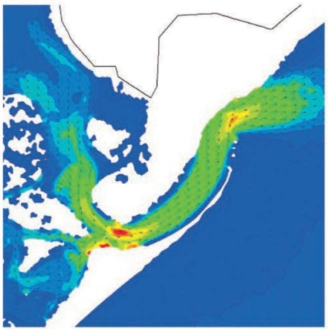
Ymgynghoriaeth Gwynedd Consultancy (YGC)

Viaduct Gardens, Barmouth

Coastal Processes Assessment

November 2023

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Document Information

Document History and Authorisation		
Title	Viaduct Gardens, Barmouth	
	Coastal Processes Assessment	
Commissioned by	Ymgynghoriaeth Gwynedd Consultancy (YGC)	
Issue date	November 2023	
Document ref	R.4365	
Project no	R/5339/1	
Date	**Version**	**Revision Details**
24/10/23	1	Issued for client review
26/10/23	2	Issued for client use
23/11/23	3	Issued for client use - updated with NRW comments

Prepared (PM)	Authorised (QA/PD)
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Suggested Citation

ABPmer, (2023). Viaduct Gardens, Barmouth, Coastal Processes Assessment, ABPmer Report No. R.4365.
A report produced by ABPmer for Ymgynghoriaeth Gwynedd Consultancy (YGC), November 2023.

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Contents

Figures

Tables

1 Introduction

A Marine Licence is being sought by Cygnor Gwynedd Council (CGC) for the construction of the Viaduct Gardens Flood Alleviation Scheme (FAS), Barmouth. Following a submission of Marine Licence CML2332 for the construction of flood defence works at Viaduct Gardens, Natural Resources Wales (NRW) concluded that without a coastal squeeze assessment and physical processes impact assessment it was unable to ascertain the extent of the direct and indirect loss of the Annexe 1 feature of the Pen Llŷn a'r Sarnau Special Area of Conservation (SAC). Therefore, potential impacts to the SAC are unable to be ruled out.

ABPmer has been commissioned by Ymgynghoriaeth Gwynedd Consultancy (YGC) to review coastal processes along the Viaduct Gardens frontage and produce a coastal squeeze assessment to support the Marine Licence. This coastal process assessment has sought to identify the direct and indirect impacts of the seawall and outfall structure on the intertidal mudflats and sandflats during construction and operation of the FAS along with any secondary effects due to the pipe and outfall structure extending above the current foreshore level.

The study has been completed following the guidance set out by NRW in Evidence Report 624 Advice on Physical Processes for Small-scale Marine and Coastal Projects. Consideration of the potential for coastal squeeze is also included making reference to NRW Guidance Note 062 Assessment of Coastal Squeeze. The results have been taken forward for consideration in the project's Habitat Regulations Assessment (HRA).

The assessment has followed a desk-based approach using expert geomorphological analysis and baseline understanding to identify potential direct and indirect effects of the FAS on coastal processes. The following datasets have been utilised along with a number of associated project reports:

- Digital Terrain Model (DTM) consisting of a range of topographic and bathymetric datasets assembled by ABPmer for NRW as part of NRW project '*Understanding the likely scale of deterioration of Marine Protected Area features due to coastal squeeze*' (underway);
- Geological data from the British Geological Survey (BGS); and
- Designated habitat mapping layers available from DataMapWales[1]

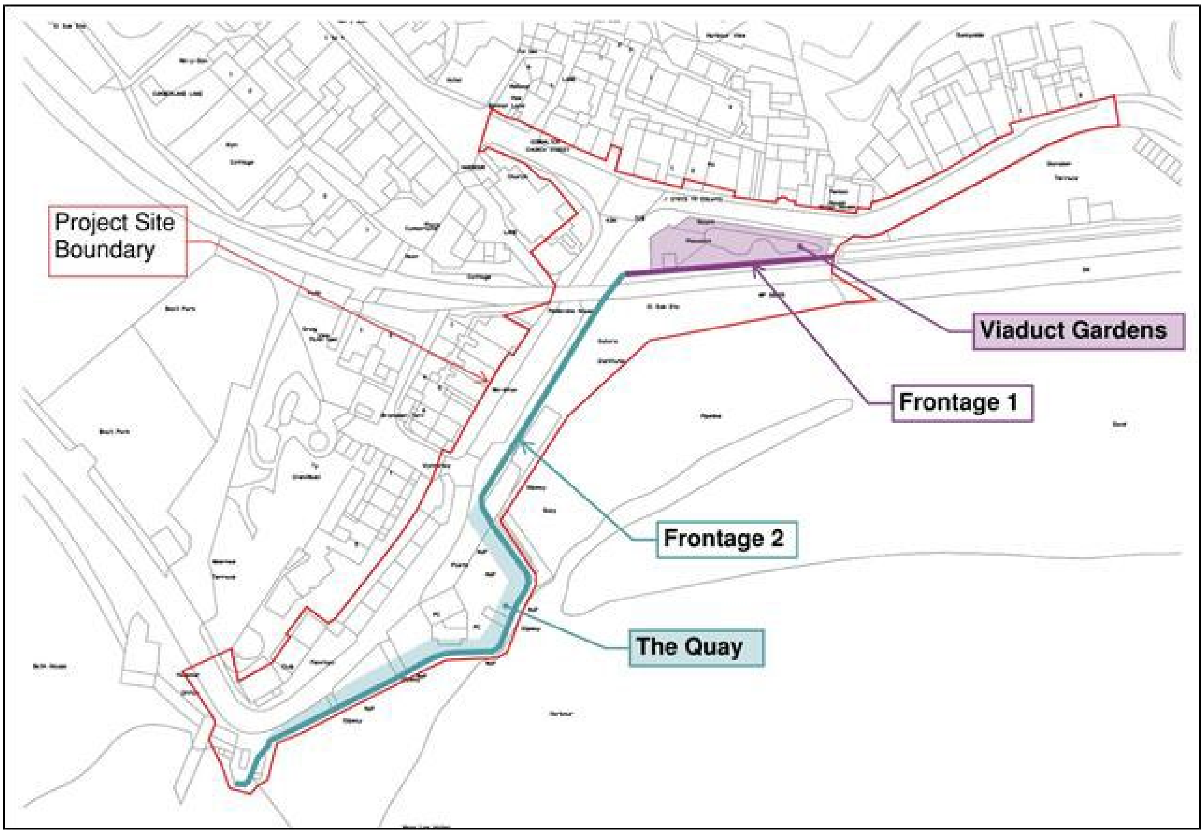
1.1 The Scheme

1.1.1 Introduction

Barmouth is located in Cardigan Bay, between Llanaber in the north and River Mawddach to the south. Viaduct Gardens is located on the north shore of the Mawddach Estuary (Figure 1).

Viaduct Gardens is a public open space to the south of the A496 Church Street. The existing sea wall is vertical blockwork with a parapet wall. Emergency rock protection was placed at the base of the wall following failure of the structure. The Cambrian Railway passes over Viaduct Gardens on a short viaduct in front of the sea wall with five support piers on the foreshore.

[1] https://datamap.gov.wales/



Source: Arup, 2022a

Figure 1. Location of Frontage 1 Viaduct Gardens

1.1.2 Scheme design and construction methodology

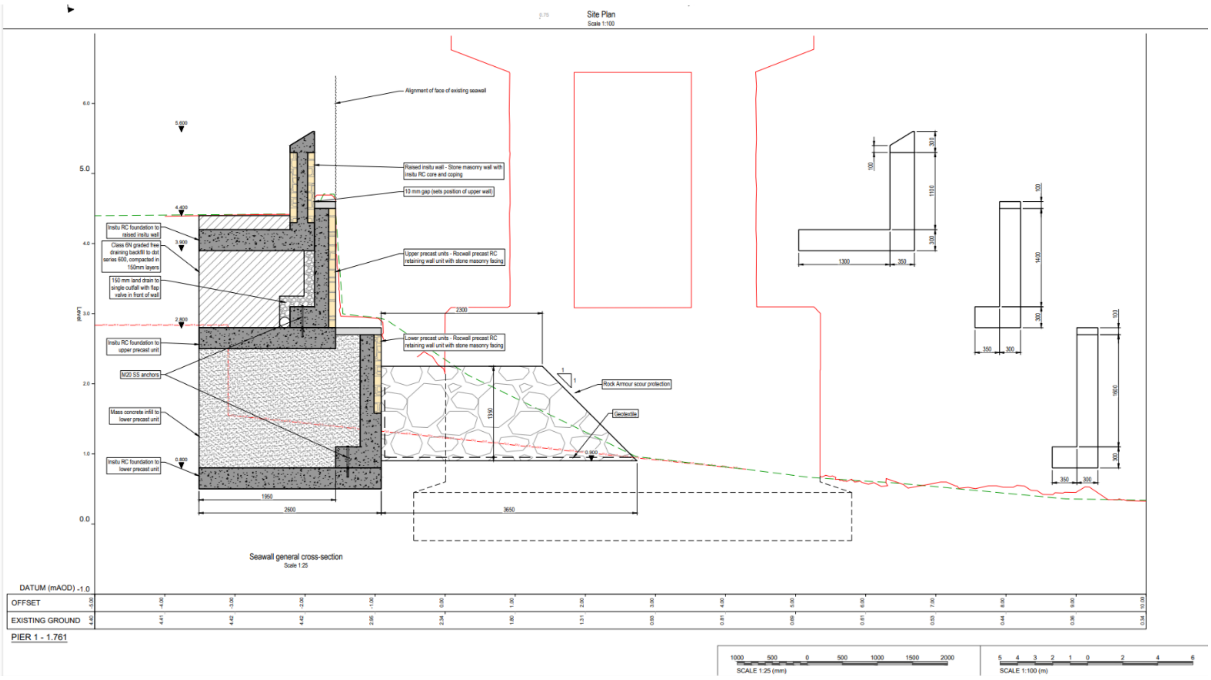
The FAS for Viaduct Gardens has been developed to address both surface water and coastal flooding of Church Street and the Barmouth seafront. The scheme protects two frontages; Viaduct Gardens (Frontage 1) and The Quay (Frontage 2) as shown in Figure 1. The Quay frontage will be upgraded using property level flood protection.

This coastal process assessment considers only those elements which could influence local coastal processes; these are the upgrade of the sea wall and installation of an outfall at Viaduct Gardens (frontage 1). The scheme is summarised as follows (YGC, 2023):

- Repairs to the existing sea wall;
- A new 450 mm culvert in Church Street with gullies;
- A new pumping station and outfall to update the existing network with additional gullies; and
- Formalisation of the rock armour placed during emergency works following a failure of the existing sea wall.

The existing wall will be carefully demolished in sections. Temporary support structures, including sheet piling and scaffolding, will be installed to stabilise the existing wall during demolition. The upper part of the existing stone wall will be removed and taken into the gardens side of the wall for re-use in the parapet. The lower part of the wall will be excavated down to the beach and loaded away for disposal or re-used as rock armour. The foundation for the replacement wall will be cast *in situ*, and the wall itself will feature a combination of precast and *in situ* sections for optimal construction flexibility. The existing rock armour will be moved back from the wall to expose the face and will be re-used as armour upon completion.

The height of the wall will be increased by ~0.9 m with the installation of a reinforced concrete parapet. (YGC, 2023). The sea wall design is shown as Figure 2 below which shows the design lies within the footprint of the existing wall and rock revetment.



Source: reproduced from scheme design drawings (Arup, 2023a)

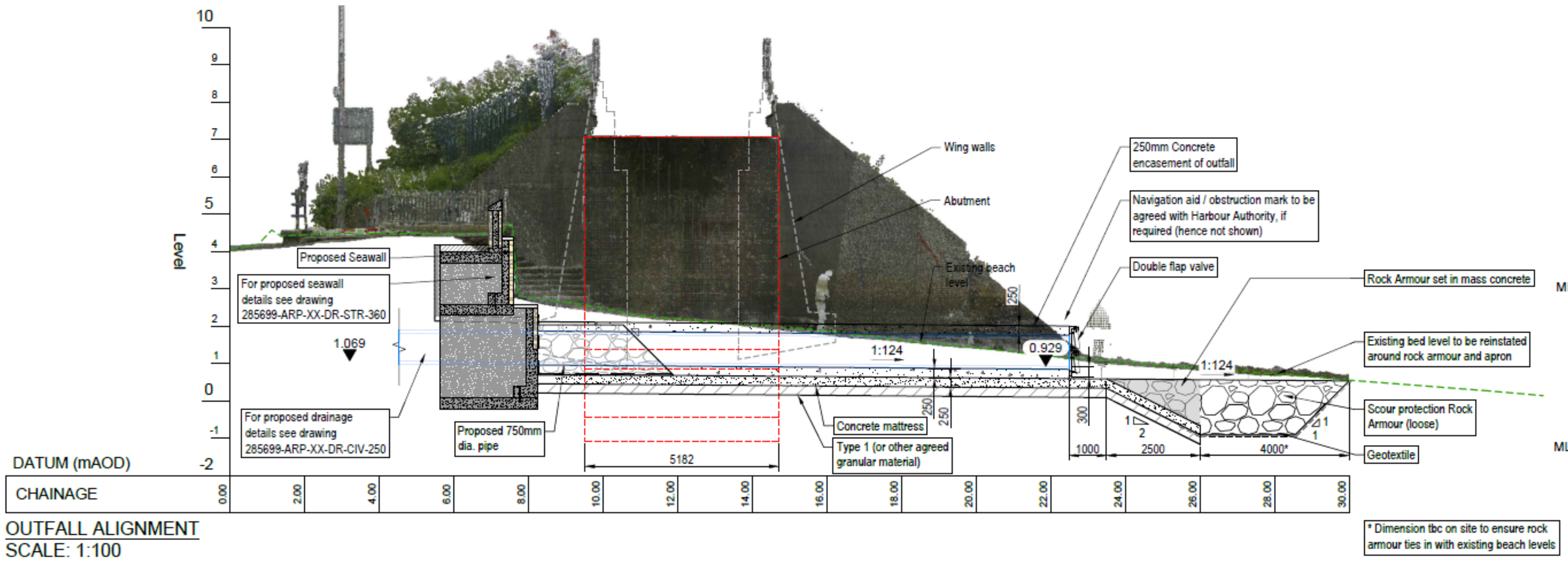
Figure 2. Sea wall improvements

In parallel with the wall renovation, the project involves the installation of a new gravity fed outfall pipe system. The 750 mm diameter pipe will extend approximately 13 m from the new wall face (Figure 3). This requires the excavation of beach material for the pipe bed, the placement of a concrete mattress for support, and laying of the pipe. Temporary anchors will ensure correct pipe positioning until the concrete surround is in place. Rock armour will be placed each side of the pipe at the lower section to prevent scour. The system will also incorporate an anti-scour basin constructed at the outfall and the installation of a one-way valve at the end of the pipe. Beach restoration and debris removal conclude the construction activities (YGC, 2023).

The peak flows from the outfall are presented below which include a 40% allowance for climate change as per design requirements so the actual present-day flows will be lower. These are peak flows which will only occur for short periods. The critical storm duration for the proposed system is predominantly the 240 minute (4 hour) storm event therefore the peaks flow will occur for an approximate 1.5 hr window during the peak period of the event (Arup 2023).

Table 1. Design flow conditions

Return Period	Free Outfall Peak Flow (l/s) including 40% allowance for climate change
1	348
5	532
30	858
100	1182



Source: reproduced from scheme design drawings (Arup, 2023b)

Figure 3. New surface water outfall

2 Baseline Understanding

2.1 Overview

The Mawddach Estuary is situated towards the northern part of Cardigan Bay at Barmouth, it is orientated along a west to east axis. The estuary has formed from a river valley that has subsequently flooded as a result of sea level rise since the last glaciation. Sand spits are present on both sides of the estuary mouth indicating that sediment can be transported along the open coast from both the north and the south, although the northern spit has been built upon and is now immobile. The shoreline adjacent to the estuary mouth is wide and sandy showing the potential for significant interaction between the estuary and the open coast (ABPmer, 2011). Barmouth estuary was heavily modified in the 19th and 20th centuries with the railway viaduct, the Ynys y Brawd causeway which closed the Bar Bach Channel and gradual harbour encroachment and hardening of the sea defences around the estuary. The coastal processes operating at the mouth of the estuary are illustrated as Figure 4 below. The Mawddach Estuary has a small ebb tidal delta formed by interactions between tidal flows in and out of the estuary and littoral drift. Most of the estuary is flood dominant and has acted as a sink for marine and fluvial sediments throughout the later Holocene (ABPmer, 2011).

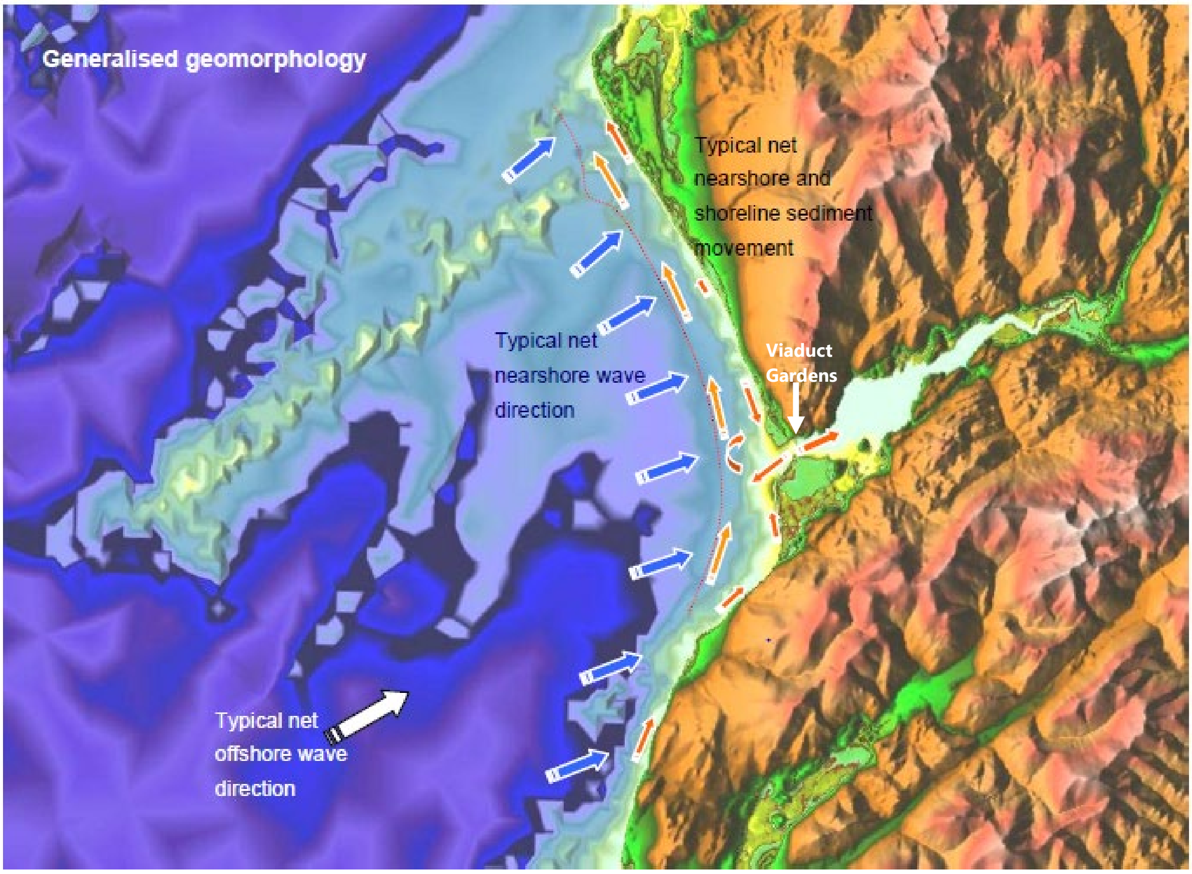


Image source: ABPmer, 2011

Figure 4. Conceptual Understanding of coastal processes at the mouth of the Mawddach Estuary.

Viaduct Gardens lie within Sub Cell 9, Policy Unit (PU) 11.14 of the current Shoreline Management Plan (SMP2) (ABPmer, 2011). The extent of the policy unit and the adjacent policy units further north are shown in Figure 5. The policy for PU 11.14 is Hold the Line (HTL) by maintaining the existing coastal defences for all three epochs: short term (up to 2025), medium term (2025 to 2055) and long term (2055 to 2105).

Source: ABPmer, 2019[2]

Figure 5. SMP policy units including Barmouth South (11.14)

[2] Shapefile data from lle.gov.wales now datamap.gov.wales

2.1.1 Nature conservation designations

Viaduct Gardens is situated on the northern bank of the Mawddach Estuary which is designated as a Site of Special Scientific Interest (SSSI). The Mawddach Estuary SSSI is designated for its biological features, including the estuary itself, a large shallow estuary which drains south-west into Cardigan Bay, and a series of adjacent habitats. It also supports other notable invertebrates and is of local importance for its breeding birds and wintering wildfowl.

The estuary also lies within the Llŷn Peninsula and Sarnau SAC. The following are the SAC designated features relevant to the coastal process assessment (Arup 2022a):

- Sandbanks which are slightly covered by sea water all the time;
- Estuaries, including the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries. The intertidal sandflats support communities of burrowing invertebrates, including dense populations of polychaete worms (such as *Levinsenis gracilis*), crustaceans (such *as Eudorella truncata*), bivalve molluscs (such as *Mysella bidentata*) and gastropod molluscs (such as *Otina ovata*);
- Saltmarsh fringing the shores of the estuaries, and the saltmarsh creeks and pools, are important habitat features for juvenile fish;
- Large shallow inlets and bays, such as the seabed of Tremadog Bay on the south side of the Lleyn Peninsula, consisting of a mosaic of different sediment types. Algal species (*Naccaria wiggii* and *Scinaia spp*.) are present. Burrowing animals, including bivalves, crabs, brittlestars, urchins and worms, dominate the muddier sediments. Beds of eelgrass (*Zostera angustifolia*) and muddy gravel shores. Gravelly beach supports a nationally rare amphipod (*Pectenogammarus planicrurus*). Several unusual species include bearded red seaweed (*Anotrichium barbatum*) and a mantis shrimp (*Rissoides desmaresti*);
- Reefs encompassing a varied range of reef habitats, including submerged and intertidal glacial moraines. There are distinctive communities on bedrock and boulders, ranging from sites exposed to very strong wave action and/or tidal streams to sites sheltered from strong water movement. Algal communities are dominant over much of the reefs, with growths of foliose red and brown algae forming very dense beds in many places, in the absence of shading from kelp. Two brown algae species (*Chorda filum* and *Laminaria saccharina*) and red algae flourish on or near the reef crest, the number of algae species on pebbles increases with depth. In certain areas there are extensive forests of sea-oak (*Halidrys siliquosa*). Rich animal-dominated biotopes are found in the deeper parts of the reefs, including crustaceans, cnidarians, sponges, hydroids and encrusting bryozoans; and
- Glasswort (*Salicornia sp*.) and other annuals colonising mud and sand.

The designated mapped habitats taken from DataMap Wales are illustrated in Figure 6 below and show both intertidal reef and sandflat and mudflat. From review of the site photographs and Google Earth imagery, it is considered that the foreshore in front of Viaduct Gardens frontage has sandflat and mudflat habitat.

Figure 6. Designated habitats around the Viaduct Gardens frontage

2.2 Geology and geomorphology

2.2.1 Geology and sediments

The bedrock at Viaduct Gardens is coarse grained graywacke that formed during the Cambrian period. It is a sedimentary rock abundant in Wales which scores a 6-7 (hard) on the Moh's hardness scale. It is composed of grains of quartz, feldspar, and small lithic fragments set in a compact, clay-fine matrix (Dott, 1964). The shore consists of mixed surface sediments and the following information has been summarised from the results of trial pits undertaken to support the design (Geotechnics Ltd, 2022).

Viaduct Gardens lies on made ground, composed of very gravelly fine to coarse sand with a medium angular cobble content of slate and slag. The gravel is angular to subangular fine to coarse comprising slate, slag, clinker, tarmacadam, concrete and brick fragments.

On the basis of trial pit surveys (Geotechnics Ltd, 2022), at the proposed outfall at the MHWS mark there is a surface layer (0.05 m) of cobbles on top of *circa* 0.70 m of silty fine to coarse sand with a high subrounded cobble content of siltstone with shell fragments. From *circa* 0.75 m to 2.30 m depth, silty fine to medium-sized sand is present with a low subrounded cobble content of siltstone and slate. Trial pit sides below approximately 0.6 m depth became unstable due to groundwater inflow and the pit was terminated at 2.30 m due to inflow and associated instability.

About 20 m west of the proposed outfall and 0.2 m lower than the MHWS mark trial pits revealed slightly fine to medium sand with high subangular cobble content of siltstone and slate in the top 0.20 m. From approximately 0.20 m to 2.10 m depth, slightly silty fine to medium sand with some shell fragments were observed. Pit sides below 0.60 m depth became unstable due to groundwater inflow and the pit was terminated at 2.10 m due to inflow and associated instability.

2.2.2 Geomorphology and sediment transport

The conceptual understanding of the sediment transport processes is illustrated as Figure 4. This shows the predominant south to north alongshore sediment transport pathway with a smaller north-south return along the Barmouth frontage with significant accumulation on the northern shore of the entrance. The Mawddach Estuary has a relatively large intertidal area relative to its total size and is a sink for sediment (ABPmer, 2011).

As noted in Section 2.1 sediment transport is both from the north and south with the entrance to the estuary is dominated by the sand spits and significant transport between the coast and estuary.

The morphology of the estuary mouth has changed significantly since records began as summarised below (ABPmer 2022):

- On the basis of 18th and 19th century records there were two entrance channels into the estuary, the southern channel that lay south of Yyns y Brawd and the Bar Bach Channel to the north;
- The Mawddach railway viaduct (constructed in 1866-7) appears to have fixed the main low water channel of the estuary close to the northern edge of the estuary and the Quay;
- This is likely to have made it more difficult for ebb tidal flows to turn sharply to the northwest into the northern channel, encouraging increased flow through the southern channel to the south of Ynys y Brawd, potentially triggering the shoaling of the Bar Bach Channel in the later 19th and early 20th centuries;

- The Ynys y Brawd causeway was then constructed in 1970-1975, fully blocking the northern Bar Back channels and fixing the single entrance channel in the present-day alignment; and
- This will also have fixed the general ebb flow tidal pattern within the estuary mouth, i.e. between the Trwyn y Gwaith breakwater and the railway Viaduct.

The flood/ebb flow regime in the entrance is now much more fixed than in the historical past, and it appears that this results in the ebb flow being forced closer to the northern edge of the entrance and the quay walls. A clear secondary channel is observed along the northern extent of the harbour and along the quay wall in all recent imagery. It is expected that the realigned flow regime in combination with wave reflection from the vertical structures within the harbour have been the main contributory factors to the bed lowering observed over the past two centuries (ABPmer, 2011).

The historic bed lowering is ongoing. Arup (2022b) identified an extract from the Network Rail archive showing drawings including the beach level in 1951, this level is shown on the present day image as Figure 7. All historic photos before 1972 show the beach level at the location of the railway viaduct to be around 0.3 m below the top of the pier pedestals which is also consistent with the MHWS shoreline shown on the historic maps at this time. By 2004 the beach level has reduced by 0.5 m and during a site walkover in January 2022, beach levels had reduced by well over 1 m at the railway viaduct near the corner of Frontage 1 and Frontage 2 (Arup, 2022b).

Photograph from: YGC, 2023 – Appendix E

Figure 7. Image showing western extent of frontage and historic beach level

Beach lowering is further evidenced by the exposure of the bases of the old timber trestles, found adjacent to the concrete pier pedestals. Figure 7 shows the extent of beach lowering increases moving east to west towards the corner between Viaduct Gardens and The Quay.

The present day elevations are illustrated in Figure 8 which shows the smaller ebb flow channel close to the frontage. Analysis of tidal water level data for Barmouth (Table 2) alongside present day topographic data (Figure 8) shows that the frontage is completely inundated from approximately MHWN.

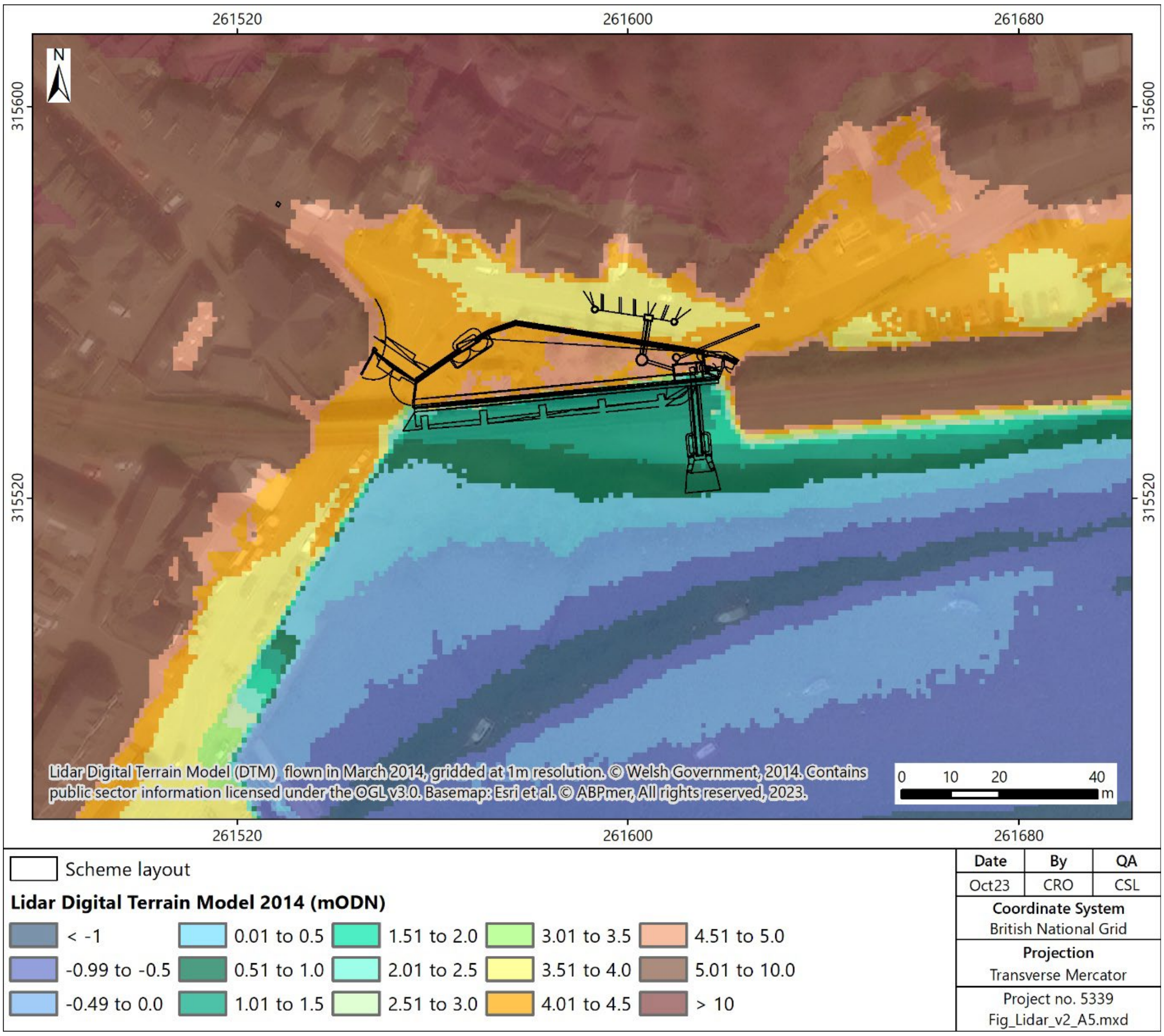


Figure 8. Present day bathymetry

Table 2. Tidal characteristics at Barmouth

Reference Still Water Level	Present day (mCD)	Present day (mODN)
Highest Astronomical Tide (HAT)*	5.69	3.25
Mean high water springs (MHWS)	5.00	2.56
Mean high water neaps (MHWN)	3.50	1.06
Mean sea level (MSL)	2.64	0.2
Mean low water neaps (MLWN)	1.80	-0.64
Mean low water springs (MLWS)	0.70	-1.74
Lowest Astronomical Tide (LAT)*	0.32	-2.12
Mean Spring Range	4.30	
Mean Neap Range	1.70	
* - Data not available from Admiralty tide tables. Extracted from NTLSF Barmouth gauge (NTLSF, 2023)		

Source: Admiralty Tide Tables (Admiralty 2023)

2.3 Water levels

Barmouth lies within Cardigan Bay, where the tide is macrotidal, with a diurnal spring tidal range of 4.30 m. Water levels from Mean High-Water Springs (MHWS) to Mean Low Water Springs have been taken from the 2023 Admiralty Tide Tables. Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) values are not included in the 2023 Admiralty tide tables and have been taken from the National Tide Level Sensor Facility (NTLSF) gauge at Barmouth. It is worth noting that MHWS was found to be in close agreement between the Admiralty data and the NTLSF gauge data, with the NTLSF data being only slightly higher by +0.05 m. The conversion from chart datum (mCD) to Ordnance Datum Newlyn (mODN) for Barmouth is -2.44 m (Admiralty Tide Tables 2023).

2.3.1 Future water levels

Climate change will affect conditions at the site through both sea level rise and storm surges. The magnitude of change is expected to increase throughout the lifetime of the development.

The associated water levels in 2124 at Barmouth are provided as Table 3 below which have been derived using UKCP18 sea level rise estimates for the higher central allowance (70th percentile) and upper end allowance (95th percentile) of Representative Concentration Pathway (RCP) 8.5. The extension of the period beyond 2100 has been applied using NRW Climate Change Guidance (Welsh Government, 2021) and sea level rise estimates have been applied from 2001 following guidance by NRW (R. Park, *pers. comm.*, September 11, 2023).

Table 3. Predicted water levels in 2124

Water Level	Present day (mCD)	Present day (mODN)	2124 RCP8.5 70th %ile (mODN)	2124 RCP8.5 95th %ile (mODN)
HAT	5.69	3.25	4.34	4.74
MHWS	5.00	2.56	3.65	4.05
MHWN	3.50	1.06	2.15	2.55
MSL	2.64	0.20	1.29	1.69
MLWN	1.80	-0.64	0.45	0.85
MLWS	0.70	-1.74	-0.65	-0.25
LAT	0.32	-2.12	-1.03	-0.63

2.3.2 Extreme water levels

Extreme water levels were derived as part of the scheme design and outlined in ABPmer (2022). These are provided in Table 4,. The water levels have used the Environment Agency's Coastal Flood Boundary Database 2017 baseline extreme levels[3] (using location 832) and predicted climate change projections from the UK Climate Impact Programme UKCP18[4].

[3] https://www.data.gov.uk/dataset/73834283-7dc4-488a-9583-a920072d9a9d/coastal-design-sea-levels-coastal-flood-boundary-extreme-sea-levels-2018

[4] https://ukclimateprojections-ui.metoffice.gov.uk/ui/home

Table 4. Extreme water level projections

Years from present day	n/a	0		20		50		100	
Epoch	2017*1	2022		2042		2072		2122	
%ile	n/a	70	95	70	95	70	95	70	95
SLR from 2017 (m)	n/a	0.02	0.03	0.14	0.18	0.41	0.53	0.93	1.27
Return Period	Extreme water levels (mODN)								
t1	3.46	3.48	3.49	3.60	3.64	3.87	3.99	4.39	4.73
t2	3.59	3.61	3.62	3.73	3.77	4.00	4.12	4.52	4.86
t5	3.75	3.77	3.78	3.89	3.93	4.16	4.28	4.68	5.02
t10	3.87	3.89	3.90	4.01	4.05	4.28	4.40	4.80	5.14
t20	3.99	4.01	4.02	4.13	4.17	4.40	4.52	4.92	5.26
t25	4.03	4.05	4.06	4.17	4.21	4.44	4.56	4.96	5.30
t50	4.14	4.16	4.17	4.28	4.32	4.55	4.67	5.07	5.41
t75	4.21	4.23	4.24	4.35	4.39	4.62	4.74	5.14	5.48
t100	4.26	4.28	4.29	4.40	4.44	4.67	4.79	5.19	5.53
t150	4.33	4.35	4.36	4.47	4.51	4.74	4.86	5.26	5.60
t200	4.38	4.40	4.41	4.52	4.56	4.79	4.91	5.31	5.65

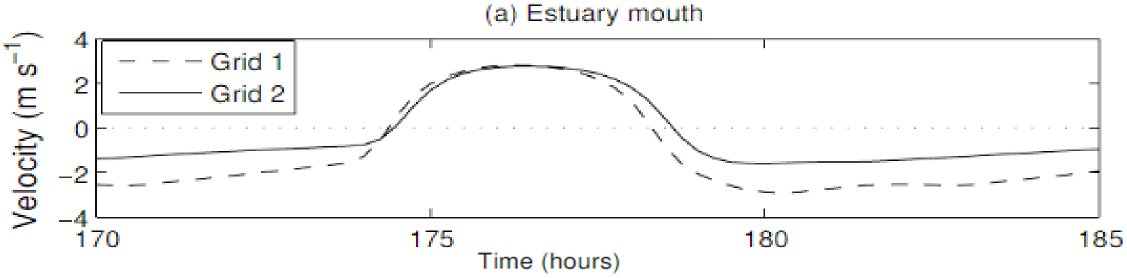
*1 CFBD base year

The scheme has used a 1:200 year design still water level in 2122 of 5.31 m ODN in accordance with the latest Welsh Government Guidance for Flood and Coastal Erosion Risk Management Authorities which recommends RCP8.5 70% as design allowance and the 95%ile as a sensitivity test (Welsh Government, 2021).

2.4 Flow regime

There is little information on the flow regime in the estuary and no survey data has been identified. Notwithstanding this, the estuary is considered to be ebb dominant (ABPmer 2011). A modelling study commissioned by the Countryside Council for Wales (CCW) undertook hydrodynamic simulations of the Mawddach Estuary and investigated the response of the estuary to future tidal and atmospheric changes (Robins, 2011). Under annual-mean river flow rate conditions, peak velocities occurred during spring tides through the estuary mouth and exceeded 2 m s^{-1}. Peak velocities in the main estuary were small on the tidal flats and up to 1 m s^{-1} in the channels, reducing to 0.5 m s^{-1} up-stream. The addition of a 1 in 100-year fluvial event causes little change to the velocities in the main estuary, whilst a 1 in 100 year storm surge of 2 m increased peak velocities at the mouth by 15% and increased the tidal prism two-fold.

Depth averaged velocity at the estuary mouth during a spring tidal cycle under mean river flow conditions is shown in Figure 9 for two model grids: Grid 1 (<10 m resolution mesh in the main estuary) and Grid 2 (same as Grid 1 but with all anthropogenic features removed e.g. rail line embankments, flood defence embankments etc.). Generally, depth-averaged flows for the flood tide exceed 2 m/s with the structures in place but are generally weaker during the ebb phase (reaching 2.5 m/s for Grid 1) (Robins, 2011).

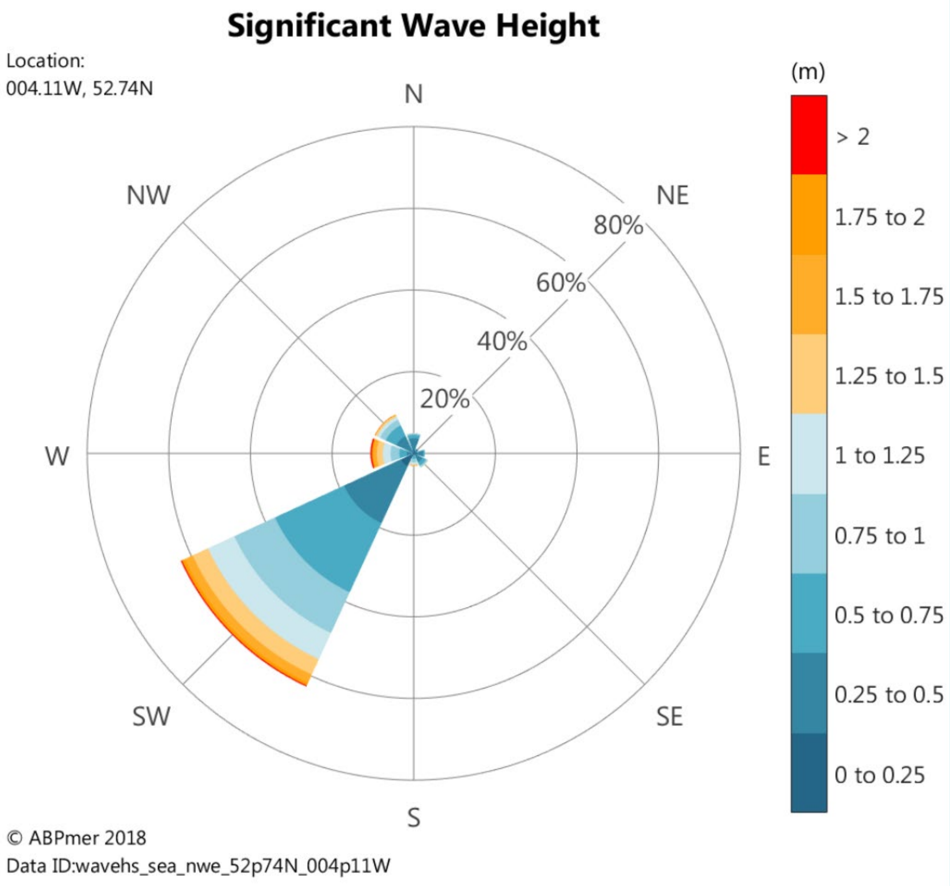


Source: Robins, 2011

Figure 9. Depth averaged velocities at the mouth of the estuary.

2.5 Wave regime

The long-term wave climate just offshore of the Mawddach Estuary is illustrated in Figure 10 below. The coast is affected by a mixture of swell waves originating in the Atlantic and Wind waves from the Irish Sea and Cardigan Bay, with a mean wave height of 0.7 m. The dominant wave direction is from the southwest, accounting for over 60% of waves, due to the offshore prevailing wind conditions. The offshore reef feature of Sarn Badrig, which extends 11 km offshore from Barmouth North beach (Figure 5), also inhibits wave energy reaching the site from more north westerly directional sectors.

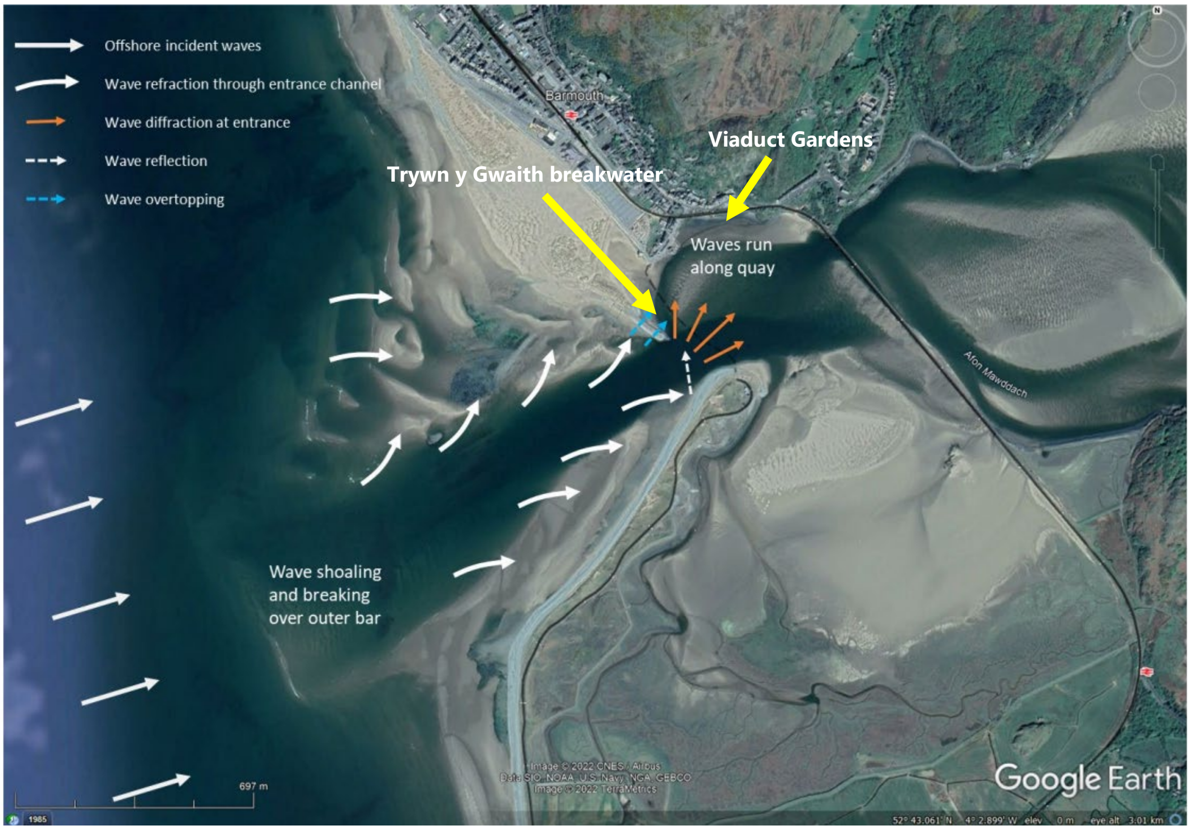


Source: ABPmer SEASTATES Hindcast Data (ABPmer, 2013)

Figure 10. Wave conditions offshore of the Mawddach Estuary

As Viaduct Gardens is largely sheltered from waves propagating eastward from Cardigan Bay, wave diffraction is the primary mechanism by which waves enter the harbour. ABPmer (2022) provided an overview of the key wave transformation processes that occur at the site as the waves propagate inshore and through the mouth of the estuary. This is illustrated as Figure 11 and shows:

- Complex wave refraction as the wave travels through the entrance with waves refracting from the edge of the channel;
- Wave diffraction as the waves pass Trywn y Gwaith breakwater;
- Wave reflection off the defences to the south of the channel;
- Wave overtopping of the Trywn y Gwaith breakwater; and
- Possible wave amplification / overtopping as waves run along the quay wall.



Adapted from ABPmer, 2022

Figure 11. Wave transformation into the estuary

2.6 Future morphological change

The future evolution of the estuary is discussed in ABPmer (2011). Although there is uncertainty associated with regard to the estuary's future evolution, due to its geomorphological form and the fact that the sediment supply from offshore and the adjacent coast is plentiful, it is considered likely that the estuary will continue to accrete with sea level rise.

More locally to the frontage, higher water levels and potentially greater wave energy is likely. Accordingly, the reflection of wave energy off the seawalls is likely to increase. Over time this could lead to gradual local scouring adjacent to the seawalls until a new 'equilibrium' bed level is achieved.

3 Assessment

3.1 Introduction

The potential changes to coastal processes and direct construction effects arising from the new sea wall and outfall have been considered with respect to:

- Construction:
    - Direct loss of foreshore; and
    - Release of sediment during construction.
- Operation:
    - Changes in flow conditions through the presence of the sea wall and operation of the outfall (blockage);
    - Potential for scour; and
    - Effects from climate change

3.2 Construction effects

3.2.1 Direct loss of foreshore

The western section of the new sea wall follows the existing alignment, with the eastern section extending approximately 0.6 m seaward. The design includes for formalisation of the existing rock armour and there is no change in the overall footprint associated with the sea wall and no direct loss of foreshore as a result.

There will be *circa* 85 m^2 loss as a result of the footprint of the new outfall (including scour protection to the side and fronting the outfall). The length of the outfall has been minimised as far as practically possible and would result in a loss of only *circa* 67 m^2 of mapped mudflat and sandflat habitat. Assessment of the implications of this loss of habitat is provided in the Habitats Regulations Appraisal currently being produced by YGC.

3.2.2 Release of sediments during construction

The excavations and plant movements on the foreshore has the potential to both compact material and release sediments into the water column. The construction activities will be undertaken during low tide conditions and the potential for sediment suspension would occur on the subsequent tide rather than any direct release into the water column. The foreshore consists of a mixture of cobbles, sand and mud and the potential for the release of significant amounts of fines above background levels causing a sediment plume would be unlikely. Where material has been disturbed, due to the low flow conditions transport and deposition is expected to be localised and aligned to the direction of flow.

3.3 Operational effects

3.3.1 Changes in flow conditions through blockage effects

There is the potential for blockage effects from the infrastructure changing flow and wave conditions and hence sediment transport. The frontage is already heavily influenced by the existing viaduct piers and existing sea walls. Raising the existing sea wall will not affect the hydrodynamic regime and formalisation of the rock scour protection will reduce wave energy and the effects of toe erosion at the sea wall.

There is the potential for blockage effects from the new outfall. However, the outfall is aligned with the adjacent Network Rail embankment and will not be extending out into the main flow path. Evidence Report 624 suggests that the maximum change to any coastal processes would be *circa* ten times the maximum dimensions of the structure: as the outfall only extends *circa* 13 m from the seawall, this would conservatively mean a maximum extent of approximately 130 m. However, the outfall is small and located in a sheltered corner of the estuary mouth high in the tidal frame above the main channel and surrounded by vertical walls. Peak velocities are thought to be low reducing the period at which sediment would be mobilised [noting the study by Robins (2011) stated 'peak velocities in the main estuary were small on the tidal flats and up to 1 m s^{-1} in the channels].

The structure will only be interacting with the flow regime when tidal conditions are above *circa* MHWN. Therefore, the percentage of time sediment would be both mobilised and the outfall structure is interacting with the flow regime is relatively small and the extent of the blockage effect on the structure on the sediment transport system is, therefore, judged to be small in this location.

3.3.2 Potential for scour

The potential for scour from the outfall has been mitigated through the use of rock scour protection reducing the risk of scour in the immediate vicinity of the outfall. Beach levels will be reinstated. In addition, the outfall is surrounded by the sea walls, viaduct piers and rail embankment which have a much greater effect on the local flow and wave regime. Therefore, the additional interaction with the outfall is considered to have only a minor effect on the local flow regime.

NRW has identified the potential for the flow from the outfall (operational only during flooding events) to affect the foreshore during lower states of the tide, potentially causing a local drainage channel across the foreshore. The design flow conditions are provided in Table 1. Due to the intermittent nature of the outfall (storm events) the number of events and volume of water being released across the foreshore will be highly variable and also be dependent upon the state of the tide during the storm duration. The scour effect of the discharge has been mitigated through the provision of the rock apron and it is considered that any local scour arising from a single event (or series of events) will be further mitigated by the natural sediment transport across the frontage during each subsequent tidal cycle.

3.3.3 Effects from climate change

The effects of sea level rise over the design life of the structure will mean that mean sea level will increase in front of the sea wall and there will be greater tide locking of the outfall (requiring more frequent pumping).

The estuary will continue to be a net sink of sediment although if the ongoing rate of sedimentation does not keep pace with sea level rise, the tidal prism will increase. Bed level lowering at the frontage is anticipated to continue but the rock protection will provide some localised reduction in scour at the base of the wall and the outfall.

The increase in tidal prism will affect the alignment of the ebb channel in front of Viaduct Gardens which is influenced by the hard structures of the Quay, Viaduct Gardens and the railway embankment. Its future alignment is uncertain but raising the wall and the new outfall structure is unlikely to noticeably influence the location of the ebb channel in the context of the surrounding vertical structures.

3.4 Conclusion

The assessment concludes that there will be very limited changes in coastal processes as a result of upgrading the sea wall and installation of the outfall. The direct loss of mapped intertidal habitat is predicted to be *circa* 67 m^2 as a result of the footprint of the new outfall. Where changes may occur due to blockage effects of the outfall they will be very minor due to its sheltered location and position in the tidal frame. As a result the assessment expects that the direct and indirect effects on coastal processes (and therefore Annex 1 habitats) will be negligible.

4 Coastal Squeeze Assessment

4.1 Screening for potential coastal squeeze

The FAS is being implemented as part of the HTL SMP 2 policy for PU 11.14 Barmouth South. The Viaduct Gardens frontage is *circa* 70 m long as shown in Figure 1. Located within the Pen Llŷn a'r Sarnau SAC the scheme requires consideration of coastal squeeze. Coastal squeeze is defined as the loss of natural habitats or deterioration of their quality arising from anthropogenic structures, or actions, preventing the landward transgression of those habitats that would otherwise naturally occur in response to sea level rise in conjunction with other coastal processes. Coastal squeeze affects habitat on the seaward side of existing structures (NRW 2022).

NRW Guidance Document GN062 also states that '*maintaining a particular coastal alignment whilst sea-levels continue to rise will lead to narrowing of the intertidal/coastal zone, and loss of habitat. The Habitats Regulations requires that the extent of designated Annex 1 habitats is stable or increasing. Therefore, projects or activities which prevent the natural ability of habitats to migrate landwards in response to sea-level rise are likely to lead to adverse effects or deterioration of the National Site Network*'.

NRW Guidance Document GN062 sets out a step-by-step approach to considering coastal squeeze. Screening Step 1 sets out four questions to identify the potential for coastal squeeze. These are listed below, with the corresponding answers for this FAS.

- Is there a plan or project to undertake works to a structure or an activity occurring which implements hold the line and/or maintains the current shoreline position (this can include works to the landward side of a defence)? Note that maintenance activities are considered at screening step 2.
    - **Answer: YES**
- Would the habitats be able to migrate landwards in response to sea level rise if there was no coastal structure or the management activity was stopped (i.e., the land behind the defence would be susceptible to flooding if the defence failed or would be expected to erode rapidly)? This includes land which is currently developed as explained in section 1.2 above).
    - **Answer: YES**
- Is there a National Site Network designated site with Annex 1 habitats present in the area seaward of the defence? Note that the designated site does not need to be immediately adjacent to the proposed works or structure, and the site boundary could be nearby or lower down the shore.
    - **Answer: YES**
- If the proposed works are in a 'Hold the line' policy unit, does the SMP HRA identify coastal squeeze losses? If the proposed works are in a 'No active intervention' or 'Managed Realignment' policy unit then this question does not apply as coastal squeeze will not have been assessed for these policy types. The preferred policy may change over time. Consideration should be given to the policy periods (SMP epochs) relevant to the proposed lifespan of the works. For works which overlap or cross 2 policy units or more than one epoch you would need to consider the policies for all
    - **Answer: NO**

The SMP2 HRA does not identify PU 11.14 as having coastal squeeze losses. However, the SMP HRA paragraph 5.5.53 states that "*Managed Realignment (PUs 11.2, 11.5, 11.6, 11.9, 11.10, 11.12, 11.13, and <u>11.14</u>) in the long term would ensure that coastal squeeze would not be an issue, as no alteration to the physical or chemical processes would be expected other than that resulting from natural variation in* *response to sea level rise*." However, PU11.14 is HTL and therefore we consider the SMP HRA to be incorrect and are proceeding on the basis that coastal squeeze losses should have been identified.

The assessment therefore proceeds to Screening Step 2:

- Does the proposed project or activity fall within the definition of maintenance?
    - **Answer: NO**, although the works are to an existing structure, it is considered that the works are upgrading and raising the defences rather than maintaining the existing structure.

The Stage 2 Test of Likely Significant Effect. This stage gives four options. Based upon concerns relating to the validity of the SMP2 HRA it is considered that the FAS falls within Option 3:

- Proposed works could lead to coastal squeeze, are not maintenance, and are in a HTL policy unit.

The guidance states that if the SMP2 HRA identifies coastal squeeze impacts, record these and proceed to stage 3 Appropriate Assessment. Due to the error in the SMP2 HRA the following section completes the coastal squeeze assessment for the frontage following guidance in Section 4 of GN062.

For reference Welsh Government (WG) policy clarification note paragraph 3.4 states: '*Provided that an individual project/plan is demonstrably consistent with the relevant Shoreline Management Plan policy, the statutory notice to WG from NRW shall include a short confirmation of the fact and therefore the plan/project is justified on grounds of no alternative solutions and the existing Shoreline Management Plan IROPI*' (NRW, 2022).

4.2 Coastal squeeze assessment

4.2.1 Methodology

The following section sets out the technical assessment requirements of the coastal squeeze assessment. It broadly follows Section 4 of GN62 along with FRS17187 *'What is Coastal Squeeze'?* (Environment Agency, 2021).

The quantification of losses in front of the Viaduct Gardens frontage is based on a hypsometry analysis, whereby the extent of available habitat space in front of the present sea wall is determined from the tidal frame and the present-day topography. The present day topography uses the 2014 LiDAR data of the estuary as illustrated in Figure 8. This LiDAR data set includes some false readings, where levels relate to the water level surface in the main channels rather than the seabed. For the analysis, these false readings were therefore removed and the depth along the centre line of the channels was assumed to be MLWS, and the dataset was interpolated. The resultant DTM, therefore covers the entire intertidal frame, extending from the centre of the main channel (to represent present day MLWS) to the sea wall. The area of assessment is shown Figure 12

The water levels and sea level rise scenarios are as follows:

- Present day assumed to be 2024 using water levels provided in Table 2;
- 2124 using sea level rise estimates following UKCP18 RCP 8.5 70th and 95%ile and using 2001 water levels as the starting year to align with UKCP18 base year[5] as shown in Table 3.

[5] As advised by NRW

Area subject to the coastal squeeze assessment

Date	By	QA
Oct23	CRO	CSL

Coordinate System
British National Grid

Projection
Transverse Mercator

Project no. 5339
Fig_Coastal_Squeeze_Assess_A5

Basemap: Esri et al. © ABPmer, All rights reserved, 2023.

Figure 12. Area subject to the coastal squeeze assessment

Using the DTM data, the hypsometry analysis calculates the extent of potential intertidal habitat that lies in the intertidal frame for each epoch as follows with the associated water levels provided in Table 5:

- **Supralittoral** (MHWS to HAT +1 m)
- **Upper Intertidal** (MHWN to MHWS)
- **Lower to Mid Intertidal** (MLWS to MHWN)

Table 5. Water levels and associated habitat groupings

Habitat	Water Level	Present day (mODN)	2124 RCP8.5 70th %ile (mODN)	2124 RCP8.5 95th %ile (mODN)
Supralittoral	HAT +1	4.25	5.34	5.74
	MHWS	2.56	3.65	4.05
Upper Intertidal	MHWS	2.56	3.65	4.05
	MHWN	1.06	2.15	2.55
Lower-mid Intertidal	MHWN	1.06	2.15	2.55
	MLWS	-1.74	-0.65	-0.25

The change in potential intertidal habitat extent as a result of sea level rise therefore captures the maximum loss (or gain) in potential habitat extent fronting Viaduct Gardens as a result of maintaining the sea wall. The outfall is not considered to result in coastal squeeze.

The coastal squeeze assessment does not consider changing morphology as a result of sea level rise or the potential for roll-back should the defences not be maintained. However, this is considered using expert geomorphological judgement using the baseline understanding provided in the Section 2 as per the requirement of guidance document '*What is Coastal Squeeze?*' (Environment Agency, 2021).

4.2.2 Results

The outputs of the hypsometric analysis is presented in Table 6 and Table 7 below using the RCP8.5 70th %ile and 95%ile respectively. It can be seen that the predicted losses are largely associated with the lower to mid intertidal. However, it should be noted that this will be significantly influenced by the movement of the nearshore channel which is included in the area for assessment.

Table 6. Quantification of potential habitat loss using hypsometric analysis and UKCP18 RCP8.5 70th %ile

Year	Lower to mid intertidal area (ha)	Upper intertidal area (ha)	Supra tidal area (ha)
Present day	1.51	0.07	0.00
2124	0.38	0.00	0.00
Coastal Squeeze	1.13	0.07	0.00

Table 7 Quantification of potential habitat loss using hypsometric analysis and UKCP18 RCP8.5 95th %ile

Year	Lower to mid intertidal area (ha)	Upper intertidal area (ha)	Supra tidal area (ha)
Present day	1.51	0.07	0.00
2124	0.21	0.00	0.00
Coastal Squeeze	1.30	0.07	0.00

It is considered that the quantification of (up to) *circa* 1.37 ha loss (under the RCP 8.5 95th %ile scenario in Table 7) is a significant overestimation of the losses which would occur due to the presence of the sea wall. This is because the conceptual understanding has identified that the estuary is a net sediment sink and likely to continue to accrete with sea level rise. Although it is not possible to determine whether the rate of sedimentation will keep pace with future sea level rise, continued sedimentation has the potential to reduce the amount of future inter-tidal habitat loss.

The area of potential 'accommodation space', i.e. the area which habitat could roll back into based solely on its topography, is shown as Figure 13. This shows a total area of 0.75 ha under the RCP8.5 95%ile scenario (pink plus green on the figure).

Assuming the worse-case scenario using the RCP8.5 95%ile sea level rise scenario and no morphological change, the assessment predicts *circa* 1.37 ha habitat loss in front of the sea wall. The maximum potential accommodation space (roll back area) is 0.75 ha.

Therefore it is concluded that there is the potential for the following losses over the lifetime of the project:

- 0.75 ha of coastal squeeze; and
- 0.62 ha of natural squeeze. Natural squeeze is defined as the loss of habitat against any natural feature that restricts the rollback of intertidal habitats, in this case high ground limiting the accommodation space available.

Figure 13. Area behind the sea wall with a topography of HAT +1 in 2124 (pink area RCP8.5 70%ile and pink plus green area RCP8.5 95%ile)

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6 Abbreviations/Acronyms

HAT	Highest Astronomical Tide
HRA	Habitat Regulations Assessment
HTL	Hold the Line
IROPI	Imperative Reasons of Overriding Public Interest
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
mCD	Metres Relative to Chart Datum
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
mODN	Metres Relative to Ordnance Datum Newlyn
MSL	Mean Sea Level
NRW	Natural Resources Wales
NTLSF	National Tidal and Sea Level Facility
OD	Ordnance Datum
PU	Policy Unit
RCP	Representative Concentration Pathway
SAC	Special Area of Conservation
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SSSI	Site of Special Scientific Interest
UK	United Kingdom
UKCP	UK Climate Projections
WG	Welsh Government
YGC	Ymgynghoriaeth Gwynedd Consultancy

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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