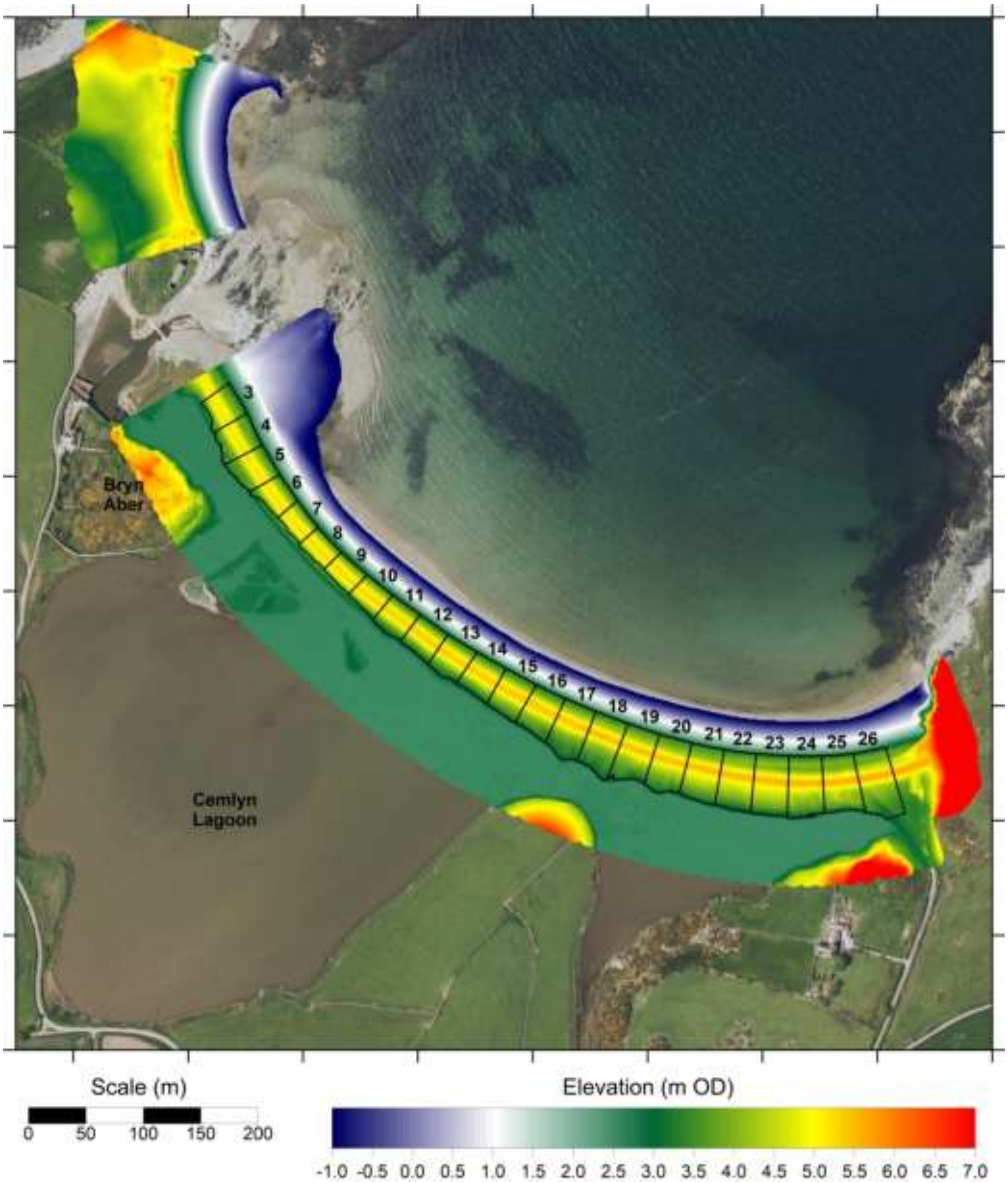

Figure 21. Modified terrain model of the shingle ridge after hypothetically increasing the height and volume to match the ridge profile in Cell 12, and with an assumed ridge crest elevation of 5.2 m ODN at NW end and 5.7 m ODN at SE end (from Pye & Blott, 2018a)

Figure 22. One possible option to increase the surface area of the tern islands using imported sediment . Base aerial photography flown spring 2014 (from Pye & Blott, 2018a)

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