Pwllheli Harbour
Crib Groyne Assessment and Review

September 2017
Draft Report

Cyngor Gwynedd Council
Swyddfa'r Cyngor
Stryd y Jel
Caernarfon
Gwynedd
LL55 1SH

Coastal Engineering UK Ltd
26 Rhodesway
Wirral
CH60 2UB
e-mail: ceuk@coasteng.co.uk
Tel. (0151) 558 1956

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Coastal Engineering UK Ltd
26 Rhodesway, Wirral CH60 2UB
Tel: +44 (0)151 214 3350
e-mail: ceuk@coasteng.co.uk
http://www.coasteng.co.uk

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1. INTRODUCTION

Pwllheli Harbour is located on the south side of the Lleyn Peninsula in North Wales (ref Figure 1). The specific local arrangements are provided in Figure 2.

In April 2014 Arup was commissioned by Gwynedd Council to review dredging arrangements in Pwllheli harbour and prepare a Maintenance Dredging Strategy for the harbour covering the period 2015-2025. The final strategy[1] published in January 2016 identified a range of options for managing siltation within the harbour in both the short term (0-3 years) and the medium term (4-10 years).

As well as revised maintenance arrangements for dredging within the harbour and arrangements for disposal of the material removed, the strategy identified that modification of the existing groyne structures located at the mouth of the harbour could play a role in managing sediment movement into the harbour. Specifically, in this respect, the strategy identified measures to be undertaken in both the short and medium term, namely:

- In the short term, reinforcing and increasing the height of the existing crib groyne on the south side of the harbour entrance;
- In the medium term, to examine in greater detail the role and function of the existing control structures to identify optimum arrangements.

The maintenance dredging strategy identified that to progress item 1, the next stage should include:

- Desktop study and examination of design information relating to the existing groyne structure;
- Examination of the structure to assess its current state;
- Specific geotechnical investigation; and
- Assessment of sea state parameters.

[1] Arup, Jan 2016. Pwllheli Harbour Maintenance Dredging Strategy Updated Strategy Report

2. BACKGROUND & GENERAL DESCRIPTION

2.1 HISTORICAL EVOLUTION

At the end of the last ice age approximately 10,000 years ago sea levels rose rapidly producing a dynamic, rapidly evolving coastline. As sea levels started to stabilise, the coastal features we see today started to evolve. The estuaries of the Afon Erch and Afon Rhyd-hir would have had extensive saltmarsh and mudflats, some of which would have occupied the space where the A499 and A497 are now located. All the land occupied by the present golf course and much of Pwllheli would have been intertidal saltmarsh/mudflats and Carreg yr Imbill would have been a small rocky island.

Waves and currents started to reshape the landscape moving sediment such that a shingle spit grew east from Carreg Y Defaid and started to force the Afon Penrhos to flow eastward. Eventually the shingle spit grew to such an extent that it joined with Carreg yr Imbill, the Afon Penrhos becoming a tributary of the Afon Rhyd-hir and both flowed east into the sea to the north of Carreg yr Imbill. These conditions are shown on the earliest known map evidence, c. late 13th century[2].

From the late 16th Century to the early 19th century maps show Pwllheli at the confluence of the three rivers (Afons Penrhos, Rhyd-hir and Erch) with the Cardigan Bay facing frontage effectively a spit of land surrounded by water with Carreg yr Imbill at its eastern end (see Figure 3).

In the early 19th century (1811-1814) a north/south orientated embankment or cob, with associated tidal gates, was built linking Pwllheli Town to Traeth Crugan, providing the present harbour area to the east.

Construction of the embankment was the catalyst for development of the south part of the town. The eastern section of frontage (South Beach) was developed from the latter part of the 19th century as part of the town's development into a holiday resort.

At the eastern end of the South Beach frontage the rock headland of Carreg yr Imbill now provides the updrift headland for a classical crenulate shaped bay to the east, with a sweeping spiral to the next rock headland at Pen-y-Chain. Immediately to the north of Carreg yr Imbill is a spit that gradually developed from the 19th century onwards as longshore drift of sediment was transported eastwards, by-passing the headland and was deposited on the east side.

During the first half of the 20th century the spit developed and extended northerly, as can be seen from the historic Ordnance Plans from this period (ref Appendix A). During the second half of the 20th century the spit continued to extend until the current harbour arrangements were implemented in the early 1990s.

These arrangements primarily comprised a combination of dredging and new shoreline arrangements within the harbour area and on the north side of the harbour entrance. However on the south side of the harbour entrance a new 90 metre long terminal groyne, orientated approximately in an ENE direction, was constructed with the primary purpose of preventing the drift of sediment that was being moved along the spit, east of Carreg yr Imbill, from entering the harbour channel.

The groyne is a 3.5 metre wide vertical sided crib construction constructed from 27 sets of 7.5 metre long vertical bullhead rail piles at 3.5 metre centres longitudinally. The pairs of piles are horizontally braced at 3.8 metres below the top of the pile and diagonally braced at each vertical pile location, alternately left hand and right hand. The sides of the groyne comprised 7/8 bullhead rail walings, along each side at 600mm centres vertically. The first 6 sets of piles were set at a top level of 4.2m ODN with the level reducing uniformly to 0.0m ODN. A section through the groyne is shown in Figure 4.

The inside of the groyne was infilled with 1-1.5 tonne rock fill down to the bottom waling level.

[2] Posford Duvivier, March 1996. South Llŷn Peninsula Shoreline Management Plan Stage 1

2.2 CURRENT POSITION

An inspection of the frontage was carried out on 19th July 2017 by Alan Williams of Coastal Engineering UK Ltd, accompanied by Dewi Cullen from YGC. Plates showing the conditions recorded, as described below are provided in Appendix B.

Working north eastwards from the headland of Carreg yr Imbrill, the foreshore initially comprises low level rock outcrop which is intermittently covered with a mixture of sand and shingle. This section fronts the Gimblet Rock Holiday Park, with a vertical masonry wall at the top of the beach, which provides protection to the holiday park infrastructure (ref Plate 1).

Moving north easterly the outcropping bedrock reduces and the beach becomes a mixture of small boulders, cobbles and shingle (Plate 2). At the top of the beach the vertical wall gives way to a low level earth embankment supplemented by large boulders with the lower parts of the beach becoming finer moving towards the harbour mouth (Plate 3). The exact provenance of the boulders is unknown but it is thought they are probably arisings from the quarry that operated at Gimblet Rock, which is shown on OS plans from 1891-1960s (ref Appendix A: Historic OS Plans). This embankment continues longshore to the landward end of the crib groyne.

Approximately 100 metres south of the crib groyne there is a Dwr Cymru Holding Tank, which is protected by a vertical sea wall with some large boulders placed in front (Plate 4). This holding tank is fed by a rising main on the south side and is connected to an outfall on the north side that runs longshore towards the crib groyne and then alongside the upstream side of the crib groyne[3]. Between the holding tank and the crib groyne the upper beach comprises predominantly boulders and cobbles with the lower parts of the beach comprising finer sediment, generally a mixture of sand and shingle (Plate 5). Moving towards the groyne the boulders have been mounded up into an informal defence along the crest (Plate 6).

On the updrift side of the groyne approximately 17 piles are visible with only the top 700-800mm of the groyne visible (Plate 7). The top walings have been damaged on this side with sections of them missing and/or bent across and over the groyne (Plate 8). On the downdrift side there are sections of damaged walings, that have been removed from the other side of the groyne, lying on the beach (Plate 9). The walings on this side remain in situ with the top three walings visible at the seaward end of the groyne (Plate 10). Moving up the groyne, the beach level increases, with only two wailings visible (Plate 11). Similarly 17 piles are visible with the top 10 pile sets on both sides completely covered by a mixture of boulders (Plate 12).

Within the groyne the rock armour has been moved about, particularly from the downdrift side where the walings have been damaged/removed (Plate 13). This armour has been moved by wave action and there is evidence that some of it has been deposited on the beach on the downdrift side (ref Plate 9).

On the downdrift side of the groyne, within the harbour mouth, the upper parts of the beach comprise mounded boulders with a lower beach of finer sediment (Plate 14). This gives way to a vast area of sand/shingle that has pushed the harbour channel towards the north side (Plate 15). Material here is regularly removed and stockpiled nearby (Plate 16)for recycling to Traeth Crugan, from where some of it eventually finds its way back along the beach and round Carreg yr Imbrill.

The boulders at the top end of the beach and over the top of the groyne may have been moved by wave action and effectively provide a degree of protection from wave overtopping.

[3] The general arrangement details for the crib groyne indicate that an existing sewer outfall connected to the Dwr Cymru holding tank was diverted along the updrift side of the crib groyne. The pre construction details suggest this is a 400 dia. ductile iron pipe but there is no visible evidence of this at the site.

3. PROBLEM DEFINITION, OBJECTIVES AND APPROACH

3.1 PROBLEM

The strategy identified that the current structure is too short and below its original crest elevation and that consequently the structure is not performing its function with material either by-passing or being transported over the crest of the structure.

3.2 OBJECTIVES

The primary aim of the review carried out here is to examine whether increasing the structure height will prevent material entering the harbour and to identify what other actions could appropriately be taken either instead of or in addition to raising the structure, to potentially reduce sediment transfer into the harbour[4].

3.3 APPROACH

The approach adopted to meet the above objectives, is as follows:

- Carry out a site visit and undertake a visual survey of the structure to provide a contemporary record of its current condition and residual life expectancy;
- Review of available historical and contemporary information relating to hydrodynamic criteria, geotechnical data, topographic/hydrographic data and design information;
- Review of the design proposals provided in the maintenance dredging strategy and consideration of other potential options;
- Preparation of budget cost estimates for the different options examined; and
- Production of a design review report, including recommendations for taking the project forward including requirements for collection of additional data/information.

[4] Note examination of the length of the structure will be assessed within the medium term arrangements but is commented on within the reporting presented here.

4. HYDRODYNAMIC REGIME

4.1 INTRODUCTION

Local-scale processes that control beach evolution and exposure conditions in the vicinity of Pwllheli harbour are primarily driven by the offshore hydrodynamic and sedimentary regimes that operate within Cardigan Bay, which are then modified by interaction with the bathymetry in the northern part of the Bay and shoreline features of the South Lleyn. The hydrodynamic regime is defined as the action of tides and other meteorological influences such as winds, which produce waves, and changes in atmospheric pressure, which can produce changes in water levels (surges).

4.1.1 Tidal Regime

Coastlines with Cardigan Bay bordering the Irish Sea are subject to the Atlantic tidal wave that propagates into the area via the St. Georges channel to the south. As the tidal wave passes, interactions with the sea bed and landforms produce variations in both elevation and flow patterns.

Tides within Cardigan Bay are semi-diurnal, i.e. the water level rises and falls twice a day, with a time difference between successive high or low waters of between 12 and 13 hours.

Predicted astronomical tide levels applying at Pwllheli are based on corrections from Milford Haven, which is the Standard Port for Cardigan Bay (Admiralty, Taunton)[5] and are provided in **Error! eference source not found.** below:

Table 4.1: Astronomical Tide Levels	
Tidal Level	**Level (m AOD)**
Highest Astronomical Tide (HAT)	3.36
Mean High Water Spring Tide (MHWST)	2.66
Mean High Water Neap Tide (MHWNT)	1.16
Mean Tide Level (MTL)	0.32
Mean Low Water Neap Tide (MLWNT)	-0.54
Mean Low Water Spring Tide (MLWST)	-1.84
Lowest Astronomical Tide (LAT)	-2.45
Ordnance Datum Newlyn (ODN) to Chart Datum (CD) Factor	+2.44

The above predicted tidal levels do not however account for changes in atmospheric conditions e.g. air pressure which can lower or increase the level of the tide (surges), or persistent wind conditions that can generate wind-driven currents and set-up water levels.

Storm surges in the Irish Sea are dominated by external forcing from outside the region. The largest surges are generated by depressions travelling from the south and south west at speeds of around 75km/hour (Halcrow, 2008).

Estimates of extreme water levels that will apply less frequently can be made based on available records and numerical modelling.

The EA/DEFRA funded R&D project (SC060064) entitled "Coastal Flood Boundaries" (formerly "Development & Dissemination of Information on Coastal and Estuary Extremes"), was completed in 2011[6] and provides the most up to date and consistent set of extreme sea levels for the coastline of England and Wales. Estimates in the vicinity of Pwllheli Harbour (ref CFB chainage 870) are provided in Table 4.2 below.

[5] UKHO, 2012. Admiralty Tide Tables, 2013, Volume 1. Published by United Kingdom Hydrographic Office.

[6] Environment Agency, February 2011. Coastal flood boundary conditions for UK mainland and islands. Project: SC060064/TR2: Design sea levels.

Table 4.2: Estimated Extreme Tidal Levels for Study frontage (ex Coastal Flood Boundaries Study published 2011)*									
Return Period (Annual Probability of Exceedance)	1 (>99.9%)	5 (20%)	10 (10%)	20 (5%)	50 (2%)	100 (1%)	200 (0.5%)	500 (0.2%)	1000 (0.1%)
Level	3.41	3.62	3.70	3.78	3.88	3.95	4.04	4.16	4.27
Confidence Limits (m)	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3
* Values provided by this study (base year 2008) can be considered accurate to one decimal place									

The nearest records of actual measured tide levels are from the National Tide Gauge Network Class A gauge at Barmouth (NGR 261961E, 315450N). Quality checked tide gauge data are freely available and have been obtained from the BODC web site (https://www.bodc.ac.uk/data/online_delivery/ntslf/).

Values recorded at Barmouth for annual probabilities defined in Table 4.2 are typically 0.1-0.2m higher than the values defined for Pwllheli.

Tidal Flows

Tidal flows or streams are pressure generated forces which act through the depth of water between the sea surface and the sea bed. They are produced by the movement of the tide and are driven locally by gradients in sea surface.

Within Cardigan Bay tidal flows are generally low along the open coast lengths, typically of the order of 0.1 to 0.2m/s during spring tides and about half these values on neap tides[7]. Flood flows are generally dominant and act to move sediments towards the shoreline[8].

Modelling studies carried out for the Abererch frontage[9] identified a number of key behaviour characteristics relevant to conditions around the harbour mouth, specifically under normal conditions (ref Figure 5a):

- the flow around the Carrig yr Imbill spit is up to 0.2m/s whilst into the harbour flows reach about 0.15m/s, and
- in the harbour entrance the maximum current speeds occur around mid ebb and flood when the rate of change of water level is the greatest which occurs. The harbour arm constrains the flow patterns in the entrance channel.

but under storm conditions (ref Figure 5b):

- the harbour arm and Carreg yr Imbill spit provide a sheltering effect; and
- there are increased flow speeds in the nearshore zones of up to around 1m/s.

These results suggest that under normal conditions with higher current speeds away from the shoreline sediment from the seabed is more likely to be washed around the crib groyne into the harbour. Under storms the speeds are higher closer to the shoreline with the potential for material to be trapped, although some will by pass the groyne due to its relatively short length.

Sea Level Rise

The long term trend in rise in mean sea level (MSL) across the northern part of Cardigan Bay is approximately 2mm per annum[10] (POL, 1997).

[7] Gwynedd Council February 1998. North Cardigan Bay SMP Stage 1 Volumes 1 and 2.
[8] Faber Maunsell/AECOM, October 2008. Traeth Crugan - Pwllheli Coastal Defence Options Study for Gwynedd Council.
[9] Halcrow, April 2006. Abererch Phase II, Preliminary Studies Report for the Environment Agency Wales.
[10] Proudman Oceanographic Laboratory, June 1997. Spatial Analyses for the UK Coast. Internal Document No. 112

The latest available climate change guidance[11] (UKCIP, 2009) provides revised predictions for the rises in relative sea level (sea level + land changes) for the whole of the UK coastline up to 2100 for different CO_2 emission scenarios. Current Welsh Government guidance[12] recommends the use of the 95%ile values in relation to examination of flood and coastal erosion risk management practice. The figures applicable for the Pwllheli frontage in this respect are provided in Table 4.3 below for up to 100 years in the future.

Table 4.3: Estimated Relative Sea Level Rise during the 21st Century (mm) [ex UKCIP, 2009]

	Year		
CO2 Emission Scenario	**2037**	**2067**	**2117**
Medium 95th Percentile	100	282	665

4.1.2 Wind and Wave Regime

Waves in Cardigan Bay are generally generated by winds blowing across the Irish Sea or as a result of longer period swell waves that have propagated into the area from the Atlantic Ocean via the St Georges Channel with the predominant exposure direction from the south west sector. The West of Wales SMP2 proposed a generalized assessment of net offshore wave exposure conditions, as can be seen in Figure 6, which also provides locations of specific wave climates in the vicinity of Pwllheli.

There are no direct measurements of wave conditions at or near the harbour mouth but wave modelling techniques have been used in past studies to provide estimates of conditions closer to the shoreline.

The Faber Maunsell/AECOM Traeth Crugan Study (footnote ref [8] above) produced a 15 year (1990-2004) wave climate for three locations along the frontage between Carreg y Defaid and Carreg yr Imbill. The nearest point being approximately 1km west of Carreg yr Imbill. A wave rose of this data is provided in Figure 7. In addition Hindcast wave conditions from the CEFAS Wavenet Hindcast database[13] are available for location 1200 (Grid ref 244830E, 326800N), which is located approximately 10km south east of the harbour mouth. This provides wave climate data for the period 1st January 1980 to 31st December 2016 and was provided by Kenneth Pye Associates Ltd (KPAL) for use in the assessment. A wave rose of this data is provided in Figure 8.

These two climates are significantly different, but reflect the overall wave regime as shown Figure 6. The one further offshore (ref 1200) shows characteristics of the predominant climate in this part of Cardigan Bay with exposure conditions centered on the SW sector, whereas the inshore climate (ref TC West) located in shallower water (bed level approx -6.0m ODN) is sheltered from waves from directions west of SSW by the shoreline features west of Pwllheli and the waves are refracted to approach the shoreline mostly from directions just east of south.

As waves approach the shoreline they are modified by a number of processes such as refraction, shoaling, and friction. The impacts of these are heavily influenced by the local bathymetry applying on the approaches (ref Figure 9). The conditions applying at the harbour mouth are likely to be marginally more severe than along the coast at Traeth Crugan, due to the shoals occurring just off the shoreline.

Towards the seaward end of the groyne it is estimated that waves of up to 2.0 metres in height could impact the structure in association with highest astronomical tidal conditions.

For extreme events such as occurred most recently in winter 2013-14 when a tidal level of 3.92m ODN was recorded at Barmouth on the 3rd January 2014, equivalent to a 1 in 20 year return period level (5%

[11] UKCP09, 2009. http://ukclimateprojections.defra.gov.uk/.
[12] Welsh Government, December 2011. Adapting to Climate Change: Guidance for Flood and Coastal Erosion Risk Management Authorities in Wales.
[13] http://wavenet.cefas.co.uk/hindcast

annual probability of exceedance), a water level of about 3.8m AOD would have been expected at Pwllheli and under these conditions higher waves could potentially have impacted the structure. Note the estimated significant wave height at the CEFAS Wave Point (1200) during that event was 3.3 metres from a direction of 240° WCB and 3.5 metres from the same direction at the time of the following high tide, when the recorded tide level was 300mm lower.

To examine how waves will be modified as they approach the shoreline a one line wave model - Swan One - (TU Delft, March 2009), has been used to transform wave and tide conditions inshore in order to define wave conditions applying in the vicinity of the crib groyne.

SwanOne is the one dimensional element of the 2D version of the SWAN wave model package developed by Delft University of Technology in the Netherlands. SWAN is a freely available third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bathymetry and current conditions. The model is based on the wave action balance equation with sources and sinks. It is used by many government authorities, research institutes and consultants worldwide. Details of the wave propagation, generation and dissipation processes can be found in the SWAN Technical Manual (Delft University, 2006).

This model uses the bathymetry along a line or section between an offshore point and the shoreline. In this case the bathymetry has been taken from Admiralty Chart data (ref Figure 9) between offshore point 1200 and the crib groyne and combinations of waves and water levels have been transformed to the 0.0m ODN contour, as shown in Table 4.4 below.

Table 4.4: Wave Transformation to Harbour Mouth

Water Level		Offshore		End of Groyne	
Ref	m (ODN)	Hs	Tp	Hs	Tp
MHWS	2.66	1	5.36	1.09	4.29
		2	7.74	1.83	6.75
		3	9.59	2.49	8.14
HAT	3.36	1	5.36	1.10	4.24
		2	7.74	1.90	6.73
		3	9.59	2.67	8.33
10% APE	3.70	1	5.36	1.10	4.23
		2	7.74	1.90	6.72
		3	9.59	2.72	8.40
		4	11.17	3.22	9.30
1% APE	3.95	1	5.36	1.10	4.22
		2	7.74	1.90	6.70
		3	9.59	2.75	8.44
		4	11.17	3.31	9.36

Generally the above indicates that waves approaching the harbour are not significantly altered in height as they approach the shoreline with waves at the shoreline being typically 80-100% of their offshore height. This provides an indication of potential conditions that can occur in the vicinity of the groyne.

Reference to the inshore conditions to the west (ref Figure 7) suggests that typically waves approaching the shoreline will be less than 2.0 metres in height.

4.2 MORPHOLOGICAL CHANGE

4.2.1 Shoreline Change

Historical changes to the shoreline and development of the spit on the south side of Pwllheli harbour up to the introduction of the current harbour arrangements in the early 1990s are detailed in Section 2.1 above with plan changes identified in Appendix A.

There are no formal records of contemporary change at the mouth of the harbour e.g. beach monitoring records, however the following provide information on change that as taken place:

- Vertical Aerial Photography - photographs from 2000, 2006, 2009 and 2017 are reproduced in Appendix C); and
- LiDAR surveys dated April 2016 (1m resolution), February 2013 (1m Resolution) and February 2015 (50cm Resolution).

4.2.2 Existing Ground Conditions

The general ground conditions across the Pwllheli frontage comprise glacial sands and gravels overlying alluvial deposits with bedrock beneath. BGS data[14] identifies the bedrock as being "Unnamed Igneous Intrusion from the Ordovician to Silurian period, whilst the superficial deposits are described as "Marine Beach Deposits". As the bedrock is exposed in the vicinity of the harbour it might be reasonable to assume that it is not far beneath the surface. The lowest level of the existing piles on the crib groyne at the outer end is -7.5m ODN suggesting that the rock level is lower than this but it is not known if the piles are founded in alluvium or gravel deposits.

The existing database provides no information on the depth of sediments at the site or the underlying strata at the site. The Traeth Crugan study (Faber Maunsell, 2008) identified glacial deposits on the beach on the updrift side of Carreg yr Imbill with no underlying alluvium or bedrock. It is presumed that some site investigation would have been carried out to identify the length of piles required for the crib groyne when it was constructed, although the available drawings provide no indication of such information.

4.2.3 Sediment Movement and Beach Change

There are no records or estimates of sediment movement along the spit between Carreg yr Imbill but the previous Traeth Crugan and Abererch studies (footnote ref [8],[9] above) identified that the drift along the Pwllheli South Beach was predominantly from west to east with Carreg yr Imbill providing a barrier to upper beach drift but that material on the lower beach could by-pass the headland.

Comparison of the levels along the upstream face of the groyne from the LiDAR data with those shown on the groyne construction details are provided in Figure 10, which shows the build up that has taken place since the groyne construction. It is apparent from this comparison that levels probably built up against the groyne fairly quickly post construction but they have remained largely at the same elevation, but with slightly more volatility at the lower part of the profile, for the past ten years or so.

In addition digital terrain models of each of the LiDAR surveys have been produced and comparisons produced to show how the conditions have changed from survey to survey. Difference plots for 2006-2013 and 2013-2015 and 2006-2015 are provided in Figure 11, Figure 12 and Figure 13 respectively.

These plots show the location of the groyne, the line of the present shoreline on the east side of Carreg yr Imbill superimposed in blue and the areas where changes in beach volumes have been calculated edged in red. The models do not include all of the foreshore area as the tide level at the time of each survey was different and comparison of beach change can only be made over the area of foreshore recorded on all three surveys. In this case the area of beach common to all surveys is the area above +0.4m ODN i.e. the area generally above mid tide level.

[14] http://mapapps.bgs.ac.uk/geologyofbritain/home.html

The results of the surveys provide a few key points:

- Loss of beach on the updrift side of Carreg yr Imbill between April 2006 and February 2013 but increase in beach elevations in the same area between 2013 and 2015;
- Over the frontage between the downdrift side of Carreg yr Imbill and the crib groyne little change in beach elevation during both periods with changes in elevation of typically ± 0.25 metres. N.b. LiDAR data is generally considered to be accurate to ± 0.15 metres;
- Changes in volumes across the beach area within 275 metres of the groyne on the updrift side, as shown in Table 4.5below;
- Changes in volumes across the beach area on the immediate downdrift side of the groyne, as shown in Table 4.6 below;
- Changes in volumes across the wider upper beach area within the harbour entrance, as shown in Table 4.7 below;
- Some gains in upper beach areas on the upper beach immediately updrift of the Dwr Cymru Holding Tank (where the shoreline juts out);
- Some build up of material as across the groyne and on the harbour side of the groyne during both periods; and
- Significant changes in the areas used for stockpiling the dredgings from the harbour.

Table 4.5: Change in beach volume on updrift side of groyne

Period	Cut	Fill	Net
2006-2013	690	683	-7
2013-2015	586	1148	562

Table 4.6: Change in beach volume in harbour immediately downdrift of groyne

Period	Cut	Fill	Net
2006-2013	0	1264	1264
2013-2015	100	530	430

Table 4.7: Change in beach volume in harbour entrance

Period	Cut	Fill	Net
2006-2013	405	2398	1993
2013-2015	12550	1163	-11387

4.2.4 Artificial Change

Previous studies have identified that sediment material has been removed from the harbour mouth since 1992 following completion of the current arrangements (Faber Maunsell, 2008). This has predominantly been carried out by land based plant. Details of the work carried out between 1992 and 2001 is provided in Appendix D, which identified that over 100,000m^3 was removed from the harbour entrance during the first ten years following re-modelling of the harbour mouth arrangements. The 2016 strategy report (Arup, 2016) identified that further removal of material has been undertaken annually, since 2009.

The exact areas where material was removed from are not known but examination of the difference plots (ref Figure 11 - Figure 13) does provide some indication of the areas where significant change has taken place. Direct correlation of the volumes identified from examination of the LiDAR (ref Table 4.7) with the amounts removed cannot be made as exact dates of removal are not known but it is reasonable to assume that the 2006 and 2013 surveys were taken when at similar times in relation to removal operations, where as the 2015 survey way well have been recorded soon after a removal operation had taken place.

4.2.5 General Statement of Behaviour

Based on the available data and evidence the following provides a summary of conditions applying with regard to sediment movement within the vicinity of the groyne and the function of the groyne itself.

Sediment movement in the vicinity of the crib groyne will be driven by a combination of tidal currents and waves. Fine sand sized sediment will be moved predominantly in suspension, due to wave and/or tidal action, whilst coarser sand and shingle will be moved predominantly by waves as bed load. Appendix E provides a brief overview of sediment transport mechanisms.

Under normal conditions sand sized sediment is likely to be moved in the sub tidal zone predominantly by tidal currents and this will be generally around the groyne. Under storm conditions sand will be moved around the groyne but also sand sized sediments on the foreshore may be moved around and potentially across/through the groyne.

Tidal currents are unlikely to have a significant effect on gravel movement but under storm conditions wave activity will move larger sediments along the foreshore and sub tidally over the sea bed. With the predominant wave direction inshore (ref Figure 7) being from directions just east of south (150-180° WCB), material across the inter tidal zone will be pushed longshore towards the groyne, passing through or over it if finer or being washed up against or into the groyne if coarser. The groyne is essentially a porous structure so material, can be washed into the voids between the rock armour infill.

Material dredged from the harbour entrance appears from photographic evidence of the stockpile to be a mixture of sand and shingle sized material but predominantly the former. A sample grading analysis from 2011 identifies that 98% of the sample taken was sand (≤2mm grain size).

Examination of the LiDAR surveys indicates that over the past decade changes in beach levels across the upper tidal zone immediately behind the groyne on the up drift side are of similar magnitude to changes on the downdrift side, whilst corresponding changes across the wider harbour entrance have been up to an order of magnitude different and similar to average annual figures for removal of material from the wider area, although it should be remembered that this does not include volumes of material removed from below mid tide level.

Levels against the groyne on the updrift side (ref Figure 10) show a clear increase following construction but little change over the past decade. This suggests that the groyne has been effective in trapping material that would otherwise have found its way into the harbour mouth, as indicated occurred historically (ref Appendix A) but that once levels reached within a metre of the groyne crest that material could be washed up against and over the groyne or potentially drawn down the beach and around the groyne. The change in beach level along the updrift side of the groyne suggests that the former is certainly feasible and visually the presence of shingle within the groyne structure itself provides further evidence to support this behaviour.

The small angular boulders that are present along the crest of the shoreline, over the landward end of the groyne and on the upper part of the foreshore appear to have been placed artificially. It is not clear from the 2000 aerial photo whether the material is in-situ at that time but it may be. Higher resolution imagery is required but the material can be seen forming the top part of the beach from 2006 onwards. The 2006 and 2009 aerial photos only appear to show blocks on the updrift side of the groyne but it is difficult to tell precisely with the grey areas on the immediate downdrift side potentially being this material with the upper parts covered with sand and shingle. Reference to higher resolution versions of this imagery[15], clearly show this material on both sides of the groyne. Groyne inspection photos[16] from 2010 to the present day also confirm that the material is covering the upper parts of the groyne and there is material on the downdrift side of the groyne.

Blocks of this size in this position in can only be moved two ways – either artificially or due to high energy wave conditions. There is no real rationale for this material to be placed artificially on the downdrift side of the groyne but it is feasible that direct wave action during storms could have moved

[15] Google Earth Pro, accessed August 2017.
[16] Gwynedd Council, 2010-2015. Terminal Groyne Inspection Photos

the material both down the beach and up against the groyne on the updrift side and also over the groyne.

It is not possible, from the available data to ascribe proportions to the material passing through/over the groyne and that being moved round by tide and wave action. However in consideration of the above and with reference to tidal levels shown on Figure 10 it is suggested that movement of material over the groyne that feeds the areas, where beach change has been examined, is only likely to be episodic i.e. driven by extreme combinations of waves and water levels that occur from time to time and that the majority of material that enters into the harbour takes place around the end of the groyne, driven by a combination of tide and wave action during both normal and extreme tidal conditions.

5. FUTURE OPTIONS ASSESSMENT

5.1 EXISTING GROYNE ARRANGEMENTS

The updated strategy study (Arup, 2016) identified that the crest level of the groyne varies between 4.8m ODN at the landward end and -3.0m ODN at the seaward end.

From the available drawings and information, the actual level of the crib structure varies between 4.2m ODN at the landward end and 0.0m ODN at the seaward end. The overall elevation is locally higher at the landward end due to the small boulders that are covering over the groyne here (Plate 12) and the infill armour stone is locally higher on the harbour side towards the seaward end with the armour apparently having been moved across the groyne towards the harbour side by wave action, particularly where the longitudinal upper waling is missing on the updrift (south) side (as can be seen in Plate 8 and Plate 13). In addition some blocks of armour can be seen on the foreshore on the harbour side (ref Plate 9) having been displaced from within the groyne.

The original scheme drawings identify the rock as 1.0-1.5 tonne in size. Visual inspection of the stone size confirms this sizing. This rock is considered to be too small for the more extreme exposure conditions identified, hence the re-profiling and displacement of rock from within the crib.

Rock of the size used for the infill armour would have been potentially moved by conditions that occurred during the winter storms of 2013-14 but reference to before and after inspection photos identifies that the damage to the groyne in terms of lost/bent walings occurred during event(s) that occurred previously (pre 2010). Reference to the Google Earth imagery shows the upper longitudinal waling on the updrift side was bent over the structure in 2009 but not in 2006, suggesting this damage occurred during the intervening period.

In its present condition the structure appears to be providing a role in preventing material from passing through and over it, but not necessarily around it, under normal conditions. Conversely material may potentially be transported through and across the groyne during more extreme events.

5.2 OPTIONS FOR CRIB GROYNE MANAGEMENT

5.2.1 Criteria and Considerations

The updated Strategy study (Arup, 2016) identified that consideration of options for modifying the length of the groyne would form part of medium term (4-10 years from present) considerations.

Works in the short term therefore need to be considered in terms of actions to maintain and/or modify the existing structure.

In considering the pros and cons of the options, the cost and performance of each options needs to be examined against a background of there being a high degree of uncertainty in what reduction in the amount of material the remedial arrangements would provide and accordingly whether the cost of the investment in remedial works outweighs the cost of removal of the material from the harbour mouth.

Key criteria that inform option definition include:

- Suitability of existing crib groyne construction – size of members, overall integrity;
- Size of armour stone;
- Overall structure permeability;
- Crest elevation of the structure; and
- Adaptability in relation to potential options for future management

Apart from the obvious defects in terms of damaged walings and moved/displaced armour stone, the overall crib groyne appears to be structural sound and not in any imminent danger of collapse or failure. The majority of the structure is buried beneath beach sediments and the condition of these crib elements is largely unknown. Accordingly, it is likely that buried elements remain intact and due to their burial are unlikely to have corroded as much as the upper elements that have been directly open to the atmosphere.

The armour stone used in the original construction is not considered to be suitable for the potential exposure conditions that could impact the structure, as witnessed by the movement that has occurred. Larger stone would be better able to provide structural stability and resistance to the hydraulic forces that are imparted. It appears that the armour stone used may have been sized to fit the structure, to potentially reduce the permeability of the structure and for ease of placing rather than from specific hydraulic considerations, in terms of stability and/or hydraulic performance.

In terms of permeability, the existing structure is permeable, with the smaller the size of rock armour used, the closer packing of the material that can be achieved and the lower the percentage voids and permeability. Where the original structure is visible, over the lower ⅔ of the structure in its present condition the rock does not appear to be densely placed or well interlocked, all of which will increase its permeability and reduce its structural integrity and performance.

All groynes generally have a sloping crest elevation, defined from consideration of a number of criteria, including:

- Tidal regime criteria; and
- Expected level of foreshore abutting the structure

From examination of the available data, to be functional the groyne elevation may be too low at the landward end but over the majority of the structure there is no evidence that the crest of the structure is being overwhelmed by beach sediments, moved across the foreshore as bedload. In contrast, high tide levels will pass over the lower parts of the structure and fine material in suspension could potentially pass over it, although the elevation of the structure in combination with the roughness of the groyne surface does act to slow the tide flow and encourage material to settle out.

Based on the evidence examined it appears likely that future medium term works to modify arrangements of the harbour entrance would more than likely involve extension of the groyne structure to reduce the amount of material from entering the harbour mouth. Accordingly short term works to improve the function of the existing groyne need to have due cognisance of these potential arrangements, with adaptability of short term arrangements an important factor in option examination.

5.2.2 Option Definition

From examination of the data, the following potential options have been identified:

1. Minimum maintenance of the existing structure;
2. Higher level maintenance and reinstatement of the existing structure;
3. Vertical extension/encasement of the existing structure using a combination of crib steelwork or sheet piling and rock armour; or
4. Encasement of the existing structure in rock armour.

5.3 OPTION DETAIL AND BUDGET COSTINGS

5.3.1 Option 1

Option 1 would involve minimum maintenance of the existing structure and would comprise the following principal tasks:

- Removal of damaged walings;
- Retrieval of rock armour that has been removed by wave action from within the crib;
- Localised excavation and side casting of shingle from within groyne;
- Replacement of the displaced rock armour;
- Importation of a small quantity of larger rock armour for placing where there is no crib protection; and

- Localised reshaping of small boulder protection at the landward end of the groyne.

This option would not increase the level of the existing groyne but reinstatement of the armour would provide for an instant improvement in functionality compared to the current position. Due to the form and nature of the construction sediment would still be able to pass through and over the structure. The provision of larger armour along the updrift flank would assist in reducing, but not entirely prevent, re-shaping of armour due to wave action.

This option provides the lowest level of improvement in terms of reducing potential material transport through and over the groyne but conversely represents the minimum cost investment for works to the groyne. Under this option it is estimated that costs for removal and recycling sediment would remain more or less the same as under existing arrangements.

The estimated cost of this option is £10-15,000

5.3.2 Option 2

Option 2 would involve maintaining the existing structure and reinstatement of the damaged elements such that the structure is restored to its original design condition (but slightly modified). This would comprise the following principal tasks:

- Replacement of damaged walings;
- Removal of the upper pieces of rock armour within the crib groyne and replacement with a layer of larger imported rock armour that will be more resistant to movement by wave action; and
- Localised reshaping of small boulder protection at the landward end of the groyne.

This option would also not increase the level of the existing groyne but reinstatement of damaged crib steelwork and rock armour would provide not only an instant improvement in functionality compared to the current position but also would provide for increased resilience and robustness of the construction compared to Option 1. Excess existing rock armour could be disposed of adjacent to the site, possibly along the crest of the shoreline on the updrift side to provide improved flood protection here. As with Option 1, due to the form and nature of the construction sediment would still be able to pass through and over the structure.

This option would require an increased level of investment compared to Option 1 but it is likely that the additional costs would provide for a modest reduction in sediment transport through the groyne but no change in material that could pass over it in suspension within the water column. Furthermore due to the nature of the works proposed the structure should endure in its revised form for a greater length of time with less chance of change.

The estimated cost of this option is £35-40,000

5.3.3 Option 3

Option 3 would involve encasement of the existing crib structure with a new structure built to either the same or an increased elevation. This option, raising the crest level by 1.8 metres, was identified as a potential option in the Strategy update report (Arup, 2016). This figure was based on the increase in bed level that had occurred at the groyne since it was originally constructed (as shown on Figure 10).

The outer edge of the crib structure could be formed of similar construction to the existing, as proposed by Arup or alternatively a steel sheet curtain could be driven around the perimeter of the existing structure. The piled curtain alternative would by its nature be impermeable and would prevent material passing through as bedload. Conversely the nature of the construction would lead to wave reflections which would cause scour of the beach /seabed in front of the structure and a localised reduction in beach levels adjacent to the structure

Topping up of fill between the structures would be carried out using armour stone of a larger size than used in the original construction – typically 1-4t in weight, rather than the 1-1.5t used originally.

Increasing the elevation would reduce the amount of material passing through the structure, although a residual amount would be expected for the existing crib extension option, due to the porous nature of the construction. The increase in elevation would most appropriately be linked to the tidal levels and an increase of 1m would be considered a minimum requirement, such that the level of the seaward end was at or above the mean high water neap tide level. An increase of 1.8 metres would allow for typically a 2 layer construction of 1-4 tonne armour over the existing. In practice the maximum increase would occur at the seaward end with a lower increase further landward.

A typical cross section for this option (ex Arup) is reproduced in Figure 14.

This option would require confirmation of arrangements with relation to the sewer outfall, as it may not be possible to create an outer curtain immediately adjacent to the existing crib on the upstream side and if not this would require the groyne to be widened slightly. Consultation with Dwr Cymru is required in this respect.

The estimated cost of Option 3a (increased cribwork) is £125-135,000

The estimated cost of Option 3b (steel sheet piles) is £225-240,000

5.3.4 Option 4

An alternative to a fixed construction that relies on corrodible steelwork would be to encase the structure in armour stone and effectively create a rock groyne rather than a crib groyne. This would require side slopes (typically at 1 in 2-3 gradient) to either side with a nominal 2-3 metre wide crest along the spine of the structure.

This structure would have a greater footprint than the current structure or any of the other options, which would be delivered within the existing footprint, and accordingly may not be able to be constructed within existing Harbour Act powers and would most likely require a Marine Consents Licence, with all the necessary approvals that entails.

As with Option 3 confirmation of sewer outfall arrangements need to be considered as the structure would be constructed directly over the existing pipe.

The estimated cost of Option 4 is £140-150,000, excluding potential approvals costs

5.4 OPTION DISCUSSION

The key criteria in consideration of what is the most appropriate short term course of action to be undertaken are:

- The change in level of performance of each of the options;
- The likely short and medium term arrangements for the groyne and potential adaptability of the structures; and
- The economic viability of each of the options when set against current expenditure.

5.4.1 Level of Performance

The available data does not provide for quantitative analysis of the performance provided by each of the options and accordingly any assessment is largely qualitative. Both options 1 and 2 will provide some but little in the way of improved performance compared to existing conditions purely by providing a structure that provides improved robustness and integrity compared to the existing conditions. There will be a reduction in transmission through the structure as bed load transport but material in suspension will continue to pass over the structure as currently happens.

Options 3 and 4 by virtue of both increased elevation and improved robustness and integrity will reduce both transmission through and movement over the structure.

5.4.2 Future Arrangements and Adaptability

The available evidence suggests that sediment movement around the groyne contributes more sediment to the harbour mouth than material which passes over/through the groyne structure and that therefore to significantly reduce the amount of sediment that enters the harbour, modification of the length of the crib groyne will be required.

Both Options 1 and 2 require minimum additional intervention. Any new steelwork in Option 2 will have no residual value but the rock armour can potentially be re-used. Adaptability for Option 3 is primarily limited to extension of the structure in the same form as at present. Conversely a revised rock groyne has more built in adaptability than the other form in that the rock provides a source of material that is more easily re-usable within any new arrangements.

5.4.3 Economic Viability

The costs of each option need to be considered against the current costs of sediment excavation and recycling but at this stage as longer term arrangements are subject to further examination, it is only appropriate to consider the costs over the timescale until such arrangements might be in place i.e. say the next 10 years.

The costs of recent dredging operations provided by Gwynedd Council are shown in Table 5.1 below

Table 5.1: Current Annual Dredging Costs

Date	Cost (£)	Supplementary Details
July 2009	18,800	
April 2011	38,000	Material recycled for beach recharge at Traeth Crugan
May 2013	47,500	Undertaken as a compensation event during the Wales National Sailing Academy contract
March 2015	40,400	
March 2016	31,900	Material recycled for beach recharge at Traeth Crugan
May 2017	34,900	

Based on the above, the average annual cost, over the last 8-10 years is of the order of £20-25,000, although based on the last three years the value is nearer £35,000.

The key to consideration of the economic viability is what reduction in the amount of material entering the harbour each of the options will provide. Due to the lack of definitive quantitative data in this respect a largely qualitative assessment has been made, considering two different scenarios.

As identified previously the data/evidence suggests that the majority of material is transported around rather than through/over the groyne. On the basis that the ratio in this respect is say 4:1, the following reductions are suggested with regard to the benefit each of the options would provide:

- Option 1: 5% of the total moved, which equates to a saving of £1-2k per annum;
- Option 2: 10% of the total moved, which equates to a saving of £2-4k per annum;
- Option 3: 20% of the total moved, which equates to a saving of £4-8k per annum; and
- Option 4: 20% of the total moved, a saving as for Option 3.

If the ratio was 1:1 then the savings would be 2.5x the values i.e. with a maximum saving of £10-20k per annum for Option 3 and 4.

With any of the options there would still be a maintenance requirement to remove material and discounting the annual capital and maintenance costs for each of the options over 10 years, based on an annual cost of removal (from above) of £30,000 provides Present Value (PV) costs for each the options for the 80/20 and 50/50 splits as shown in Table 5.2 below:

Table 5.2: Summary of PV Costs		
	PV Costs (£k) over 10 years	
Option	**4:1 Ratio**	**1:1 Ratio**
Present Arrangements	258	258
Option 1	258	238
Option 2	270	231
Option 3	337	259
Option 4	352	274

It can be seen that if the suggested reductions in material arriving in the harbour entrance as identified in the bullet points above are correct then based on a 4:1 ratio of material being transported round the groyne compared to through/over the groyne, then in purely economic terms, it would only be economical to either not carry out any short term works or just carry out minimum maintenance. If the alternative scenario of a 1:1 ratio was correct then economically options 1, 2 or 3 potentially would cost the same or less over the ten years.

Due to the uncertainties with regard to the ratio of volumes of material passing round rather than through the groyne, the above analysis can only be considered as providing an indication of the relative economic viability of each of the options considered, compared to the present arrangements. Nonetheless the figures do provide some useful information and comparison for consideration in the overall decision making process.

6. OVERALL CONCLUSIONS

The present study has examined available data and identified current arrangements and hydrodynamic/morphological conditions applying in the vicinity of the existing crib groyne on the south side of the entrance to Pwllheli harbour, from which a range of costed maintenance and capital investment options to improve performance, have been suggested.

It should be particularly noted that due to the lack of detailed quantitative data in relation to the volumes of material that are both passing through/over and around the groyne there is a high degree of uncertainty as to the level of performance being provided by the structure and, accordingly, the benefit in terms of reduction in material volumes entering the harbour each option would provide.

The updated strategy study identified that examination of longer term arrangements for the groyne (lengthening / increasing the elevation of the groyne), alongside a wider review of harbour mouth arrangements should form part of the medium term arrangements (4-10 year action plan) and accordingly it has been appropriate to consider short term actions within that timescale.

The options considered range from minor maintenance to increasing the height of the existing structure and reconstructing the structure in a different form.

The cost of major capital reconstruction to increase the height of structure (Option 3) or reform it in armour stone (Option 4) is significantly higher than the likely benefit in terms of reduction in dredging costs such works would provide.

Although it is also difficult to make a purely economic case for maintenance works, these lower cost options will at least reinstate the structure to its original design level of performance whilst not limiting options for adaptability in the future, pursuant to the medium term option examination and evaluation proposed, which it would be recommended should be actioned at the earliest opportunity.

7. GLOSSARY & ACRONYMS

Above Ordnance Datum	The vertical height or level of a feature relative to the Ordnance Datum, Newlyn
Bathymetry	The level of the sea bed across an area of water.
BODC	British Oceanographic Data Centre
CEUK	Coastal Engineering UK Ltd
CFB	Coastal Flood Boundaries
EA	Environment Agency.
GC	Gwynedd Council
Highest Astronomical Tide (HAT)	The highest tide level predicted to occur under any combination of astronomical conditions.
Inter Tidal Zone	The area of foreshore exposed when the tide is at lowest.
Joint Probability	The probability of return period wave and tide level events of a given magnitude occurring simultaneously.
Lowest Astronomical Tide (LAT)	The lowest tide level predicted to occur under any combination of astronomical conditions.
Light Detection and Ranging (LiDAR)	A method of measure beach topography using a laser mounted on an aeroplane.
Mean High Water Neap Tide (MHWNT)	The average height of high waters occurring at the time of neap tides.
Mean High Water Spring Tide (MHWST)	The average height of high waters occurring at the time of spring tides.
Mean Low Water Neap Tide (MLWNT)	The average height of low waters occurring at the time of neap tides.
Mean Low Water Spring Tide (MLWST)	The average height of low waters occurring at the time of spring tides.
Mean Sea Level (MSL)	The sea level halfway between the mean levels of high and low water.
Neap Tide	Tide of the lowest range that occurs twice a month.
Present Value (PV)	
Return Period	The average predicted time period over which an event of given magnitude will occur e.g. 1 in 20 years. Usually used in relation to the occurrence of specific still water levels or wave heights and periods.
Rock armour	Quarried stone commonly used in coastal defence works
Spring Tide	Tide of highest range that occurs twice a month, when the moon is new or full.
Topography	The arrangement of the natural and artificial physical features of an area e.g. beach or dunes.
Tidal Flows or Currents	The speed and direction of flow of a body of water due to the action of the tides
UKCIP	United Kingdom Climate Impacts Programme
Wave Breaking	The Condition that occurs when the depth of water beneath a wave is insufficient to maintain the sinusoidal wave amplitude and the crest of the wave overturns releasing energy onto the foreshore or defence structure
Wave Period	The time taken for successive peaks or troughs in a wave train to pass a fixed point
Wave Refraction	Bending and changing in height of the waves due to the directional contours of the beach
Whole circle bearing (WCB)	A bearing (direction) measured clockwise from north (0°)

FIGURES

Figure 1: General Location Plan

Figure 2: Local Location Plan

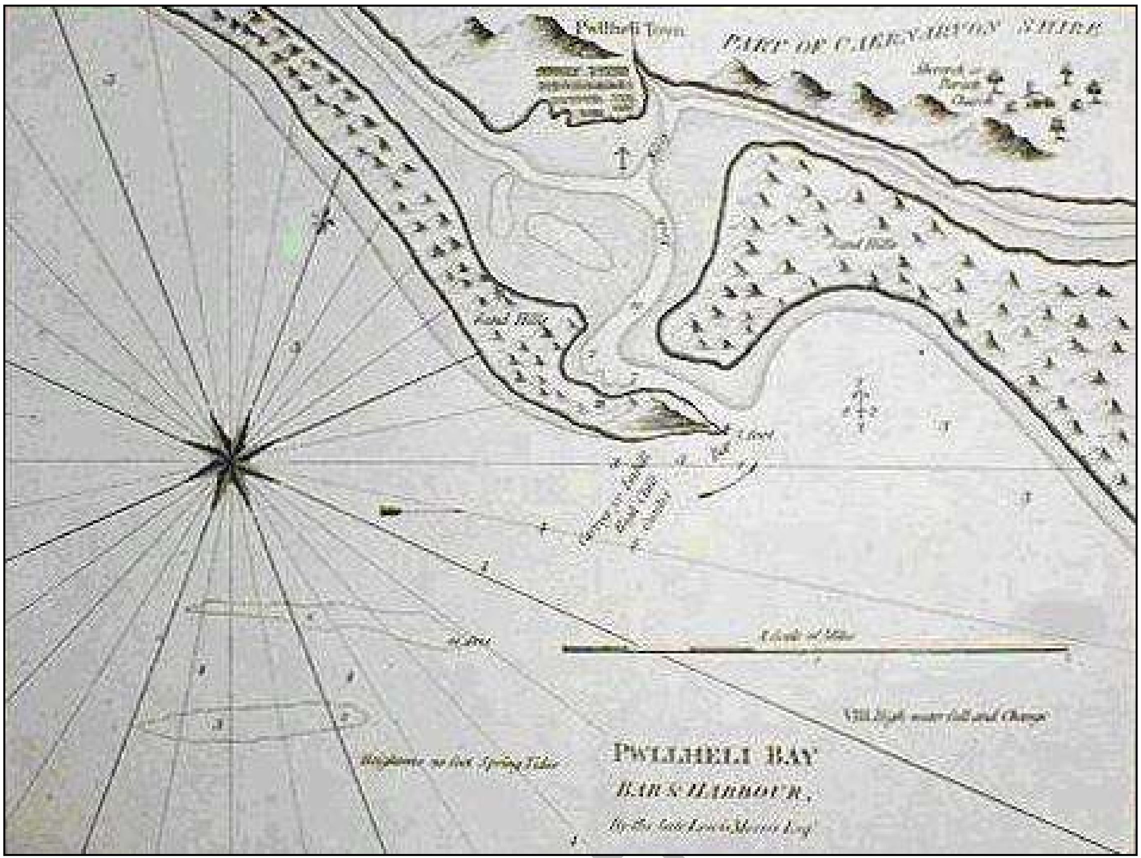


Figure 3: Historical Maps from Early 19th Century
(Top: William Morris c1801- Bottom: Robert Creighton c1835-1848)[17]

[17] http://freepages.genealogy.rootsweb.com/~genmaps/genfiles/COU_Pages/WAL_pages/CAE.htm

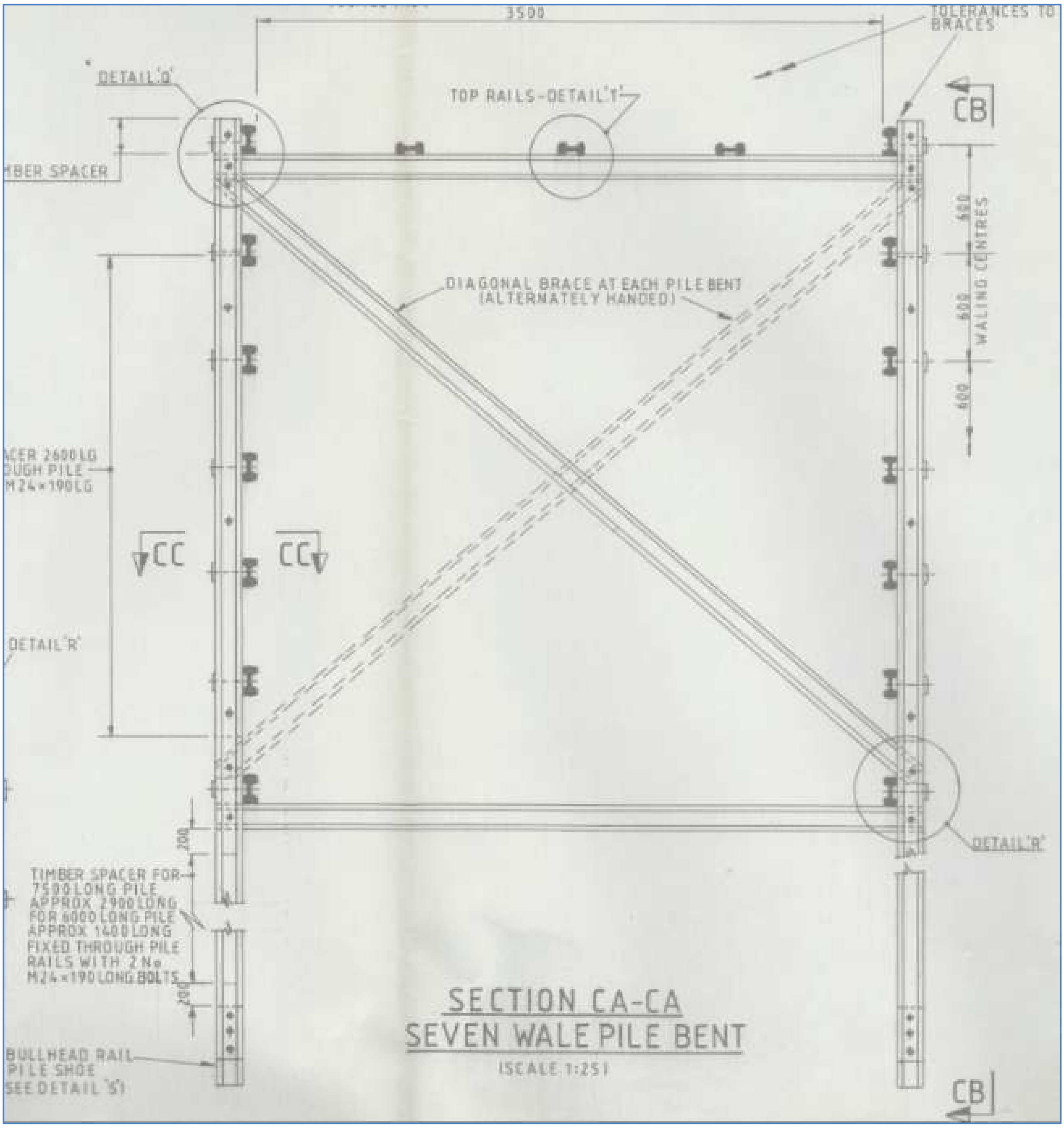
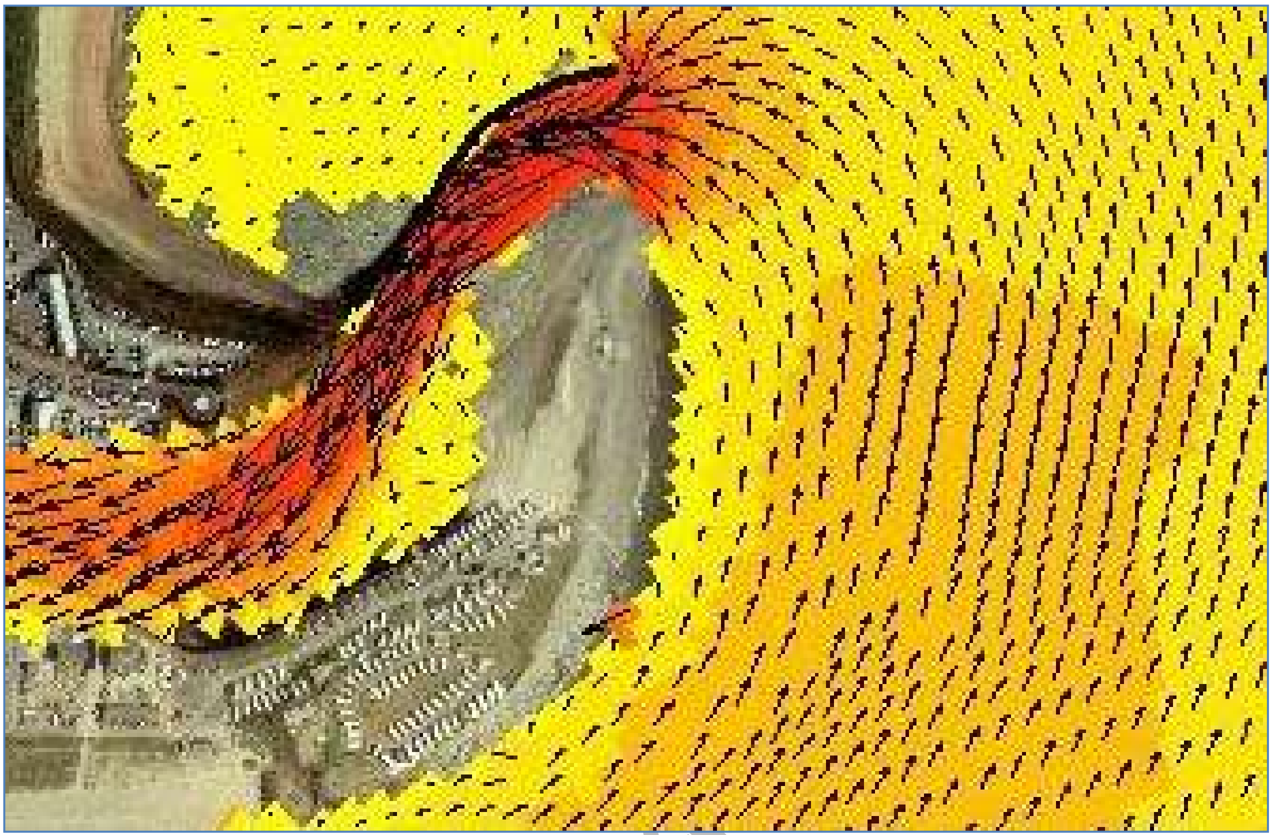


Figure 4: Cross section through existing groyne
(from original scheme drawings)



(a)

(b)

Figure 5: Extracts from model simulation results of current flow behaviour around harbour mouth (a) mid flood current speeds (m/s), for typical spring tide scenario and (b) during peak water levels for 1 in 10 year surge event, including effects of wind and waves[18]

[18] From Halcrow, April 2006. Abererch Phase II, Preliminary Studies Report for the Environment Agency Wales

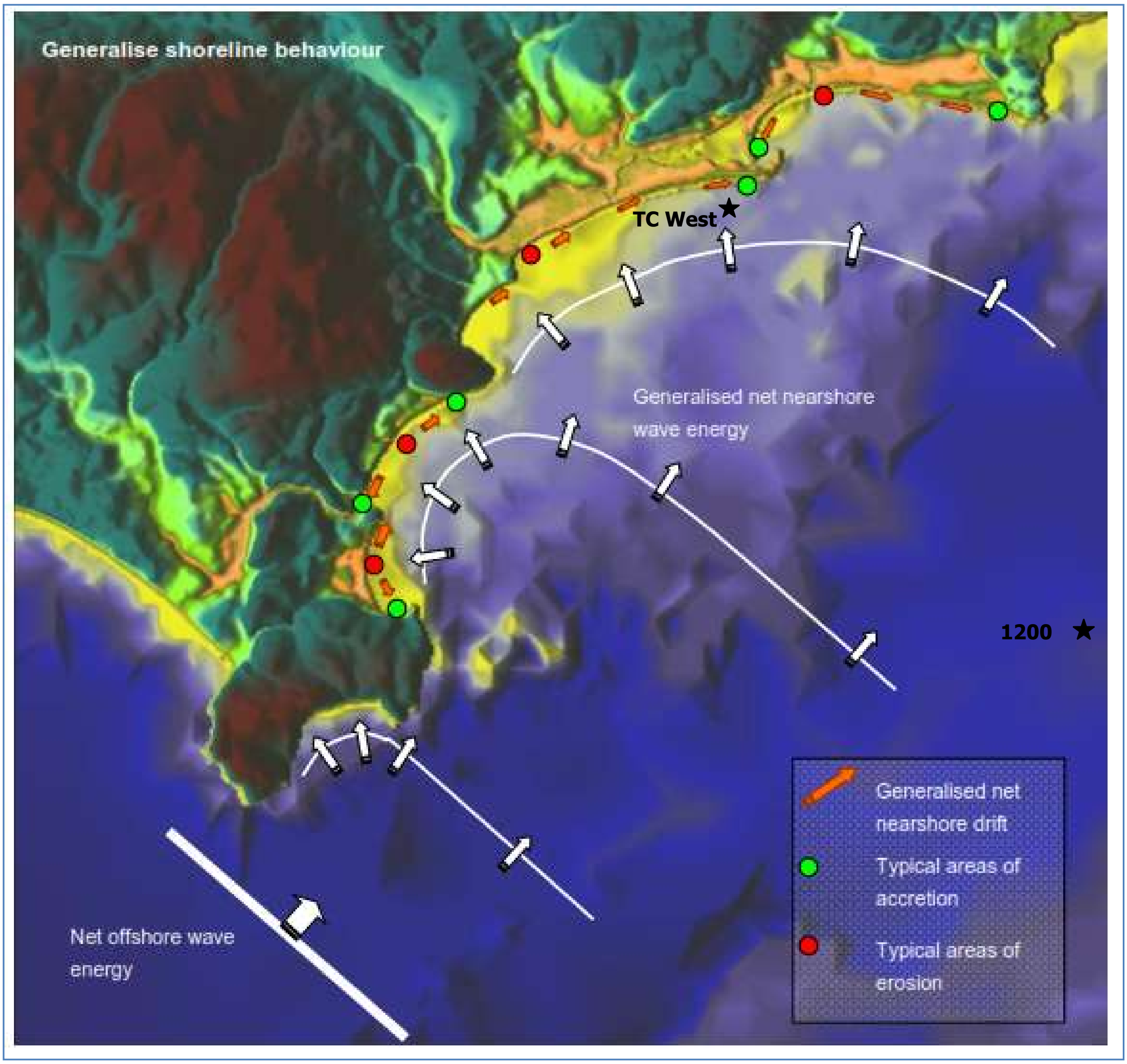


Figure 6: Generalised process behaviour for the western part of the South Lleyn

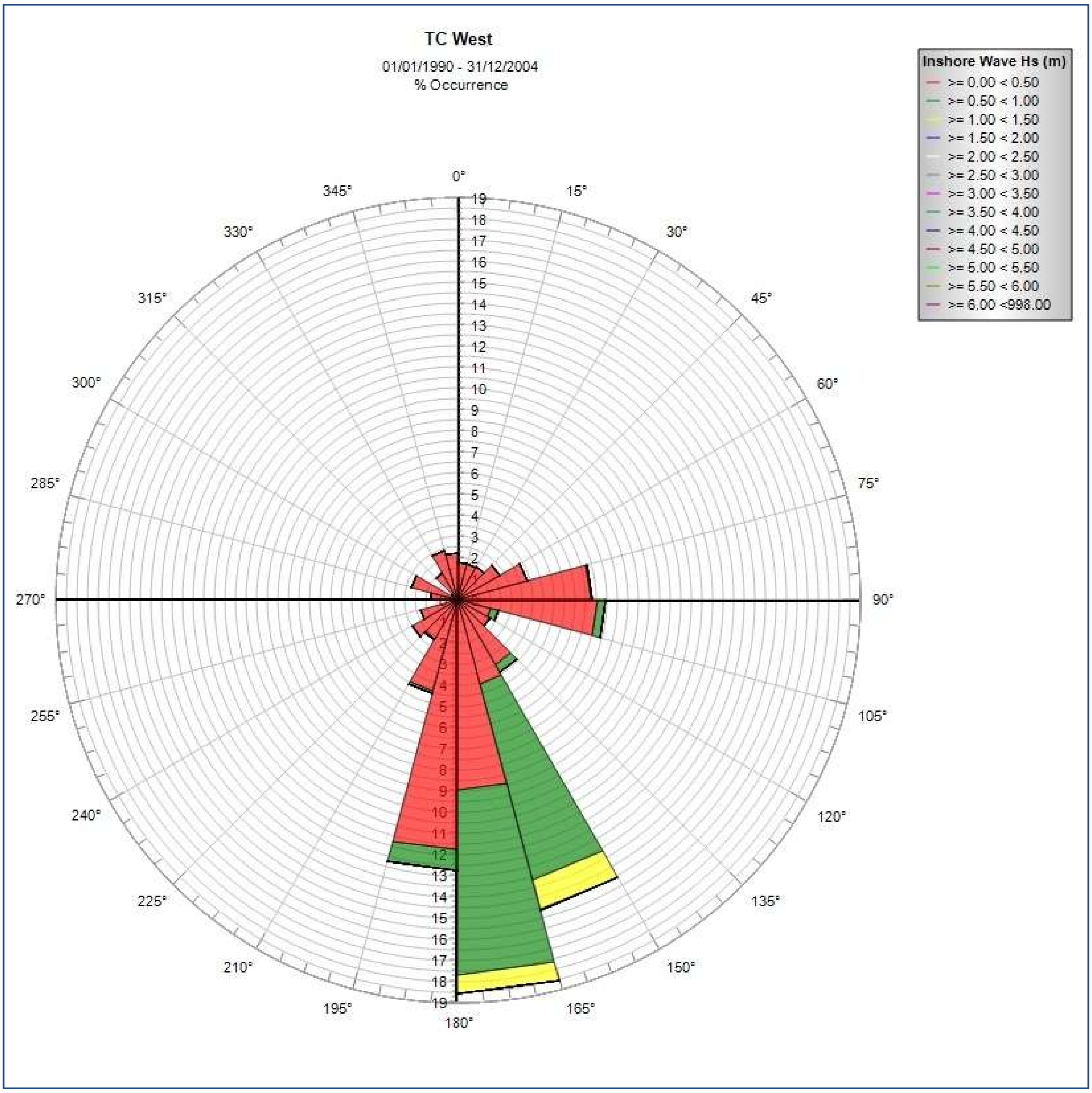


Figure 7: Modelled Wave Climate Rose 1990-2004 – Traeth Crugan West

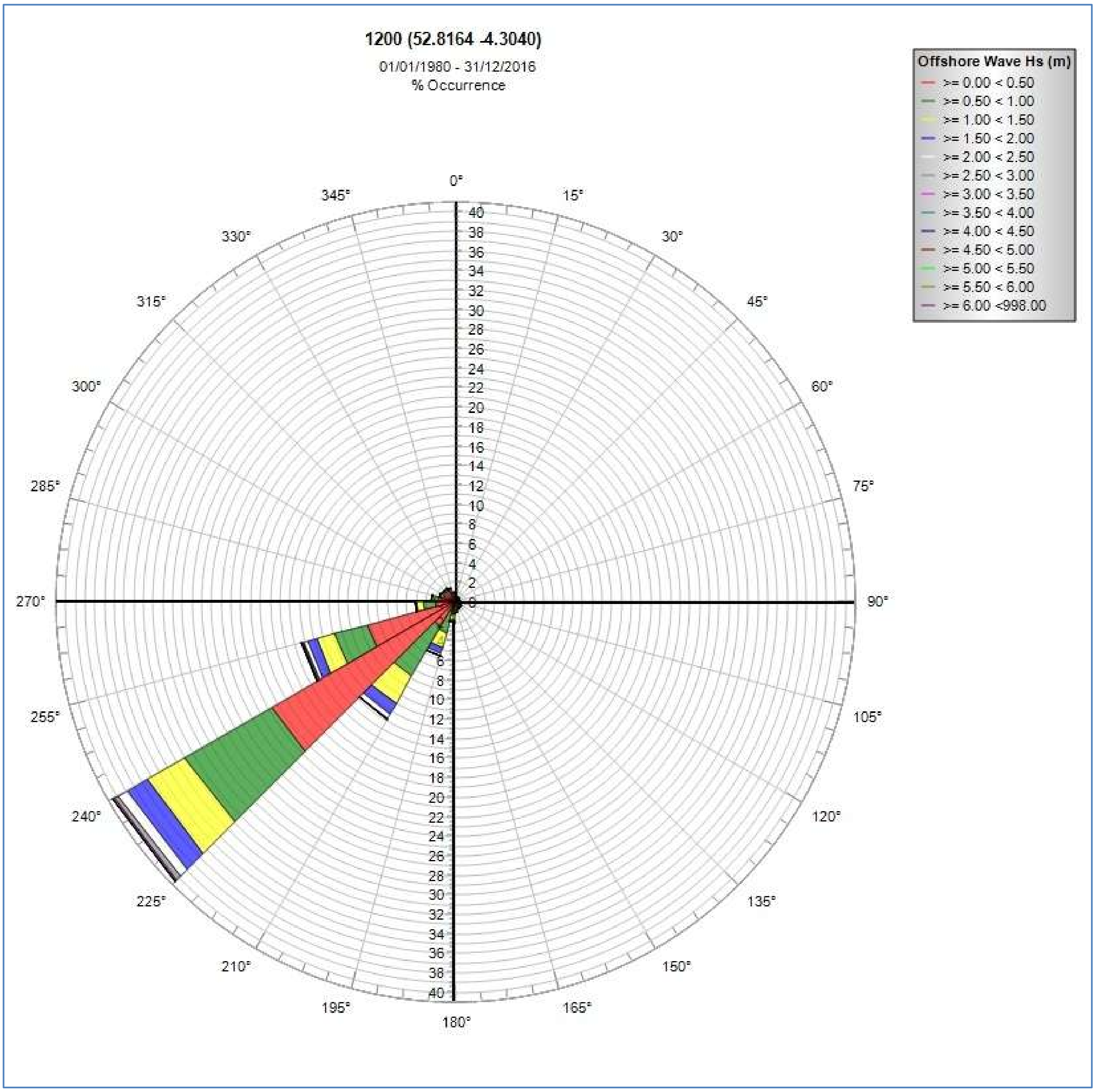


Figure 8: CEFAS Hindcast Modelled Wave Climate Rose 1980-2016 – Offshore Point 1200

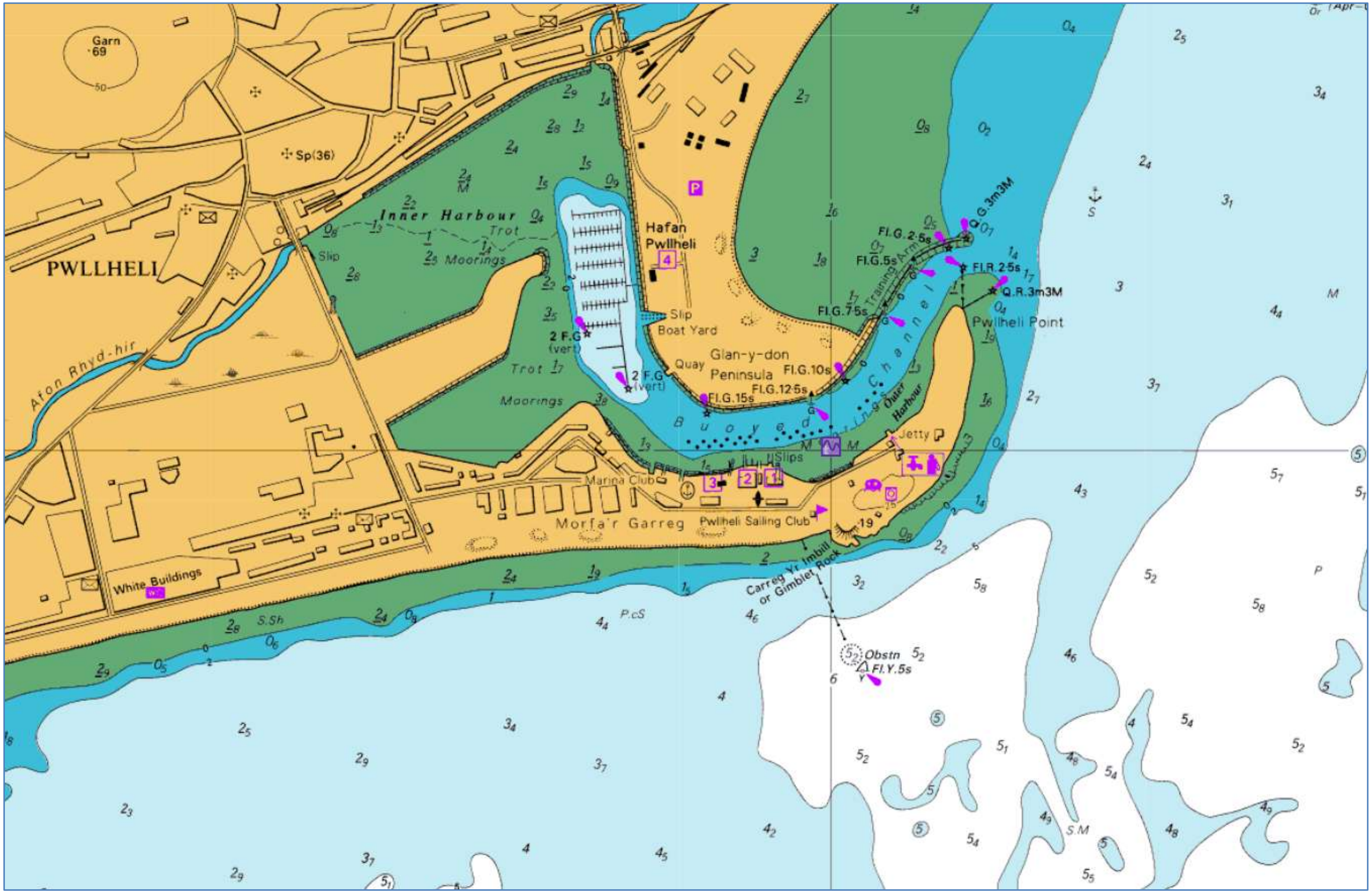


Figure 9: Extract from Admiralty Chart 1512

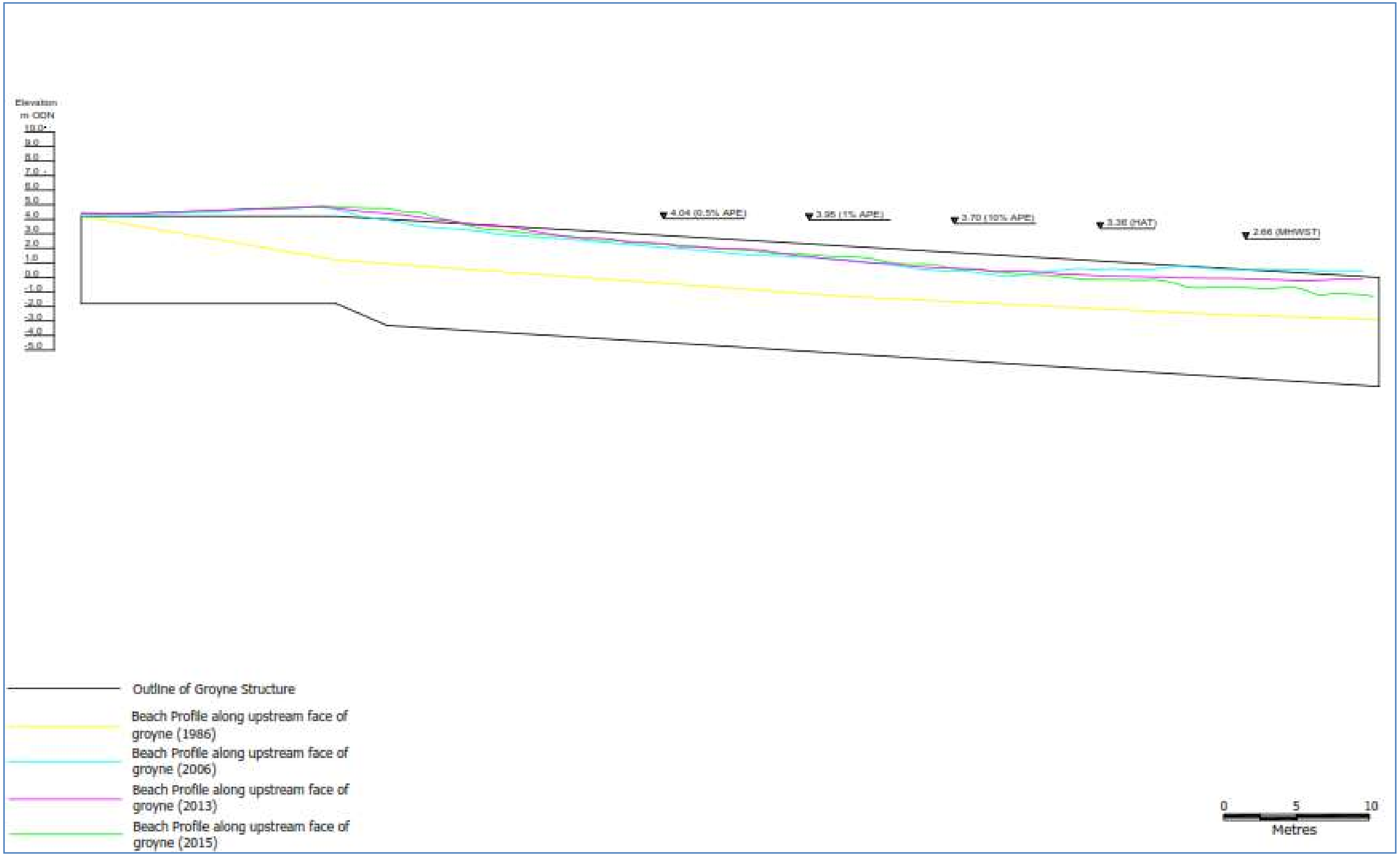


Figure 10: Groyne Long Section showing change in beach elevation

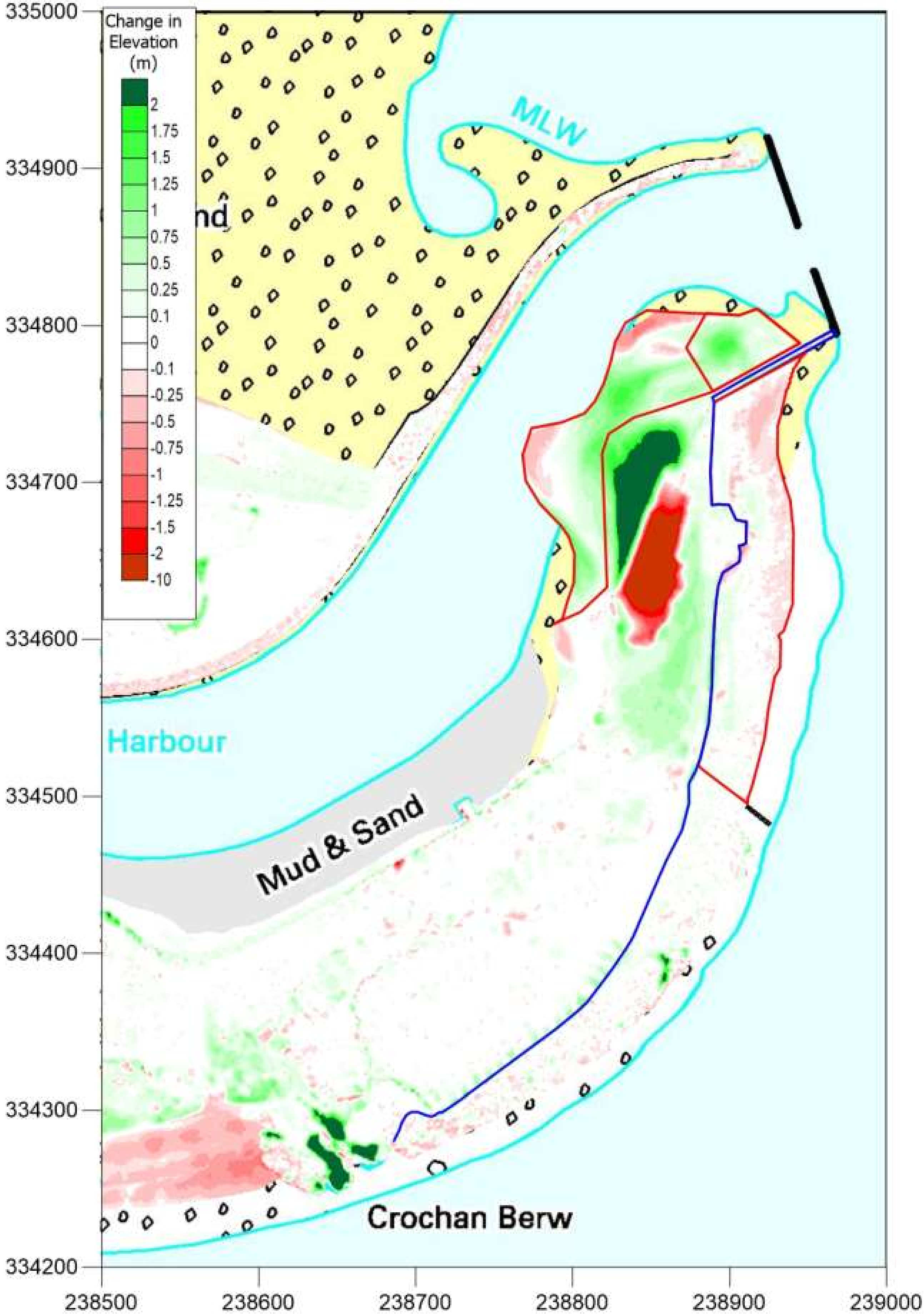


Figure 11: LiDAR Elevation Comparison Plot – April 2006 to February 2013

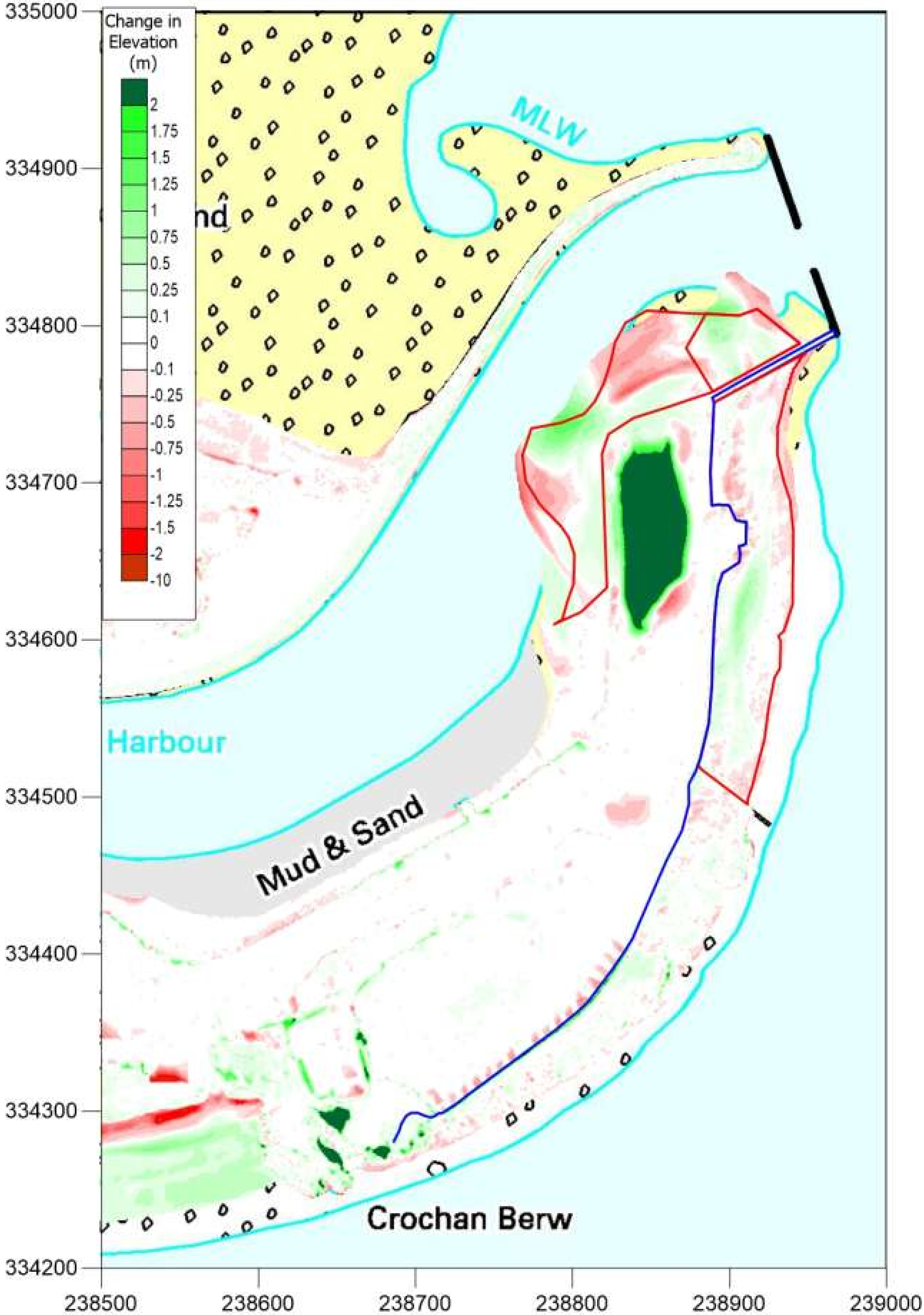


Figure 12: LiDAR Elevation Comparison Plot – February 2013 to February 2015

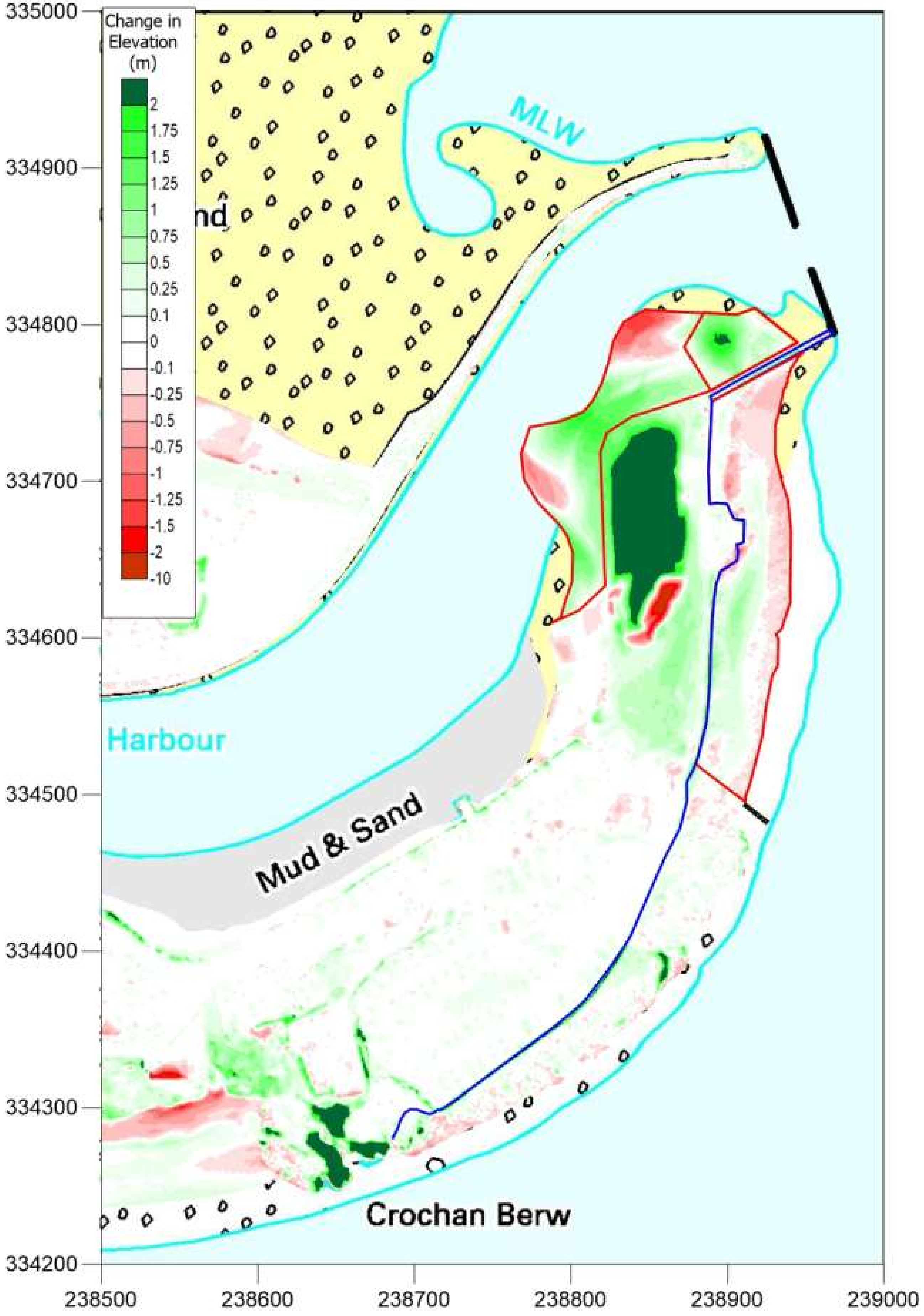


Figure 13: LiDAR Elevation Comparison Plot – April 2006 to February 2015

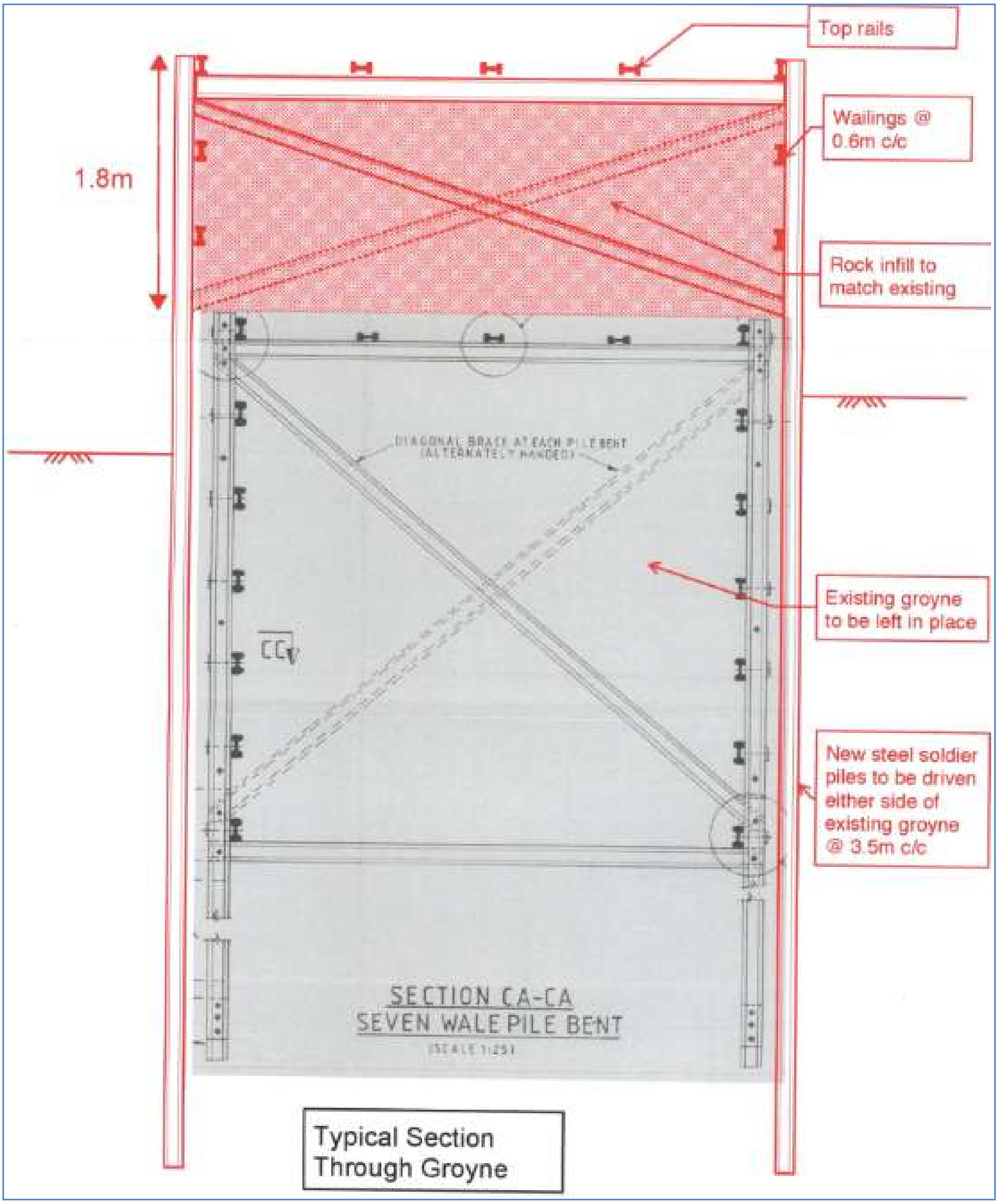


Figure 14: Suggested Increase in Existing Groyne Elevation – Option 3 (ex Arup, 2016)

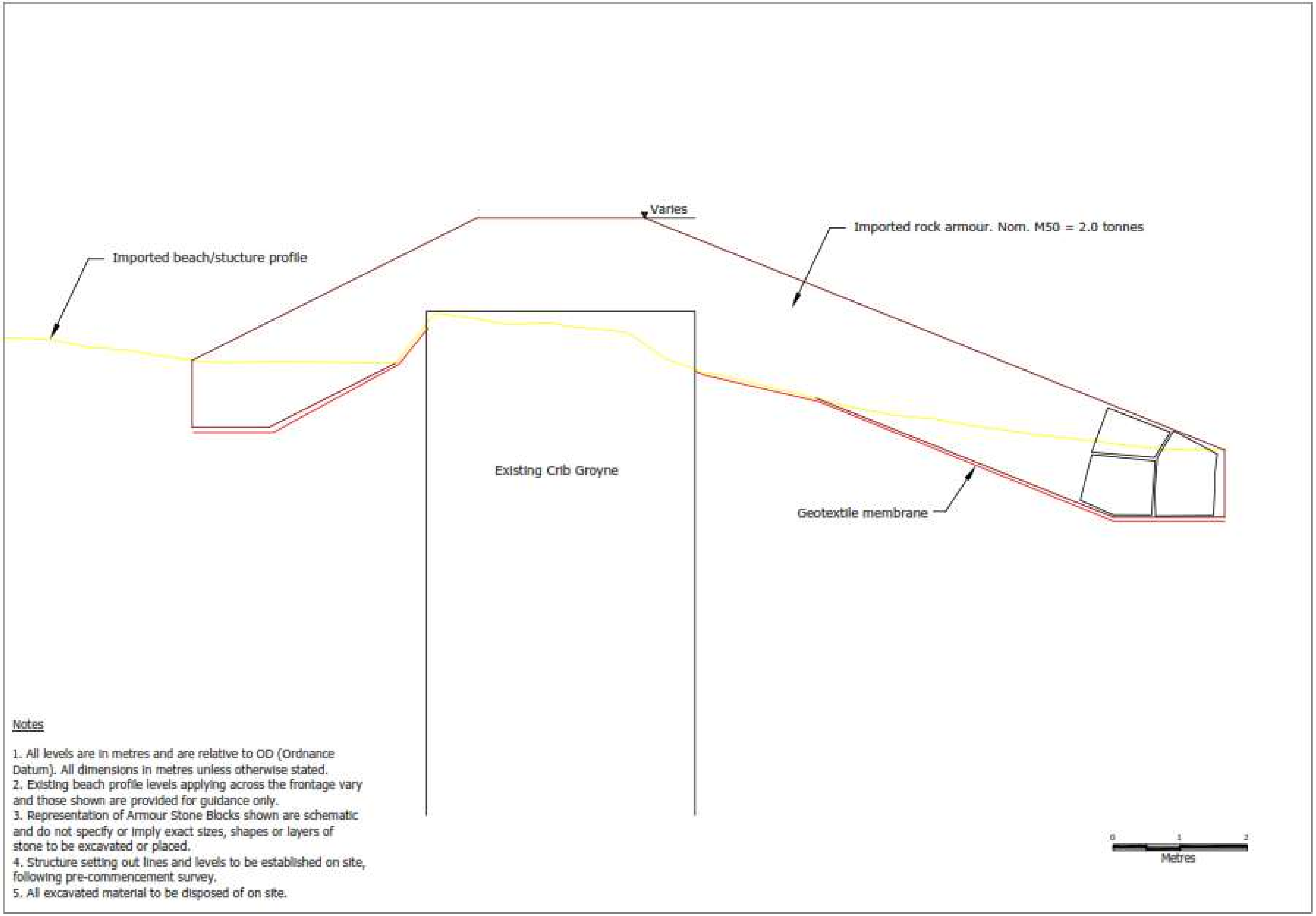
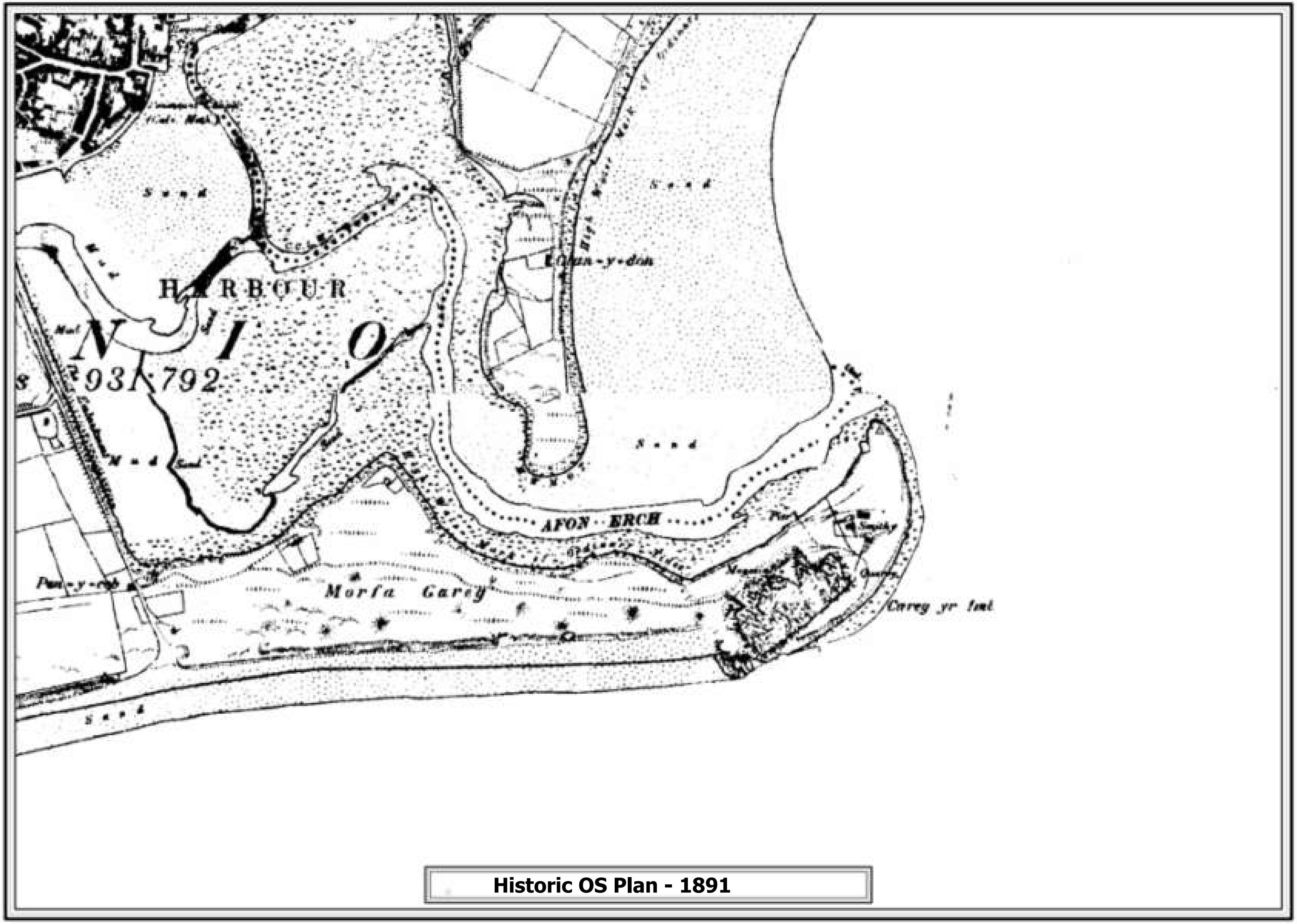
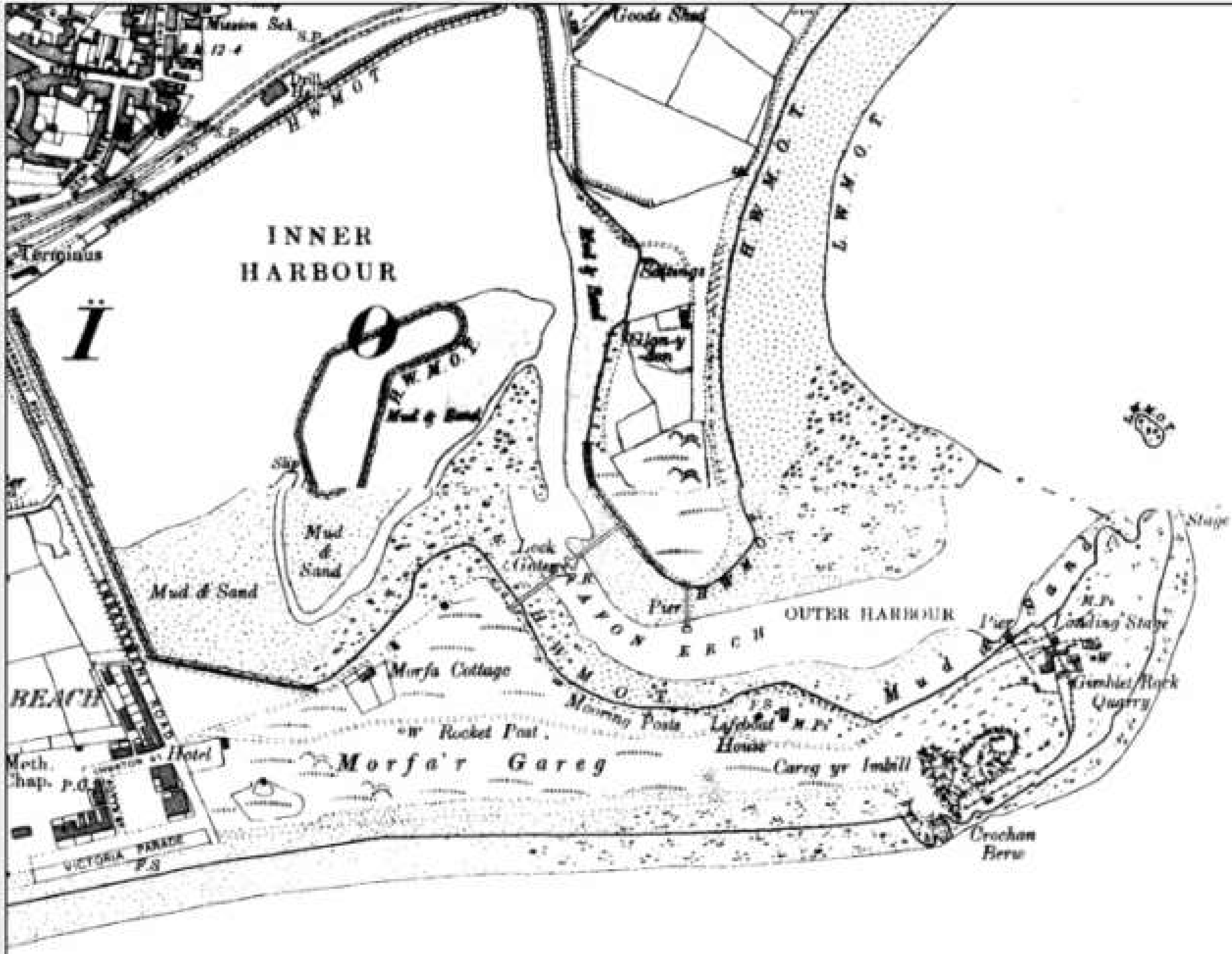


Figure 15: Typical Rock Groyne Section – Option 4

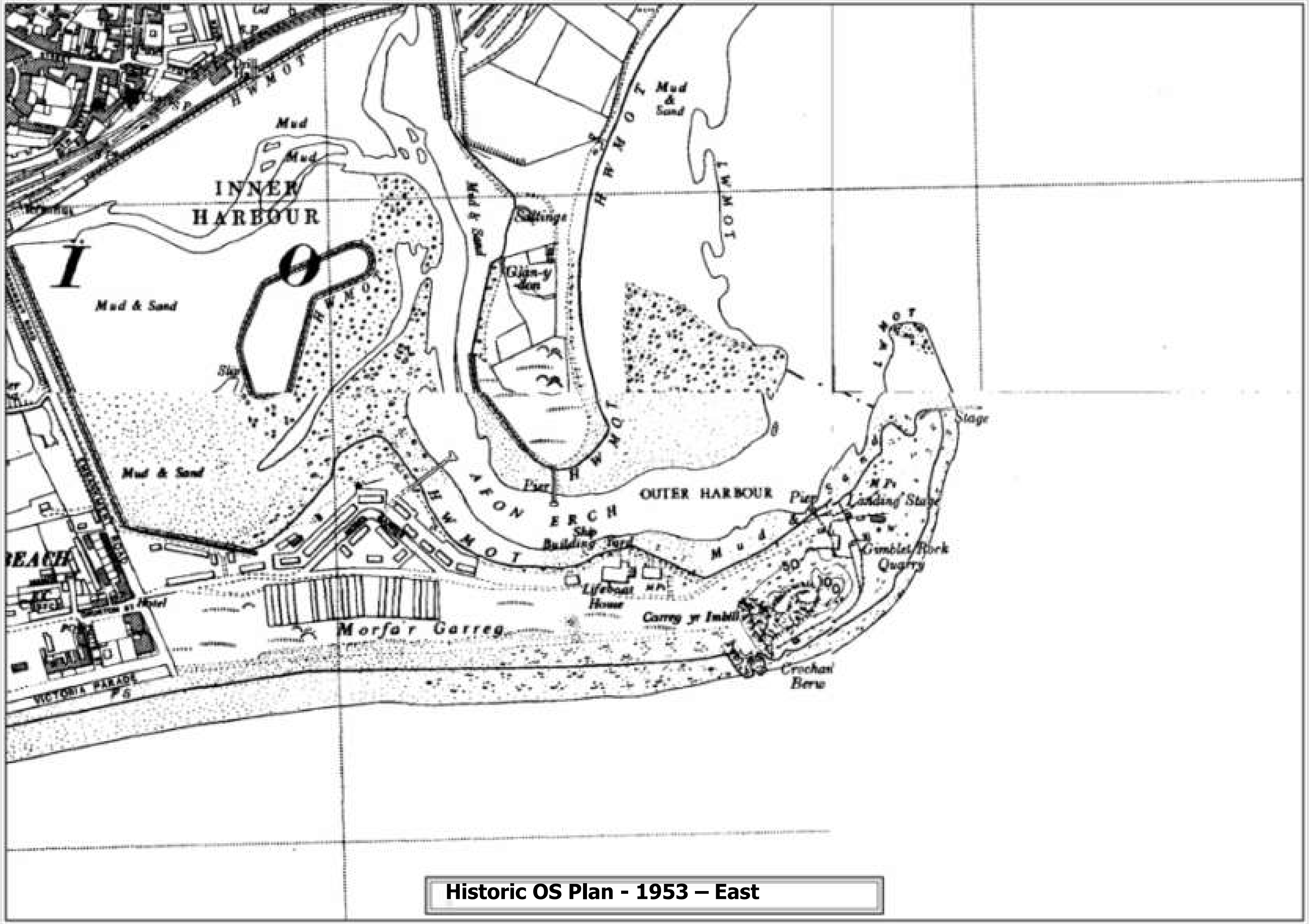
Appendix A: Historic OS Plans



Historic OS Plan - 1891



Historic OS Plan – 1919/20



Historic OS Plan - 1953 – East

Appendix B: Illustrative Photographs

Plate 1: Rock Foreshore in front of Gimlet Rock Caravan Park

Plate 2: Rock Foreshore in front of Gimlet Rock Caravan Park

Plate 3: Foreshore on updrift side of Dwr Cymru Holding Tank

Plate 4: Protection to Dwr Cymru Holding Tank

Plate 5: Foreshore between Dwr Cymru Holding Tank and Crib Groyne

Plate 6: Mounded rock at top of beach between Dwr Cymru Holding Tank and Crib Groyne

Plate 7: Side Elevation of Crib Groyne on Updrift Side

Plate 8: Missing side walings on updrift side of groyne

Plate 9: Foreshore on downdrift side of groyne, showing displaced walings and rock armour

Plate 10: Seaward end of crib groyne on downdrift side

Plate 11: Elevation of Crib Groyne on downdrift side

Plate 12: Rock protection mounded over landward section of crib groyne

Plate 13: Armour rock within groyne structure

Plate 14: Beach moving from groyne into harbour

Plate 15: Beach looking into harbour

Plate 16: Stockpile of sand and shingle excavated from harbour mouth for recycling

Appendix C: Contemporary Vertical Aerial Photography

Aerial Photo 2000

July 19, 2017

1:5,000

0 0.0425 0.085 0.17 mi

0 0.05 0.1 0.2 km

Aerial Photo 2006

July 19, 2017

1:5,000

0 0.0425 0.085 0.17 mi

0 0.05 0.1 0.2 km

Aerial Photo 2009

July 19, 2017

1:5,000

0 0.0425 0.085 0.17 mi

0 0.05 0.1 0.2 km


Aerial Photo 2017

Appendix D: Harbour Entrance Dredging Summary 1992-2001 (ex Civil Engineering Solutions Report CES037, 2007)

REVIEW OF THE PWLLHLEI HARBOUR NAVIGATION MANITENANCE MANAGEMENT PLAN & FACTUAL SEDIMENTATION REPORT CPF/1671

Cyngor Gwynedd Council Date16/02/2007

Harbour entrance

Gwynedd council has undertaken a number of land based dredging contracts at the harbour entrance to maintain/improve navigation into the harbour. Table 3 below provides a summary of the Gwynedd council information and a timeline for the dredging operations is area.

Table 3: Pwllheli Harbour Entrance dredging summary

Date	Reference	Remarks
March 1992	Jones Bros	A total of 8,000m^3 of material was removed from the entrance area.
Aug 1994	(Unknown contractor)	A total of 26,000 m^3 of material was removed from the harbour entrance.
Jan 1996	Seascot Shipmanagement	A total of 12,000 m^3 of material was removed from the harbour entrance.
1997	Gwynedd Council	Gwynedd Council's CPU took over responsibility for dredging operations at Pwllheli stockpiled material at Careg y Imbill quantified at 6000m^3
1997	Unknown	Carried out a small dredge of 3000 m^3
1998		Stockpile of dredged material at Careg y Imbill = 9000m^3
1998	GH Jones	Construction of stilling lagoon adjacent to Morfa'r Gareg used 4600m^3 from the stockpile area.
2000	Environment Agency	EA required material for emergency repairs to the dune system at Abererch. Remainder of stockpile removed (4400m^3)
2001	CPU/Wyre Marine Services	Undertook a small dredge in the harbour entrance to improve navigation ahead of the "One Ton Cup" Dredge material stockpiled on Careg y Imbill approximately 5000m^3.
2001/2	CPU/Wyre Marine Services	Gwynedd Council's cutter suction dredger, Nessie sank. Therefore dredging budget for 2001/02 used to improve navigation at the harbour entrance and to provide material for a beach nourishment scheme at Traeth Crugan. Total volume dredged 47500m^3, stockpile at the end of the dredging and nourishment operations remained at 13000m^3.

Note:

Total volume of dredged material from the harbour entrance since construction in 1991 is 101500m^3 approximately 198000 tonnes,

Total volume of material dredged from the harbour entrance since 1997 is 55500m^3 approximately 108000 tonnes.

Appendix E: Sediment Transport Mechanisms Overview

General

Sediment particles are transported by stresses caused by the motion of the fluid. These stresses initiate movement of particles on the seabed, sometimes lifting them into suspension, and maintain the movement of these particles once they are being transported.

To initiate transport the fluid stresses have to overcome the inertia of the particles resting on the bed. For a single grain of sand on the beach surface, the threshold of motion is very low, and will be reached and exceeded under even very modest wave and current action. Larger particles such as pebbles and cobbles are obviously more difficult to move, especially if they are embedded in a layer of sediment that reduces flows beneath them. The geometry of a particle's position on the bed in relation to other bed particles is therefore important. Since the geometry of each particle in a graded population will vary, so there will be many individual threshold conditions. It is necessary to distinguish the threshold for individual movement (which corresponds to a few particles) and the threshold for general movement (where many particles move). The threshold of motion is most applicable to the offshore zone where particles may be stationary under certain conditions and move under more severe conditions (i.e. individual movements can be identified). In the surf and swash zones most of the fine particles tend to move continuously (i.e. conditions exceed the threshold of general movement).

Modes of transport

Once the particles are in motion there are various modes of transport. Each mode has characteristics that will determine the rate and direction of movement and the consequent morphological response. Three modes of sediment transport are generally recognized in the coastal environment:

- Bed load: In this mode, particles roll and saltate along the bed in a layer a few particles thick above the bed. The weight of the particles is supported wholly by the bed. The collision of moving particles with those on the bed is an important mechanism for the initiation of further movement and the modification of existing motions.
- Suspended load: In this mode, the ambient fluid motions above the bed load layer advect the particles. The weight of the particle is supported wholly by the fluid.
- Sheet flow: If the stress due to the motion of the fluid exceeds a certain value then ripples on the seabed may be washed out and replaced by a thin moving carpet of particles of high concentration. Particle to particle interactions are very important in this mode, which is dependent upon both the hydrodynamic size of the particle and the magnitude of the fluid motions.

The hydrodynamic size of the particle is usually described by its fall velocity. The maximum wave orbital velocity at the bed can describe the magnitude of the fluid motions. These can be used to indicate the expected mode of transport for particular particles. As the wave conditions vary so will the mode of transport for any particular particle.

Movement due to Waves

Waves are important contributors to sediment movement, especially during storms, and particularly in relatively shallow waters, such as the Irish Sea. Waves with periods of 5-8 s feel the influence of the bottom in 20-100m of water. The bottom stresses generated by wave activity are generally greater than those associated with current activity alone. In the offshore zone, the primary effects of waves are therefore to enhance seabed stresses and to stir bottom sediment into motion so that it can be transported by tidal or other long-term flows. However, in the nearshore zone, the direct effects of waves assume a greater importance in sediment transport. Firstly, the waves themselves can induce steady surface flows in the direction of the wave propagation, which may move suspended sediment shorewards. Secondly, as waves travel into shallower water the ratio of the wave height to the water depth increases. This causes the wave profile to become asymmetric, which in turn causes the current under the wave crest to become greater, but of shorter duration, than the return flow under the wave trough. The consequence of this is again a net transport of sediment in the direction of the wave propagation.

The effect of wave action at the entrance to estuaries is to increase the supply of sediment available for transport into the estuary. Wave action increases sediment transport rates on the flood tide while ebb tidal currents limit wave penetration on the ebb tide. Consequently, there is a net movement of sediment into the estuary over a tidal cycle. The combined effect of storm surge, wave and wind action is thus likely to be an increase in mean water level, a removal of beach sediment offshore along adjacent coastlines, a lowering and re-circulation of nearshore shoals and an increased movement of sediment into the estuary.

Tidal Currents

Tidal currents have a strong influence on the direction and intensity of sediment transport. Coarse sediments, such as sand, are moved in the direction of the strongest currents, once the threshold of movement is exceeded, and consequently are moved preferentially in either ebb or flood directions. In contrast, fine sediment is moved in suspension and is carried in the direction of the long-term average flow. Much sediment, however, moves in suspension for part of the tide and then settles on the seabed around slack water. Predictions of the overall movement of such material are more complex, and both the maximum near-bed currents and the residual flows must be taken into account.

As well as oscillatory currents produced by the rise and fall of the tide a residual flow of water can take place associated with density, wave or wind induced currents. This movement is the flow that remains when tidal (and storm surge) effects are eliminated. Such flow is variable over time, being dependent upon a number of factors such as wind stress, inflow of waters into the Irish Sea, density distribution through the water column etc.

The tide is generally the dominant influence on the maximum current, the exception being in shallow water where wave motion becomes more important.

Rate and direction of Transport

Sediment transport is generally considered to occur in either an on/offshore direction or in a longshore direction. The wave and current regime applying at any site will largely dictate the direction and rate at which transport occurs. In the majority of cases sediment transport will have components in both directions.

As waves move onshore they are modified by a number of processes such as shoaling and refraction. There is a consequent spatial variation in the fluid motions at the bed. This is reflected in changes in the mode, magnitude and direction of sediment transport. These spatial changes are apparent in the morphological response of the beach profile. In the nearshore zone four major hydrodynamic regions have been identified as shown in Figure C.1 below.

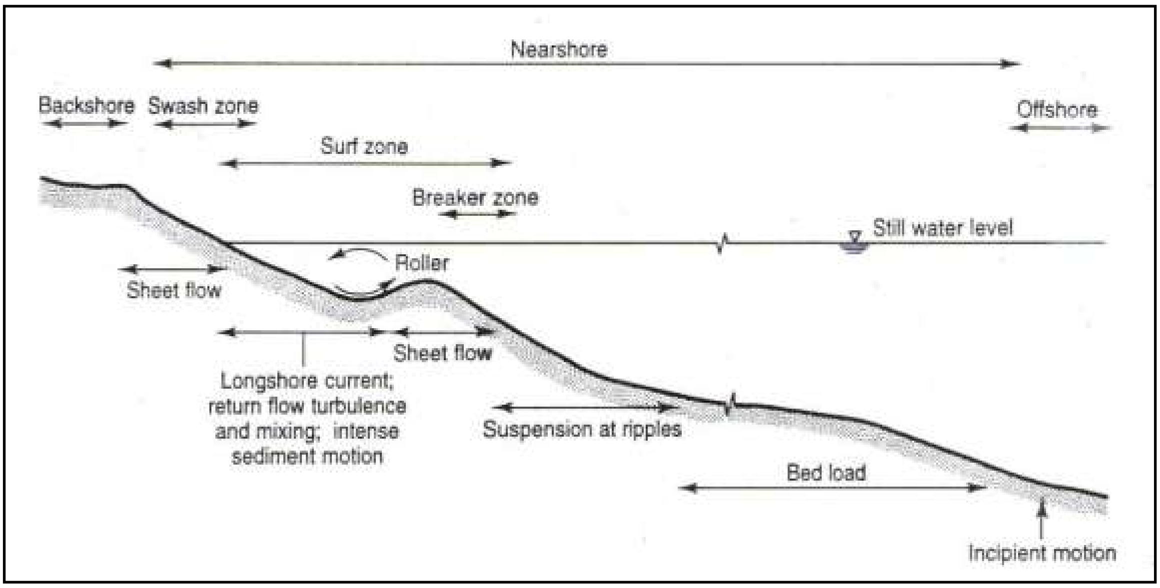


Figure C.1 – Definition of Foreshore Zones of Activity

- Offshore to breaker zone: In this zone waves begin to shoal as they are influenced or begin to feel' the bed. Flows at the bed become large enough to initiate the movement of particles. Initially the mode of transport is predominantly bed load. As the wave continues to shoal the flows increase in intensity and the suspended load increases. Ripples are formed which are parallel to the wave crests and sediment is suspended above them.

- Breaker zone: As the wave approaches the breaker zone the near bed velocities become very high and the ripples are washed out. The predominant mode of transport is sheet flow over a flat bed. Onshore of the breaker zone the stirring of the bed is much greater.

- Surf zone: This zone is characterized by turbulence generated by the breaking waves, downward jets of the breaking waves impinging on the bed and large-scale horizontal roller movement. Large amounts of material are suspended in the water column, the concentration being much greater than further offshore. There are strong indications that the amount of suspended load is correlated with long-period oscillations, which are of the order of 100 seconds), rather than with individual short-period waves. Wave-induced currents are present along with the oscillatory wave motion. In addition there is often a return flow offshore. The presence of large amounts of suspended material and strong currents results in high transport rates. Ripples are usually absent from the surf zone indicating the presence of sheet flow.

- Swash zone: This interface between the dry and wet areas of the beach is important for the understanding of event driven accretion and erosion. Both long-period oscillations and short-period waves may be important in this zone. Sediment moves in high concentrations as sheet flow under swash and backwash.

Longshore Transport

The transport, or 'drift', of beach material along a coastline, caused principally by the action of waves and tidal currents, is the major factor in the long-term development of beaches.

Significant volumes of beach material will only be moved if there is a steady, or quasi-steady, current to carry it, in this case running parallel to the beach contours. There are a number of possible causes for these currents, but in the UK there are just three main ones, namely:

(1) Waves which break at an angle to the beach contours
(2) Tidal currents
(3) Variations in breaking wave heights along the beach

Other factors sometimes cause, or contribute to the creation of shore-parallel currents, for example wind-induced stresses and river flows.

It is important to introduce the concepts of 'gross' and 'nett' transport. In very few situations does the transport of sediment along a coast travel only in one direction. As the winds change direction, so do the waves, with the result that on some days the beach material will be transported in one direction, and only to be transported back in the opposite direction a few days, or even a few hours later. When tidal currents are important contributors to the transport process, this variability in drift direction can be even more marked. The contribution of sediment from both directions is important. This is known as the gross drift, and is the summation of the volumetric transport rates independent of direction.

In most circumstances however, including the development of the beach plan shape, it is the nett result of the to-and-fro movements of the sediment that is more important. This is calculated by subtracting the two components of drift (i.e. up and down coast) from one another, and is called the nett longshore transport.