Llanddulas to Kinmel Bay Coastal Defence Improvements Environmental Impact Assessment

Coastal Processes Chapter

Draft Report

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21/09/2022	Draft report for comment	Amey Consulting / Conwy County Borough Council

Contract

This report describes work commissioned by Balfour Beatty, on behalf of Denbighshire County Council, and JBA Consulting carried out this work.

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Purpose

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Contents

1.0 Introduction

JBA Consulting were commissioned by Amey on behalf of Conwy County Borough Council (CCBC) to produce a series of conceptual defence options for a series of strategic locations between Llanddulas and Kinmel Bay on the North Coast of Wales. These defences are intended to reduce the risk of coastal flooding and wave overtopping in the area. The proposed defence scheme adopts both a hard and soft engineered approach. This incorporates the use of rock armour protection to the coastal frontage (hard) and beach replenishment (soft) where episodes of historic erosion have occurred.

1.1 Baseline Conditions

The purpose of establishing the baseline conditions is essential to identify how the area under investigation functions in response to a range of physical coastal processes. In determining the linkages between process and response it is possible to establish the potential natural evolution of the coastline as well as highlighting future impacts. The key interest areas for this chapter are:

- Hydrodynamics (wave climate and tidal regime)
- Sediment dynamics and transport
- Coastal morphology

The assessment of the coastal processes was undertaken through the use of a range of source material, including but not limited to the following:

- North West England and North Wales Shoreline Management Plan 2: Main SMP2 Document[1];
- North West England and North Wales Shoreline Management Plan 2: Appendix C – Baseline Process Understanding[2];
- DTI Strategic Environmental Assessment Area 6, Irish Sea, seabed and surficial geology and processes[3];
- Kinmel Bay to Llanddulas Beach – Detailed Design Stage: Review of beach profiles (1997 – 2020)[4];
- Channel Coastal Observatory[5], referred to herein as CCO, and;
- Remote assessment via site photographs, historic maps, LiDAR imagery[6], aerial imagery, [7]geological maps[8] and engineering design plans[9].

1.2 Limitations

The data collated withing this chapter has been obtained by undertaking a desk-based assessment of coastal processes and the potential impacts of the proposed defence

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[1] Halcrow Group Limited (2011). North West & North Wales Coastal Group. North West England and North Wales Shoreline Management Plan 2: Main SMP2 Document
[2] Halcrow Group Limited (2011). North West & North Wales Coastal Group. North West England and North Wales Shoreline Management Plan 2: Appendix C – Baseline Process Understanding
[3] British Geological Survey (2005) DTI Strategic Environmental Assessment Area 6, Irish Sea, seabed and surficial geology and processes. Continental Shelf and Margins Commissioned Report CR/05/057
[4] HR Wallingford (2021). Kinmel Bay to Llanddulas Beach – Detailed Design Stage: Review of beach profiles
[5] Channel Coastal Observatory (2022). Realtime data – Rhyl Flats. Data accessed via: https://coastalmonitoring.org/realtimedata/?chart=100&tab=waves
[6] National Library of Scotland (2022). Data accessed via: https://maps.nls.uk/
[7] Google Earth Pro (2022). Llanddulas to Kinmel Bay area – date range 1985 to 2022.
[8] British Geological Survey (2022). British Geological Survey – Geology Viewer. Data accessed via: https://geologyviewer.bgs.ac.uk/?_ga=2.232864214.919077300.1664180314-1446653846.1664180314
[9] Amey Consulting (2022). Detailed design general arrangement drawings - Llanddulas To Kinmel Bay Coastal Improvements

scheme on those identified process mechanisms. This assessment has drawn upon existing published documentation including grey and academic literature sources and previously published reports relevant to the study site. Given the uncertainty associated with predicting natural change in the coastal environment predictions of anticipated changes in beach morphology and geomorphic processes cannot be stated definitively but are estimated using the best available data and specialist expertise.

1.3 Site Context

The second iteration of the Shoreline Management Plan (SMP2) for North-west England and North Wales was published in 2011. It covers the coastal zone which extends between Great Ormes Head in North Wales and the Scottish Borders. This area, known as Cell 11, is sub-divided into cells with Sub-cell 11a, stretching from Great Ormes Head to Southport Pier which includes the Clwyd, Dee and Mersey Estuaries.

The Llanddulas to Kinmel Bay Scheme falls within this sub-cell which is further divided into multiple cells based on linked processes. The coastal zone incorporating Llanddulas and Kinmel Bay is Sediment Sub-cell 11a.2 (Figure 1).

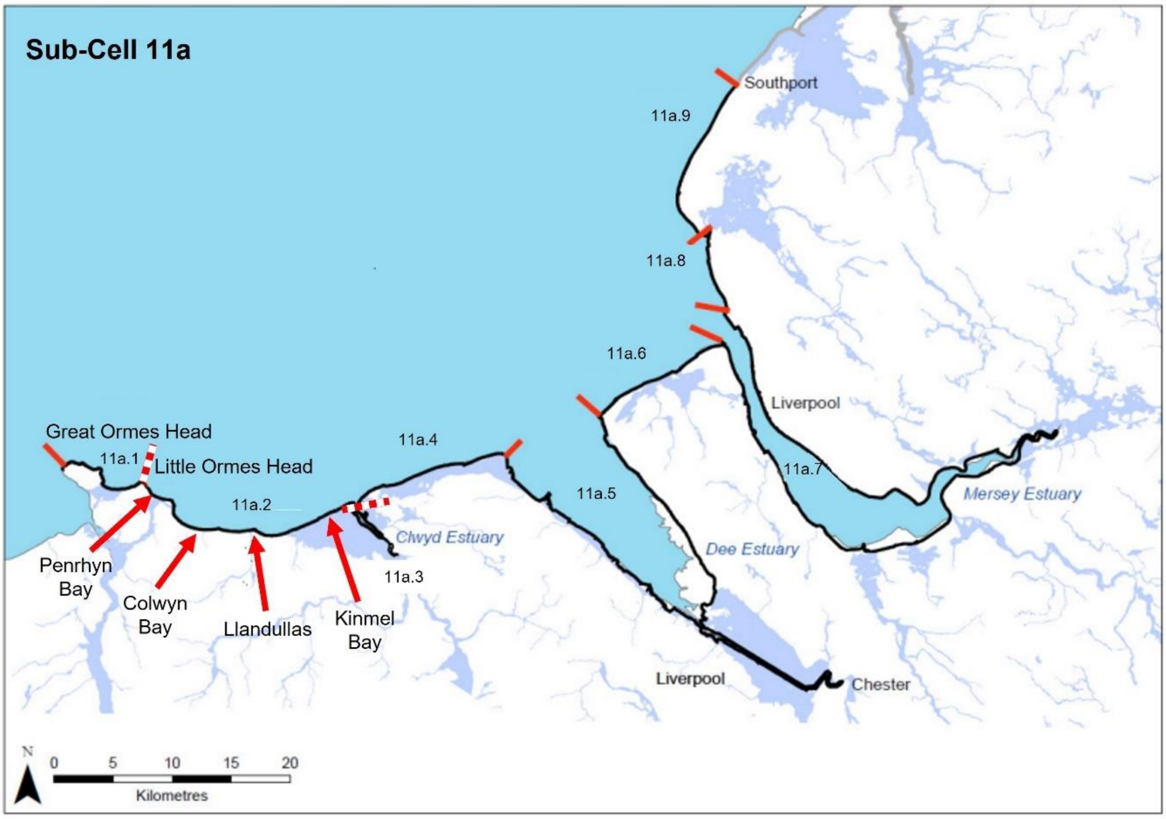

Figure 1. Overview map of Sediment Sub-Cell 11a with the western and eastern boundaries of cell 11a.2 recorded as the red and white hashed lines. Key locations including Llanddulas and Kinmel Bay are also identified.

The area between Llanddulas and Kinmel Bay is relatively low-lying in comparison to the western section of the sub-cell, thus making it more susceptible to coastal inundation in response to future rises in sea-level. However, the coastal frontage is protected against long-period oceanic swell waves, due to its location within the Irish Sea (Figure 3). Dominant wave conditions resulting from the prevailing winds and available fetch lengths occur mainly from the north-west, resulting in predominantly high wave angle conditions along the north-facing coast. The combination of tide and wave conditions has resulted in the formation of wide beaches comprised of a shingle backshore and sandy foreshore.

There are a number of existing coastal defence interventions that provide limited protection against wave overtopping and coastal flooding. These range from an existing rock revetment and timber groynes in the west (Llanddulas Beach), and a series of rock revetments that are located along the coastal frontage between Belgrano Beach and Kinmel Bay in the east. Under a 'Do Nothing' scenario these defences are given a residual life 0f between <20 – 50 years[10].

The area of the proposed scheme lies adjacent to the Liverpool Bay Special Protection Area (SPA) – (Site code - UK9020294). The SPA area covers 252,757.73 ha and extends approximately 17.5 km from the coastal frontage of Llanddulas and Kinmel Bay and lies in both English and Welsh territorial waters. The site qualifies as an SPA under The Birds Directive (2009/147/EC) for regularly supporting breeding Common and Little Terns and overwintering Red-throated Divers. The site also forms part of the Natura 2000 network.

The proposed scheme also encompasses the Traeth Pensarn Site of Special Scientific Interest (SSSI). This is a 51.7 ha site recognised for supporting species of special botanical interest within the vegetated shingle beach. The site supports both 'pioneer' and 'stable vegetated' shingle, extending approximately 1.7 km along Pensarn beach, from the promenade westward towards Llanddulas. The SSSI has been subject to episodic erosion due to exposure to wave activity.

The Water Watch Wales website identifies the proposed scheme lies within the 'North Wales coastal waterbody' (WFD Ref: GB641011650000) and the 'Clwyd Permo-Triassic Sandstone' groundwater waterbody (WFD Ref: GB41001G202100).

The North Wales coastal waterbody encompasses a 45 km stretch of the North Wales coast from Great Ormes Head to the Wales/England border, equating to an area of 146.25 km^2. The waterbody is designated as a Heavily Modified Waterbody (HMWB) due to modification associated with coastal protection. The waterbody is currently assessed as having an overall status of 'Moderate'. The driving elements for not achieving good are:

- Mercury, and its compounds - confirmed as arising from diffuse pollution from contaminated bed sediments and atmospheric deposition.
- Phytoplankton blooms - arising from an unknown pollution source (currently under investigation).

The Clwyd Triassic Sandstone groundwater body spans a broad area along the North Wales Coast, from between Colwyn Bay and Llanddulas to Prestatyn, and south to Llysfasi. It encompasses an area of 237.32 km^2 in size. The waterbody has a quantitative status of 'Good' and a chemical status of 'Good', giving it an overall status of 'Good'.

There are two designated bathing waters located along the coastal frontage between Llanddulas and Kinmel Bay. The status of these bathing waters is assigned under the Bathing Water Directive 2006/7/EC, these are:

- Abergele (Pensarn) - (BWD Ref: GB40450). The bathing water was designated in 2011 and was rated as 'Sufficient' for the 2021 bathing season (May – September). Short term pollution arises following periods of heavy rainfall when faecal contaminants wash into the sea from livestock, sewage and urban drainage via local rivers and streams. There are four identified origins of point source pollution surrounding the sampling location including sewage and surface water outfalls, storm water overflows and river intersections.

[10] North West England and North Wales SMP2 Appendix C, Section C4 - B – Baseline Processes – Little Orme to Point of Ayr

- Kinmel Bay (Sandy Cove) - (BWD Ref: GB40400). The bathing water was designated in 1988 and was rated as 'Good' for the 2021 bathing season (May – September). Short term pollution arises following periods of heavy rainfall when faecal contaminants wash into the sea from livestock, sewage and urban drainage via local rivers and streams. There is one identified origin of point source pollution surrounding the sampling location, a storm water overflow.

1.4 Tidal Regime

The coast of North Wales has a semi-diurnal tidal cycle which is the dominant physical process within the wider Irish Sea. The coastline incorporating Llanddulas and Kinmel Bay is subject to a macrotidal regime whereby the mean spring tidal range is approximately 7.5 m, the mean neap tidal range is 3.9 m, as obtained from nearby tidal data recorded at Rhyl 1.5 km northeast of Kinmel Bay (Table 1).

Table 1. Astronomical tide levels at Rhyl

Parameter	Tide Level (mAOD)
Highest Astronomical Tide (HAT)	5.03
Mean High Water Springs (MHWS)	3.97
Mean High Water Neaps (MHWN)	2.17
Mean Sea Level (MSL)	0.22
Mean Low Water Neaps (MLWN)	-1.7
Mean Low Water Springs (MHWS)	-3.5
Lowest Astronomical Tide (LAT)	-4.56

Admiralty TotalTide (ATT) software has been used to extract the underlying astronomical tidal diamond data in the vicinity of the study area. Values relate to locations approximately 15 km north of the Llanddulas to Kinmel Bay coastal frontage (Figure 2).

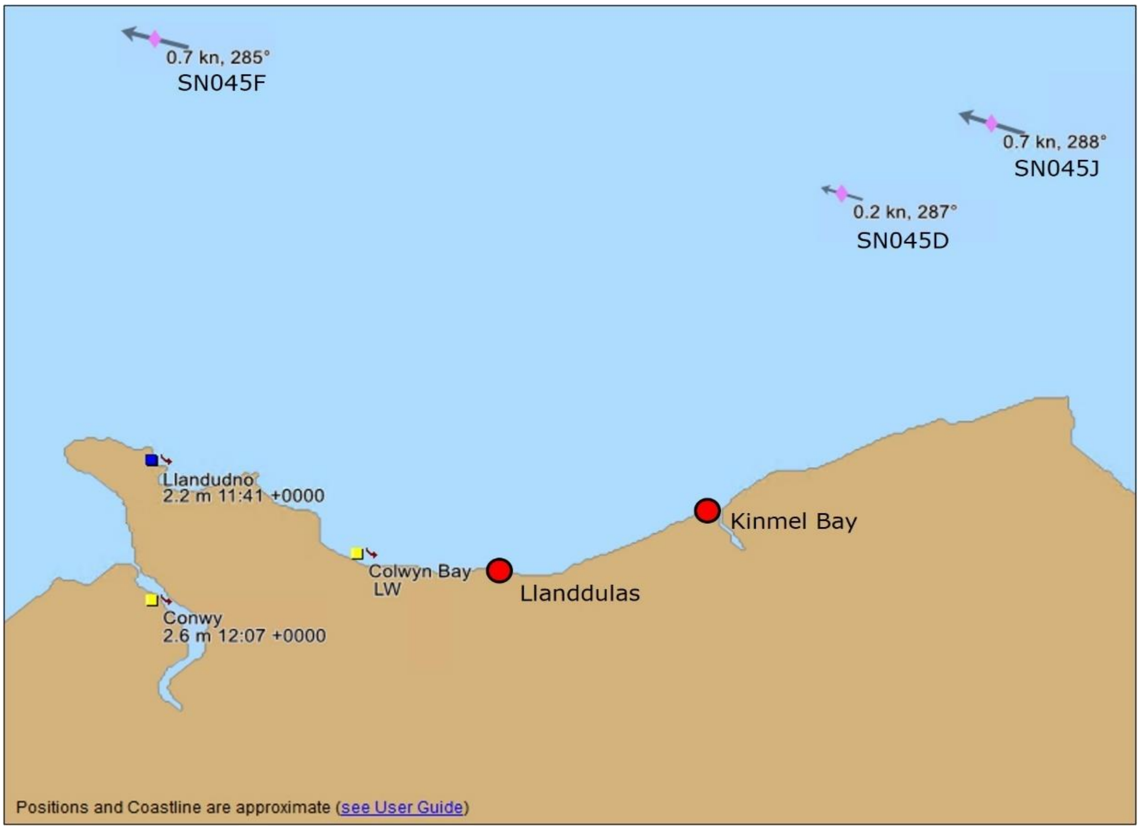

Figure 2. Tidal diamond data locations (Source: Admiralty TotalTide)

Astronomical tidal diamond data obtained from the nearest datapoint (SN045D) is shown in Table 2. This Table 1indicates a general west to east (flood), and east to west (ebb) tidal stream. Maximum flow rates on the flood tide are recorded 3 hours prior to HW with typical values of 1.4 kn (spring tide) and 0.8 kn (neap tide). This is followed by a period of slack water (0.1/0.2 kn) at HW, prior to the ebb tide which occurs in a near westerly direction. Ebb peak tidal flows occur 2 hours after HW with typical values of 1.4 kn (spring tide) and 0.8 kn (neap tide). Additional tidal diamond data retrieved from ATT is available in the Appendix (Section 1.14).

Table 2. Typical tidal conditions as derived from the tidal diamond data - for SN047D (Source: Admiralty TotalTide)

Time during tidal cycle	Direction (°)	Spring tide flow rate (kn)	Neap tide flow rate (kn)
-06 h	057°	0.3	0.2
-05 h	088°	0.7	0.4
-04 h	100°	1.2	0.7
-03 h	104°	1.4	0.8
-02 h	092°	0.9	0.5
01 h	079°	0.4	0.1
HW	289°	0.2	0.1
01 h	268°	1.1	0.6
02 h	270°	1.4	0.8
03 h	271°	1.1	0.6
04 h	275°	0.7	0.3
05 h	313°	0.4	0.2
06 h	020°	0.2	0.1

Tidal flow propagates into the Irish Sea from the Atlantic Ocean through the North Channel between the coasts of Northern Ireland and Scotland and from the south via St. George's Channel, between the coasts of The Republic of Ireland and Wales (Figure 3). The tidal flow velocities reportedly increase as volumes of water are directed through narrow inlets, between and around headlands[11]. Most notably, in the vicinity of sub-cell 11a.2 around the Isle of Anglesey. The tidal currents within sub-cell 11a.2 are relatively weak compared with those around the Isle of Anglesey. This corresponds with the low mean bed stress and limited sediment disturbance reported by Polton et al, (2011). The rocky outcrops of Great Ormes Head and Little Ormes Head provide a protective function to the area eastward by reducing the level of exposure to both tidal and wave forces. The tidal flow values suggest that whilst tidal influence dominates the wider Irish Sea within proximity to the coast these processes diminish.

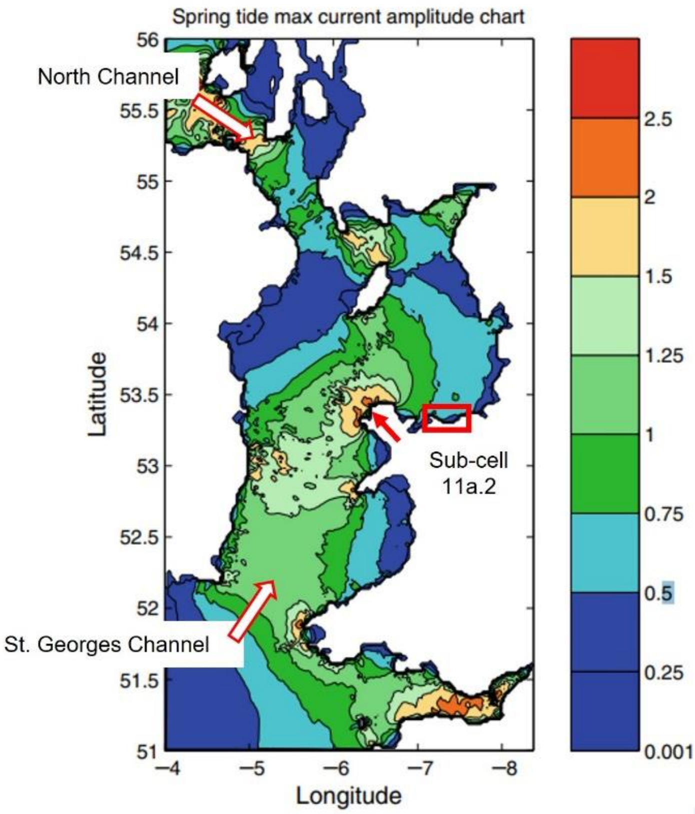

Figure 3. Depth averaged maximum currents on an average spring tide (in m/s). Sub-cell 11a.2 is highlighted, and the Isle of Anglesey is identified by the red arrow, figure adapted from Polton et al, (2011).

1.5 Wave Climate

Wave action is a complex process controlled by a range of factors that influence coastal process and shape the landscape. The way these factors combine determines the magnitude of any wave induced flood impacts, including the overtopping of coastal structures. Waves generated in deep water propagate towards land. On entering the nearshore the shallower bathymetry transforms wave processes. This is initiated via the interaction with the seafloor and coastal structures leading to wave

[11] Polton, J. A., Palmer, M. R., & Howarth, M. J. (2011). Physical and dynamical oceanography of Liverpool Bay. *Ocean Dynamics*, *61*(9), 1421-1439.

shoaling, diffraction, refraction and breaking. The consequence of these processes is that the properties of the inshore waves differ to those generated in deeper water. It is these nearshore waves that directly interact with coastal defences and lead to wave overtopping and incidence of coastal inundation. The magnitude of the waves arriving at the coast depends on the duration and distance across which the wind has blown, the fetch, which results in generation of swell waves.

The Irish Sea is semi-enclosed, meaning wave activity is fetch-limited which impedes the generation of swell waves. However, swell waves do occur, although generally only from the south via St. George's Channel and the northwest from the North Channel (Figure 3). The paucity of low frequency, high magnitude swell generated waves means that locally generated, lower magnitude wind waves are more frequent.

The morphology of the coastline within, and to the west of sub-cell 11a.2 also influences wave climate and the level of exposure to wave-generated forces. There are a series of rocky outcrops, Great Ormes Head and Little Ormes Head, that provide partial shelter from long-period swell waves. Penrhyn and Colwyn Bay are located in lee of these rocky protrusions and are afforded a greater level of protection than the coastline between Llanddulas and Kinmel Bay which is more open and exposed to the incident wave angle.

Wave data have been derived from parameters recorded by the Datawell Directional Waverider Mk III buoy at Rhyl Flats (Table 3). The wave buoy forms part of the Channel Coastal Observatory (CCO) National Network of Regional Monitoring Programmes located around the English and Welsh coastline. The wave buoy is located within Liverpool Bay, at Rhyl Flats, approximately 10 km north of Llanddulas in an approximate water depth of 10 m.

Table 3. Wave parameters - mean monthly averages recorded from Rhyl Flats (2007 – 2022). Source - Channel Coastal Observatory.

Month	Hs (m)	Direction (°)	Tp (s)
January	0.86	253	4.8
February	0.80	244	5.0
March	0.68	236	4.5
April	0.56	221	4.1
May	0.53	228	3.9
June	0.50	238	3.8
July	0.50	253	3.7
August	0.57	259	3.9
September	0.66	252	4.2
October	0.75	236	4.4
November	0.88	248	4.7
December	0.89	253	4.9

The significant wave height (H_s) is defined as the average wave height of the highest one-third of recorded waves. The reported wave climate at Rhyl Flats is naturally variable which reflects seasonal influence. Larger waves occur during autumn and winter months, compared with reduced wave heights associated with spring and summer. A maximum wave height of 4.65 m was recorded at Rhyl Flats on 23rd February 2017. Storm activity associated with Storm Eunice resulted in maximum wave heights of 4.5 m recorded on 21st February 2022. Wave periods also reflect the same seasonal variation. The dominant wave direction occurs from the northwest which corresponds with the mean and maximum significant wave heights and is supported by the accompanying wave rose directional data (Figure 4). The wave data from Rhyl indicates a north-westerly wave direction which corresponds with the area of greatest fetch and the generation of swell waves from the North Channel. The dominant easterly/westerly tidal flow and the north-westerly wave direction result in net littoral drift of sediment within the sub-cell from west to east.

The orientation of the coastline and the relative shelter afforded by the coastal geological forms and offshore sand banks reduces wave energy at the coast. The gentle gradient of the beach foreshore along the Llanddulas to Kinmel Bay frontage influences wave transformation producing spilling breaker wave types. These waves propagate across the wider bay area and lose energy as they approach the shore and interact with the seafloor.

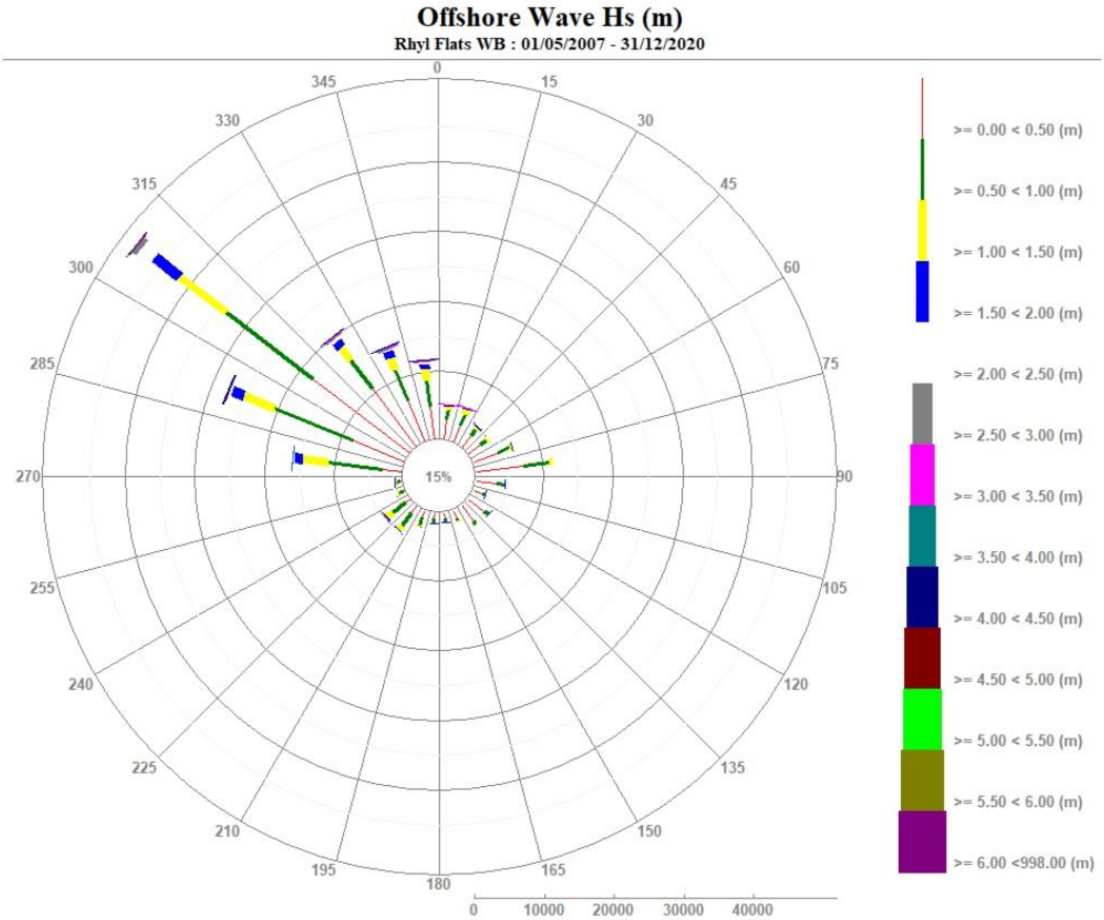

Figure 4. Wave rose diagrams of significant wave height (Hs) by wave direction (°). Rhyl Flats (2007 – 2020). Source - Channel Coastal Observatory.

1.6 Coastal Geomorphology

The coastal zone within sub-cell 11a.2 displays two distinct morphologies. In the west, Penrhyn and Colwyn Bays are derived from the erosion of the raised till cliffs, alluvial sands and gravels and the underlying sandstone bedrock through which the Afon Ganol drains into Penrhyn Bay. Moving eastwards to Llanddulas and beyond the topography changes to one dominated by low-lying terrain fronted by sand and shingle barrier beaches. The low elevation of this coastal section makes it vulnerable to wave inundation and flooding, as witnessed in 1990 and during the winter storms of 2013/2014. The likelihood of such occurrences is expected to increase due to rising sea levels and the anticipated increase in storm frequency and intensity arising from climate change[12].

The western boundary of sub-cell 11a.2 is defined by Little Ormes Head, a resistant Carboniferous limestone outcrop that influences the level of exposure of tidal and wave activity to the east. This landform acts as a natural obstruction impeding littoral drift. The eastern boundary at Kinmel Bay is defined by the Afon Clwyd and the estuary as it enters the Liverpool Bay. A key feature of this fluvial input is the training wall that acts as a breakwater to the east. This man-made feature has instigated perturbations to coastal processes in the form of reducing sediment connectivity between adjacent sub-cells and is seen as a point of termination with regards the supply of coarse gravels that are absent on the beaches to the east of this point. Beach sediments supplied from the west alter along the Llanddulas to Kinmel frontage with coarse material (shingle) diminishing eastward and fine sediment (sand) beaches dominating to the east. This reflects a limited supply of coarse sediment arising from extensive coastal protection to the west.

A series of rocky limestone outcrops between Little Ormes Head and Llanddulas are interspersed between softer sandstone and mudstone deposits creating a series of cuspate bays including Penrhyn Bay, Colwyn Bay and the arcuate embayment that extends from Llanddulas to Kinmel Bay. Both Penrhyn Bay and Colwyn Bay are aligned to the northwest which ensures the bays are protected from the dominant influence of wave and tidal activity. Wave energy is refracted around the headlands and sediment is deposited on the western flanks of the defence structures (e.g., breakwaters and rock armour groynes) within the bays. The coastal frontage between Llanddulas and Kinmel Bay is aligned more shore normal to incoming wave activity. The east-north-east to west-south-west orientation decreases the net sediment transport rate along the frontage as far as the Clwyd Estuary[13]. The combination of geology, shore orientation and hydrodynamic conditions (wave and tidal) has resulted in the formation of a long and wide beach along the Llanddulas to Kinmel Bay frontage. At Kinmel, the eastward littoral drift has formed an extensive sand dune system (Kinmel Dunes Local Nature Reserve), much of which is now built upon with a mixed provision of residential properties and holiday caravans. The most easterly section of the dune system remains connected to the beach and is stabilised by well-established vegetation. Management of this area has seen the construction of a network of raised wooden walkways aimed at reducing pedestrian trampling.

The majority of the coastline between Llanddulas to Kinmel is characterised by mixed sand-shingle barrier beaches with the lower shore generally comprising of sand. The deposition and reworking of beach face sediments is organised to present a series of shore parallel shingle ridges that form a reflective barrier to incoming wave activity, this is particularly evident at the coastal frontage of Pensarn and Belgrano beaches[14].

The wave and tidal conditions dictate that sediment transport occurs from west to east. This is confirmed by the direction of sand wave crests found on the mobile offshore seabed bedforms of Rhyl Flats and Constable Bank[15]. However, the presence of natural and artificial barriers impedes the transport process. These take the form of resistant rocky outcrops, outflow from the River Dulas and River Clywd, and the numerous coastal defence structures.

[12] Berg, P., Moseley, C., & Haerter, J. O. (2013). Strong increase in convective precipitation in response to higher temperatures. *Nature Geoscience*, 6(3): 181.
[13] North West England and North Wales Shoreline Management Plan 2: Appendix C – Baseline Processes

[14] Lee, M (2005). Investigation of beach levels at Pensarn Shingle Ridge. Conwy County Borough Council. CCW Contract Science Report no. 695

[15] DTI Strategic Environmental Assessment Area 6, Irish Sea, seabed and surficial geology and processes Continental Shelf and Margins Commissioned Report CR/05/057.

In response to the dominant wave and tidal influence fluvial inputs from the River Dulas and Clywd also contribute terrestrial sediments to the system as well as partially interrupting littoral drift. The rivers flow through semi-rural hinterland prior to reaching the coastal towns of Llanddulas and Kinmel respectively. Flow from the Clywd Estuary cuts through a sandflat at Kinmel and Rhyl creating a physical barrier which influences sediment connectivity. The notable lack of shingle eastward of the Clywd suggests it is a barrier to the mobilisation of gravels that are found extensively along the Llanddulas to Kinmel frontage.

Outflow from the River Dulas and Clywd Estuary are managed by rock armour training walls which channel flow, and entrained sediment into Liverpool Bay. These structures facilitate the accumulation of sediment creating extensive sandflats that extend seaward from the coastline. The Kinmel/Rhyl sandflat is a source of sand-sized sediment to the extensive coastal sandflats at the mouth of the Dee Estuary 15 km east of Kinmel. Aerial imagery indicates these landforms extend to the mean low water mark, approximately 250 m at Llanddulas and 1.5 km at Kinmel Bay. The sand accumulation at Kinmel Bay forms part of the more expansive Rhyl Flats, an extensive network of offshore sandbanks and flats upon which an offshore wind farm is located approximately 9 km north of Llanddulas. Rhyl Flats is formed in the shallow offshore waters (10 – 20 m) and extends west to incorporate Constable Bank, a linear submarine sand spit positioned roughly parallel to the shore. The dominant north-westerly wind-driven currents, waves and tidal processes interact with these submerged features which provide a source of onshore transport of sand-sized sediment to the coastline of Kinmel and Llanddulas. They also act to maintain the recirculation of sand sediments within the system[16]. The offshore sandbanks and flats also have an impact on wave hydrodynamics by exerting influence on the nearshore wave climate. Wave interaction with the subtidal bedform features reduces wave energy at the coast and alters wave patterns within the area.

In response to the development of the coastal towns of sub-cell 11a.2 a series of defence structures have been constructed to protect coastal assets including housing, road and rail infrastructure from coastal flooding. The defences include concrete seawalls (Colwyn Bay), rock armour revetments (Towyn), fishtail groynes (Penrhyn Bay), timber groynes and rock armour groynes (Llanddulas Beach). However, these structures have contributed to sediment deficits in the littoral drift budget leading to a lowering of beach levels via the reduction in sediment supply from the west[17]. This has subsequently led to a narrowing of the intertidal zone. Interpretation of historic mapping indicates a landward progression of the low water mark of 65 m between the early 1900's and 1960's. The implication of extensive coastal defence is the increased likelihood of future coastal squeeze, whereby existing levels of protection prevent the natural rollback of coastal landforms in response to rising sea levels and the expected increase in storm frequency and intensity.

The range of artificial defence structures not only interrupts the natural sediment flux but in the case of sea wall defences they eliminate the input of sediment derived from the cliffs, dunes and low-lying areas landward of the walls. This process limitation affects the land-coastal interaction resulting in a lack of additional sediment input altering flux rates. The reduction in sediment at a local-scale leads to starvation of beach-building material which can leave coastal areas exposed to increase risk of inundation during periods of heightened wave activity. Sediment scarcity subsequently becomes a dominant control in beach evolution.

1.7 Beach Profiles

The proposed defence scheme is to be undertaken within six Coastal Management Units (CMU) located along the Llanddulas to Kinmel coastal frontage (

[16] North West England and North Wales Shoreline Management Plan 2: Appendix C – Baseline Processes
[17] North West England and North Wales Shoreline Management Plan 2.

Table **4**). These locations are listed below with the proposed defence option; these are ordered sequentially, from east to west. Figure 5 provides detail regarding the scheme site location, proposed area of work and beach profile locations.

Table 4. Components of the proposed coastal defence scheme

CMU 3-2A: Llanddulas Revetment
The proposal is to maintain defences to current defence standard by regular monitoring and maintenance and appropriate actions as any issues become apparent. No further intervention is considered along this area. Monitoring and maintenance of the existing structure's toe will be required since beach levels may lower with time.
CMU 3-2B: Llanddulas Beach
It is proposed to include a setback flood wall along the CMU and the enhancement of the rock revetment at the eastern end of the frontage. The new defence will stretch roughly 350 m, along two existing bays bound by substantial rock groynes. The raised embankment will be tied into existing raised ground to prevent the new defence being outflanked in coastal flood conditions. The level of the embankment crest will provide adequate protection considering the recommended allowances for sea level rise. The new defences are designed to offer a standard of protection (SoP) up to a 1 in 200-year coastal flooding event through to the year 2041. The purpose of the intervention proposed is to reduce the risk of flooding and to reduce damage from flooding due more extreme and less frequent events.
CMU 3-4: Pensarn Beach

This area is of great importance due to the presence of the Traeth Pensarn SSSI, an area of special botanical interest for its vegetated shingle beach plant communities. The stretch of frontage is suffering from long-term retreat and consequent realignment caused by the limited supply of shingle material from the west. The preferred option proposes an initial substantial capital beach nourishment with a programme of maintenance including periodic beach recharge which will provide supply of material to the starving beach, allowing the ridge to recover and vegetation to flourish. The nourishment will need regular maintenance to make sure the area of vegetated shingle does not narrow, given that there is limited supply of shingle material from the west due to existing coastal defence works. It is however expected that storms will still potentially affect the ridge, though a larger beach will provide valuable dissipation of wave energy. Beach recharge at this location will benefit the adjacent Pensarn Beach to the east via the eastern littoral drift of sediments.
CMU 3-4: Pensarn Beach
Further along this frontage there is a need to maintain defences to the current defence standard by regular monitoring and maintenance. Appropriate actions are to be taken as any issues become apparent (e.g., breached defences). Overtopping analysis has shown that although the standard of protection will decline with time, due to sea level rise, the stretch of frontage will still provide adequate protection, though may suffer from coastal squeeze in the future.
CMU 3-5A. Belgrano Beach
The coastal defence upgrade in this CMU has been divided into two schemes, one at the western end of Belgrano beach, where an existing sea wall currently offers limited coastal flood protection and the other at the eastern end where there is a set-back seawall from the beach. The proposed designs for the coastal defence upgrade will be new rock armour defences in both sites: In the western site, rock armour will be placed in front of the existing sea wall, with a crest width of 6 m and a slope angle of 1 in 4. The total length of this rock armour installation will be 500 m. The rock armour is designed to offer wave overtopping protection for a 1 in 200-year event in 2041. The eastern site will involve new rock armour, extending eastwards from the existing rock armour. The total length of the western rock armour unit will be 300 m, with a crest width of 5 m, and transitions from a 1 in 3 slope to 1 in 2 as the beach gets wider. The rock armour is designed to offer wave overtopping protection for a 1 in 200-year event in 2041.
CMU 3-5B. Towyn Revetment
The proposed upgrade will significantly increase the level of coastal flood protection offered by the current rock armour unit. The new design will keep the 1 in 4 slope angle of the current rock armour unit but increase the crest width and height so that a SoP is achieved for a 1 in 200-year event up to the year 2041. The new design reuse and repurpose the current rock armour material. The existing sea wall is being raised by 0.75 m.
CMU 3-5C. Kinmel Bay Beach
This section requires several actions comprising an increase in the height of the seawall crest by 500 mm along the entire unit, and upgrade/replace existing flood gate at the car park. The level of the seawall crest will be increased to provide improved wave overtopping flood protection to Kinmel Bay, accounting for Sea Level Rise (SLR) up to 2041. The section also includes re-profiling the level of the entrance to the car park located at the end of St Asaph Avenue. This localised change in elevation will provide flood protection landwards by preventing water entering the main town, with any flood water returned to the sea by flap gates.

The existing rock revetment at the eastern end of Kinmel Bay Beach will be enhanced and upgraded. The existing seawall behind the rock armour will be raised by 500 mm and new rock armour installed in front. The rock armour will have the same crest level as the wall, a crest width of 5.6 m and a slope angle of 1 in 3. The length of the new rock armour unit will be approximately 420 m. Additional to the coastal flood protection offered by the rock armour design, ecological enhancements are being provided with the creation of artificial rock pools to provide new habitats and texture to the surface of the rock armour to encourage colonisation by marine invertebrates. The rock pools will be placed at different levels on the cross section of the rock armour to provide habitat opportunities during different tide cycles. Re-instate sand dunes where necessary along the stretch to the east of the car park at the end of St Asaph Avenue, where gaps exist along the landward side of the foot/cycle path. The reduction of the overtopping along this CMU is characterised by the enhancement of the existing revetment at the eastern end. The benefit of this action is in the reduced risk of siltation problems at the mouth of River Clwyd.

Cross-sectional beach profile data was provided to HR Wallingford by Conwy County Borough Council (CCBC) to determine historic changes to beach profile and a qualitative assessment of sediment volumes over time. The graphed beach profiles reported have been obtained from this source data[18]. Topographic beach profile data was collected in 1998, 2014, 2018 and 2020 and seven cross-sectional profiles have been selected to represent the nearest locations relative to the proposed coastal defence scheme along the Llanddulas to Kinmel Bay frontage, these are indicated by the triangular markers (Figure 5). Profiles are interpreted to assess changes in beach morphology over time.

The profile data demonstrates the extent to which coastal processes and anthropogenic influence have altered beach morphology over the period of data collection and can highlight erosion and accretion of sediment at specific site locations. Limitations exist in that the data is derived from a limited number of periodic assessments over a period of 22 years, and therefore the data provides a brief insight of beach conditions at a specific time and location. Furthermore, the dates of the surveys are unknown which limits any assessment of geomorphic modification arising from changes associated with seasonal weather patterns. These data do not necessarily represent historic trends and only allow for a descriptive assessment of beach modification opposed to a quantitative estimation of sediment gains and/or losses along each transect.

[18] HR Wallingford (2021). Kinmel Bay to Llanddulas Beach – Detailed design stage. Review of beach profiles. Report to Conwy County Borough Council (CCBC) – Report no. RT003.

Figure 5. Site location – the coastal frontage is sub-divided into Coastal Management Units (CMU). Beach profile locations are indicated by triangular markers.

1.7.1 CMU3-2B: Llanddulas Beach - Rock armour

The beach profile data obtained from the proposed location of the rock revetment at Llanddulas Beach indicates limited morphological change in the cross-sectional beach profile and associated sediment volumes over a 22-year period (Figure 6). Although the beach profile is vertically exaggerated, the steep backshore and upper foreshore reflects the presence of the shingle ridge which enables increased percolation of uprushing spilling waves within the swash zone. This percolation, and associated reduction in energy limits the size of material that can be transported on the receding downrush, pushing coarser shingle up to and against the sea wall to the rear. Smaller sand particles (<2 mm) are subsequently deposited lower on the foreshore.

The limited profile modification reflects the stability of the beach given its northeasterly orientation and relative shelter in lee of the rock armour training wall at the point of discharge from the Afon Dulas to the west. This structure has aided the accumulation of sediment creating a sand bar that extends approximately 250 m from the coastline. This landform provides added protection to the leeward area reducing wave energy and erosive capacity. Moreover, it acts as a source of sediment to those beaches located to the east. Additionally, there are numerous other defence structures in proximity to the profile transect including a series of timber and rock armour groynes which act to retain sediment providing an increased level of stability to the beach.

Aerial imagery identifies several of the twelve wooden groynes immediately west of Llanddulas (Afon Dulas outflow) are in a state of disrepair and may only be providing limited functionality in terms of retaining sediment. Furthermore, the rock armour groynes to the east of the Afon Dulas outflow are partially eroded at upper beach levels where landward emplaced blocks have been moved by wave activity. These minor breaches to the defences may allow for the mobilisation of sediment between groyne cells higher in the tidal frame. This may be reflected in the marginal increase in sediment in 2018, at and around the MHWS mark. The remaining foreshore, to the level of MLWS has seen a marginal increase in deposition since the original topographic survey in 1998. In general terms the beach profile data suggests a net gain in sediment over time.

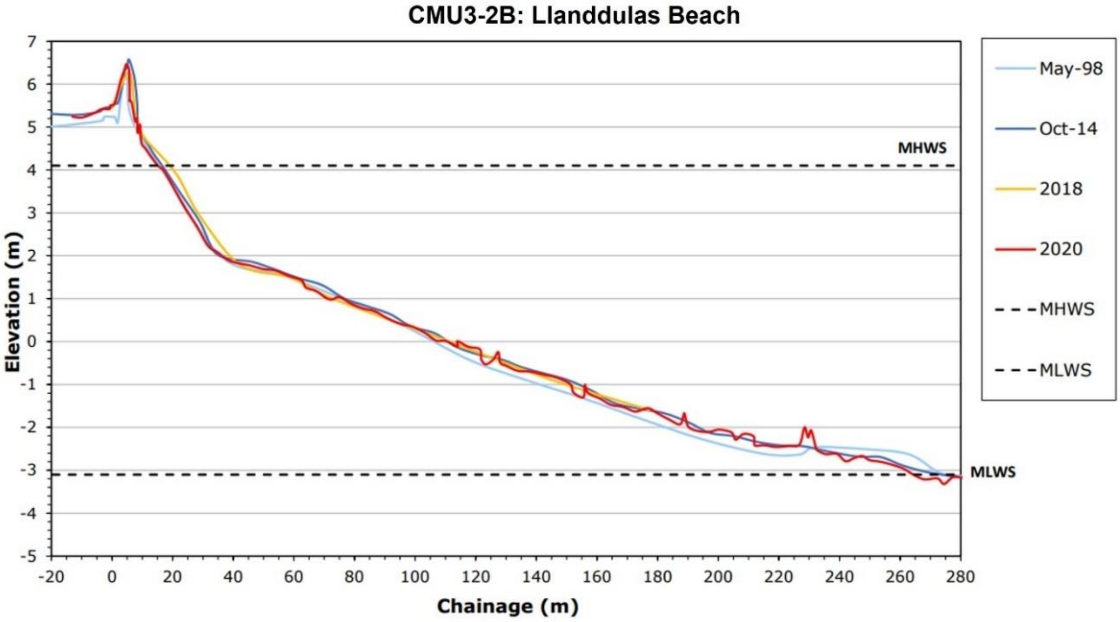

Figure 6. Cross-sectional beach profile – Llanddulas Beach

1.7.2 CMU3-4: Pensarn Beach - Beach recharge

The beach profile from Llanddulas Tip / Pensarn Beach displays considerable modification and loss of sediment volume relative to the initial topographic survey in 1998 (**Error! Reference source not found.**). The profile data indicates the beach crest has receded landward by approximately 30 m between 1998 and 2020.

This beach section is located immediately adjacent to an existing rock revetment. Using historic aerial imagery, it is possible to identify periodic erosion which occurred between 2006 and 2020. In 2006, the beach was characterised by a large beach crest, approximately 15 m wide, with well-established vegetated sand and shingle habitat. Between 2006 and 2009 the adjacent rock revetment was outflanked by wave activity, leading to the partial erosion of the sand and shingle habitat. Measurements suggest the landward extent of this habitat receded by approximately 7 m during this period.

The aerial imagery from June 2009 to April 2015, and beach profile data from 1998 to 2014, indicate extensive erosion occurred between these periods with the removal of sediment from behind the revetment as well as considerable loss of the sand and shingle habitat. This loss is potentially ascribed to the extreme storm activity which occurred during the winter of 2013/2014. This loss of sediment resulted in the fragmentation of this valuable coastal habitat. Following this loss of sediment additional rock armour was used to extend the revetment up to a sheet piled sea wall and a programme of beach recharge was undertaken to reinstate lost material. This was supplied via quarried material deposited adjacent to the area in August 2015. This exposure to wave energy and sediment scour arising from the extension to the rock revetment has since led to considerable loss of sediment and habitat. This has resulted in the removal of the deposited beach recharge material which has since been eroded from the site; further recharge to reinstate beach levels has not since taken place. Such is the extent of erosion the MHWS mark has migrated landward over 25 m between 1998 and 2020.

Despite sediment loses from the backshore the profile data identifies accretion in the mid-intertidal zone relative to the initial survey in 1998. Material loses from the backshore, particularly in response to the winter storms of 2013/2014, may have resulted in drawdown of material onto the lower foreshore. Alternatively, erosion of material at this location will have acted as a source of sediment to the beaches to the east.

Considering the proximity of the Traeth Pensarn SSSI to this profile (Figure 5), continued erosion is expected to impact on the existing area coverage of the SSSI. It has therefore been proposed that further beach replenishment could offer suitable intervention to reduce wave overtopping, erosion and protect the SSSI. This would involve the sourcing and placement of suitably sized, quarried material at Ty Crwn, which is located between CMU3-3 and CMU3-4. This will act to prevent the undermining of the sea wall and provide suitable habitat for colonisation of valuable shingle vegetation. The deposited material will then be profiled to meet the required design specification. The deposition of recharged material will also act as a sediment source to the beaches east of this area, potentially increasing sediment volumes.

Given the limited supply of sediment from the west the expectation is that a regular programme of monitoring and maintenance will be required to ensure the width of the beach crest is maintained to offer the necessary design standard of protection against wave overtopping. Continuous wave activity and seasonal storm waves are expected to remove sediment providing a rich source of material for beaches to the east. However, the larger beach which will be created from the deposition of recharged beach sediment will have a dissipative effect on incoming wave energy.

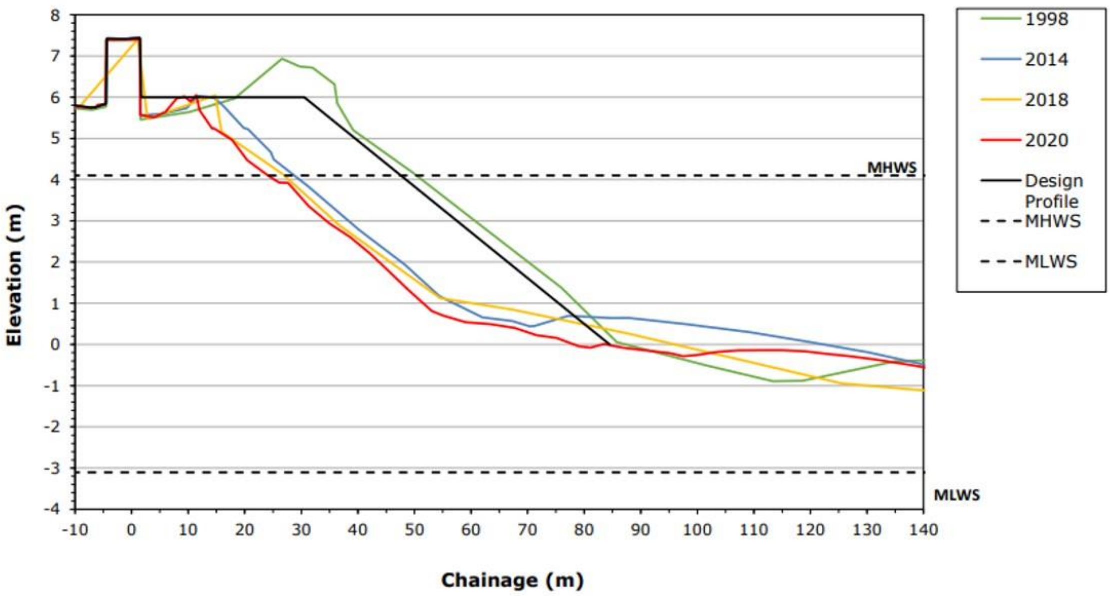

Figure 7. Cross-sectional beach profile – Pensarn Beach

The proposed beach recharge will be sourced from a local quarry to reduce the likelihood of introducing invasive species to the area. All material is washed prior to export to site to further mitigate against this. In order to reflect the existing sediment at the site particle size analysis of sediments obtained from the Ty Crwn SSSI in 2015 have been used in conjunction with the specification of beach recharge material from 2015. The particle size grading has been adjusted to accommodate the required engineered design and to provide a suitable substrate for the colonisation of vegetated shingle habitat. This is expected to enhance biodiversity and create connectivity with the SSSI. Opting for an increased percentage of coarser graded material compared with the 2015 recharge programme will help prolong the retention of material at the site, providing increased opportunity for habitat colonisation. The sediment specification for beach recharge material is presented below, Figure 8. The proposed particle size grading envelope for the 2022 beach recharge is denoted by the green solid lines.

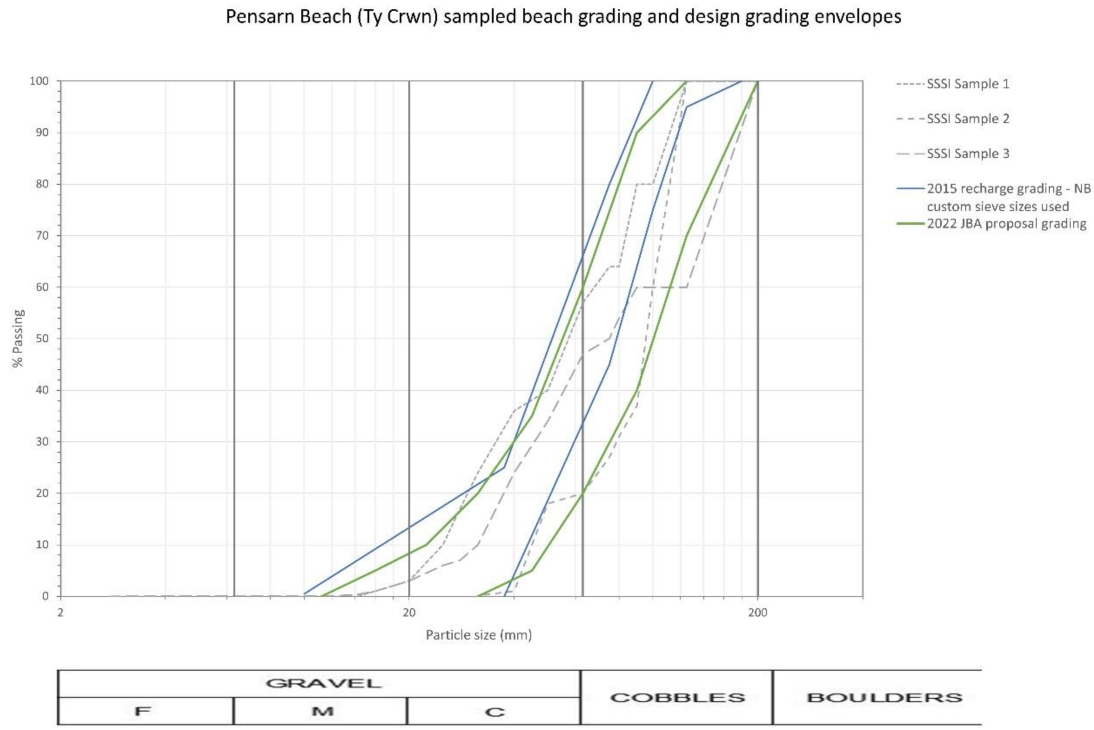

Figure 8. Proposed beach recharge specification

This particle size data used in the above figure has been tabulated in Table 5. The data utilises sieve aperture sizes in accordance with British Standard, BS EN 933-2.

Table 5. Particle size data for proposed beach recharge

Equivalent Sieve Size (mm)	2022 JBA proposal grading Lower & upper limit (%)
200	100
125	70 - 100
90	40 - 90
63	20 - 60
45	5 - 35
31.5	0 - 20
22.4	0 - 10
16	0 - 5
11.2	0

1.7.3 CMU3-5A: Belgrano Beach (West) - Rock armour

The beach at Belgrano Beach (West) is orientation east-north-east to west-south-west ensuring that the beach is aligned more shore normal to the prevailing wind and wave direction. Being swash aligned reduces the net sediment transport rate along the frontage and helps build up the beach profiles, providing increased protection to the hinterland. As at Llanddulas Beach the steeper backshore and upper foreshore reflects the morphology of the protective shingle bank that is located at the rear of the beach (**Error! Reference source not found.**).

The profile identifies evidence of sediment erosion and accretion with losses relative to the initial survey (1998) on the steep upper foreshore whilst instances of deposition and erosion are evident lower in the tidal frame. This may reflect periodic response to storm activity with sediment being removed over time. Loss of material around MHWS, may be attributed to storm events and associated wave surge or limited sediment supply from the west. Increases in beach volume are evident in the mid-intertidal range in 2018 although these are subsequently eroded by 2020. Accretion may have resulted from onshore sediment transport from the offshore sand accumulations of Rhyl Sands and Constable Bank during increased wave activity. Alternatively, this may be ascribed to the erosion of sediment from the beach replenishment that occurred in August 2015 at Llanddulas Tip to the west. The removal of sediment reflects the dynamic nature of the intertidal zone in response to hydrodynamic conditions.

Other geomorphic features exert influence on the changing cross-sectional profile of the beach and explain periodic accretion and erosion of sediment within the intertidal range. Aerial imagery from 2022 indicates a well-established ridge and runnel morphology, whereby deep, longshore troughs, or runnels, are formed within the intertidal zone. The development of the runnel is attributed to the drainage of tidal water. The subsequent incision and removal of sediment leads to the formation of adjacent sand ridges. These features are found in depositional, swash-aligned, fetch-limited locations with a surplus supply of sand and tidal ranges exceeding 3 m[19].

Measurements obtained from the 2022 aerial imagery indicate runnel formation at this location, as identified by the red arrow. This corresponds with the ridge and runnel feature recorded in the 2020 cross-sectional profile. However, the profile also indicates considerable accretion of sand at this location with beach levels increasing by approximately 1.5 m between May 1998 and October 2014, with a further increase in profile height of 0.5 m by 2018. Runnel deformation is often a response to changes in hydrodynamic conditions, e.g., storm wave activity, which flattens intertidal ridges leading to the infilling of adjacent runnels[20]. Alternatively, the eastward littoral migration of sand, potentially from the sand bar at Llanddulas Beach, may have contributed to increased beach volumes.

By 2020, ridge and runnel formation had been reinstated and beach levels have been reduced. The changing beach morphology reflects a dynamic coastline and suggests the ridge and runnel morphology is ephemeral and cyclical, with migration occurring in response to wave activity within the intertidal range. The large ridge and runnel forms act to drain tidal water retained with the mixed gravel sedimentary matrix of the upper beach and act as conduits contributing to the active longshore transport of sand generating localised changes in sediment accumulation altering cross-sectional beach profiles.

[19] Anthony, E. J., Levoy, F., Monfort, D., & Degryse-Kulkarni, C. (2005). Short-term intertidal bar mobility on a ridge-and-runnel beach, Merlimont, northern France. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *30*(1), 81-93.

[20] Masselink G. 2004. Formation and evolution of multiple intertidal bars on macrotidal beaches: application of a morphodynamic model. Coastal Engineering 51: 713–730.

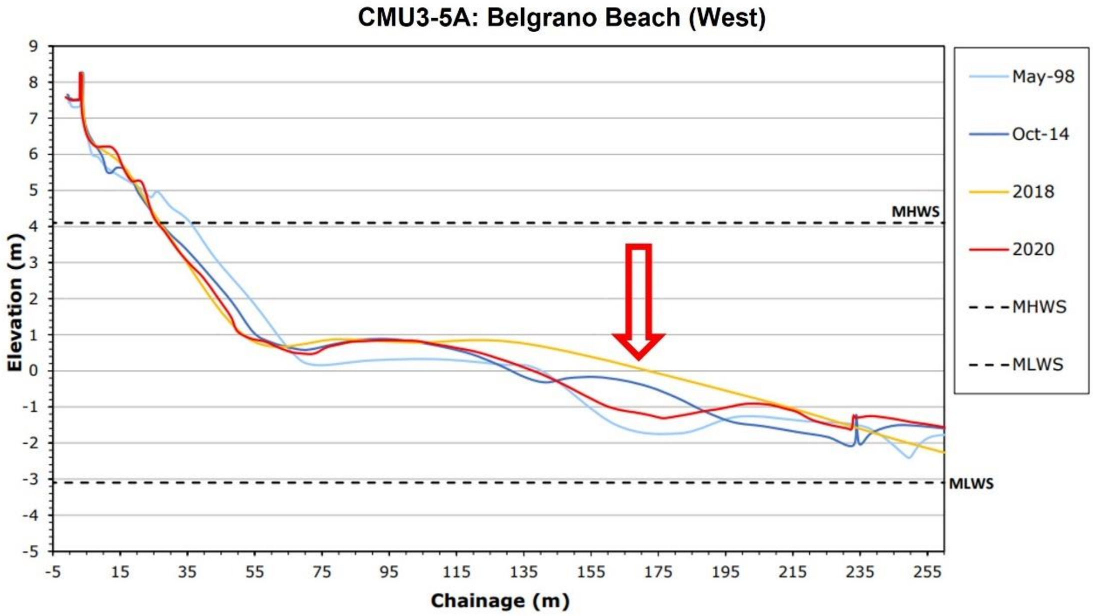

Figure 9. Cross-sectional beach profile – Belgrano Beach (West). Arrow indicates location of the ridge and runnel landform as identified using 2022 aerial imagery.

1.7.4 CMU3-5A: Belgrano Beach (East) - Rock armour

A notable profile difference between Belgrano Beach (West)**Error! Reference source not found.**, and Belgrano Beach (East), Figure 10, is the width of the shingle backshore and upper foreshore which extends approximately 90 m from the rear of the beach, compared with approximately 50 m at Belgrano Beach (West)**Error! Reference source not found.**. This is considered, in part, to be attributed to the existing rock revetment constructed in 1993[21] which lies immediately east of the profile along the Towyn frontage. The west to east migration of sediment accretes at the toe and the flank of the revetment and extends to the adjacent beach profile. The stability of this area is characterised by the vegetated mixed shingle and sand grassland habitat to the rear of the beach. The continued accumulation of mobile sediment leads to the increased seaward extent and the progressive accretion of sediment volume. The steep profile at the rear of the beach, albeit vertically exaggerated in **Error! Reference source not found.**, represents this accumulated shingle. The cross-sectional profile data suggests an accumulation of sediment over time either in response to increased hydrodynamic conditions, whereby coarse sediment is deposited on the beach and is pushed landward by exposure to storm waves, or alternatively, sediment accretion may have resulted from the translocation of eroded beach sediment from the replenishment that occurred in August 2015 at Llanddulas Tip to the west.

As with Belgrano Beach (West) the historic cross-sectional profiles of the foreshore are characterised by the same ridge and runnel morphology. Visual interpretation of aerial imagery from 2022 also identifies the presence of two longshore ridges and runnels at Belgrano Beach (East) as indicated by the red arrows. Modification of the ridge and runnel morphology and the associated changes to the cross-sectional profile within the mid, and lower intertidal zone suggests the runnels are migratory, shifting across the foreshore in response to hydrodynamic conditions. As previously described these features enhance the known eastward littoral transport of sediment providing beach forming sand to those areas to the east.

[21] Northwest England and North Wales SMP2, Appendix C – Baseline Processes Little Orme to Point of Ayr

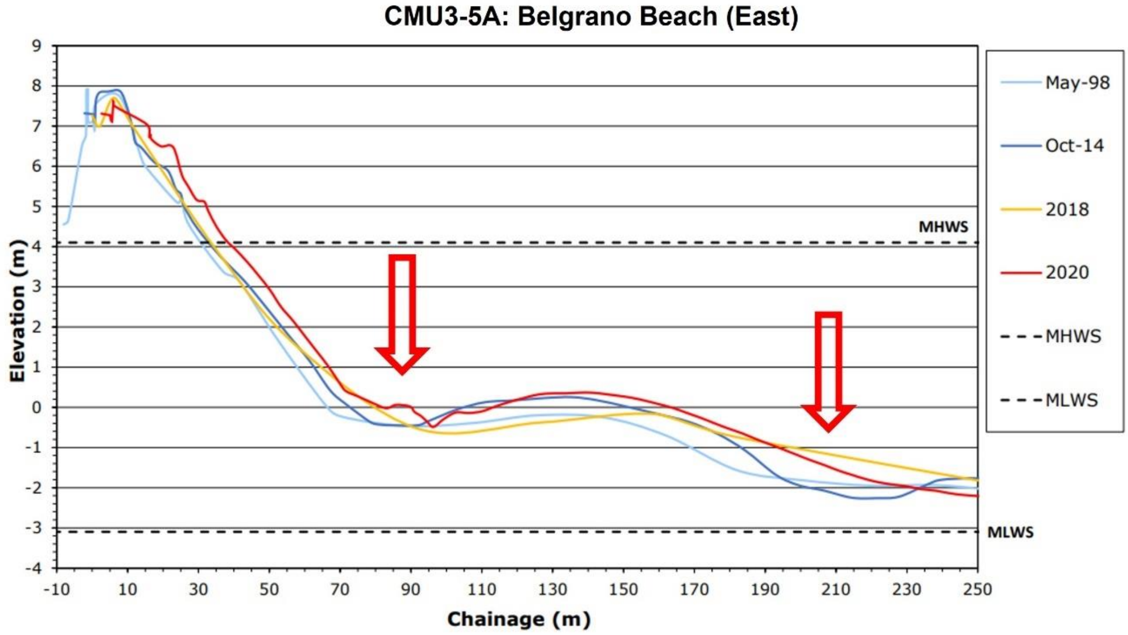

Figure 10. Cross-sectional beach profile – Belgrano Beach (East). Arrows indicate the location of the ridge and runnel landform as identified using 2022 aerial imagery.

1.7.5 CMU3-5B: Towyn Revetment - Rock armour

Data from the Towyn profile is restricted to three date periods (2015, 2018, 2020) which limits historic interpretation (Figure 11). However, the data indicates limited change in the supratidal zone above MHWS reflecting the limited exposure to wave action. Beach profiles from within the intertidal zone reflect a change between the different cross-section profiles. A notable difference between the previous profiles on the beaches to the west, is the gradient of the upper beach. The presence of a rock revetment against the sea wall at this location ensures a different profile. The accumulated shingle is narrower by comparison to sites located to the west as this area is partially shadowed from the littoral sediment pathway and dominant wave energy, as it lies in lee of the large rock revetment positioned along the Towyn frontage. The effect of this is a reduction in wave energy which limits the extent to which coarse sediment can be mobilised and deposited.

The upper intertidal profile remains relatively unchanged between 2015 and 2018 although within the mid to lower-tidal frame considerable accretion has occurred by 2018. The vertical exaggeration of the profile suggests the formation of a sizeable scarp-like feature measuring approximately 2 m in height. However, the topographic change occurs over 5 m indicating a gradual gradient more likely associated with a response to wave activity. The increase in beach volume may have occurred due to the littoral drift of beach recharge material deposited to the west at Llanddulas Tip, or active onshore deposition from offshore sediment sources (e.g., Rhyl Flats and Constable Bank). The profile recorded in 2020 indicates a considerable reduction in beach volume from the upper and mid foreshore. Beach lowering may have resulted from wave scour at the base of the rock revetment, progressive drawn down of sediment during wave backwash and/or the formation of an intertidal ridge and runnel system.

There is a notable accumulation of sediment on the lower foreshore between 2018 and 2020. This may indicate that a proportion of sediment losses from the upper beach are deposited lower on the foreshore due to wave backwash. Alternatively, the increase in beach volume at the lower foreshore may represent a broad ridge adjacent to a longshore runnel which appears to be present between 55 and 85 m (chainage). Coincidently, the aerial imagery from 2022 identifies a runnel measuring approximately 40 m in width that runs parallel to the shore. The red arrows indicate the approximate location of the runnel edges which correspond with the area of erosion during the 2018 – 2020 timeframe. Despite the accumulated sediment in the lower foreshore the overall trend at this location seems to be one of net sediment loss.

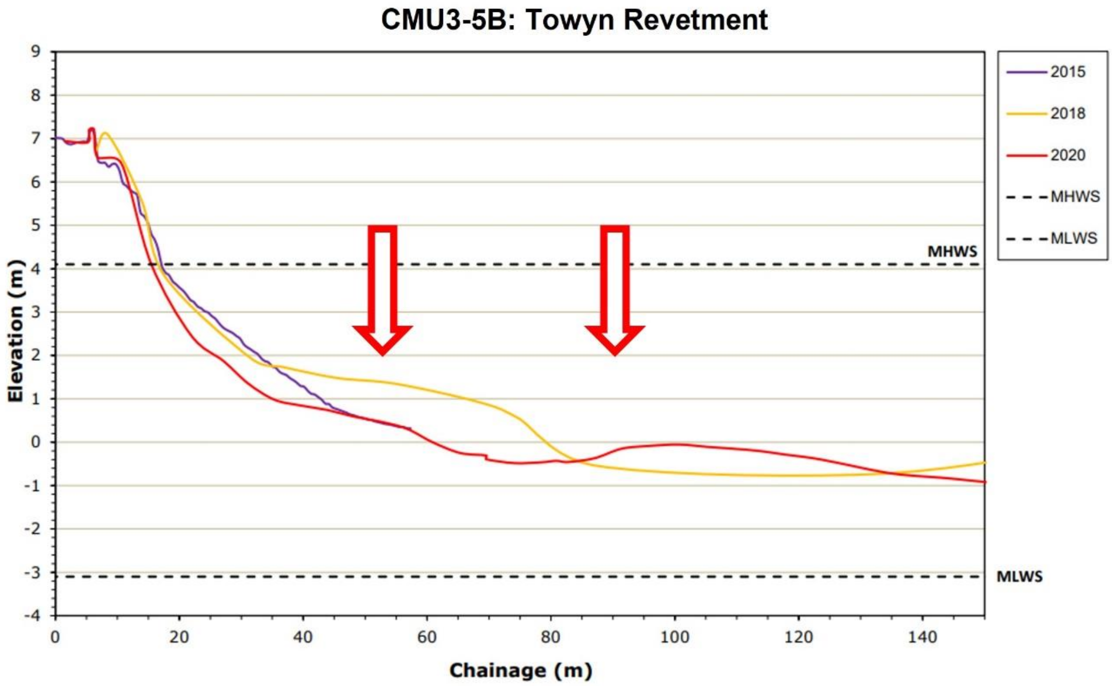

Figure 11. Cross-sectional beach profile – Towyn Revetment. Arrows indicate the location of the ridge and runnel landform as identified using 2022 aerial imagery.

1.7.6 CMU3-5B: Kinmel Bay (East) - Rock armour

Profile data (Figure 12**Error! Reference source not found.**) indicates a periodic change in beach morphology and volume over time. The beach profile of the supratidal area reflects limited change over the monitoring period with volumes remaining relatively unchanged between 2014 and 2020. Conversely, the intertidal zone is characterised by dynamic response to wave and tidal processes as illustrated by the shifting ridge and runnel landforms that pervade the sandy foreshore. The undulating topographic profile is best demonstrated by the 2020 profile data which shows two distinct runnels that have formed perpendicular to onshore wave/tidal exposure.

The greatest degree of change in profile is evident within the mid-intertidal zone where wave energy is most concentrated over the course of the tidal cycle. There is little evidence to suggest qualitative changes, either erosional or depositional, to beach volumes since 2014. However, sediment volumes appear to have increased relative to the original profile obtained in 1998 suggesting the eastern end of the sub-cell (11a.2) is accreting sediment opposed to suffering from extensive erosion.

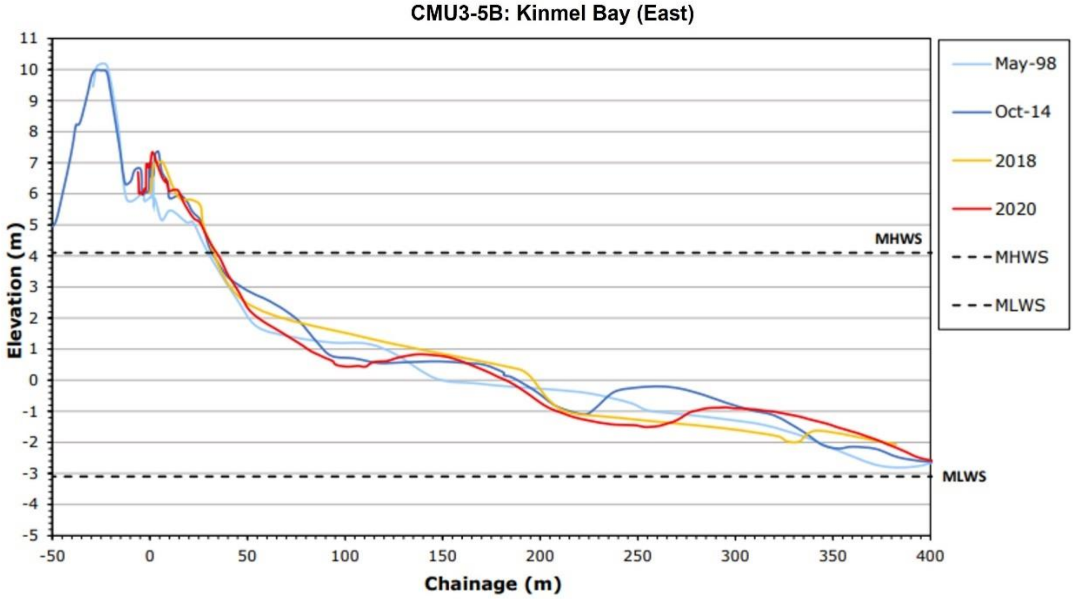

Figure 12. Cross-sectional beach profile – Kinmel Bay (East)

Figure 13 identifies the ridge and runnel morphology and illustrates the cross-shore extent of these features which stretch hundreds of metres along the sandy foreshore. The image was taken at the approximate location of the above profile, towards the eastern end of Kinmel Bay, 20 minutes prior to low water on 9th August 2022. The image reveals two ridge and runnel forms, similar to those recorded in the profile data. The flat topography of the intertidal zone demonstrates the extent to which the tide recedes allowing for a suitable working window within which defence construction can be undertaken.

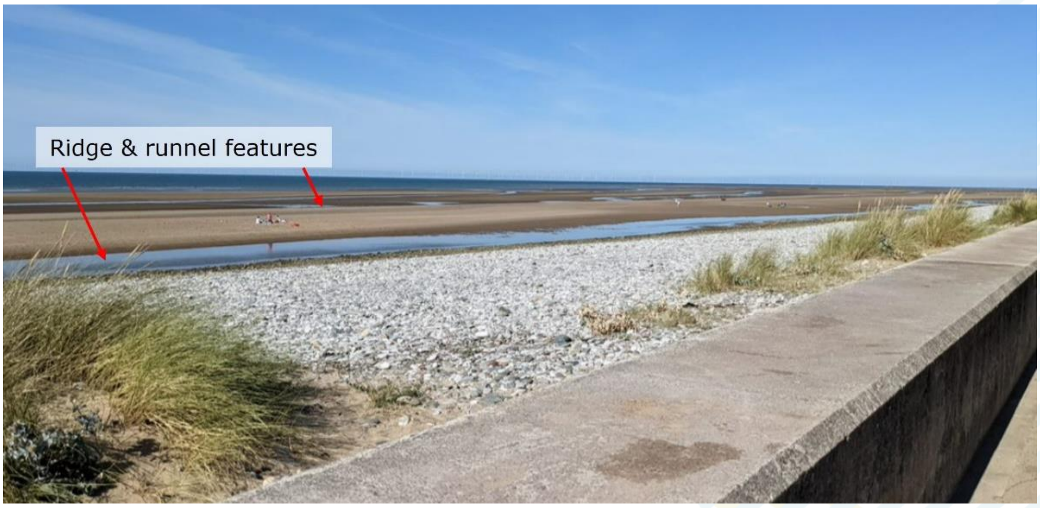

Figure 13. Ridge and runnel formation – Kinmel Bay

1.7.7 CMU3-5C: Kinmel Bay - Rock armour

The beach profile (Figure 14) indicates considerable change in beach morphology over time suggesting the area is more dynamic and responsive to hydrodynamic conditions than other areas along the coastal frontage. The historic profile data identifies the presence of a migratory ridge and runnel network as found at other locations to the west. Sediment losses and major changes in beach morphology are evident prior to, and between 2018 and 2020 with the greatest degree of change occurring within the mid-intertidal zone where wave energy is more concentrated throughout the duration of the tidal cycle. The formation of a notable storm ridge crest in the supratidal zone and accreted sediment in the upper intertidal in 2018 suggests a response mechanism associated with storm wave activity. Sediment supply may be attributed to the erosion of material from the beach replenishment that occurred to the west at Llanddulas Tip in August 2015. The removal of this ridge by 2020 may be in response to wave activity and the reworking of sediment.

This area at the eastern end of the Llanddulas to Kinmel frontage represents a sediment sink. The accumulation of sand, transported by littoral drift, has resulted in the formation of an extensive sand bank that protrudes approximately 600 m seaward from the proposed siting of the rock revetment. The greater degree of modification to the beach profiles at this section is attributed to the accumulated sand which is more mobile than the coarse gravels found extensively to the west.

The temporal change in beach profiles reflects sediment loses and gains within the mid-tidal range. Whilst this may be attributed to storm wave activity changes in beach profile are also affected by the runnel network found on the sandy foreshore. Aerial imagery from 2022 identifies this area as being characterised by a series of drainage runnels formed parallel to the shoreline. A runnel measuring 10 - 15 m wide is located approximately 30 m from the narrow sand dune at the rear of the beach. This corresponds with the trough-like, runnel feature as indicated by the red arrow. A further two, larger runnels measuring 40 – 50 m wide are separated by a sandy raised ridge measuring approximately 100 m, as indicated by the red-line markers. The migration of this sand bank and other similar foreshore landforms relative to the 2020 survey profile represents a key process in the evolution of beach morphology.

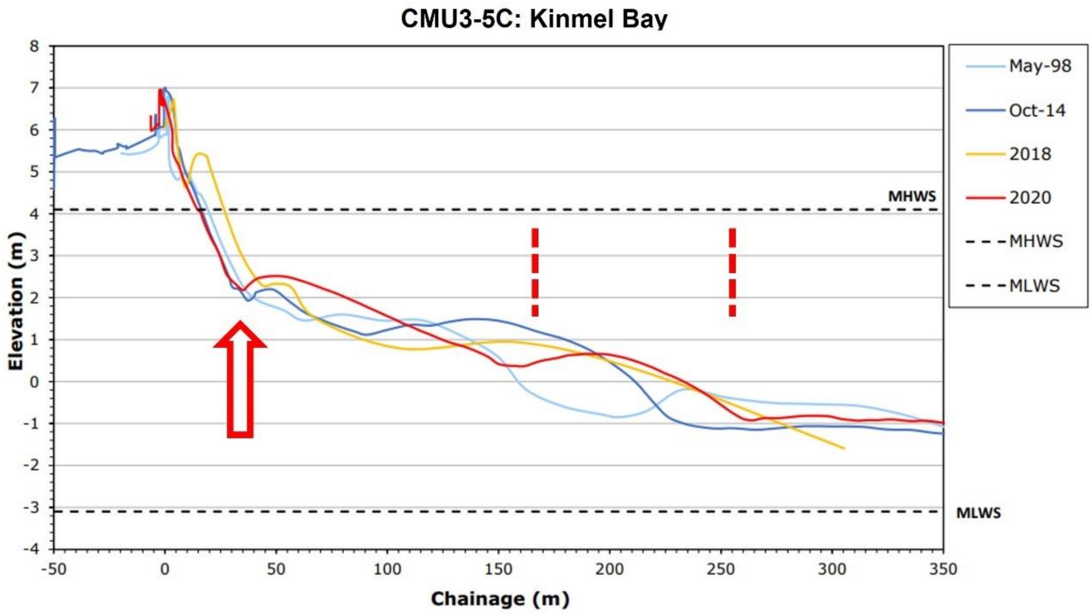

Figure 14. Cross-sectional beach profile – Kinmel Bay. Arrow indicates the location of a runnel feature, the dashed lines indicate presence of an extensive ridge, as identified using 2022 aerial imagery.

1.7.8 Summary

Collectively the beach profiles reflect cyclical modification of beach morphology over time. However, without quantifiable volumetric data it is not possible to establish the overall sediment losses and/or gains at each location and within the wider sub-cell. The profiles indicate the area is responsive to hydrodynamic conditions, particularly increased wave activity associated with storm events. The combination and interaction between littoral drift, tidal activity and wave action contributes to the accretion and erosion of both coarse (gravel) and fine (sand) grained beach material.

A key mechanism in the modification of beach morphology and subsequent evolution of the beach profiles are the ridge and runnel features found within the intertidal zone along the Llanddulas to Kinmel Bay coastline. The onshore movement of these landforms also acts as a primary driver in sediment supply within the sub-cell. The migration of these features across the sandy foreshore suggests a dynamic, ephemeral landform created in response to hydrodynamic conditions. The ridges form under low to moderate wave conditions, water draining from the gravel beach at the rear of the profile flows adjacent to the ridges creating runnels that enable drainage and the transfer of sand. Storm waves flatten the ridges which leads to the periodic loss and reformation at different elevations in the intertidal zone relative to wave response (Masselink and Hughes, 2014).[22]

Existing assessments of sediment supply, beach profile data, and aerial imagery suggest a limited input of coarse gravel-sized material within the sub-cell. Moving from west to east along the coastal frontage the shingle ridges become narrower, favouring the wider foreshores with shallow gradients associated with the availability and deposition of finer sand-sized particulates; this is particularly evident at Kinmel Bay. This supports the conclusion of Lee (2005)[23] that generally, the sedimentary cycle is one of erosion in the west and accretion in the east.

The supply of coarse sediment has reduced since the implementation of coastal defences, west of Llanddulas. The construction of seawalls has eliminated wave-induced erosion of the cliffs to the west, between the Little Orme headland and Llanddulas. Subsequently, the once ready supply of shingle sediment has since been lost. Additional beach defences (groynes/revetments) have further limited sediment supply from the west disrupting the sediment system. The net budget is one where output exceeds input therefore presenting an erosional coastline.

Beach profiles appear to indicate that sediment volumes have decreased during the monitoring period. The loss of sediment and associated beach lowering may be a response to the existing coastal defences that inhibit natural coastal processes. The defence structures fix the shoreline position and prevent the landward migration (roll-back) of the beach in response to wave and tidal conditions. The beach is unable to adjust to a natural state of equilibrium, leading to coastal squeeze, whereby beach widths narrow as sediments are eroded. The sediment transport pathways within this area lead to a sink/deposition eastward towards the dune system at Kinmel Bay. The accumulation of sand deposition at the frontage to Kinmel results in an extensive sandbar that extends over 1 km from the shore.

Long term trends reflect episodic erosion and accretion relating to sediment flux and wider sediment supply beyond the sub-cell. The beach profiles demonstrate that the process of erosion and accretion are cyclical however, the net trend appears to be one of beach volume loss.

1.8 Climate Change

The impacts of climate change are expected to pose a threat to coastal communities and infrastructure in the future, primarily as a result of the predicted increase in sea level rise. Rising sea levels are the most significant mechanism by which future coastal inundation and flooding is expected to occur[24]. A direct impact of sea level rise is a change in tidal range whereby both low and high-water levels are set to increase beyond contemporary elevations. This is also expected to impact on the extent to which storm surges affect coastal communities and infrastructure particularly when storm events coincide with spring tidal cycles.

[22] Masselink, G., Hughes, M., & Knight, J. (2014). *Introduction to coastal processes and geomorphology*. Routledge.

[23] Lee, M (2005). Investigation of beach levels at Pensarn Shingle Ridge. Conwy County Borough Council. CCW Contract Science Report no. 695

[24] Lowe, J.A., Bernie, D., Bett, P., Bricheno, L., Brown, S., Calvert, D., Clark, R., Eagle, K., Edwards, T., Fosser, G. and Fung, F. (2018). UKCP18 Science Overview Report. Met Office. *Reading, UK*.

Met Office modelled predictions indicate that global sea levels have risen throughout the 20th century and will continue over the coming centuries irrespective of future reductions in greenhouse gas emissions. Modelling of future sea levels based on low and high emission scenarios suggest a mean average sea level change of between approximately 0.4 and 0.7 m by 2100 within the area of the proposed coastal defence scheme between Llanddulas and Kinmel Bay[8]. These figures are subject to change depending on a range of variables including thermal expansion, based on increases in global temperatures and the uncertainty regarding the retreat of ice sheet masses.

To mitigate against the impacts of these predicted rises it is necessary to implement coastal defence schemes that account for and adapt to future changes to sea levels and tidal characteristics. Without constructing defences to protect the coastal frontage between Llanddulas and Kinmel Bay the likelihood is that coastal flooding will occur more regularly resulting in damage to property and infrastructure as well as posing a threat to life.

1.9 Assessment Methodology & Assessment Criteria

An assessment of the impacts arising from the potential short-term (construction) and long-term (operational) effects of the proposed detailed design on local and regional coastal processes are addressed. These are considered with respect to the Zone of Influence (ZoI) defined by NRW as "the area of the seabed or foreshore that could be affected by the proposed development or activity, during both construction and/or operation."[25]

The assessment of the coastal processes and geomorphology has been undertaken as a desk-based assessment drawing upon a range of sources as described previously, (page 1).A number of sources of potential impacts on coastal processes have been identified from activities associated with defence construction, presented in (Table 6).

Table 6 . Sources of potential impacts on coastal processes.

	Material storage on the foreshore	Excavation for defence construction	Sediment mobilisation	Vehicle movements on the foreshore	Modification of natural beach morphology	Modification of beach face gradients
CMU3-2B	✓	✓	✓	✓	✓	✓
CMU3-4	✓	✓	✓	✓	✓	✓
CMU3-5A: West	✓	✓	✓	✓	✓	✓
CMU3-5A: East	✓	✓	✓	✓	✓	✓
CMU3-5B (West)	✓	✓	✓	✓	✓	✓
CMU3-5C (East)	✓	✓	✓	✓	✓	✓

The assessment criteria used to determine the magnitude of impact arising from the scheme and the scale at which those impacts occur is highlighted in Table 8 and Table 8. The activities associated with scheme construction and operation have been assessed with regards to their potential to impact on coastal processes; namely, changes to nearshore wave climate, beach-sediment exchange (erosion and/or accretion) in the upper shore and sediment transport within the intertidal and nearshore zones. Where the consequences of the changes in coastal processes would impact on specific environmental receptors of value (i.e., ecological receptors), these

[25] Natural Resources Wales. 2020. GN041. Marine Physical Processes Guidance to inform Environmental Impact Assessment (EIA).

are addressed as secondary effects in the relevant section of the Environmental Statement.

Table 7. Criteria for defining the magnitude of impacts on coastal processes

Magnitude score	Criteria
Major	Major change in the magnitude of the process operating.
Moderate	Moderate change in the magnitude of the process operating.
Minor	Minor change in the magnitude of the process operating.
Negligible / No Change	No perceptible change in the magnitude of the process operating.

Table 8. Criteria for defining the sensitivity of coastal processes

Sensitivity score	Criteria
High	Coastal processes operating at the scale of Sub Cell 11a (Great Ormes Head to Southport)
Medium	Coastal processes operating at the scale of Sub Cell 11a.2 (Little Ormes Head to the Clwyd Estuary)
Low	Coastal processes operating at the scale of the site or limited to the immediate nearshore zone

1.10 Potential Impacts & Significant Effects

Construction impacts

The work required to implement the proposed rock amour design along the coastal frontage involves construction within the intertidal zone. Excavation of beach material to formation level to accommodate the rock revetment should be undertaken during periods of low water when tide levels expose the work areas. To further reduce the potential for sediment mobilisation small sections of the toe trench should be excavated within a tidal window with all arisings being placed, where possible, above the MHW mark to increase beach levels. This will minimise sediment dispersal within the adjacent waterbody. **Negligible impact.**

Based on current design drawings the toe of each rock revetment is positioned approximately at, or above mean sea level (MSL) based on recorded beach levels from 2021. The exception is the proposed rock revetment at CMU3-5B (West) whereby the toe of the rock armour extends to MLWN level. With construction being limited to the upper tidal frame, impacts associated with the scheme, primarily the mobilisation of sediment, are expected to be reduced. The shallow topography of the foreshore seaward of the proposed scheme will also provide a favourable tidal window within which excavation and construction can be undertaken. However, consideration of tidal conditions will be required to maximise the working window which will vary depending on daily tide levels. Continuous reference should be made to tide tables, weather conditions and coastal flood forecasts and construction works planned accordingly. **Negligible impact.**

In advance of, and during construction, rock armour will be temporarily stored and sorted on the beach near to the rock revetment section being constructed. If stored within the tidal frame this material is likely to cause small scale changes to the current flows over and around the rock piles. This increase in turbulence around the rock piles may result in increased localised sediment mobilisation and/or scour around the piles. The potential rate of erosion will depend on the current velocity and will therefore be dependent on the tidal state, water depth over the rock pile, the presence of waves and the duration that the piles remain on the beach. The turbulence created, and therefore the erosion potential, will also be influenced by the dimensions and shape of the pile. Following the removal of the rock pile, the beach profile will tend to return to its previous state. It is recommended that the storage of rock armour on the beach/foreshore should, where possible, be restricted to as high as possible within the tidal boundaries of the site at the time of delivery and storage. Following construction of the rock revetment the beach profile should be reinstated using excavated beach materials, no permanent impacts are anticipated. **Negligible impact.**

Storm activity during construction may result in wave interaction encroaching higher in the tidal frame potentially mobilising any temporary stored sediments. The increased volume of material being made available is expected to be negligible during a short-term storm event in comparison to the volume of material mobilised across the tidal sub-cell and is therefore assessed to have a **Negligible impact** on turbidity of the affected waterbody.

The proposed design allows for repurposing the existing rock armour present on the beach as a secondary filter layer or a lower primary armour layer providing it meets the dimensional requirements outlined in the specification. Revetment infill should be emplaced and profiled to the required levels during low water to restrict transfer of construction material and sediments to the coastal water body. Any storage of material for repurposing should be, where possible, restricted to as high as possible within the tidal boundaries of the site relative to the tidal conditions at the time. Surplus beach arisings following excavation are to be used to reinstate the beach profile to the required design specification. **Negligible impact.**

The preferred construction method for excavation, emplacement and arrangement of rock armour is for works to be completed from a 5 m wide temporary running strip placed at the rear of the beach. This will allow excavation to take place reducing the need for plant machinery to access the beach, minimising sediment disturbance. However, the need for plant machinery to access the beach will remain. Access will be made from an existing 6.5m wide concrete access slope at Pensarn Beach.

Movement of plant machinery along the foreshore is expected to produce tracks in any beach sands. The rate of beach material disturbance by vehicles will be dependent on factors including vehicle type, drive type (tracked or wheeled), track/wheel type and dimensions, weight of vehicle (including loads), friction angle between wheels/tracks and the beach and the nature of the sediment (cohesion and adhesion, etc.). Vehicular movement on the beach should be along designated routes, thereby limiting the potential impacted area and allowing for continued visual monitoring. Any modification of beach levels will be periodically restored using a mixture of the displaced sands and the excavated material from rock revetment construction. It is therefore considered that the short-term implications of plant machinery on beach morphology, local hydrodynamics and sediment regimes will be of a **Negligible impact.**

The proposed beach recharge at CMU3-4 reflects a similar scheme conducted in 2015 to reinstate the coastal shingle habitat and improve biodiversity of the adjacent Traeth Pensarn SSSI. The deposition of sediment at this location presents an opportunity for the increased mobilisation of beach material at a local scale. Sediment of a suitable size grade, as proposed Table 5, will be deposited to reinstate material lost following episodic erosion and sediment mobilisation. Vehicular access and operation to facilitate beach recharge should comply with the measures stated above to limit sediment disturbance. Recharged sediment will be placed in accordance with the design specification and profiled to the required levels during dry conditions to restrict transfer of sediments to the coastal water body. Over time it is anticipated that beach volume will be reduced with eroded material feeding the beaches to the east. Periodic monitoring of topographic changes in response to hydrodynamic conditions and measurements of sediment volumes will be required to determine sediment loses of beach recharge material. This data will inform future requirements for further beach replenishment. The anticipated erosion of this recharge material over time is expected to have a beneficial impact on the wider sediment regime within the sub-cell in that it will supply sediment to the beaches east of Ty Crwn. Based on the magnitude of the disturbance, and its localised nature, it is considered that the proposed recharge will have a favourable **Minor Impact** on the sediment regime.

Impacts relating to sediment dynamics during the construction phase are expected to be limited and small-scale with no long-term detrimental effects. There is no expectation of significant change in beach morphology arising from construction practices, as long as construction works are undertaken in accordance with good practice and the mitigation measures stated herein. Given the position of the proposed revetment design in the upper tidal frame and the mitigation measures stated it is anticipated that the construction phase of the scheme will have **No Significant Effect** on the local hydrodynamic and sediment regimes.

Operation impacts

Much of the coastal frontage is already highly modified with existing rock armour defences currently in place. Subsequently, the natural morphology of the site has already been modified within the footprint of the proposed scheme and beach processes have already adapted to the presence of the rock armour revetments. The extension and modification to the existing defenses is expected to result in an initial period of readjustment in beach morphology. Sediment supply via littoral drift may be altered due to defence encroachment into the intertidal range. However, design specifications indicate that intrusion of the rock revetments within the intertidal, based on mean high-water spring, will be limited to a maximum of approximately 2 m at Kinmel Bay, 7 – 10 m at Llanddulas Beach, 10 m at Belgrano Beach and 25 m at Towyn. The extent to which the revetments extend into the intertidal range are limited to the highest tidal ranges and represent a small proportion of the overall beach backshore and foreshore. This is expected to present a **Minor impact** on sediment processes and beach morphology.

Where the structure encroaches on the sandy foreshore beach width will be reduced. The rock armour is expected to result in small-scale changes to current flows over and around the structure which may result in localised scour of beach material at the toe of the defence and from the sandy foreshore. However, the shallow beach foreshore and profile data suggests that some areas within the intertidal zone are depositional as opposed to erosional, and the dissipative function of the rock armour may provide potential for accretion of sediment over time enhancing shoreline progradation. This may offer increased protection at the toe of the structure and further act to dissipate wave energy. The retention of sediment, intercepted by the rock revetment, limits sediment availability, although this is expected to have a minimal impact on sediment flux at a scale beyond the immediate area of work. **Negligible impact.**

The current designed slope gradient of the proposed rock armour revetments ranges from 1:2 to 1:4. The shallow gradient is designed to dissipate wave energy and minimise wave reflection. It is anticipated that this should reduce the potential for the scour of beach material at the toe of the defence and reduce the potential for sediment mobilisation, and associated impacts on beach morphology, water quality (WFD and BWD) and ecology. The proposed location of the rock armour revetments and subsequent construction diagrams indicate that most revetments will be constructed at levels approximate to, or above mean sea level (MSL). This will allow for a greater working window relative to tidal levels at CMU3.2B, CMU3.5A (West & East) and CMU3.5C. The elevation of the defence structures within the tidal frame means the extent to which they encroach seaward of the MHWS water level is reduced. Therefore, they have limited interaction with water flow except during spring tides meaning the impact on the longshore processes of littoral drift, (e.g., sediment retention) are reduced. The revetment at CMU3.5B – Kinmel Bay (West)encroaches seaward of the MLWN level and therefore is expected to retain sediment by partially interrupting supply from the west. However, this defence structure is in a setback position in lee of the existing Towyn rock revetment, therefore it is expected that the setback location will reduce interaction with longshore sediment processes.

The proposed beach recharge at CMU3-4 is expected to provide improved protection against wave overtopping and suitable substrate for the development of valuable coastal shingle plant communities. Current proposals estimate a need for deposition of between 20,000 and 30,000 m^3 of sediment suitably matched in terms of size grade and mineralogy to the existing in-situ material. The expectation is that the recharged material will be colonised by pioneer plant species improving biodiversity in the area. Furthermore, an established community of vegetated shingle plants will trap, and retain wind-blown sands and help to stabilise the recharged material. The deposition of recharge material will encroach into the intertidal range. Depending on the finalised sediment size grade to be used a shallow 1:7 slope gradient is proposed which will dissipate incoming wave energy. The sloped beach profile will encroach approximately 20m seaward of the MHWS level. As the reinstated profile adjusts to the increased beach width and exposure to wave activity and littoral drift the expectation is that sediment will be eroded over time. This sediment will provide a source of sediment to those beaches located to the east. The increased volume of material being made available is expected to be negligible once reinstated in comparison to the volume of material mobilised across the tidal sub-cell. Subsequently, the deposition of recharge sediment is therefore assessed to have a **Minor impact** on water quality (turbidity) of the adjacent waterbody. The local extent to which this impact will occur is expected to be of a **Low Sensitivity**.

The development proposals are expected to have a beneficial impact with regard to current and future coastal flood risk, opposed to any significant negative impact. Furthermore, it is considered that the impacts on coastal processes, hydrodynamic regime and sediment dynamics resulting from the proposed coastal defense scheme and subsequent operation will be negligible. In conjunction with the sensitivity being confined to the immediate site opposed to the Sub-Cell level, the development presents **No Significant Effect** on either the tidal or sediment regimes. Any subsequent alterations are considered to be of low sensitivity with the magnitude of any such impacts anticipated to have a **Negligible impact.**

1.11 Mitigation Measures

In addition to the measures suggested within the site-specific 'Potential Impacts & Significant Effects' section the measures below should also be applied at all sites along the Llanddulas to Kinmel Bay coastline.

- Potential coastal process impacts would be mitigated through the adoption of good construction practices. As much work as possible should be conducted under dry conditions during periods of low water to minimise the mobilisation of sediments and construction materials.
- All work schedules should be assessed two weeks in advance to confirm compliance with the stated mitigation measures. Works should cease during storm events, where increased wave activity could mobilise sediments and present hazardous working conditions.
- Ecological enhancements will be incorporated into the scheme in the form of carved rockpools in boulders within the intertidal zone. These indentations in the emplaced boulders retain tidal water creating habitat availability and ecological opportunities for colonisation by intertidal species. Attention needs to be given to the placement of modified boulders, so they are suitably positioned to receive and retain water during each tidal cycle.
- Beach monitoring (e.g., topographic surveys) are already undertaken on an annual basis. It is recommended that this continues, post-construction, at

the same/similar time each year to identify changes in beach slope gradient and elevation. Monitoring will provide insight to any potential impacts associated with the newly constructed defenses and the morphological response. This will help inform any future requirements for additional beach recharge.

1.12 Residual Effects

Accounting for projections in sea level rise due to climate change each of the locations will be subject to coastal squeeze in the future. The existing defences and subsequent proposed designs to protect against wave overtopping and flooding will prevent the beach and intertidal habitats from naturally adapting to rising sea levels by migrating landward. As sea level increases and the tidal range alters accordingly, the naturally occurring landward migration will not be possible, and the habitat and access to it will become more limited than at present. The timescales for such impacts are not yet known and will reflect external factors beyond the scope of this scheme.

The proposals are considered to have no significant residual effect on coastal processes and geomorphology. By adopting considerate construction practices and the mitigation measures detailed above potential risks will be further reduced. Any alterations to the hydrodynamic and sediment regime during construction and operation are considered to be negligible and confined within the extent of the immediate zone of influence as opposed to operating at the scale of Sub Cell 11a.2 (Little Ormes Head to the Clwyd Estuary) and/or Sub Cell 11a (Great Ormes Head to Southport).

There is predicted to be no significant effect on the sediment budget and on beach morphology. No significant effects on coastal processes are predicted, whilst any impacts on beach habitat, including damage and disturbance during construction, would be temporary in nature and therefore not significant. The proposed scheme will have a positive effect on flood risk considerably reducing the likelihood of coastal flooding in the future. Additionally, the proposed beach recharge at Llanddulas Tip is expected to provide benefits beyond its protective function with ecological opportunities for creating valuable vegetated shingle habitat and supply of sediment to beaches to the east.

The localised nature of the anticipated disturbance to sediments is not expected to have any immediate, or long-term impacts on WFD status and or effect the current Bathing Water status which is more readily impacted by urban and wastewater discharge. Similarly, ecological receptors, e.g., Liverpool Bay are not considered to be impacted by the limited scale of disturbance, either during construction, or subsequent operation.

1.13 Cumulative Effects

The cumulative effects from the proposed scheme are expected from the loss of habitat by placement of rock armour over intertidal habitats. However, the rock armour structures will provide refuge and habitat for a range of intertidal species which is considered beneficial. The use of strategically placed intertidal rockpools and carved inundations in rock armour boulders will also provide additional suitable habitat for intertidal species.

Additionally, the proposed beach recharge at Llanddulas Tip is expected to provide benefits with ecological opportunities for creating valuable vegetated shingle habitat and supply of sediment to beaches to the east.

Impacts relating to sediment dynamics at each site during the construction phase are expected to be limited and small-scale with no long-term detrimental effects. There is not expected to be any significant change in beach morphology arising from construction practices, as long as they are undertaken in accordance with good practice and the stated mitigation measures.

Post construction, long-term impacts, on sedimentary processes are not fully known. However, the shallow gradient of all beaches suggests sediment fluxes favour deposition and accumulation of sediments opposed to erosion and extensive loss of beach-forming material. Placement of the rock armour is not expected to alter that ongoing process significantly, and no impacts are anticipated outside the nearshore zone and proposed site boundaries.

1.14 Appendix - Tidal Diamond Data

Table 9. Tidal diamond data: SN045D

1. SN045D

53°25.71'N 3°26.48'W

Data Area 1-4. Europe, Northern Waters & Mediterranean - Version 19,0,0,520

Predictions are based on Liverpool (Gladstone Dock)

Time	Direction	Spring rate	Neap Rate
-06 h	057°	0.3 kn	0.2 kn
-05 h	088°	0.7 kn	0.4 kn
-04 h	100°	1.2 kn	0.7 kn
-03 h	104°	1.4 kn	0.8 kn
-02 h	092°	0.9 kn	0.5 kn
01 h	079°	0.4 kn	0.1 kn
HW	289°	0.2 kn	0.1 kn
01 h	268°	1.1 kn	0.6 kn
02 h	270°	1.4 kn	0.8 kn
03 h	271°	1.1 kn	0.6 kn
04 h	275°	0.7 kn	0.3 kn
05 h	313°	0.4 kn	0.2 kn
06 h	020°	0.2 kn	0.1 kn

Table 10. Tidal diamond data: SN045J

2. SN045J

53°25.21'N 3°21.38'W

Data Area 1-4. Europe, Northern Waters & Mediterranean - Version 19,0,0,520

Predictions are based on Liverpool (Gladstone Dock)

Time	Direction	Spring rate	Neap rate
-06 h	027°	0.2 kn	0.1 kn
-05 h	089°	0.9 kn	0.5 kn
-04 h	098°	1.6 kn	0.9 kn
-03 h	102°	1.8 kn	1.0 kn
-02 h	109°	1.5 kn	0.8 kn
01 h	127°	0.7 kn	0.4 kn
HW	215°	0.3 kn	0.1 kn
01 h	270°	0.9 kn	0.4 kn
02 h	280°	1.3 kn	0.8 kn
03 h	282°	1.7 kn	0.9 kn
04 h	286°	1.5 kn	0.8 kn
05 h	293°	1.0 kn	0.5 kn
06 h	327°	0.3 kn	0.2 kn

Table 11. Tidal diamond data: SN045F

3. SN045F

53°29.02'N 3°49.88'W

Data Area 1-4. Europe, Northern Waters & Mediterranean - Version 19,0,0,520

Predictions are based on Liverpool (Gladstone Dock)

Time	Direction	Spring rate	Neap rate
-06 h	343°	0.2 kn	0.1 kn
-05 h	083°	0.7 kn	0.4 kn
-04 h	101°	1.5 kn	0.8 kn
-03 h	105°	1.7 kn	1.0 kn
-02 h	105°	1.4 kn	0.7 kn
01 h	099°	0.7 kn	0.4 kn
HW	N/A	0.0 kn	0.0 kn
01 h	280°	0.5 kn	0.3 kn
02 h	277°	1.0 kn	0.6 kn
03 h	280°	1.4 kn	0.8 kn
04 h	286°	1.4 kn	0.8 kn
05 h	283°	1.0 kn	0.5 kn
06 h	308°	0.4 kn	0.2 kn

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