H Coastal Processes & Hydromorphology

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2016s5126 - East Rhyl coastal defence scheme - coastal processes assessment and modelling

Final Report

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Denbighshire County Council

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Purpose

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Executive Summary

A coastal assessment and modelling study identified the key attributes of the Rhyl coastline, including onshore ridge-runnel dynamics and a net eastward sediment transport along the beach face. An existing onshore delivery of approximately 20,000 m^3/yr occurs through the migration of sand ridges, which is balanced by the alongshore loss.

The modelling study indicated that the offshore breakwater needs to be located further offshore and westward than its original proposed position to operate effectively. In addition, a recharge volume of approximately 156,000 m^3 would be required to infill the sheltered area behind the breakwater.

The existing rate of onshore supply is only capable of supporting a low beach. A higher beach, such as placed by recharge, is likely to experience rapid erosion. Secondary structures such as groynes would be required to retain a recharge beach for a time scale in the order of 8-10 years.

Although both the offshore breakwater and groynes are theoretically capable of being designed for coastal stability, it is prudent to allow for the potential ongoing loss of recharge. Allowances of 5,000 m^3/yr and 7,000 m^3/yr are recommended for the offshore breakwater and groynes respectively. The larger potential rate of loss for the groyne is due to the greater capacity for post-storm recovery of the beach retained by the offshore breakwater.

Options involving beach recharge will increase the sediment supply to the downdrift coast. This effect will be dispersed by the intervening distance and effect of coastal protection works at Prestatyn. The sediment supply is minor compared with existing year-to-year variation in beach volumes occurring in the environmentally sensitive areas of Gronant and Talacre.

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Abbreviations

BedW .... Wave related bed-load sediment transport

CD.................................. Metres Above Chart Datum (Local)

CERC.............................. Coastal Engineering Research Centre (US Army Corp of Engineers)

DCC .... Denbighshire County Council

DOC................................ Depth of Closure

Delft3D........................... Delft 3D (modelling software)

D50 .... Median grain size

HHW .... Higher-High Water (highest water level over a day)

HWAI.............................. High Wave Angle Instability

Hs................................... Significant Wave Height

LiDAR............................. Light Detection and Ranging (photogrammetry methodology)

mAOD .... Meters above Ordinance Datum (Newlyn)

MorFac........................... Morphological accretion factor

MSL................................ Mean Sea Level

m^3 /s............................... Metres cubed per second

m^3 /year.......................... Metres cubed per year

PAR................................ Project Appraisal Report

Sec................................. Abbreviated for seconds

SusW .... Wave related suspended sediment transport factor

Tp................................... Spectral peak wave period

WWIII .... Wavewatch III (broad scale wave transformation model)

2D .... 2 Dimension (U, V)

3D .... 3 dimensions (U, V, Z)

1 Introduction and modelling concepts

This technical study clarifies the sediment dynamics associated with two potential options for the East Rhyl coastal defence scheme, and addresses the previous uncertainties regarding associated capital and ongoing sediment recharge estimates. The model was also developed to help select a preferred single option and support an addendum to the 2016 East Rhyl project appraisal report (PAR) to satisfy Welsh Government queries.

This coastal assessment has included analysis of observational data and numerical modelling to:

- Refine estimates of the required sediment recharge volume and timing;
- Evaluate the effects of each option upon the physical distribution of sediment;
- Refine the offshore breakwater position with regards to coastal stability; and
- Characterise the impacts of the defence options on areas of environmental significance located downdrift (further east).

1.1 East Rhyl coastal defence project

The East Rhyl Coastal Defence (ERCD) project is a proposed new coastal defence scheme to be constructed to protect the east of Rhyl from flooding; primarily caused by wave overtopping of the existing seawall. The scheme has been designed to protect the Garford Road area of East Rhyl, from Splash Point to Rhyl Golf Course as shown in Figure 1-1.

Figure 1-1: Location map of East Rhyl

1.2 Project background

The ERCD project is a key Denbighshire County Council (DCC) flood defence scheme, of great significance to the residential and commercial stakeholders in Rhyl currently at risk of flooding. A Project Appraisal Report (PAR) was produced by JBA Consulting (2016) on behalf of DCC to investigate potential options for the required form of coastal defence and justify further investment in the project. Following submission of the PAR, DCC engaged Balfour Beatty through the Scape National Civil Engineering and Infrastructure Framework to progress the project through a feasibility study into the cost, and programme for delivery of the pre-construction and construction stages of this project.

This was conducted in three stages: pre-construction, including design (stage 3); construction (stage 4); and post construction (stage 5). JBA Consulting have been nominated by DCC and appointed by Balfour Beatty to provide consultancy services during the pre-construction stage (Stage 3b and Stage 3c) of the project.

The PAR completed in 2016 identified six options:

- Option 1 – No active intervention (do nothing)
- Option 2 – Do minimum – regular maintenance through beach recharge
- Option 3 – Do something – Beach Recharge scheme with a terminal groyne
- Option 4 – Do something – Offshore breakwater with a beach recharge
- Option 5 – Do something – Rock revetment with beach recharge
- Option 6 – Do something – Beach recharge scheme with a sand engine

Option 4, Offshore Breakwater with a beach recharge, with a cost benefit ratio of 1.7 was selected as the preferred option in the PAR. This option provides a 1 in 200-year standard of protection (including climate change impacts to the year 2116) for the Garford Road area of East Rhyl. This option is described in the PAR as an offshore breakwater, however, an assumption was made at PAR stage that it would not truly be an offshore breakwater, but will be located in the intertidal zone, with dry beach behind the structure at low tide.

Although Option 4 was identified within the PAR as the preferred solution, the selection of this option is subject to approval by the Welsh Government. The Welsh Government queried the potential use of Option 5, re-facing the existing structures with rock armour, which had a similar cost benefit ratio to Option 4. There were also concerns over the accuracy of the cost estimates at this stage, considering to the lack of sediment modelling which would assist in the determination of the sand retention rates of sand on the beach and hence the recharge requirements.

2 Coastal process observations and setting

2.1 Background

East Rhyl is located on the North Wales coast, which is comprised on mostly low-lying land, formed from alluvial deposits (Welsby & Motyka 1989). Its position determines the coastal oceanography, with tidal flows and ambient wave conditions controlled by the structure of the Irish Sea. The tidal regime is dominant, with a spring tide range of 7.5m, and almost total shelter from long-period oceanic swell waves. Ambient waves 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 formation of wide beaches, commonly sand overlying glacial till (clay), with occasional expressions of peat or shingle deposits.

The pattern of prevailing west to east sediment transport from Great Orme's Head towards the Dee Estuary has long been identified, through both the interpretation of morphology and observations of downdrift erosion to the east side of coastal and flood defences after they were installed (Welsby & Motyka 1989). This transport pathway is the major attribute used to classify this section of coast as a regional sediment sub-cell, Sub-cell 11a (Cooper & Pontee 2006), which implies a strong spatial coherence of coastal sediment transport (Figure 2-1).

Within Sub-cell 11a, the coastal morphology changes near Abergele. To the west, carboniferous limestone headlands occur at Great Orme, Little Orme, Rhos Point and the eastern end of Colwyn Bay, providing structural control to arcuate bays. These controls support clay scarp formation along the coast, fronted by sand and shingle beaches. To the east, there is a relative absence of rock formations, with coastal curvature developed near the mouth of the Clwyd River and large-scale spits at Gronant and Talacre, with associated dune fields. The continuity of the coastline is naturally disturbed at the Dee Estuary, which forms a large potential trap for sediments, including finer clays and silts.

Most of the North Wales coast has been extensively modified through the installation of coastal defence structures; with 47 artificial structures being identified between Little Orme and the Point of Ayr, along with several points of recharge (Halcrow 2011). Shingle beaches, which occur naturally close to headlands, have been highly modified since the 1840s, with limited apparent opportunity for material renewal.

The practice of 'holding the line' where coastal assets were deemed to be at risk, has gradually proliferated along the coast over the last 200 years, and is now central to the coastal management strategy (Halcrow 2011). The prevalence of defensive structures, including groynes and seawalls, has led to progressive beach lowering across much of the shore from Little Orme through to Prestatyn.

Figure 2-1: Sediment Sub-cells, defined in Halcrow (2010)

Figure 2-2: Coastal locations from Little Orme to Dee Estuary. The study site (Splash point) is located at Rhyl

The irregular arcuate coastal shape west of Abergele, provides an almost linear coast to Gronant. This and the presence of the spit features located at the Point of Ayr, are geomorphic indicators of a large scale ‘conceptual model’ for the North Wales coast. Simplistically, this structure suggests that the western section has (over millennia) supplied material to the alongshore littoral zone, transporting sediment eastward to be deposited in the dunes and spits near Gronant and Talacre (Figure 2-2). This is evidenced at a beach scale by sediment deprivation on the coarse sediment beaches to the west, and the wider, fine sediment beaches to the east. Sedimentary analysis has suggested that this large-scale behaviour has occurred since the mouth of the Conwy River shifted to the west side of Great Orme Head, removing an external supply of littoral material (Welsby & Motyka,1989).

The conceptual source-pathway-sink model is partly supported by the nature of irregularities in the coastal structure. To the west, convex forms are related to geological features, and suggest partial retention of sediment on the updrift side. The less pronounced convexities at Rhyl and Gronant are hydraulic and related to the Clwyd River and tidal exchange from Prestatyn Gutter, and support natural bypassing.

Modern interpretation of simple source-pathway-sink behaviour is obscured by the substantial amount of structural modification occurring along the coast, including material extraction, flood protection works and coastal stabilisation. Beach lowering is observed along almost the entire coast between Great Orme Head and the Point of Ayr during the 20th century, along with substantial narrowing of the intertidal zone for the coast between Rhyl and Prestatyn (Welsby & Motyka 1989, HR Wallingford 2008).

Coastal behaviour near East Rhyl, identified from historic mapping, includes:

- Substantial retreat of the low water mark for 5km east of Splash Point between 1871 and 1900, of up to 600m, with subsequent relative stability;
- Progressive retreat of the high water mark for 2km east of Splash Point from 1871 to 1945, subsequently sitting on the revetment face;
- No clear demonstration of further movement of the intertidal zone from the 1950s, although subsequent installation of structures suggests either continued erosion to downdrift, or an objective to increase the quantity of sand on the beach. Initial efforts to increase beach volume using an extensive field of timber groynes is considered to have failed (Welsby & Motyka 1989), with greater success for a more recent field of rock T-groynes at Prestatyn (Burgess et al. 2014).

Modifications described in previous studies (Halcrow 2011, Burgess et al. 2014) considered likely to influence the coast east of the River Clwyd include:

- Extraction of material (2 million m^3) for Liverpool Docks, 1871-1900;

- Concrete revetment constructed on Rhyl foreshore, 1900-1920;
- River Clwyd training wall, 1930s;
- Eastward extension of Rhyl revetment, 1950s;
- Timber groynes constructed Clwyd to Prestatyn, 1971-1975;
- Rock T-groynes constructed along Prestatyn (replacing timber groynes), 1989-1991;
- Beach recharge at Prestatyn (210,000 m^3), 1993.

Although the scale of these modifications has been identified in various reports (Welsby & Motyka 1989, HR Wallingford 2008, Halcrow 2011), their relative influence on local coastal erosion or accretion has not generally been incorporated in evaluation of dynamics:

- Welsby & Motyka (1989) indicated that material extraction for Liverpool Docks plus downdrift erosion following defensive works along Rhyl foreshore, arguably including the Clwyd training wall, contributed to local erosion east of Rhyl;
- HR Wallingford (2008) estimated alongshore transport rates using the Coastal Engineering Research Centre (CERC) bulk formula for alongshore littoral transport, based on shoreline aspect relative to incident waves;
- Halcrow (2011) provides an interpretation of alongshore transport rates based on shoreline aspect.

The only direct estimate of alongshore littoral drift is provided by HR Wallingford (2008), who derived 'nearshore' wave climate at four points along the Denbighshire coast, at seabed depths varying from -4.4m to -6.0mCD (-8.5 to -10.1mAOD). Transport rates calculated from the CERC bulk transport formula, which includes only wave height and direction relative to the shore, increasing west to east from 217,500 m^3/yr at West Rhyl to 474,300m^3/yr at East Prestatyn. The limitations of the CERC formula are discussed later, and the derived transport rates are inconsistent with observed behaviour (see Section 2.2). However, they do suggest a high potential for eastward alongshore transport due to the incident wave angle, which increases towards the east, implying a net tendency for erosion.

Physical evaluation of coastal change for East Rhyl has previously been reported using analysis of coastal profiles along the Denbighshire coast (CEUK 2015; HR Wallingford 2008). These analyses indicate that most variation is cyclic, related to nearshore movements of sand ridges and runnels. No clear spatial pattern was demonstrated, although net losses were inferred for east Rhyl and downdrift of the Prestatyn groyne field.

2.2 Summary of previous investigation

Previous analysis of the cross-shore profile data for the frontage from Llanddulas to Prestatyn golf club was undertaken by HR Wallingford (2008). This investigation assessed contemporary shoreline trends using modern profile data and estimated longshore transport from hindcast transformed nearshore waves. Profile analysis was undertaken for selected cross sections and extrapolated along the shoreline between sections (Figure 2-3).

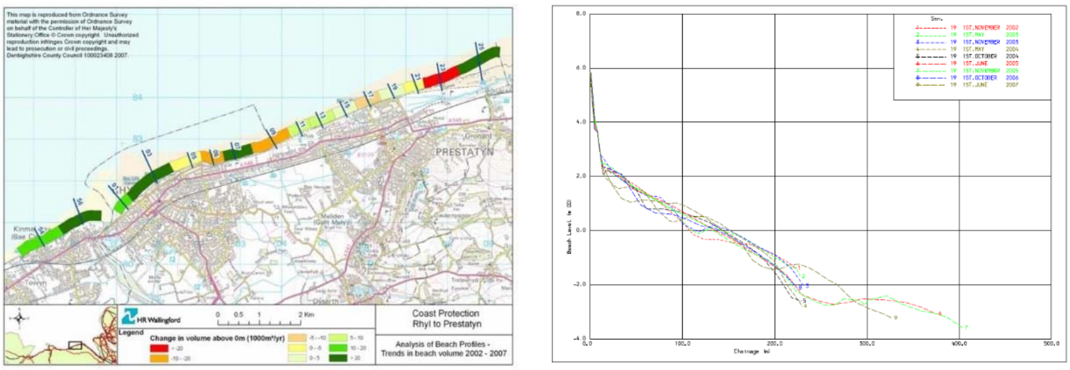


Figure 2-3: HR Wallingford output cross sectional trend analysis (left) and beach cross-sections analysis for section DCC19 (right)

Along the frontage, alongshore transport was estimated using hindcast waves transformed to nearshore (via a 2D TELEMAC model) with longshore transport rates estimated using the CERC formula. CERC is a bulk sediment transport formula that can be considered "crude" due to its inability to incorporate representation of grain diameter of beach profile and has been observed to overestimate longshore transport for grain sizes between 200-600µm and where beach slopes are in the range tanβ = 0.01-0.1 (van Rijn 2002). Although the measured grain size satisfies this parameter, the observed natural beach slope does not lie within the valid range. Sediment transport rates estimated along the coastline were high, increasing from 217,500m^3/yr west of Splash Point to 474,300m^3/yr along Prestatyn coast. The potential sensitivity of model outputs to the selection of shoreline contour was acknowledged.

Longshore transport calculations were supplemented by COSMOS-2D modelling, which is an in-house HR Wallingford numerical shoreline model to estimate cross-shore distribution of alongshore transport. This was intended to identify the role of groynes in regional sediment transport patterns. The results predicted ongoing shoreline erosion across the entire frontage from Rhyl-Prestatyn, expected to lead to lowering of beaches in front of defensive structures.

2.3 Evaluation of Coastal Profile Data

An analysis of the Denbighshire coastal profiles has been conducted with the objective of assessing coastal sediment transport characteristics. Denbighshire has arranged semi-annual surveys of 26 fixed profile locations since the establishment of the coastal monitoring programme in 2002 (Figure 2-4). Surveys from November 2002 to October 2009 were obtained as part of this project. It is understood that subsequent surveys have been conducted, with CEUK (2015) reporting a further 6 surveys over the years 2010, 2013 and 2014.

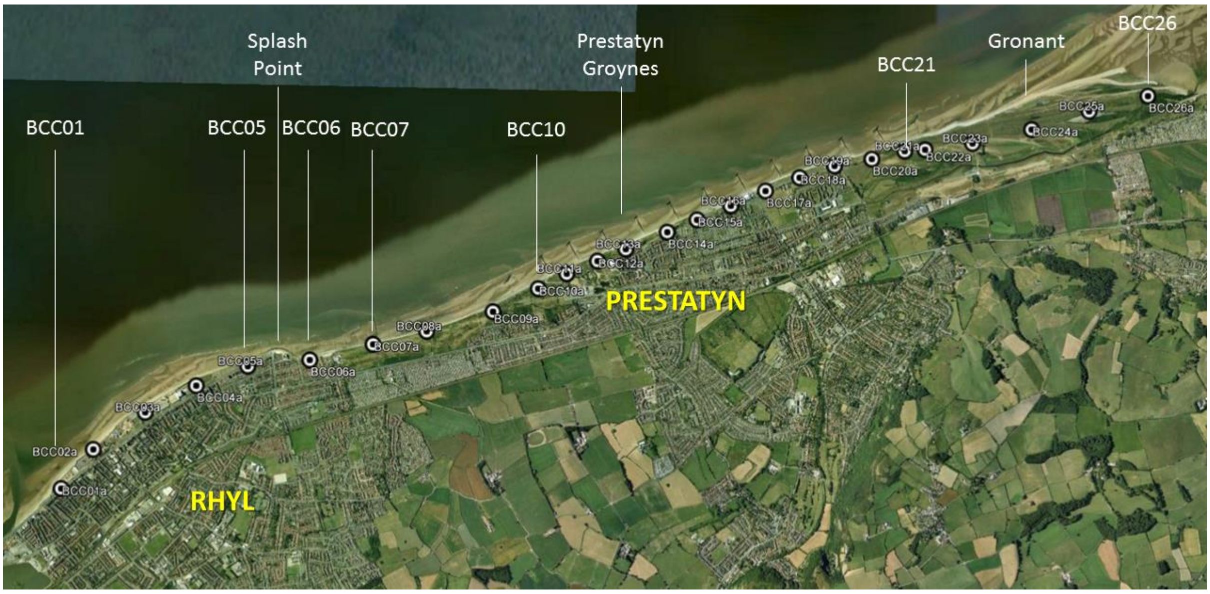


Figure 2-4: Coastal monitoring profile locations (Note: BCC label prefix is interchangeable with the prefix DCC within subsequent figures and the report text)

The evaluation of sequential profile surveys and aerial imagery has confirmed that the coastal dynamics are mostly associated with the movement of ridges and runnels along the Rhyl-Gronant coast. The profiles suggest three distinctive sections of coast:

East Rhyl, between profiles BCC02 and BCC09 (Figure 2-4), has undular (wavy) profiles, resulting from alternating ridges and runnels, occurring between mean low water spring tide and mean high water neap tide (Figure 2-5. Evaluation of the profile time sequence indicates that these features are bounded within planar envelopes with a grade of approximately 1:55-60, with material contained within the ridges moving landwards over time.

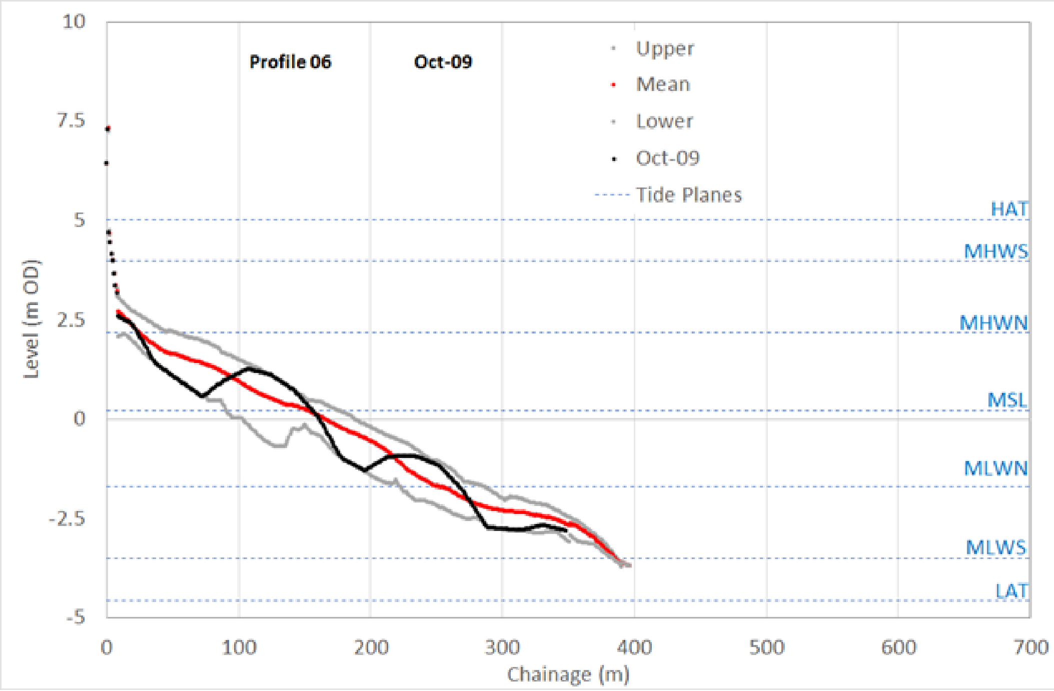


Figure 2-5: Profile DCC06 envelope of surveys 2002-2009 (East Rhyl)

Evaluation of the cross-sectional area above the lower envelope limit (Figure 2-5) shows that although the area for individual ridges may vary substantially (up to 160m^2 between surveys), the total area varies more slowly (up to 70m^2 between surveys and a total range of only 90m^2). As the profiles show landward ridge movement, this suggests sequential material supply, rather than direct exchange between ridges.

Differences in ridge behaviour occur between profiles DCC05, DCC06 and DCC07. At DCC06, which is located east of Splash Point, the ridges arrive distinctly on an annual basis, with volume loss only occurring after they have reached the beach. This is consistent with the onshore migration of the ridge and alongshore transport at the beach, which follows from their relative orientation (see Section 2.3.1). For DCC05 and DCC07, the ridges are less discrete, with some breaking down or splitting before reaching the shore. Some explanation is provided by aerial imagery (Figure 2-6) which shows the ridges between DCC01 to DCC05 transition in structure and orientation from the trained mouth of the Clwyd River, towards Splash Point. For DCC07, the stability of individual ridges is apparently affected by interactions with the substantial outfall pipeline.

Evaluation of sequential profiles at several locations shows that onshore delivery of sediment from ridge migration varies along the Rhyl and East Rhyl shore (Figure 2-6). The timing and volume of sediment supply has been analysed at selected locations, suggesting that the onshore delivery rate varies spatially, with the most rapid and consistent delivery occurring at East Rhyl (Table 2-1).

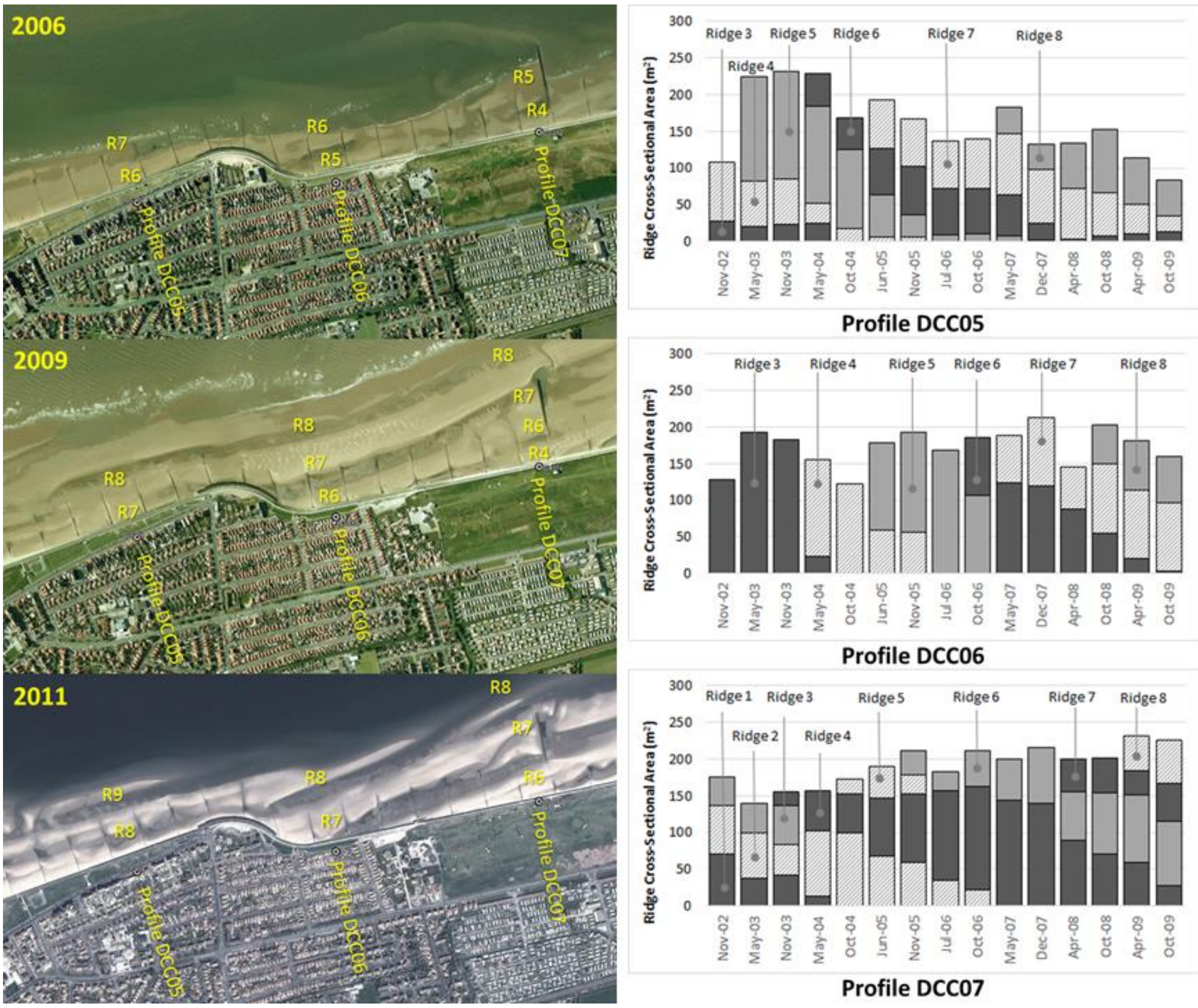


Figure 2-6: East Rhyl nearshore ridge aerial imagery and sequences

Prestatyn, between profiles DCC10 and DCC22, is dominated by the influence of a field of rock T-head groynes. These dampen the ridge and runnel behaviour, with planar profiles between mean low water neap tide and mean high water neap tide, with approximate grades of 1:40-45 (Figure 2-7). Ridge and runnel behaviour continues to occur outside the influence of the groynes, with the upper beach responding. Consequently, although the vertical variation at any point along the upper profile is far smaller than for the less controlled shore at East Rhyl, the variation of profile volume (indicated by cross-sectional area) is almost equivalent.

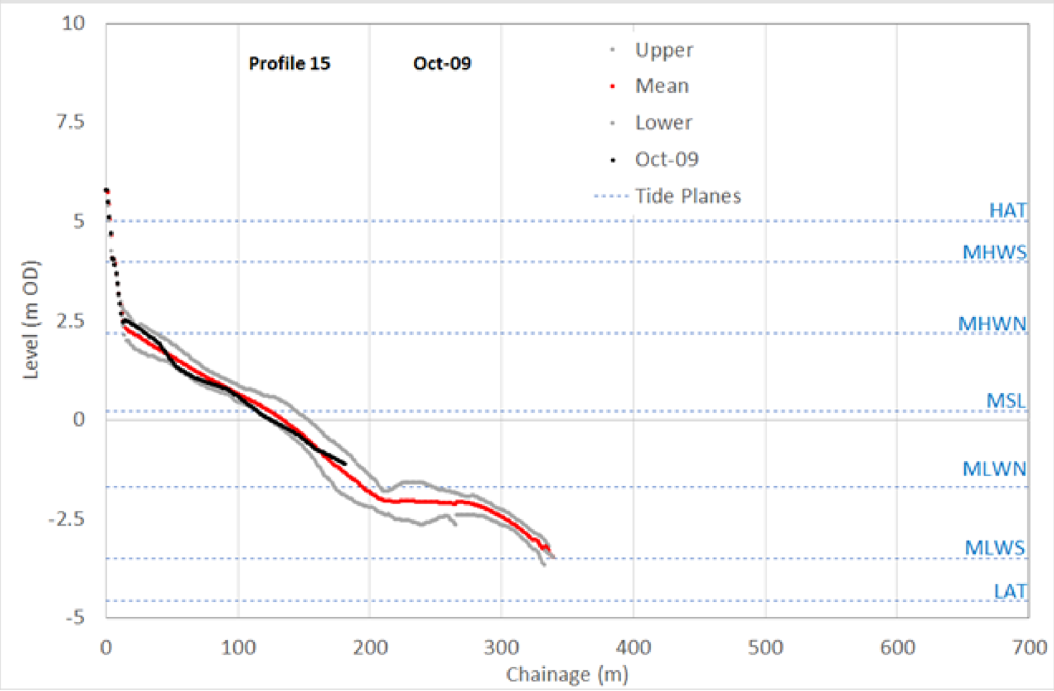


Figure 2-7: Profile DCC15 envelope of surveys 2002-2009 (Prestatyn)

The influence of the groyne field upon improved beach presence has been reported (Burgess et al. 2014). The anticipated mechanism for enhanced stability is the capacity for beach rotation, without substantial loss of sediment. This mechanism could not be observed from the spatially and temporally discrete profile surveys.

Gronant, between profiles DCC23 and DCC26, has undular profiles, resulting from ridges and runnels which extend between mean low water spring tide and mean high water neap tide (Figure 2-8). The observed profiles are bounded by planar envelopes with grades of 1:75-95. Above the beach plane, the profile shows high dune ridges, which were generally stable over the period of observation. An exception to this behaviour was observed at DCC25 and DCC26, where material from a landward migrating ridge built up a supra-tidal berm (above MHWS) with 40-50m^2 cross-sectional area growth in one year. Based on aerial imagery, the associated feature has a length of approximately 900m, and therefore this change represents a sediment delivery of approximately 40,000m^3. At DCC26, the berm subsequently moved landward and eroded gradually at about 5m^2/yr, representing a transport rate between 1,500-4,500m^3/yr, which is presumed to be alongshore.

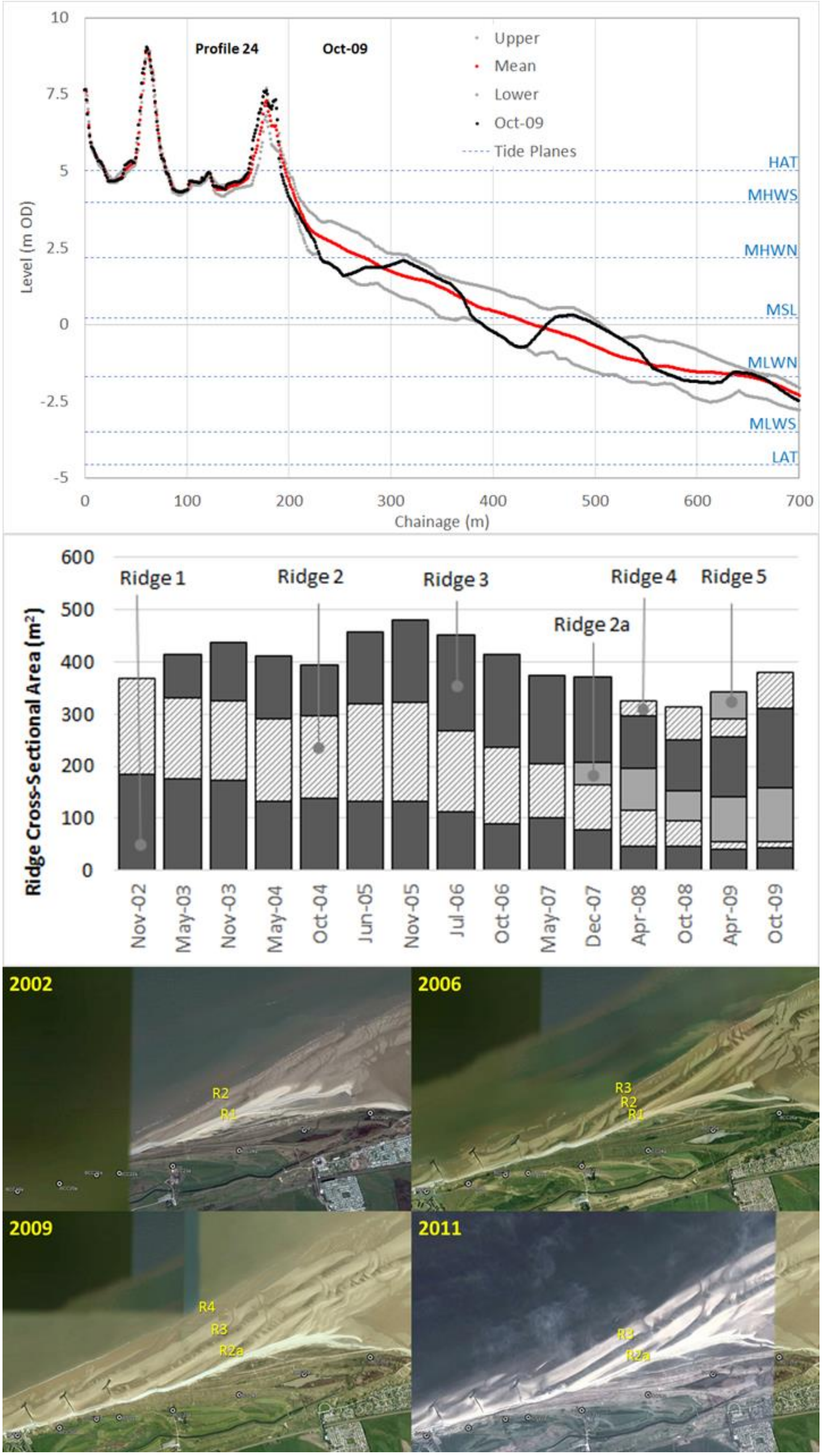


Figure 2-8: Gronant nearshore ridges

Table 2-1: Onshore sediment delivery derived from ridge dynamics

Location	Profile	Ridge Area (Cross-Section)	Delivery Time Scale	Annual Delivery	Length Scale	Transport Rate
Rhyl	DCC05	150 m^2	4 years	38 m^3/m	675m	25,000 m^3/yr
East Rhyl	DCC06	180 m^2	3 years	60 m^3/m	370m	22,000 m^3/yr
East Rhyl	DCC07	200 m^2	7 years	29 m^3/m	550m	16,000 m^3/yr
East Rhyl	DCC08	190 m^2	6 years	32 m^3/m	525m	17,000 m^3/yr
Prestatyn	DCC15	n/a	n/a	0 m^3/m	3,300m	0 m^3/yr
Gronant	DCC24	400 m^2	15 years	27 m^3/m	900m	24,000 m^3/yr
Gronant beach	DCC26	40 m^2	8 years	5 m^3/m	500m	2,500 m^3/yr

The relatively small rates of profile change occurring along the Rhyl-Gronant coast imply a relationship between onshore and alongshore sediment transport that leads to an approximate nearshore balance. Material that is supplied onshore through the shoreward migration of ridges becomes subject to an increased rate of alongshore sediment transport at the beach; mainly due to the beach orientation (see Section 2.3.1). This sediment moves downdrift (east), supplying a feed to the next (older) nearshore ridge, allowing it to maintain its presence.

The inferred rate of alongshore transport can therefore be estimated by multiplying the onshore supply rate by the alongshore length. Several length scales may be relevant:

- Splash Point provides a disconnection between the updrift ridge and the beach, and therefore the nominal length scale is between 350-700m (considered to the beach access ramp or outfall). To develop stability, an average annual transport rate of 20,000-33,000 m^3/yr would balance the onshore supply;
- Along Rhyl and East Rhyl, typical ridge lengths are between 1.0-1.4km in length. Using the estimated rates of onshore supply, an alongshore transport rate of 29,000-53,000 m^3/yr would develop a balance;
- Gronant has longer ridges of between 2.0-3.0km in length, which suggest a 54,000-80,000 m^3/yr average annual alongshore transport rate for a nearshore balance.

The capacity for alongshore transport is affected by the active beach face. Consequently, along East Rhyl, the comparatively low beach level (approximately 2.5mAOD) is a result of the low sediment supply rate. The construction of a higher beach, say through recharge, will consequently result in enhanced alongshore sediment transport.

The effect of the Prestatyn groyne field is to modify both the onshore and alongshore transport pathways. A reduced rate of alongshore transport is apparent, based on the elevation of the ridges, although the link between features across individual groynes implies that a net eastward transport continues to occur.

2.3.1 Influence of Beach Grade and Shore Aspect

The beach gradient influences the sediment dynamics by affecting the type of wave breaking that occurs. For flatter gradients, wave breaking is increasingly 'spilling', which typically results in enhanced onshore sediment transport. For the entirety of the Rhyl-Gronant coast, the moderate height and low period wave conditions, combined with relatively flat beach grades, indicate that spilling waves occur almost exclusively. This attribute is significant to provide mainly onshore ridge migration (which is more like spit behaviour), rather than the oscillatory cross-shore storm bar movement that occurs on beaches which can shift between spilling and plunging breaking waves.

Shore and ridge alignment have a substantial role in the potential for sediment dynamics along the Rhyl-Prestatyn coast. The relative rate of wave-driven alongshore transport can be estimated as a function of the difference between the incoming wave angle and a line normal to the shore, with the peak transport occurring when this difference is approximately 45^o. The importance of this parameter is demonstrated in the CERC bulk alongshore transport formula, which expresses transport solely as a function of wave height and wave direction relative to the shore. More complex formulae, such as the Kamphuis (1991) formula, also account for other parameters, including sediment size and nearshore bed grade, with effective alongshore length important on groyne-partitioned sections. As discussed in Section 4.4, application of these extra parameters based on geomorphic characteristics at Rhyl generally results in decreasing estimates of alongshore sediment transport.

On the Rhyl coast, prevailing (most common) and predominant (largest) wave conditions are principally from the northwest, which provides a high angle of wave to the shore. The Simulating WAves Nearshore (SWAN) spectral wave model has been used to develop a nearshore wave transformation matrix, which has been applied to hindcast offshore conditions to estimate the nearshore wave conditions (Figure 2-9).

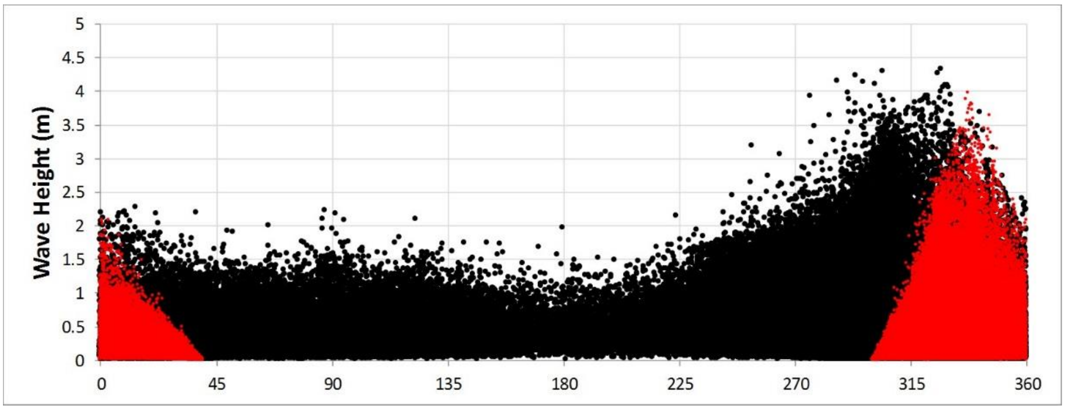


Figure 2-9: Hindcast Offshore and Transformed Nearshore Wave Height

The inshore wave conditions have been used to estimate the role of shore aspect on alongshore transport potential, based on the non-dimensional effects of wave height and direction included in the CERC and Kamphuis formulae (Figure 2-10). A key outcome of this analysis is that shore alignment supports net eastward sediment transport, whilst the ridge alignment supports negligible net transport. This provides a mechanism for higher coastal stability than suggested by the wave climate alone.

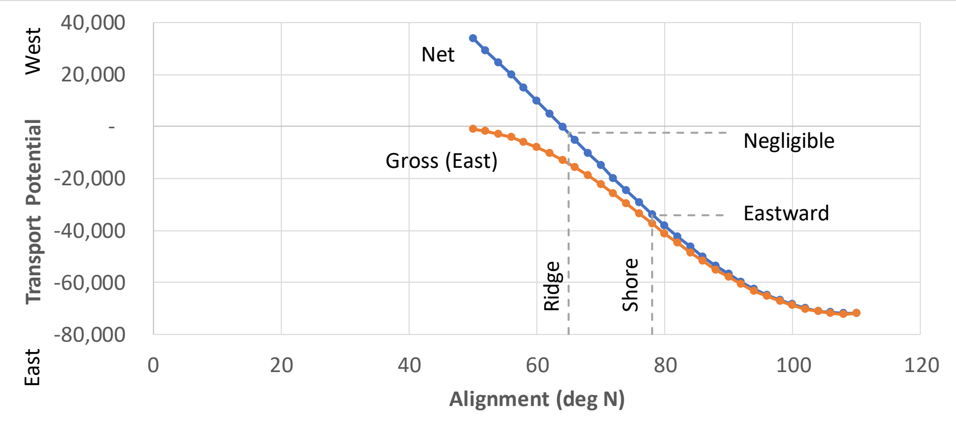


Figure 2-10: Derived Non-Dimensional Transport Potential

2.3.2 Regional Coastal Processes

Regional variations of coastal process characteristics typically influencing alongshore sediment transport (Figure 2-11), along with the derived rates on onshore sediment transport, provides a basis for a conceptual model for sediment dynamics between Rhyl and Gronant.

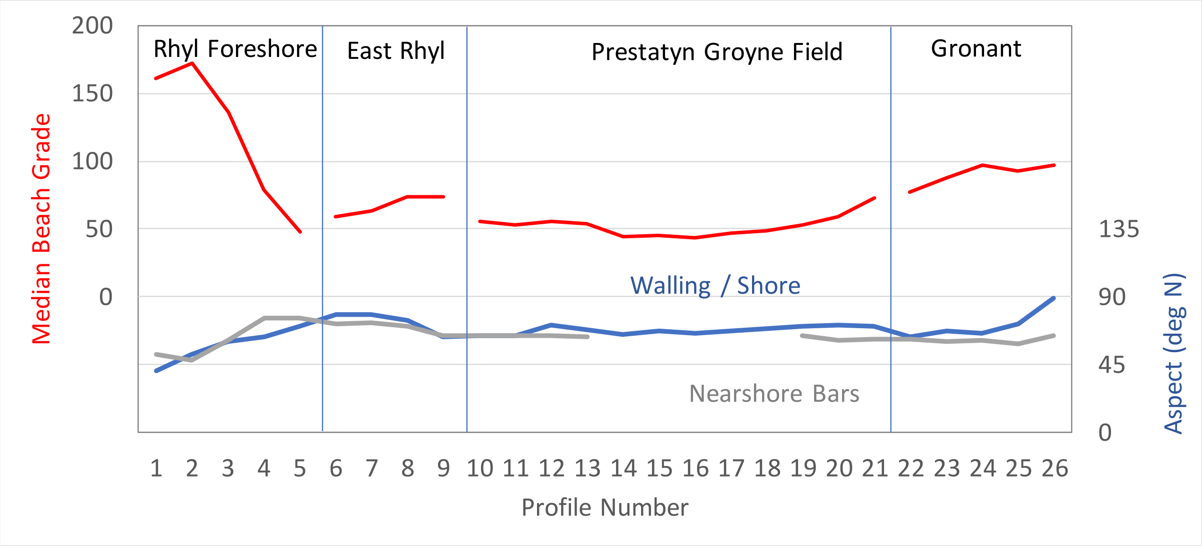


Figure 2-11: Variation of Profile Grade and Shore Aspect from Rhyl to Gronant

Four sections of coast are apparent. The comparative coastal stability since 2002 suggests that the various mechanisms for sediment transport provide an approximate balance:

- At the mouth of the Clwyd, tidal hydrodynamics cause distribution of sediment across the nearshore, including shoals extending approximately 1km offshore. The relative alignment of nearshore ridges and nearshore gradient enhance both alongshore and onshore transport potential which offsets the more westerly facing aspect of the shore alignment;
- At East Rhyl, the coastal orientation supports locally enhanced alongshore transport (as simulated using one-line modelling), but this is offset by the alignment of nearshore ridges, which reduces alongshore transport, and the localised high rate of onshore supply;
- Along Prestatyn coast, the groyne field has reduced the onshore sediment supply and truncated the alongshore transport potential;
- The Gronant shore has higher potential for alongshore transport, which is offset by the alignment of nearshore ridges and the nearshore gradient.

The apparent near balance of these sediment transport mechanisms implies continuity of the alongshore transport rate. The mechanisms are also relevant to the effectiveness of coastal management options.

The importance of offsetting mechanisms is important for interpretation of regional-scale modelling. Previous bulk transport modelling using the CERC formula gives a differential transport rate of 256,800 m^3/yr, which would correspond to an approximate erosion rate of 3m/yr across the entirety of the Rhyl-Gronant coast. This behaviour is not supported in modern observations. Additional parameters (beach grade and beach elevation, truncation by seawalls) can be included in conventional 1D alongshore transport models, with the effects of nearshore ridge alignment and onshore sediment supply requiring more complex 2D/3D representation.

3 Modelling approach and options

Modelling performed in this investigation was aimed at quantifying the impact of two design options; one being an offshore breakwater and the other being an upgraded revetment. Model selection and development was considered dependent on option design. Consequently, slightly different modelling methodologies were devised for each option (breakwater or revetment) to appropriately model the processes contributing to the impacts. Both options are proposed to incorporate beach recharge. Impacts of the intervention can be loosely separated into near-field and far-field impacts with all options modifying the sedimentological and geomorphological processes along the shoreline. Numerical modelling included 2D and 3D hydrodynamic modelling, wave transformation modelling and shoreline 1-line modelling. These are each reliant upon different conceptual models for sediment dynamics.

Three options were proposed to mitigate the current overtopping risk at Splash Point:

- Option 4: Offshore breakwater with capital and recharge nourishment regime. Three different breakwater positions were considered;
- Option 5a: Increased revetment height at Splash Point with capital and annual recharge regime;
- Option 5b: Increased revetment height at Splash Point with capital and annual recharge regime and placement of groynes to restrict the alongshore loss of sediment;

Further details of the options and their modelling approaches are outlined below.

3.1.1 Option 4: Offshore breakwater option

Underlying the breakwater option is the nourishment and maintenance of a sand salient in the area sheltered from waves (shadow zone behind the breakwater). This sheltering of a significant section of shoreline will modify the cross-shore and long-shore sediment transport in the nearfield. The 3D modelling performed is only considered applicable to assess the nearfield impacts in sufficient detail and not at the scale required to assess the far-field impacts of the breakwater due to predicted domain size and the requirement for 3D vertical layering. Therefore, the nearfield impacts were modelled in Delft3D and supported by a conceptual model of breakwater bypassing. This uses the concept of the salient as a sediment store, supplied by the reduction in longshore sediment transport in the nearshore. The salient will release sediment downdrift, via longshore transport, under specific conditions, and in response to fluctuations in the wave climate. The conceptual modelling undertaken assumed the maintenance of the salient feature (i.e. preventing closure), thereby, allowing sediment transport around its apex through hydrodynamic processes. In the event of tombolo formation (closing the gap between the shore and the breakwater), transport in the lee of the breakwater will break down, greatly reducing downdrift sediment supply.

The breakwater option was considered to be more complex than the revetment option, due to the more extensive modification of the cross shore and shoreline process. The lack of similar constructions along the North Wales shoreline meant that a case studies were not available for concept comparison. To facilitate indicative breakwater design, three potential breakwater positions were modelled at various locations relative to Splash Point (Figure 3.1). The western extent of schemes 2 and 3 were schematised to give greater sheltering at Splash Point under ambient and extreme wave conditions. These iterations of breakwater design were schematised 75m westward, along the shoreline from Breakwater 1. Breakwater 3 was schematised to investigate the role of distance in the mitigation of salient closure and was anticipated to have a greater distance between salient apex and breakwater midpoint.

Figure 3-1: Modelled breakwater positions

The impact of a breakwater on nearshore wave heights and associated sediment transport is complex and timescale dependent. Modelling software that reliably predicts salient formation behind a breakwater and associated sediment dynamics is not presently available, with most such facilities derived from empirical design methods (Hsu & Silvester 1990). The complexity is further compounded by the curvature of the coast behind the breakwater and the high angle of prevailing incoming waves. Outputs of the numerical modelling were therefore considered in the context of the model uncertainty.

Modelling representation

The breakwater option was identified to be a significant modification of shoreline processes, dynamically changing the processes of the nearshore. This complexity was not easily modelled for long term processes in Delft3D (due to limited diffraction processes and poor nearshore process validation data) and Unibest was considered too simplistic to represent modelling. Subsequently, whilst being modelled in Delft3D, an extensive conceptual modelling was constructed to identify the optimum position of the breakwater but also, it's impact on nearshore processes

For this option, it is expected that nearshore wave heights will be reduced along a large section of the shoreline, Figure 3-2, reducing the longshore transport rate significantly in the lee of the breakwater. This decline in nearshore wave height will simulate aggradation. It is expected that if undisturbed and under constant wave duration and sediment supply, a salient formation would form behind the breakwater responding to the drop-in wave activity. Once fully, formed this geomorphic feature will facilitate a reduced longshore transport rate in the nearshore as easterly waves cause erosion and the longshore transport of sediment from the salient.

Figure 3-2: Sheltering of the shoreline under average ambient wave conditions

Transport along the cross section offshore from the breakwater is estimated to be largely unchanged between present day and post construction, although the beach is likely to change in response to ambient wave conditions this assumption is conservative as it produces a low estimate of sediments bypassing the structure (Q1).

As sediment is eroded from the downdrift (eastern) side of the salient it will be replenished by the transport of sediment from the updrift side of the salient by longshore and hydrodynamic processes, through the gap between the breakwater and salient apex. This transport is expected to be maintained by the processes outlined in Figure 3.3.

Including;

- The longshore transport of ambient, high angle waves causing the continued longshore migration of sediments around the tip of the Salient (Q2)
- supplemented by the hydrodynamic transport (Q3) of sediment between the salient headland and the breakwater. These hydrodynamic flows are expected to assist in the maintenance of equilibrium between up-drift and down-drift sections of the salient.
- Both mechanisms (Q2 and Q3) are expected to offset the sediment deficit introduced by the reduction in longshore sediment transport (Q4) caused by the construction of the breakwater the remaining sediment in the nearshore is expected to be met by artificial nourishment or sediment recycling, maintaining the current sediment supply to areas down-drift.

It is expected that the sum of Q1, Q2 and Q3 will be less than the existing longshore sediment transport rate at DCC06 and so, the sediment deficit downdrift is expected to be required to maintain the nearfield sediment supply to coastal features down drift and particularly the beach and dune systems between Prestatyn and Point of Ayr. The modelling undertaken herein has been undertaken to accurately identify the longshore sediment deficit induced by breakwater construction and the associated decline in longshore sediment transport in the lee of the intervention.

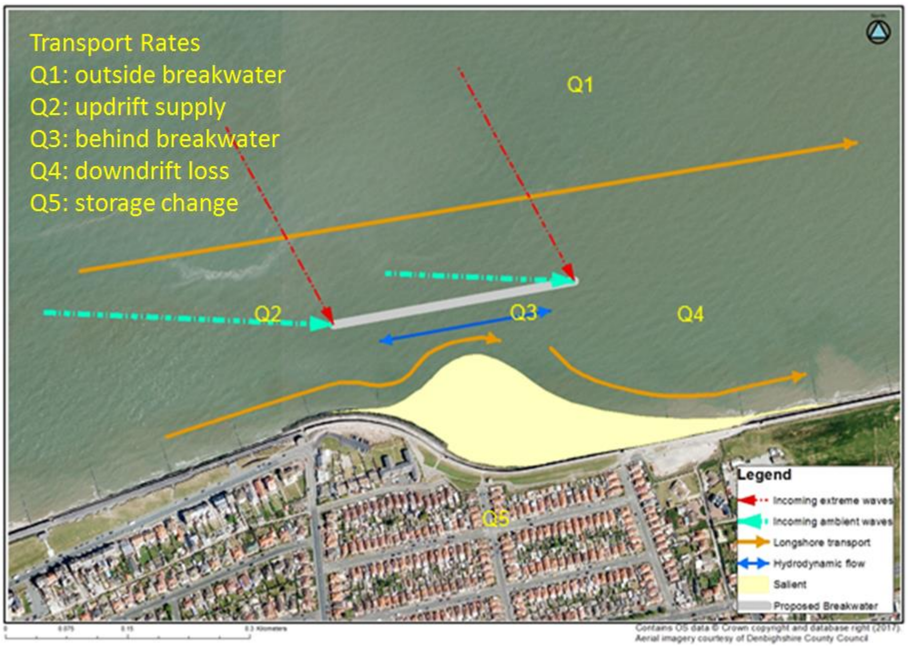


Figure 3-3: Conceptual model of salient bypassing and approximate salient extent

It is important to note that due to the oblique nature of the ambient wave conditions (Figure 3-4), transport modelling performed may not adequately represent shoreline transport due to "high angle wave instability" (HWAI) present in the models (Ashton & Murray 2006). Longshore sediment transport models are set up to cope with waves originating from approximately shore normal positions (as with most of the wave directions along this shoreline. Subsequently waves approaching the shoreline at an angle oblique to the shoreline orientation are subject to "anti-diffusional instability" decreasing the validity of longshore transport estimates and adding increasing uncertainty in transport

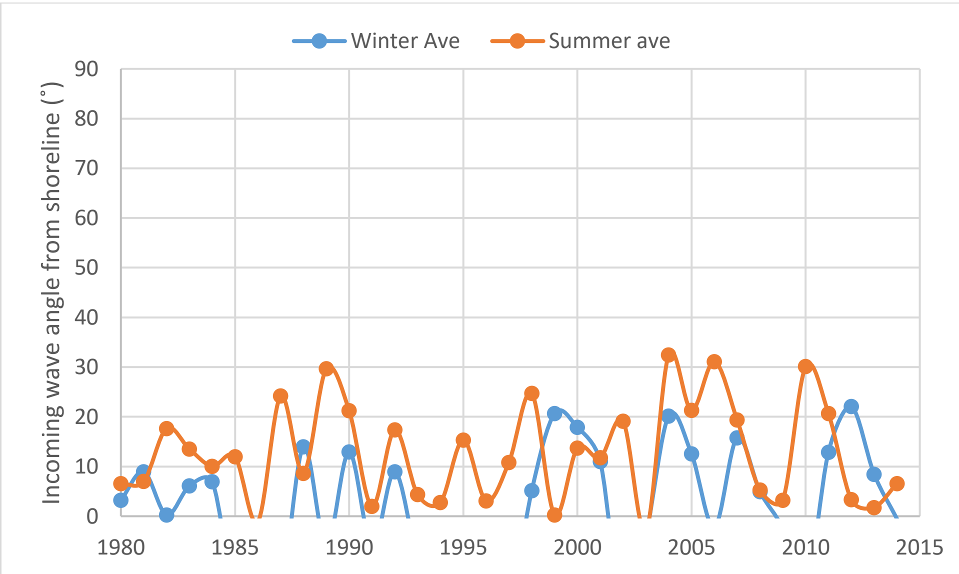


Figure 3-4: Seasonal average offshore wave angle to Rhyl Shoreline

3.1.2 Option 5a: Revetment option

The proposed revetment upgrade is considered unlikely (on its own) to have significant impact on the existing beach processes downdrift of Splash Point. Although the structure will affect wave breaking along its length, it is not anticipated that this will have a noticeable impact on longshore transport in the near-field/far-field. However, the large volume of beach recharge required to provide sustained public amenity (>50-100,000m^3) is considered likely to have a significant impact on the down drift shoreline, with uncontrolled sediment released downdrift (eastward). To assess the erosion and dispersal of this sediment, and estimate the annual rate of nourishment required, it was necessary to represent the processes in a 3D hydrodynamic numerical model, with the highest definition in the nearshore.

As the mitigation of flood risk is not contingent upon the presence of a beach, the objective to provide sustained beach amenity was not considered essential to the design of defence options. A smaller quantity (20,000m^3) of capital beach recharge was considered for costing (Figure 3-5). 20,000m^3 was identified as a value for nourishment as it allowed a sufficient frontage that would facility maximum spacing between nourishment exercises, given contemporary sediment trends at Splash Point.

Modelling approach

Minimal modification of shoreline processes is anticipated to be induced by the intervention in the form of an improved revetments feature, whilst this feature was included in model development, its impact was anticipated to be minimal and refined to the immediate vicinity of the development. Of primary concern to modelling was the accompanying artificial nourishment along the frontage to improve amenity value and maintain existing local conditions. This additional sediment is predicted to significantly perturb the existing sediment regime, both at this location and along the coastline and requires additional modelling. It was identified that the nearshore impact of this sediment could be sufficiently modelled within 3D hydrodynamic software.

Nourishment to the frontage at Splash Point was modelled to have the same properties as the sediment already positioned on Splash Point (D50 and specific density). The nourishment region was estimated to uplift an area of 20,000m^3 directly fronting the revetment which was proposed to extend from the existing wall.

In the farfield, beyond Prestatyn, the impacts could not be reliably identified due to the small schematised increase in longshore sediment transport rates (2-4,000m^3/yr) and the presence of the remaining groyne field including fish-tail groynes. It was anticipated that this longshore transport volume would be of sufficient volume to be dissipated within the groyne field and well within the error of longshore transport rates for this section of coastline (50-75,000m^3/yr).

Figure 3-5: Modelled revetment and nourishment area (20,000m^2)

3.1.3 Option 5b: Revetment and groyne option

The revetment option was considered likely to lose sediment rapidly as longshore currents act upon it, dispersing nourished sediments rapidly along the beach face (mainly eastward). To mitigate this loss a set of four groynes were devised to assist in the retention of sediments in front of the revetment. These groynes were of varying length (Figure 3-6) and designed to allow greatest retention to the west of the intervention. This intervention was devised to reduce the annual replenishment requirements of the intervention and aimed at the reduction of costs.

Modelling representation

The cross-shore groynes were included in the modelling at appropriate length to ensure an accurate representation of the intervention

Figure 3-6: Modelled revetment and nourishment area with cross shore groynes (length denoted in meters)

4 Model development

4.1 Conceptual approach

Sediment movement in the nearshore is typically distinguished in orthogonal directions of cross-shore (perpendicular to the shoreline) and longshore (parallel to the shoreline). Longshore transport is predominantly governed by the incoming wave directional component, causing oblique wave run up, stimulating transport via a 'saw tooth' swash-backwash regime. This allows the even distribution of sediments along the shoreline and the horizontal redistribution of sediments along the shoreline. Cross-shore transport is governed by incoming wave height and so is associated with 'Cut and Fill' cycles associated with storm and benign wave conditions. Both mechanisms are considered to influence contemporary erosion along the shoreline here, albeit at different timescales.

Intervention in the contemporary coastal system will perturb the cross-shore transport of sediments in the near field and far field by interrupting and modifying the cross-shore and longshore processes. The upgraded revetment and nourishment option will result in larger volumes of sediment becoming available for longshore transport, and so significantly modifying the capacity for longshore transport in the area. Conversely, the Breakwater and salient option is expected to reduce longshore transport volumes and make them episodic by intercepting waves and modifying sediment interaction between the upper and lower inter-tidal sections of the beach face. Both interventions will have a measurable impact to longshore and cross shore processes.

4.2 Hydrodynamic modelling

To identify the potential impact of intervention on hydrodynamic flows in the nearfield area a suite of two nested Delft3D (Delft3D) models was created to allow an accurate representation of the hydrodynamic processes within the area surrounding the intervention. A 2D model was constructed to provide accurate boundary conditions for a higher resolution 3D model near the development. The 3D modelling was deemed necessary due to the horizontal shear in the water column resulting from wave breaking.

4.2.1 2D hydrodynamic modelling

The 2D (depth averaged) Delft3D hydrodynamic and morphology model was constructed to derive accurate nearshore conditions at the Rhyl; and to be subsequently used as boundary conditions for the higher resolution modelling near Splash Point. The grid cell sizes used in this larger model ranged from 75x75m at the boundary of the smaller nested Delft3D model to 150x150m at the north-western boundary. In total, the model contained 71,689 grid cells with the higher definition located within the nearshore region between Colwyn Bay and Point of Ayr.

The northern boundary of the larger model was divided into three sections. Each boundary section was forced with astronomic predictions containing 14 constituents from the TPX0 7.2 Global Inverse Tide Model and coupled as a “set”. The coastline features of the Point of Ayr and Great Ormes Head were identified as important boundaries and control features for hydrodynamic processes along this shoreline and were considered appropriate. Eastern and western boundaries were set to passive Neumann boundaries (applying a zero water surface gradient between offshore boundary and the shoreline) .

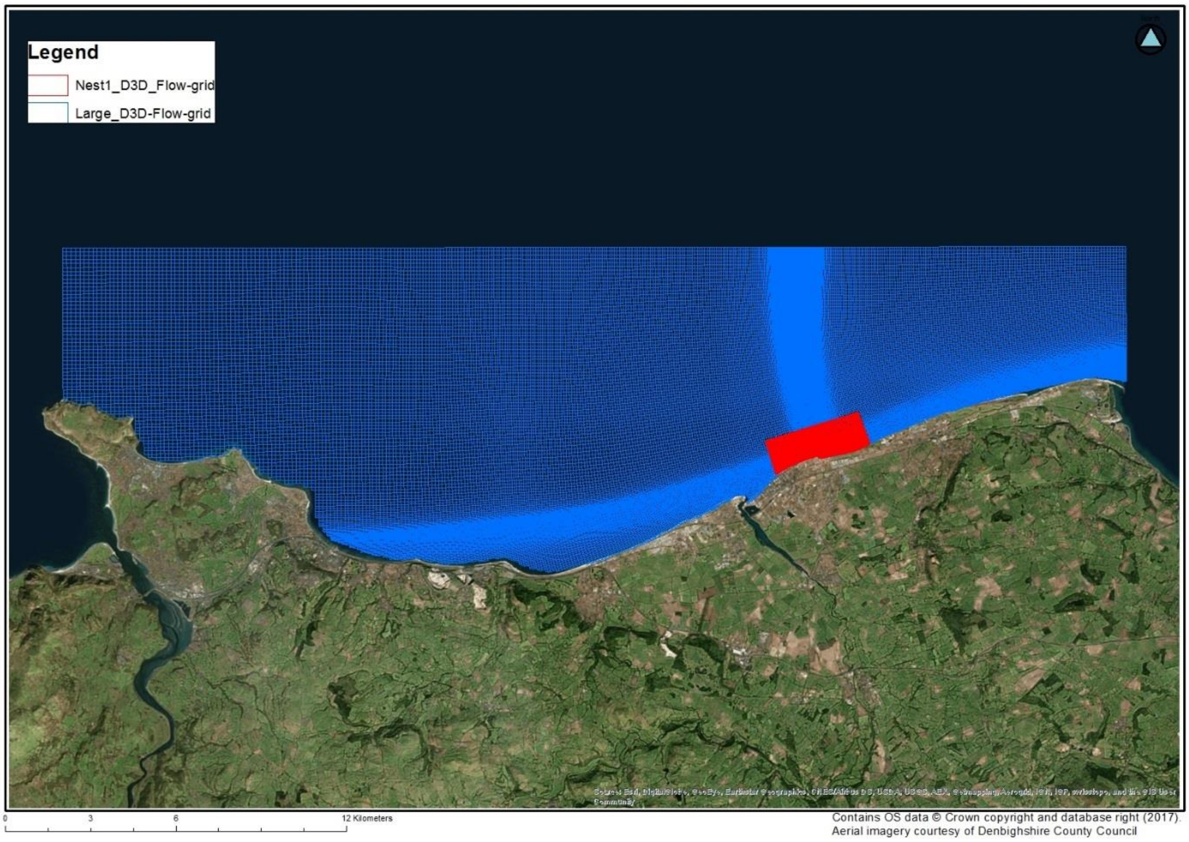


Figure 4-1: Large Delft3D model grid with nested grid (red box). From Great Ormes Head (west) to Point of Ayr (east)

4.2.1.1 Wave conditions

For shoreline modelling the larger Delft3D model was used to transform schematised annual wave conditions from the Met Office's hindcast wave model WaveWatch III (Point Id:1440) to the nearshore. These transformed waves were used to derive the longshore sediment transport patterns in the nearshore. It should be noted that due to the extent of the model boundary the significant have heights (Hs), wave periods (Ts) and wave directions for the schematised inputs were input directly into the UNIBEST longshore transport calculations for all cross sections, except DCC26. This section was located within the model shadow zone from the eastern boundary and so wave heights and directions were not appropriate. Wave conditions from the toe of DCC25 were therefore used in modelling.

4.2.2 3D hydrodynamic modelling

4.2.2.1 Boundary hydrodynamics

The 2D, depth averaged modelling approach calculates the net sediment transport within a cell. This approach is not applicable where significant directional shear is experienced within the water column. Subsequently, an additional Delft3D hydrodynamic model was constructed to allow higher grid resolution within the area of interest. The model grid contained 13,203 lateral grid cells incorporated into an area of 4.25km^2, and extending 1.25km offshore from Splash Point (Figure 4.2). The grid cells were aligned with the possible breakwater aspects and had a grid resolution of approximately 5x6m. The model was nested within the larger 2D model, with the boundary conditions extracted for a 28-day simulation period and applied across six boundary segments along the 3.5km northern extent of the model. The east and west boundaries were set as Neumann boundaries with zero gradient, ensuring water levels were extrapolated to the nearshore.

The adopted 3D grid resolution also allows the accurate representation of wave breaking, and the associated return currents within the model; and there impacts on sediment transport within the nearshore and near the breakwater. To ensure modelling efficiencies, five grid layers were integrated into the model domain. These layers were not spread evenly throughout the water column, but with thinner layers being located at the base and top of the profile to better represent current and wave interactions at the bed and sea surface. The model calculations were performed for 66,015 grid cells within the model grid at 3 second intervals for a period of 31 days (3 days spin-up and 28 days of simulation). With Morfac (morphological accretion factor, multiplying morphology change to accelerate landform change within modelling) this was extrapolated to simulate a period of 403 days.

Figure 4-2: Delft3D nested model grid

4.2.2.2 Boundary wave conditions

The Influence of incoming waves was deemed to be of great importance to the establishment, and maintenance, of a salient behind the breakwater, and in the longshore shoreline transport of sediments. Therefore, the wave climate was schematised to be representative of 1 year of ambient conditions. The wave data was analysed and grouped (binned) into 20 degree directional sectors. The average Hs, Tp and direction of these conditions, as well as their average annual duration was collected from the offshore Wavewatch III (WWIII) data. These average annual conditions were then redefined to remove the offshore wave directions (as these will have minimal impact on longshore currents and salient development) and randomised to be input into Delft3D wave module (D-WAVE) over the 28-day period at 60 minute intervals. This methodology allowed for the appropriate representation of the schematised wave climate to represent annual conditions, yielding indicative, annual, onshore sediment transport currents. This schematisation of the wave climate also allowed the application of the morphological accretion factor for morphology change in Delft3D, giving an appropriate representation of salient development under a schematised hydrodynamic climate.

The sediment characteristics used in the model represented the average (D50) particle sizes (262µm) identified during the sediment sampling (undertaken by Partrac (2017). This was modelled as a non-cohesive sediment within the domain. The sediment sampling identified a small percentage of cohesive sediments within the particle size distribution, particularly within samples obtained close to the mouth of the Afon Clwyd (Figure 4-3). Cohesive sediments were not included within the modelling due to their scarcity in the sediments of the intertidal beach, and their negligible role in longshore sediment transport and the dominance of sandy sediments at the study site.

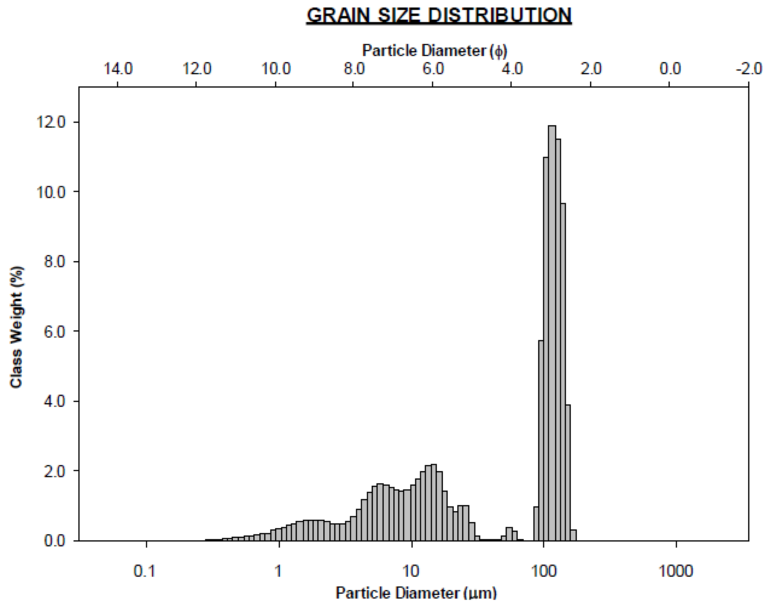


Figure 4-3: Grain size distribution at site 5_c1, taken beyond the surf zone, at the mouth of the Afon Clwyd

The morphology module of the Delft3D computations was configured to have a spin up period of 4320 minutes (3 days) with another 28 days of simulation time with morphological updating active. The morphological bed changes at each timestep were then extrapolated using a morphological accretion factor of 13.036 to extrapolate the 28 day simulation period and facilitate the simulation of a year of sediment processes post breakwater implementation.

4.2.3 Boundary Conditions

In a coastal morphology and hydrodynamic model, the boundary conditions are considered of vital importance. In this instance the boundary conditions were derived from depth averaged, off-line coupling of a larger scale Delft3D model, in 2D depth-averaged mode. This offline coupling insured greater numerical stability within the smaller domain, as well as reducing the computational processing required to represent large domains at high resolution. It also provides a more accurate definition of boundary conditions, due to the high model grid resolution for nested grids than astronomic predictions or larger scale national models (POLTIPS-3, 2017). Offline coupling of data also allows quicker run times and easy attribution of accurate Dirichlet boundary conditions.

This model setup was then used to generate a representative 672 hour time series of wave data over the domain, allowing appropriate representation within the 28 day hydrodynamic simulation. A representative hourly record for the hindcast period was thus created. This record was randomised to minimise the impact of ordering/ seasonality and input into the Delft3D model, coupling at 1 hour intervals, directional spreading was set to a constant value of 4˚.

4.2.4 Boundary allocation

As the boundary conditions were derived for the 3D model, there was little influence of boundary condition allocation. The offshore boundary was run as a single boundary and split into six segments, each driven by the 2D model output. It was found that for iterations with multiple boundary conditions the model stability decreased, and the run times increased.

4.3 Parameter selection and model sensitivity

Throughout the modelling process various other modelling assumptions were made. Although multiple calibration values are available within the Delft3D software (including calibration parameters, discussed in section 4.3.2), the three main parameters that were assessed to investigate model sensitivity were:

- The computational time step (varied between 1.8 and 3 second)
- The number of vertical layers (number of vertical layers doubled)
- The morphological Accretion Factor (model run for longer with half MorFac factor, 6.57)

The output of these sensitivity tests along a northerly cross section can be seen in Figure 4-4 and shows small variations in bed elevation for variations in the model timestep, (average deviation of 0.0002m) and so it was concluded that the model was not sensitive to changes in model timesteps. The model was however found to be sensitive to the vertical layering of the domain, with a max deviation of 0.1m noted. This deviation was particularly evident in the nearshore where the stratification of flow is larger with greater shear in the water column. This doubling of vertical layering greatly increased model run times and doubled the computations required at each timestep. Given that the average deviation observed in bed level change from a baseline condition in this cross section was +0.5mm, it was considered appropriate to maintain 5 vertical layers for modelling.

The sensitivity testing of the MorFac parameter produced significant deviation in modelled bed level producing a max deviation of -0.42m. This deviation however cannot solely be attributed to variation in MorFac. The sensitivity test for MorFac required additional simulation time to the baseline conditions and as a result was exposed to a varying wave regime. This regime included an additional two high energy wave events that caused incision of the beach face (at chainages 120m and 310m, as can be seen in Figure 4-4). Although the selection of the MorFac factor causes significant deviation in modelled bed level, is use was deemed appropriate to simulate annual conditions and assess the impact of the options presented.

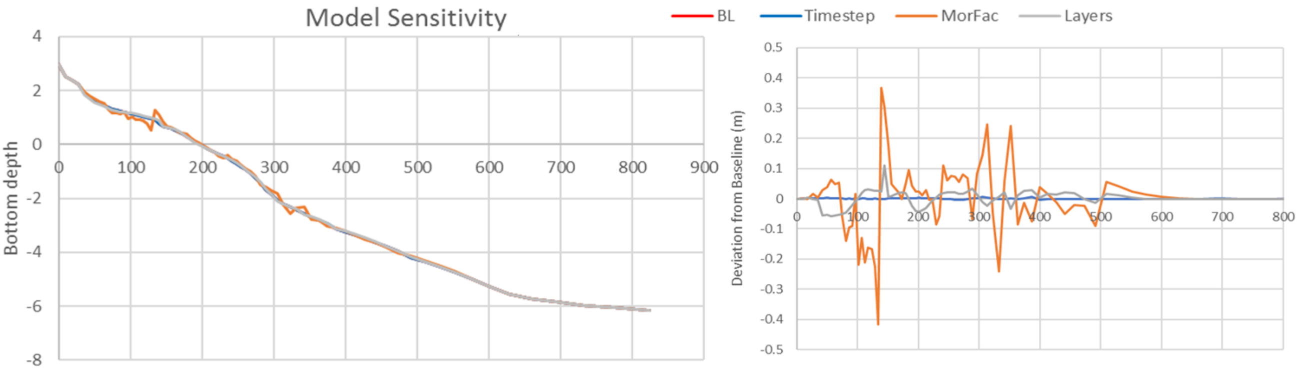


Figure 4-4: Model sensitivity to parameter selection along a cross section

4.3.1 Model sensitivity

The sensitivity of the 3D model to experimenter calibration parameter selection. Assumptions made in the selection of these parameters was assessed with model variations in the wave parameters (diffraction & non-linear wave interaction), boundary allocation, timestep (hydrodynamic), vertical layering, and MorFac. This was to identify the impact of experimenter selection and the limitations of the modelling software on model outputs.

4.3.1.1 Wave parameters (Diffraction & Non-linear wave interaction)

The inclusion of advanced wave transformation features (Diffraction and Tirads) within the D-Wave module greatly decreased the stability of the modelling. Increasing the risk of non-convergence, particularly for options with breakwaters present within the model domain. These functionalities were excluded from all model runs due to the instability they induced within the computations performed. This action provides implications for the modelling of the options, particularly the breakwater options. As these rely on the diffraction of incoming waves at the breakwater apex (Figure 4-5) to assist in the throughput of sediments at the salient, thereby reducing the ability of the model to simulate salient dynamics efficiently. This selection was however considered appropriate, as it allowed the model to run and simulate the impact of intervention in the area surrounding the breakwater.

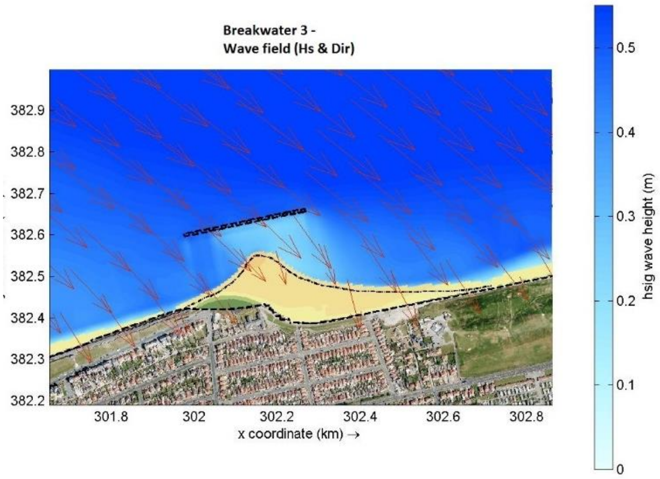


Figure 4-5: Impact of no diffraction on wave vectors behind breakwater. Variation in wave vector is attributed to wave refraction

4.3.2 Model validation

The 2D Delft3D model was found to calibrate well with water level records within Rhyl Harbour (Figure 4-6). The model was found to have a low RMSE score for water levels during a 28-day period from August 2011 to September 2011 (two spring-neap cycles), with a spin up period of 4 days. This period was selected due to the negligible surge observed (on average the residual over this period was 0.026m / 26mm). The comparison of modelled and gauged water levels show a bias of 5% and RMSE of 7%, which is considered appropriate for further use in this study.

It should be noted however that as the gauge within the harbour dries out below 2m (MSL). The bathymetry in the model was extruded to -2m at this location to avoid instability associated with cell wetting/drying. Due to the quality of the gauge record however it was not possible to calibrate low tide ranges at this location.

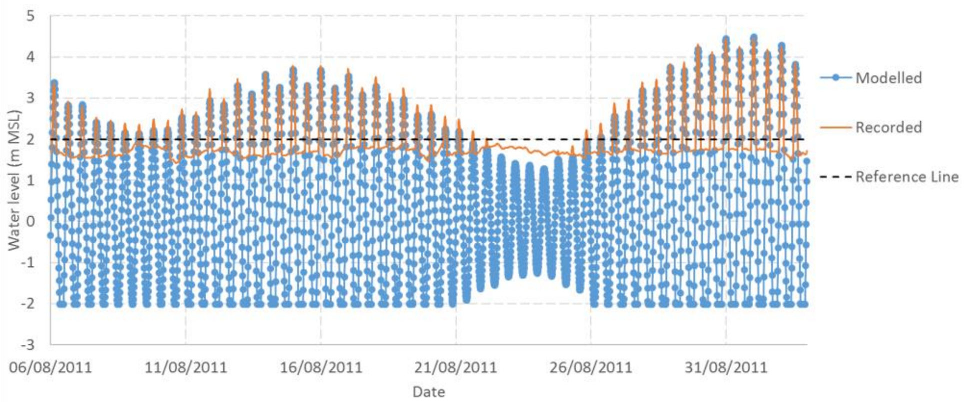


Figure 4-6: Model validation of 2D Delft3D model at Rhyl Harbour

4.3.2.1 Nearshore sediment transport

When modelling shoreline processes in 2D with waves active, the Delft3D model simulates constant onshore sediment transport, as no wave return or undertow is represented within the model. The model output was interrogated, and the model was found to represent the return flows of surging waves, thus allowing a more accurate representation of nearshore wave processes. The impact of shadowing was also assessed by interrogating the maximum bed shear stress outputs. These show high levels of bed shear stress in shallow areas, as can be seen in Figure 4-7. This figure also shows the functionality of the “obstacles” (SWAN model) and “Dry points” (Delft3D model) in denoting the breakwater option in providing reduced bed shear stresses in its lee. These features were thus considered appropriate.

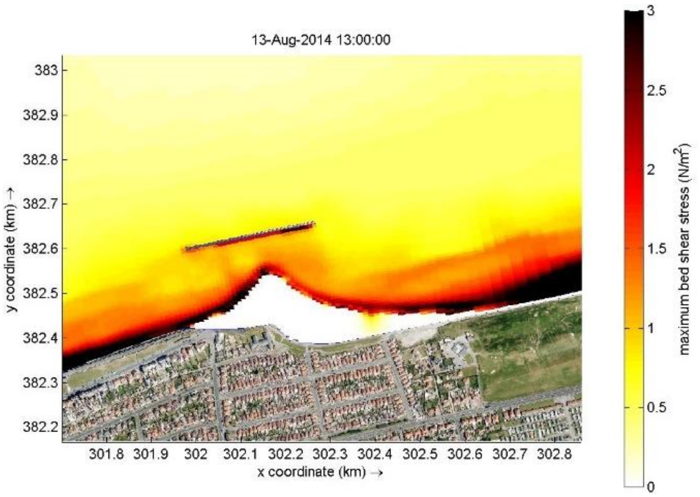


Figure 4-7: Maximum bed shear stress for full tide north westerly wave event for Breakwater option 3

4.3.2.2 *Hydrodynamic-wave interaction*

The model hydrodynamics and wave interactions within Delft3D are known to grossly overestimate onshore transport in the nearshore (Grunnet et al 2004) and is known to be poor at cross shore modelling, particularly in 2D but also in 3D (Raton et al 2006). Therefore, the interaction between wave-related suspended and bed load transport was reduced greatly (through an iterative process involving calibration factors) to ensure nearshore processes and the variation in nearshore bars was evident. This was considered more appropriate than the default model values. The derived values used were 0.1 for suspended loads (SusW) and bedload (BedW) and are similar to those in comparable studies.

4.3.3 *Long term morphological trends.*

The available long term sediment data was not considered to be of sufficient resolution (temporal and spatial) to provide either a meaningful insight into sediment trends or to be used for model validation.

Aerial imagery (Figure 4-8) showed that a major geomorphological feature of this coastline is the migration of longshore bars from the nearshore to onshore. This cross-shore movement was found to be emulated within the modelling with longshore bar migration observed in cross-sectional outputs, particularly in the nearshore with the shoreward migration of cross shore bars as sediment was moved around the nearshore. Although the modelled movement was less dynamic than the inferred movement of the beach face (attributed to a lack of phase shift between bathymetry and sediment transport), the model was subsequently considered appropriate to model defensive options along this coast due to its appropriate representation of the shoreline processes at Splash Point.

Figure 4-8: Aerial imagery showing cross shore bars at Splash Point (imagery dated 10/2011, courtesy of Google Earth)

4.3.4 Intervention representation

The salient and breakwater were accurately represented in the Delft3D model through the changing of the appropriate grid cell properties.

The breakwater was represented as a series of “dry points” and so were denoted as inactive grid cells within which no hydrodynamic calculations could be performed. These points are considered to isolate cells either side and so do not permit bathymetry modification (unlike “Thin Dam" representation). This form of representation simulates a breakwater that is not overtopped by hydrodynamic processes as it obstructs interaction between cells on either side of the breakwater. The apex of the salient was calculated and fitted at an appropriate distance from the midpoint of the breakwater (discussed in Section 5.1.2). The surrounding bathymetry was then smoothed to represent a beach slope. The representation of the artificial beach was also included by bathymetry extrusion and slope smoothing was employed to uplift the surrounding beach face.

The revetment option was modelled within the domain by representing the additional rock armouring required as “dry points” (inactive cells) within the domain. The accompanying nourishment was extruded to a level of directly fronting the intervention prior to being smoothed into the surrounding bathymetry. The proposed nourishment extent was represented by extrusion of the bathymetry to a level of 4m(MSL) for an area of 20,000m^2.

4.4 Shoreline modelling

Longshore transport is the primary mechanism for the redistribution of sediments on sheltered coasts. Sediments are washed alongshore as incoming waves entrain sediments and transport these along the incoming wave vector resulting in net sediment transport in the dominant wave direction.

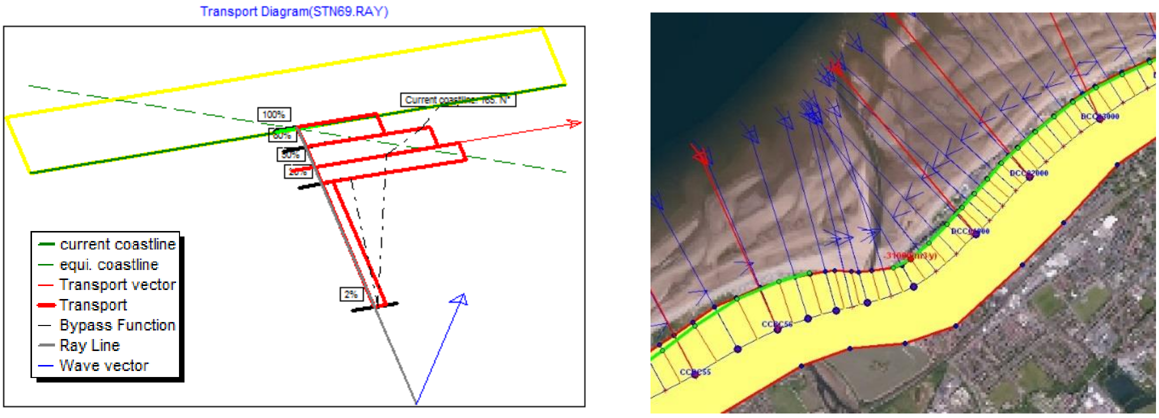


Figure 4-9: Sample Output from UNIBEST LT module (left) and CL module (right)

Longshore transport and shoreline modelling methodologies seek to summarise longshore sediment processes by focusing on the annual conditions and annual trends in sediment movements to derive the net sediment transport. The Unibest CL+ modelling software used in this study requires calculated longshore sediment transport rates at numerous sections along a shoreline, as well as an initial shoreline. The calculated cross sectional longshore transport rates were then extrapolated along the shoreline and adjusted according to variations in coastal aspect to assess the change in shoreline position. Particular interest to this study is the modification of the near-field longshore transport rate near the proposed breakwater and the impact of this modification along the shoreline.

4.4.1 Longshore transport modelling

The longshore transport in the nearshore was calculated at 38 cross sections along the shoreline, from Llanddulas to Prestatyn drain. These cross sections were integrated into longshore transport calculations and 1-line modelling undertaken in Unibest, (Figure 4-9). As these cross-sections were derived using low tide topographic survey it was necessary to extrapolate the profiles to the depth of closure using the measured gradient between MLW and MWL. The cross sections were truncated at the defence toes, or at the dune crest where applicable. Sediment sampling conducted along the shoreline indicated an average measured d50 of 263µm and d90 of 479µm. Therefore, the Van Rijn (1992) formula for longshore transport rates was used, as this computation was successfully calibrated against grain sizes of between 200 and 1000µm and does not integrate flows in computations. The methodology incorporates transformed waves and long-term sediment transport rates, removing assumptions, reducing uncertainty, and refining estimates of annual rates. Annualised wave data was used to compute the average net sediment transport of sediments, discussed in Section 4.2.2.2.

4.4.1.1 Unibest boundary conditions

Prior to modelling, an assessment was undertaken to identify the characteristics of the sediment along the beach as well as the governing wave climate impacting the longshore movement of sediments. The offshore wave climate was obtained from the WaveWatch III (WWIII) forecast location and found to be highly asymmetric, with a high proportion of incoming waves originating from the north-west with an average Hs of 0.58m. The depth of closure (depth below which limited wave interaction occurs with the bed) was defined using Hallermeier (1980) and referenced to the MHWS level. The depth of closure for offshore waves was calculated as -7.92mAOD, as identified from the equation below. This was deemed to be the terminus of the active portion of the beach, in which longshore transport occurs. The upper boundary for this active zone was identified at MHWS.

$$h_c = 2.28\,H_e - 68.5\left(\frac{{H_e}^2}{gT^2}\right)$$

Where:

H_e = significant wave height exceeded 12 hours per year

T = corresponding wave period

This depth subsequently identifies the deep-water boundary for the model domain with negligible interactions occurring in water depths greater than 7.92mAOD.

To derive these annual conditions the 33 year hindcast WWIII offshore wave record was simplified into 132 bins based on H_s (0.5m intervals), direction (20° intervals) and the duration that offshore conditions satisfied each category over the hindcast period. The offshore wave boundary conditions will therefore be provided by WWIII point 1440, as this is deemed most representative for the predominant wave direction (north east).

The procedure for annualising the wave climate using this method can be summarised in the following steps:

1. Divide WWIII data into 0.5m H_s and 20° bins;
2. Determine the number of days per year each bin occurs;
3. Estimate corresponding T_p and wind speed from empirical relationships;
4. Generate annualised climate for D-Wave input.

These simplified offshore wave conditions were then transformed to the nearshore toe of surveyed cross sections using the D-Wave module within the Delft3D hydrodynamic model (discussed in Section 4.5). This wave modelling software relies on SWAN, a third-generation wave transformation model to transform waves from the offshore to the nearshore. The outputs from the D-Wave modelling were input into Unibest CL+, a coastline modelling package consisting of a longshore transport module. The net longshore transport as well and the one-line model module (coastline module) were used to simulate shoreline change corresponding to calculated longshore transport rates.

The D-Wave model output locations for the annualised climate were set to correspond with the offshore extents defined in the UNIBEST model. All output locations were in water depths of approximately 5-10m. To account for variations in water level along the shoreline, the spring tidal range was divided by 6 and the occurrence of each water level identified from a 28-day period.

4.4.1.2 Breakwater intervention impact

To implement the developed breakwater case for each option, the schematisation of cross section DCC06, was edited by the methodology outlined in (Figure 3-3). Q1 was calculated independently to schematise the longshore passage to the north of the breakwater. This proportion of longshore transport was considered unperturbed by the construction of the breakwater. It is accepted that, over time, a more natural cross shore profile will develop as sediment is deposited in front of the breakwater. This will increase longshore transport rates within this section.

It is conceptually understood that sediment passing the apex of the salient will be dispersed over the eastern salient extent through residual action of wind generated reflected/diffracted small waves in the lee of the breakwater. This sediment is subsequently available for longshore transport to the east of the breakwater, driven by waves originating from the west. To identify the magnitude of Q2, the incoming waves at the nearshore section DCC06 were diffracted around the western extent of the breakwater using formulae presented in Kamphuis (2000). The longshore sediment transport was then calculated for an equilibrium profile orientated along the salient to 300 degrees (45 degree from the western extent of the breakwater) within Unibest between MHWS and the depth of closure. This sediment was then assumed to be transported longshore around the tip of the salient apex and distributed along the eastern front.

The longshore transport rate is anticipated to increase eastward from the tip of the salient as shadowing from the breakwater decreases. This shadow zone is expected to extend relatively far downdrift due to the oblique angle of incoming ambient wave conditions.

4.4.1.3 Model sensitivity

The longshore sediment calculations performed herein are sensitive to the selection of modelling variables, particularly as the calculation formula used, the incoming wave direction and its angle to the shore. Table 4-1 shows the sensitivity of calculations to the selection of longshore transport equation. The Van Rijn (1992) equation was used to calculated longshore transport for these equations, as it was more complex than the Bjiker formula and yields a conservative estimate of longshore transport volumes. The CERC bulk equation can be considered a relatively simple formula with no control for sediment grain size or profile shape. Research has also indicated that the CERC approach does not accurately predict longshore rates for grain sizes between 200 and 600 µm and with profile scale parameter of 0.01-0.1. The calculations performed were also identified as highly sensitive to the shoreline aspect, with a 5° variation in shoreline aspect generating a difference in longshore transport rate of approximately 40,000m^3/yr. The majority of shoreline orientations were taken directly from the x/y change in coordinate system derived from cross shore profiling. Following visual inspection however, several sections (including DCC06, Table 4-1) were found to not be perpendicular to current shoreline extents. These were adapted appropriately.

Table 4-1: Unibest sensitivity to formula selection for profile DCC06 at 345˚

Formula	Calculated Qs (m3/year)
Bijker (1962, 1972)	45,190
Van Rijn (1992)	45,190
Van Rijn (1993)	44,180
Van Rijn (2004)	27,470
Soulsby/Van Rijn	2,560
CERC	115,610
Kamphuis (1991)	34,740
Van Rijn (1992) (348˚)	62,640

4.4.2 Coastline modelling

The coastline modelling performed was an extension of the modelling performed above, building on the longshore transport rates at individual cross sections to identify longshore transport along the shoreline. The coastline modelling was undertaken in the CL module of Unibest, a 1-line model that assesses shoreline modification because of longshore transport rates. The model allows the representation of cross shore features such as revetments, groynes, sediment sinks and sources.

Revetments

Revetments were integrated into the model domain. Four stretches of revetments were included within the 1-line model along stretches of significant rock armouring observed from aerial imagery. The position of these interventions along cross sections were identified at the first and last cross section crossing each defence and pinned to this chainage along the coast. These model features act as a wall behind which no shoreline recession can occur. Figure 4-10 shows the occurrence of cross shore revetments integrated into the 1D shoreline model.

Groynes

The groyne interventions along this shoreline were not included in the modelling. This was in part due to the lack of data available on groyne bypassing rates and porosity, but also due to the limited influence of these features on the contemporary shoreline.

Figure 4-10: Revetment placement in shoreline model

Sources and sinks

Only one sediment sink was identified along the coastline; the Afon Cwyd was modelled as a sink to longshore sediments. As sediment moves longshore it is schematised to be drawn into the estuary by flood tide flows. Although some of this sediment is expected to be returned by the ebb tides it is anticipated what a proportion will be lost to the estuary. It is also expected that the Afon Clwyd constitutes a source of fine, fluvial sediments into the model domain, however fluvial silts are considered to have minimal impact on longshore sediments, due to their fine grain size and associated water column retention properties. These properties cannot be modelled effectively in shoreline modelling and so were not incorporated into this study.

Boundary conditions

Boundary conditions were identified at the western and eastern model extents, both of which were set at a constant shore angle. This was considered appropriate given the large distance between the boundaries and the area of interest. The shoreline remains relatively constant beyond the extreme western cross section (CCBC47). To the east, the Point of Ayr is a spit formation and sediment passing eastward beyond this feature will not be returned to the system. A shoreline constant wave regime exiting the domain at this location was subsequently considered appropriate.

Additional features

Several additional features were noted along the model domain, the most common being the groynes which are present from Rhyl to Prestatyn. The modelling of groynes within Unibest is performed by defining groyne length and bypassing percentages.

4.4.2.1 Model validation

1-line modelling is known to be an extremely unstable method of modelling shoreline changes due to changes in shoreline causing divergence and instability in the longshore computations. Particularly during model spin-up, where irregularities in the schematised shoreline are stabilised. Following model spin-up, and the smoothing of the shoreline causes the model is seen to emulate variations in longshore sediment well. However, due to the large amount of uncertainty inherent in shoreline modelling, it was necessary to validate the model against longer term shoreline trends. However, validation of this model against geomorphic features in this region proved difficult given the scarcity of historic data on shoreline migration and the lack of measured longshore transport rates. The primary feature found along the shoreline that facilitates the validation of the model was the change in shoreline aspect at Splash Point.

Historically, this section of shoreline has undergone shoreline recession associated with a terminal defence sediment deficit. Model runs show that when defences are removed to the east of Splash Point, the erosion resumes. The shoreline model also displays a general west to east trend in longshore transport with the acceptation of the shoreline between the mouth of the Afon Cwlyd and the Aquarium. It Is expected that this reversal in longshore transport patterns, contrary to observed patterns, is a result of the non-representation of longshore hydrodynamic currents induced by the outflow of the river channel and tidal flows. This systematic error was eliminated by reducing the angle of the incoming wave climate by 10˚. With this minor adaption, the shoreline model was therefore considered appropriate for use along the shoreline as it accurately simulates shoreline response to variations in the wave climate.

4.5 Profile adjustment to sea level rise

To assess the requirement to increase nourishment to address sea level rises of 1.09m by 2117, the equilibrium profile was estimated using the measured d50 grain size, and the profile extended from MHWS to the depth of closure (DOC, derived by Hallermeier 1980) at the offshore wave location. The shoreline re-adjustment to sea level rise was calculated and the volume required to offset the retreat at the top of the beach was taken to be the required nourishment volume to address climate change on the undefended coastal sections

The concept of the beach equilibrium profile was adapted by Bruun (1962) to derive the shoreline response to a change in forcing. The approach was modified by Hallermeier (1980) to quantify the profile depth of closure estimates as a consequence of a "natural" shoreline adjusting to sea level rise supported by a static store of sediment (such and a dune system). Valid for undefended sections of shoreline, this profile readjustment facilitates the volume required to offset retreat in the upper section of the profile as material is eroded and deposited on the lower sections of the profile (Figure 4-11).

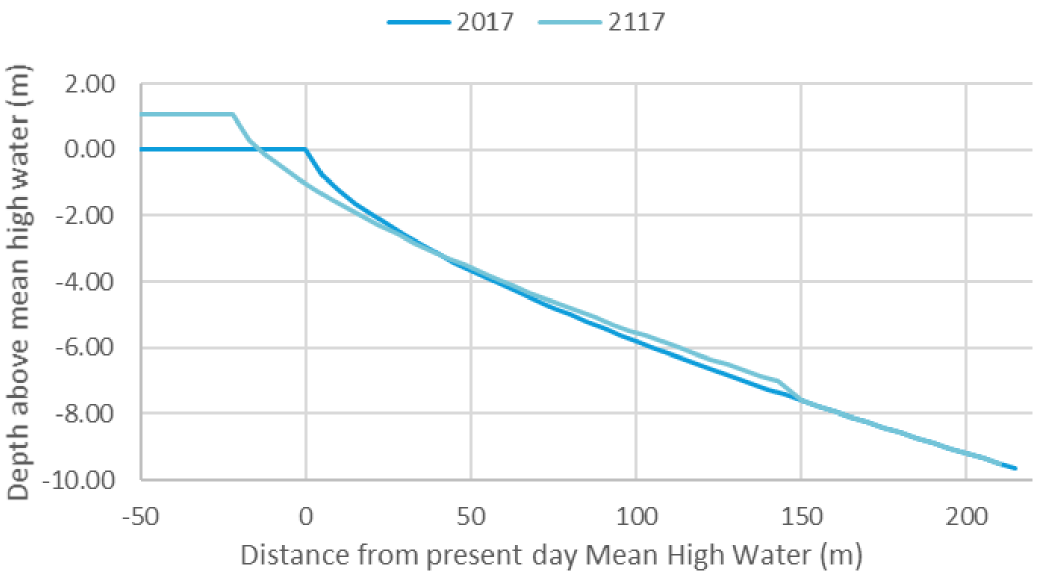


Figure 4-11: Example equilibrium profile re-establishment using the Bruun Rule

Whilst the Bruun rule provides a relatively simplistic method for estimating shoreline recession, and is not without criticism, alternative, more sophisticated methods have only been developed for specific shoreline and are not universally applicable.

This calculation for shoreline readjustment to a rising sea level makes numerous assumptions including the current beach climate (incoming sediment and wave regimes remain constant over the period analysed) and a constant D50 and wave forcing over time. The application of the Bruun rule also relies on the concept of a beach equilibrium which has been disputed by modern research, citing greater influence of incoming wave characteristics and grain characteristics than is incorporated into the mathematical rule. The Bruun rule is considered applicable to the current relatively simplistic study of shoreline response along a relatively active zone between depth of closure and MHWS. The rule doesn't incorporate responses to sea level rise below the depth of closure, including estuarine/ shoreline responses to increases in shoreline. It has been computed to measure the shoreline retreat, representing the consequence of a "natural" shoreline adjusting to sea level rise supported by a static store of sediment (such as a dune system). This analysis does not account for the response of "stabilised" beach sections (defended by rock armour or sheet piling) or breach occurrence.

Despite these constraints, the Bruun rule is considered the standard method used to estimate the volume of sediment required to adjust the shoreline to a rising sea level.

The Bruun Rule for estimating shoreline recession is provided in the relationship below:

$$R = S\frac{W}{h_c + B}$$

where:

R = shoreline recession

W = width of the active profile

S = sea level rise

h_c = depth of closure

B = berm/dune height

The width of the active profile was estimated by using the calculated h_c derived from Hallermeier (1980) and rearranging the equilibrium profile relationship where the scale parameter *A* was determined using the measured D50 for the profile. The length of the active profile for the frontage with modelled using WWIII offshore wave heights and was calculated as 501m. Where direct defences occur along the shoreline, the active profile was truncated at the approximate toe of defences. Therefore, these defences were assumed to be maintained until 2117 with nourishment requirements for the remaining active zone calculated.

Profile re-adjustment to sea level rise was estimated to be constant and independent of the option taken, as nether option (breakwater or increased rock armour defences) will have an impact on the width of the active profile of the beach system. Upon determination of shoreline recession (*R)* from the Brunn Rule for each epoch, the required nourishment volume (per m length of beach) can be estimated from rearranging the rule to form:

$$V = (h_c + B) \times R$$

Dean (1991) makes the distinction in the application of the Bruun rule for “natural” and "modified" beach profiles. With the equilibrium profile truncated at the toe of defences for defended sections. The average elevation of the toe of defended sections along the frontage was 2.19mAOD. To hold the line and maintain current beach profile form a requirement for 545m^3 of beach nourishment was calculated for undefended dune sections and 376m^3 for the average defended section by 2117. The projected nourishment requirements for 5 epochs between 2017 and 2117 with a projected sea level rise of 1.08m (welsh Government, 2016) can be seen in Table 4-2.

Table 4-2: Projected nourishment rates for undefended frontages

	Nourishment Required in each epoch (m^3) per meter of coastline					
	2017-2037	2037-2057	2057-2077	2077-2097	2097-2117	Total
Undefended section	65	85	115	135	145	545

5 Modelling findings

A modelling study was undertaken to identify the potential impact of potential coastal interventions (Breakwater or Revetment) on the longshore sediment transport). An appropriate complexity modelling methodology was undertaken to use procedural/process based on the understanding of the coastal processes involved in the vicinity of the intervention options. This approach allowed the breakwater and revetment options to be assessed independently, using appropriate conceptual and numerical techniques, to assess the impacts of each option.

5.1 Conceptual overview

Due to the complexity of the coastal processes at Splash Point, t conceptual modelling was required to supplement the insight provided by the computational modelling (3D hydrodynamic/morphodynamic and 1-line modelling), particularly for the complex modification resulting from breakwater and salient development. This conceptual modelling was employed to improve the understanding and modification of coastal processes using an "appropriate complexity" approach.

5.1.1 Revetment transport modification

Under present conditions the wave climate produces the greatest amount of ambient longshore transport during the summer season, with months June to September having, on average, more days with onshore waves stimulating longshore movement. This can be seen in Figure 5-1 which shows summer waves are on average 12° closer to shoreline normal than winter waves. Given that only wave directions greater than the shoreline orientation (248˚) summer waves will generate ambient longshore transport.

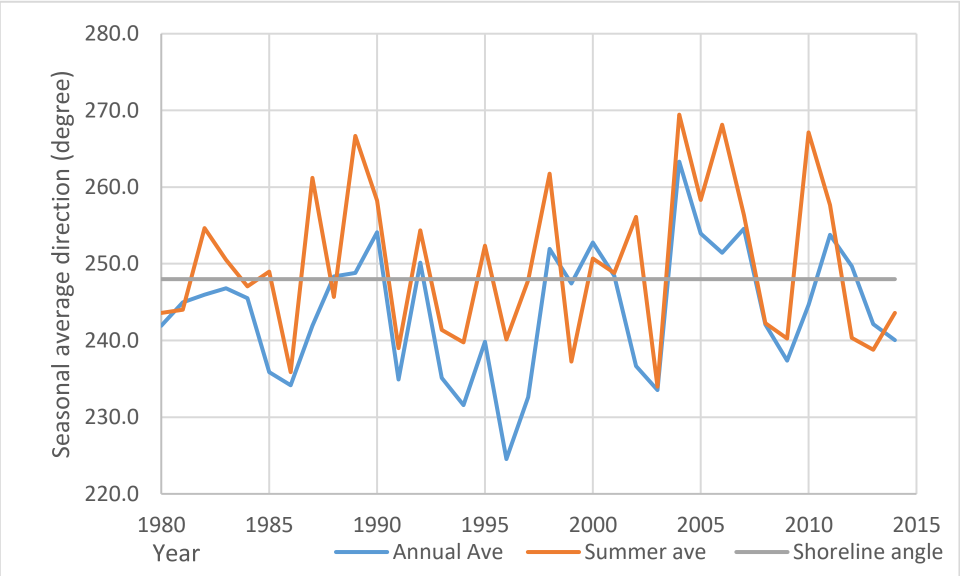


Figure 5-1: Seasonal average incoming wave direction

The analysis does also highlight a significant veering in incoming wave angles for extreme events, classed as events with an offshore Hs of over 4m in deep water. These events were deemed to result in large levels of energy dissipation in the nearshore but also had a more obtuse wave angle along the shoreline, stimulating greater longshore transport. Wave heights are larger in winter (Figure 5-2 and the probability of an extreme event is higher therefore in addition to the ambient longshore transport rate in summer, the longshore transport rate is punctuated and episodic in winter and directly related to storm occurrence

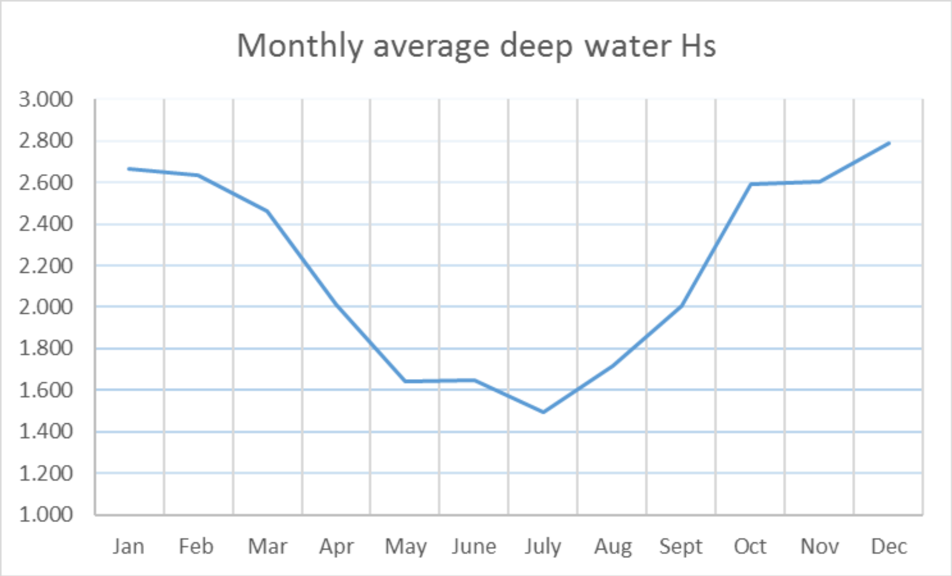


Figure 5-2: Average modelled WWIII deep water wave height at Rhyl

The presence an artificial beach will modify the shoreline profile, moving greater volumes of sediment in front of the rock armour, and increasing depths where there is greater wave driven disturbance. Thereby increasing longshore transport rates and capacity. The impact of this localised increased transport is uncertain; however, it is likely that this increased rate will remove sediment from the nourished area and deposit it further longshore, bolstering beach supply downdrift.

This intervention is predicted to elevate the cross-shore beach profile in the nearfield, as storm events and fill periods cause the re-distribution of sediments along the profile. In the far field this additional sediment will increase the sediment transport at the site of the lowest longshore transport rate along the frontage. Resulting in larger volumes of sediment available at other cross sections/sections of the frontage. Increased longshore transport rates through storm driven pulses and ambient summer conditions is anticipated to increase the sediment available for longshore transport along the frontage toward Point of Ayr. It is anticipated that this will have a significant impact on the shoreline transport of sediments with increasing sedimentation in the summer period, and increasing variability in sediment deposition currents.

5.1.2 Breakwater storage and extent

The salient can be seen as a dynamic shoreline feature that responds to variations in wave climate direction and associated longshore sediment transport. A wealth of research has been undertaken to estimate volumes of sediment storage within the feature and their response to variations in wave climate (Figure 5-3: Salient storage potential fluctuations corresponding to average incoming wave climate directions. The Hsu & Silvester (1990) model of salient development behind a single breakwater was used to calculate the annual fluctuations in salient storage, the approximate volume of sediment and the fluctuation of this sediment. According to the incoming weekly average wave direction from the 30 year hindcast modelled data, the maximum area of the salient associated with Breakwater 1 was 39,000m^2, which when related to the profile gradient of section DCC06 produced a maximum approximate salient volume of 156,000m^3. It should be noted that this calculation is a conservative estimation assuming an elevation of 4mAOD, a level base at 0mAOD, derived from apex calculations for the western extent.

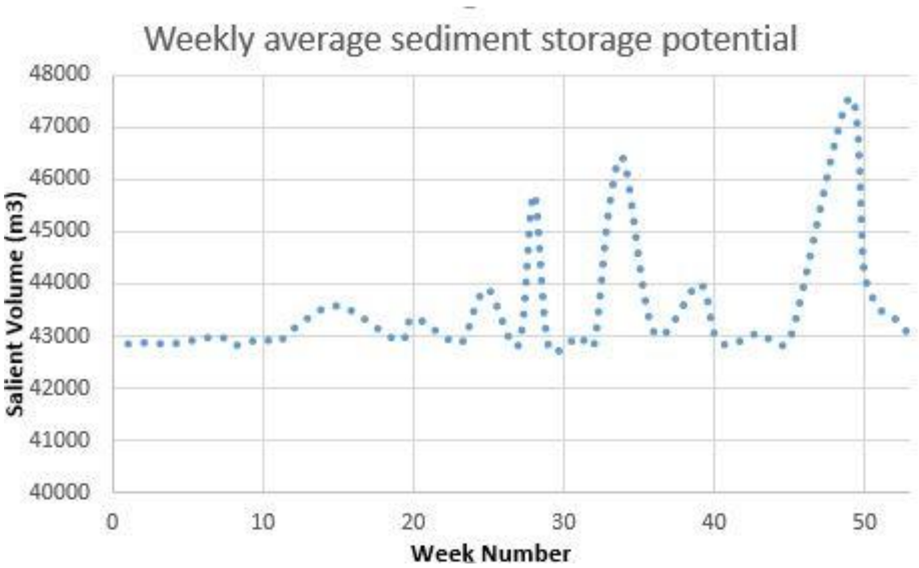


Figure 5-3: Salient storage potential fluctuations corresponding to average incoming wave climate directions

The distance between the breakwater and the apex of the salient was also calculated using the Hsu & Silvester (1990) method. This methodology was selected as it is the only model for salient development that incorporates incoming wave climate into salient development and form (Barbaro & Foti 2011). In these calculations, the distance from the breakwater was taken to be the midpoint of the line from breakwater apexes. The width of the structure was assumed to be zero. Output differing apex distances from the midpoint and angle from the western apex can be seen in Table 5-1.

Table 5-1: Salient extent and distance from closure

Breakwater	Position	Angle from western Apex (˚)	Distance from Breakwater (m)
Breakwater 1 (110m offshore from Splash Point)		21.8	33.96
Breakwater 2 (117m offshore from Splash Point, 75m West)		23.3	38.65

Breakwater 3 (185m offshore from Splash Point, 75m West)		33.35	79.85

This analysis has shown that the risk of closure from Breakwater position 1 is the most likely, given the width of the channel between the salient and the breakwater is likely be approximately 15-20m in diameter. Breakwater position 2 increases this spacing but only to a spacing of 23-26m. Therefore, this breakwater option was deemed unsuitable in its position due to the risk of closure and tombolo formation, due to the relatively small gap through which sediments can pass behind the breakwater. This breakwater position also did not offer the same degree of wave shadowing of Splash Point as Options 2 and 3.

Breakwater Option 2 was deemed more suitable than option 1 due to its increased sheltering of Splash Point and the increased distance from the apex tip to the breakwater. Option 3 was located an additional 50m offshore, which reduced the potential for tombolo formation. The additional offshore distance of this breakwater facilitated an additional 10m of salient formation as calculated by the Hsu & Silvester model.

5.1.2.1 Salient adjustment

The dynamism of the salient allows the salient shape and form to respond to variations in incoming wave heights and directions, as shown in Figure 5-3. This fluctuation in forcing causes the potential storage capacity of the salient to grow and collect incoming longshore volumes. These volumes will then be lost when capacity is reduced through the reduction in incoming wave angle. The change in forcing will also cause the position of the salient apex to shift east and west (dependent on wave direction), with high angle waves (under normal conditions) causing an average apex position to be to the west of the centreline of the breakwater. The more extreme waves, which tend to approach as shoreline normal to a greater degree, cause the salient to hold an asymmetric shape.

This change in apex position can be approximately related to seasonal variation associated with winter storms and summer fill cycles.

5.2 Numerical modelling findings

Numerical simulations, discussed in Section 4, were undertaken to identify the impact of intervention (breakwater or revetment option) on longshore processes and specifically transport. Unibest and Delft3D numerical models were employed to assist in the conceptual modelling of the salient development and assess its downdrift impact, respectively.

5.2.1 Shoreline modelling

Shoreline modelling was undertaken to identify the contemporary (pre-construction) shoreline trends and to yield a better understanding of the shoreline processes, particularly longshore transport. As discussed earlier this can be broken down into two modelling tasks; longshore transport modelling and one-line modelling (shoreline adjustment). Both modelling approaches were used as an initial assessment to identify the shoreline trends along the frontage and to inform additional model design and conceptual modelling.

5.2.1.1 Longshore transport modelling

The shoreline modelling (together with SWAN wave transformation modelling) allowed an identification of the general trend of longshore sediment transport to be identified as from west to east, transporting sediments from the Pensarn frontage longshore to the Point of Ayr. Generally, along the frontage the longshore transport rate increases from west to east, as the sheltering afforded by Great Ormes Head is exceeded. Calculated rates are significantly smaller than the rates outlined in previous investigations along this frontage (attributed to the more complex calculations performed in this study). These rates can be seen below in Table 5-2.

Table 5-2: Calculated longshore transport rates for Rhyl to Point of Ayr (left) and Pensarn to Kinmel Bay (right)

Cross section Rhyl - Point of Ayr	Transport rate (m^3/yr)	Cross section Pensarn - Kinmel Bay	Transport rate (m^3/yr)
DCC01	36,700	CCBC47	113,500
DCC02	69,700	CCBC48	111,000
DCC03	30,200	CCBC49	71,700
DCC04	78,200	CCBC50	69,800
DCC05	116,200	CCBC51	145,900
DCC06	78,400	CCBC52	121,800
DCC07	108,800	CCBC53	85,800
DCC08	142,500	CCBC54	32,100
DCC09	36,500	CCBC55	46,800
DCC10	87,600	CCBC56	89,600
DCC11	91,700	CCBC74	57,000
DCC12	128,700		
DCC13	99,200		
DCC14	121,800		
DCC15	118,400		
DCC16	118,900		
DCC17	117,600		
DCC18	152,800		
DCC19	135,800		
DCC20	109,600		
DCC21	146,900		
DCC22	178,400		
DCC23	170,200		
DCC24	174,000		
DCC25	178,600		
DCC26	170,400		

The modelling highlighted the relatively low longshore transport rates along the frontage from the mouth of the river Clwyd to section DCC05. This is attributed to a change in shoreline orientation when compared to the Towyn frontage, where longshore transport rates are 200% larger. It is anticipated that the west to east longshore transport is maintained along this frontage with the hydrodynamic flows from the River Clwyd and tidal flow, assisting in the throughput of sediments through this section of coastline. It is however anticipated that this decline in longshore transport rate contributes to the lower beach storage at Splash Point. To allow appropriate representation of the longshore transport of sediments at this location, an eastward current was added to these sections to simulate the role of hydrodynamic flows. The calculations showed an increase in longshore sediment transport rates moving east from the rock armoured frontages of Rhyl and Prestatyn (109,000 -150,000m^3/yr to 170,000-178,000m^3/yr). This is anticipated to be a result of the return to a natural dune system from rock armoured upper foreshore, facilitating increased transport along the beach face and interaction with sediment stored in dune systems behind.

5.2.1.2 1-line modelling

For longshore transport, 1-line modelling, no groynes were simulated, and the revetments were extended to their appropriate distances. Care should be taken when interpolating the results of the longshore transport modelling, as a high degree of extrapolation from inferred conditions (groyne bypassing, hydrodynamic influence of River Clwyd) was required to ensure the appropriate modelling of shoreline characteristics. In addition, the ambient wave conditions produce a high level of modelling uncertainty (due to high wave angle instability) therefore the extent to which 1-line modelling represents reality is inexact.

The longshore sediment transport modelling is also highly sensitive to shoreline aspect and cannot appropriately represent cross shore variations in the orientation of the features (as with the longshore bars discussed in Section 2.3). These pulses of nearshore sediment supply and their wave normal aspect are subsequently not represented in the longshore modelling, and so longshore reported modelled transport rates are anticipated to be higher than observed rates.

The modelling shows increased deposition in the mouth of the River Cwyld. However, this is not deemed to be representative of the future coastline, as this sediment is anticipated to be spread along the coastline to the east. This would offset the erosion observed at the termination of sea walls (at Prestatyn and Barkby Beach). During a five-year model simulation, the model illustrated a decline in beach frontage along Prestatyn, which reduced longshore sediment transport to approximately 32,200m^3/yr. At the termination of defences, the modelling showed a significant rate of retreat (approximately 20m/yr), this however is anticipated to be mitigated by the presence of two groynes offsetting erosion at Prestatyn sailing club

The total transport rate simulated over 5 years at the termination of the frontage sections (east of DCC26) was approximately 160,000m^3/yr. It was not possible to accurately determine the rate of sediment passage at the Point of Ayr due to the lack of cross sectional data at this location.

The intervention in the longshore sediment transport processes and the impact of increases in shoreline modification (orientation and beach profile) were assumed to impact on the longshore transport rates along the Prestatyn frontage. The inclusion of a breakwater is anticipated to increase the variability in longshore transport, eliciting sediment pulses, as sediment is released longshore from the salient under appropriate wave directions. This, while increasing the variability of transport is not anticipated to be at timescales relative to shoreline change, and so not appropriate to model in a 1-line model. For the revetment option, it was hypothesised that the addition of nourished sediments would generate an initial spike in longshore sediment transport, as this sediment is redistributed along the beach face and transported longshore. It was not possible to model this sediment pulse as it is highly dependent on incoming wave climate, and the modified beach profile. In the longer term the increased availability of sediment has been modelled to percolate along the Prestatyn frontage, bolstering beach levels and marginally increasing transport along this frontage, slightly reducing the erosion issues at Prestatyn Sailing Club.

To identify the impact of intervention methodologies, the model sensitivity was tested through the varying the amount of sediment at Splash Point (simulating a breakwater construction and revetment options). It was found that the removal or addition of quantities of sediment of less than 5,000m^3/yr resulted in fluctuations in longshore transport rates at the termination of the defences at Prestatyn of between +12% to -16% respectively, over a modelled six-year period. When an additional 10,000m^3/yr was made available at Splash Point a 23% increase in longshore transport rate was observed at Prestatyn, increasing the longshore transport rate to 40,800m^3/year.

It was concluded that perturbation in the longshore transport rates at Splash Point will be percolated longshore to the natural frontages east of Prestatyn. If this perturbation elicits a decline in sediment availability (as is possible from a breakwater intervention and possible tombolo formation), then this will cause an increase in erosion of these natural frontages. If additional sediment (by nourishment as with the revetment option) is made available for longshore transport this will bolster the sediment supply downdrift along the armoured defences at Prestatyn, mitigating erosion here by increasing updrift sediment supply, increasing longshore transport rates along the entire frontage.

5.2.2 Hydrodynamic/morphological modelling

Hydrodynamic modelling was devised to identify the modelled salient development and extent and confirm the modification of hydrodynamic and geomorphological processes conceptualised above. This modelling used calculated distance between the salient and the centreline of the breakwater position an indicative salient form for each breakwater formation. The nested 3D models confirmed general geomorphic processes and confirmed the build-up of sediment on the western end of the salient, and a general decrease in sediment volumes stored in the beach to the east of the breakwater, for breakwater options. The modelling also confirmed a general loss of sediment from the nourished section of beach and an elevation increase to the beach face in the nearfield to the revetment option.

5.2.2.1 Revetment option

The option to upgrade the beach along this frontage was assessed to identify the annual nourishment rate required to maintain a beach at the frontage. The beach area was assumed to be approximately the same extent as the present minimum salient, and the dispersal of this volume over an annual average year was assessed using Delft3D.The beach was simulated to be shore parallel and extending to a distance of 40m offshore at a level of 4mAOD, to match the salient area. The Delft3D model was then run with a MorFac (Morphological accretion factor) of 13.036 over a 28-day simulation period (with a 3-day spin-up period) to simulate an annual year. The results then being compared to a baseline simulation and the original bathymetry input.

It was found that the artificial beach face was significantly diffused by the incoming wave climate, with a high volume of the artificial nourishment dispersed along the beach face. This was primarily to the east of Splash Point, but also to the east, where the dispersal of sediments extends beyond the 3D model boundary under an annual simulation (Figure 5-4). This preferential deposition to the east is a direct result of longshore transport mechanisms and the asymmetry of the governing wave climate.

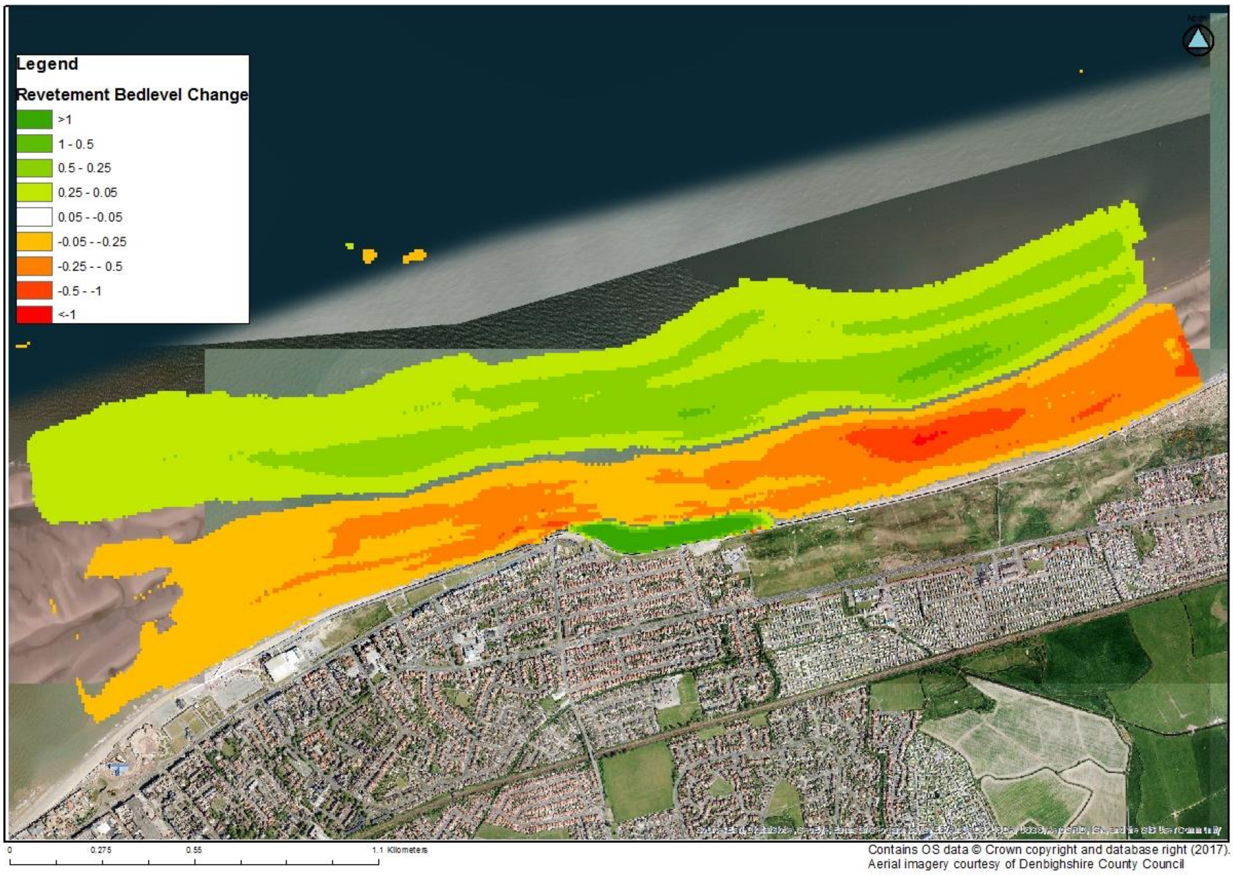


Figure 5-4:Delft3D model output bed level change post annual simulation for revetment and nourishment option

The Delft3D 3D model output shows the majority of accretion is focused in the lower foreshore, with a relative, post simulation decline in bed level modelled foreshore of this. This large change is anticipated to be due to a transient sentiment of sediments in the proximity of the nourishment and a decline in the offshore erosion rates moving sediments onshore the sediment accumulation was primarily confined to the lower beach face with the upper beach face experiencing an increase in erosion (Figure 5-5) but not a marked decline in bed level from initial conditions. The patterns of sedimentation and erosion is similar to baseline conditions however the divide between upper and lower foreshores is more defined with flattening of the beach evident with the additional nourished sediments.

It is anticipated that this significant change is likely due to the short-term redistribution of sediments in the vicinity of Splash point, with much sediment being distributed in deeper water. This change is predicted to be confined to positions not further west than the model domain but to extend further east to Prestatyn as the sediments are washed longshore.

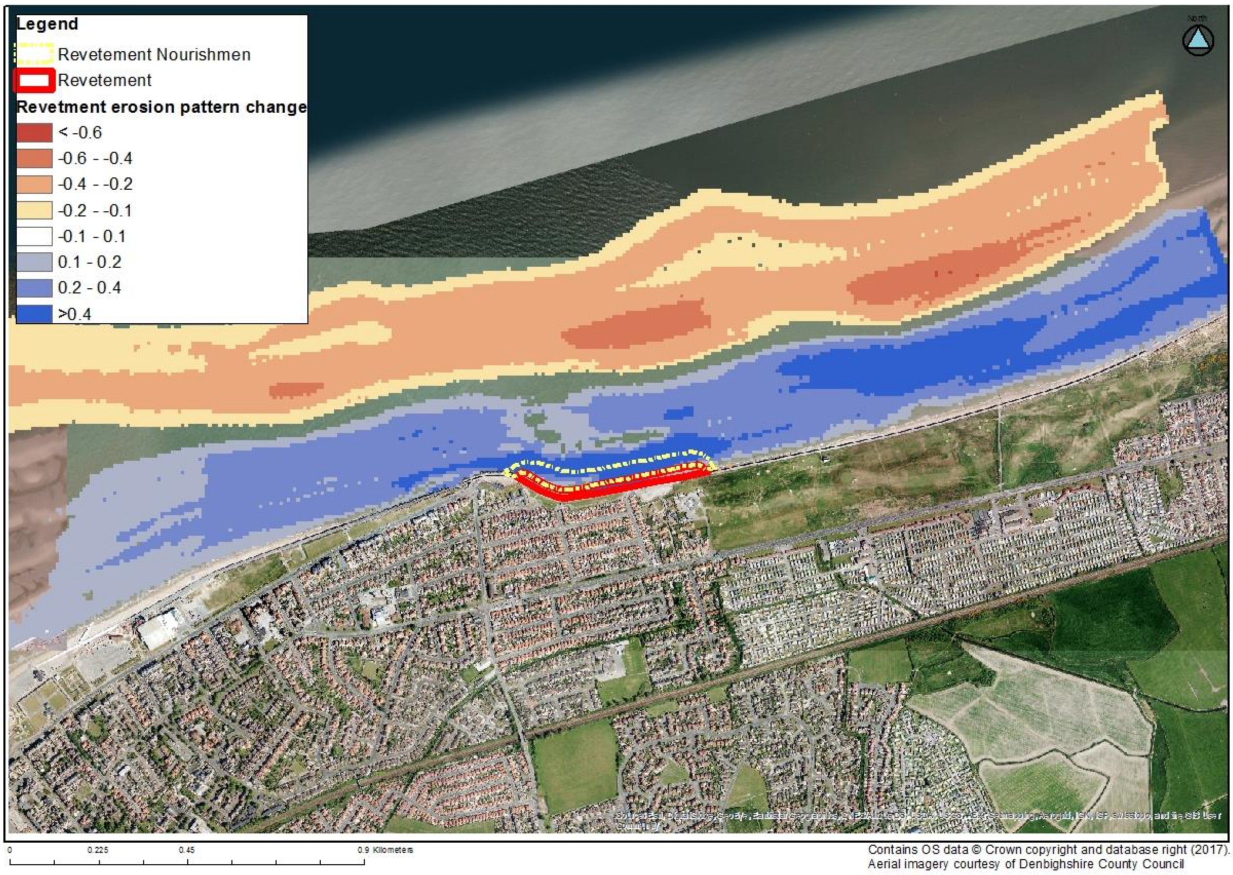


Figure 5-5: Change in sedimentation and erosion patterns or a revetment option

In total the sediment required to maintain a beach at suitable nourishment intervals (8-10yr) is estimated to be up to 20,000m^2 along the proposed breakwater upgrade. This was considered the annual nourishment rate required to maintain a similar level of amenity to the salient position associated with breakwater position 3.

5.2.2.2 Revetment option with additional groynes

This option was similar to the revetment option with nourishment, however a set of four groynes were included within the modelling to demonstrate their impact on enhancing the retention of sediments at splash point and reducing longshore transport rates.

The modelling confirmed that the addition of groyne features would increase the retention capabilities in the area fronting the intervention, Figure 5-6, thus confirming the decrease in losses from nourished sediments. The modelling however did show accretion without erosion for the schematised annual conditions modelled

Figure 5-6: Model output for Revetment with groynes option

5.2.2.3 Breakwater option

The modelling of breakwater positions 2 and 3 was performed to identify their impacts on velocities and sediment transport rates. The hydrodynamic modelling showed a difference in depth averaged velocities at the tip of the Apex, with position 3 having four times the average velocity between apex and breakwater than breakwater position 2, corresponding to a greater total sediment transport in the lee of the breakwater. However, due to the lower depth of the toe of breakwater position 3 there is greater simulated transport than that simulated for breakwater position 2. However, this declines sharply to a consistently lower value than the simulation of breakwater option 2. The average total transport throughout the study period remains higher for breakwater position 2. Mean total transport was also used to corroborate the assumption that sediment will follow the predicted pathways and round the salient apex.

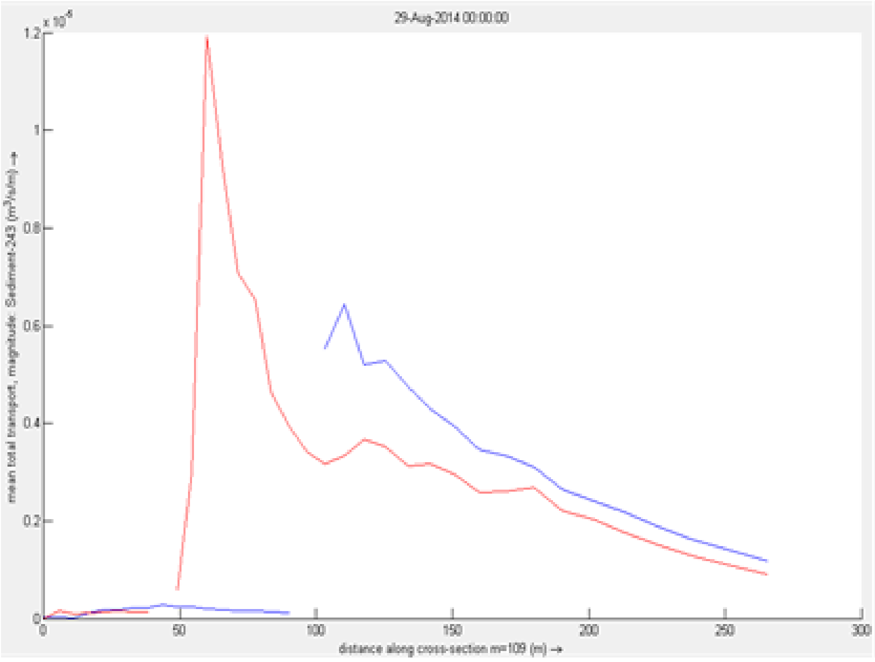


Figure 5-7: Average total transport along the cross-section from apex of Salient. Blue is breakwater position 3 and red is position 2.

Figure 5-7 illustrates the direction of net total transport for the simulation. The model illustrates net onshore transport of sediment in the nearshore. This is primarily due to the modelling of wave shoaling and breaking within Delft3D (with an underestimation of undertow) and the schematisation of onshore waves only in the schematised annual conditions, as discussed in Section 4.2.2. The simulation does however show significant wave related scour at the eastern extent of the breakwater. This is considered a result of the angling of the breakwater away from incoming waves, allowing greater wave induced currents to round the breakwater tip, inducing a high rate of net onshore transport. This should be noted as of special concern for the engineering design of the structure.

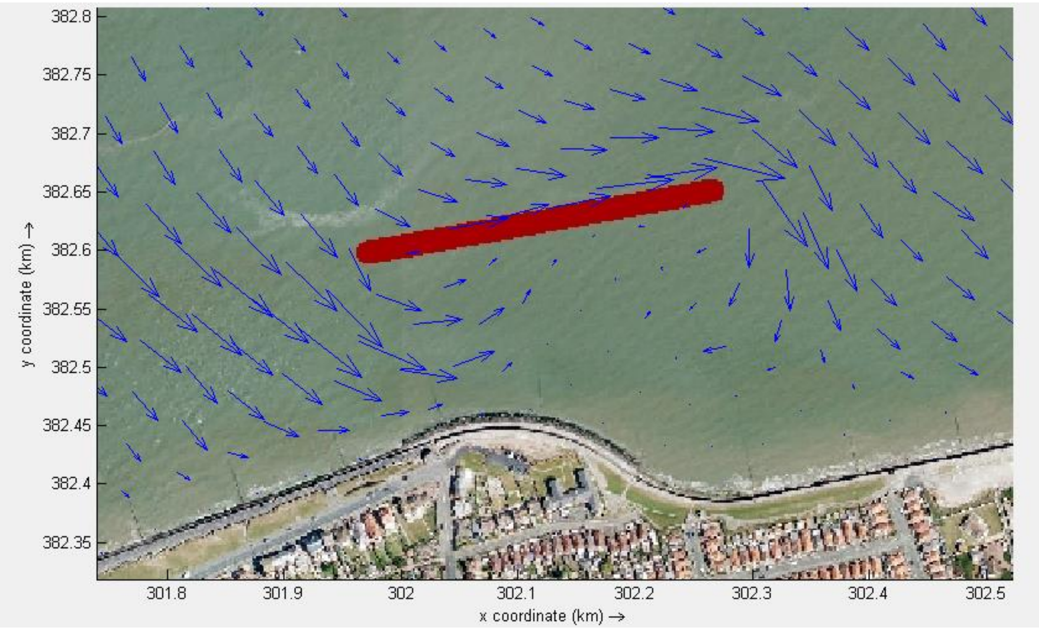


Figure 5-8: Mean total transport vectors at high tide during simulation of breakwater option 3 (NB. diffraction has not been modelled).

The salient shape and volume will respond to the predominant wave climate, with extreme wave climates. As high angle waves reach behind the breakwater, their impact will cause the salient to adopt an asymmetric form with the salient apex situated east of the breakwater midpoint.

All options show significant alteration in beach face sedimentation and erosion patterns during all simulations (including baseline simulations) illustrating a net onshore transport of sediments. This can be largely attributed to the inclusion of wave induced sediment transport in Delft3D, and the simulation of nearshore processes. It could also be attributed to the schematisation of incoming wave heights using only onshore wave angles, which prevent the ability of the beach to recharge following high energy events. The inclusion of intervention structure has been seen to reduce the signature bar formation within Delft3D outputs, facilitating greater onshore transport and erosion of the lower foreshore. It is expected that this mechanism, and its performance within Delft3D, is not completely representative of shoreline processes and their modification following breakwater construction. This modelled response is likely to be an overestimation of the dampening of existing processes following construction

5.2.2.4 Breakwater Option 2

This option was modelled for an annual average schematised year. The output was them compared to the baseline simulation for the same schematised average year. The output shows significant sedimentation between the head of the salient and the breakwater, extending the salient apex beyond the calculated distance from closure (as discussed in Section 5.1.2.). The model was not able to simulate sediment transport in the lee of the breakwater option for this frontage and simulated large volumes of sedimentation updrift of the western salient Apex. The decline in sediment erosion (when compared to baseline) is a representation of a drop in sedimentation rate following breakwater implementation. The impact of wave diffraction was not modelled, and so the representation of process in the lee of the breakwater was not comprehensively modelled. The significant sedimentation observed at the updrift extent of the salient and in the immediate lee of the breakwater suggests a high risk of closure for this breakwater option.

5.2.2.5 Breakwater Option 3

Simulations of breakwater option 3 were found to be increasingly stable, as the wave interaction behind the breakwater was better represented with addition cell definition. The intervention was found to produce the smallest reduction in longshore transport with downdrift total transport (a cumulation of bedload and suspended transport) generally higher than observed with position 2 (Figure 5-9). Despite the lack of representation of diffraction, the model shows sedimentation at the head of the salient, extending to its downdrift, eastward limb. This then shows sediment rounding the salient as a result of hydrodynamic processes. It is anticipated that the inclusion of diffraction will assist in the redistribution of the sediment about the eastern limb of the salient.

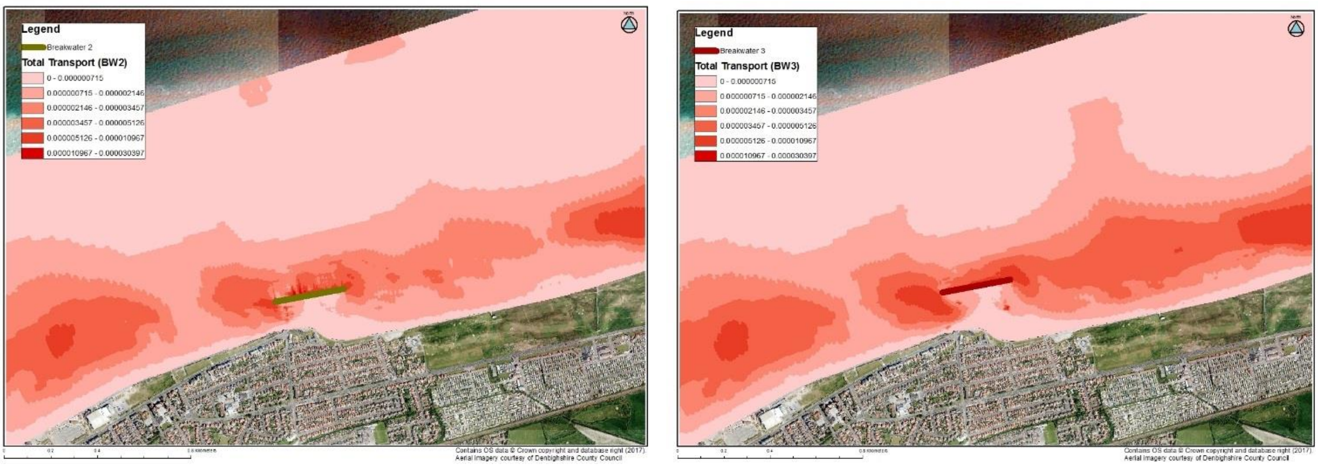


Figure 5-9: Change in mean total transport for the complete simulation between breakwater position 2 and 3 for a modelled 28-day period

In addition to the minimal disturbance downdrift, breakwater option 3 also showed decreased sedimentation at the updrift side of the salient, decreasing the likelihood of salient closure and tombolo formation. This option does show increased sedimentation in the nearshore for the remainder of the shoreline compared to the baseline simulation, particularly in the region of the western extent of the breakwater. When compared to breakwater option 2 this is greater in extent but less in magnitude, and shows greater infiltration behind the breakwater. The downdrift shoreline from the breakwater shows a significant setback in the areas of accumulation, suggesting a decline in longshore sediment supply due to the blocking of longshore sediments by the breakwater.

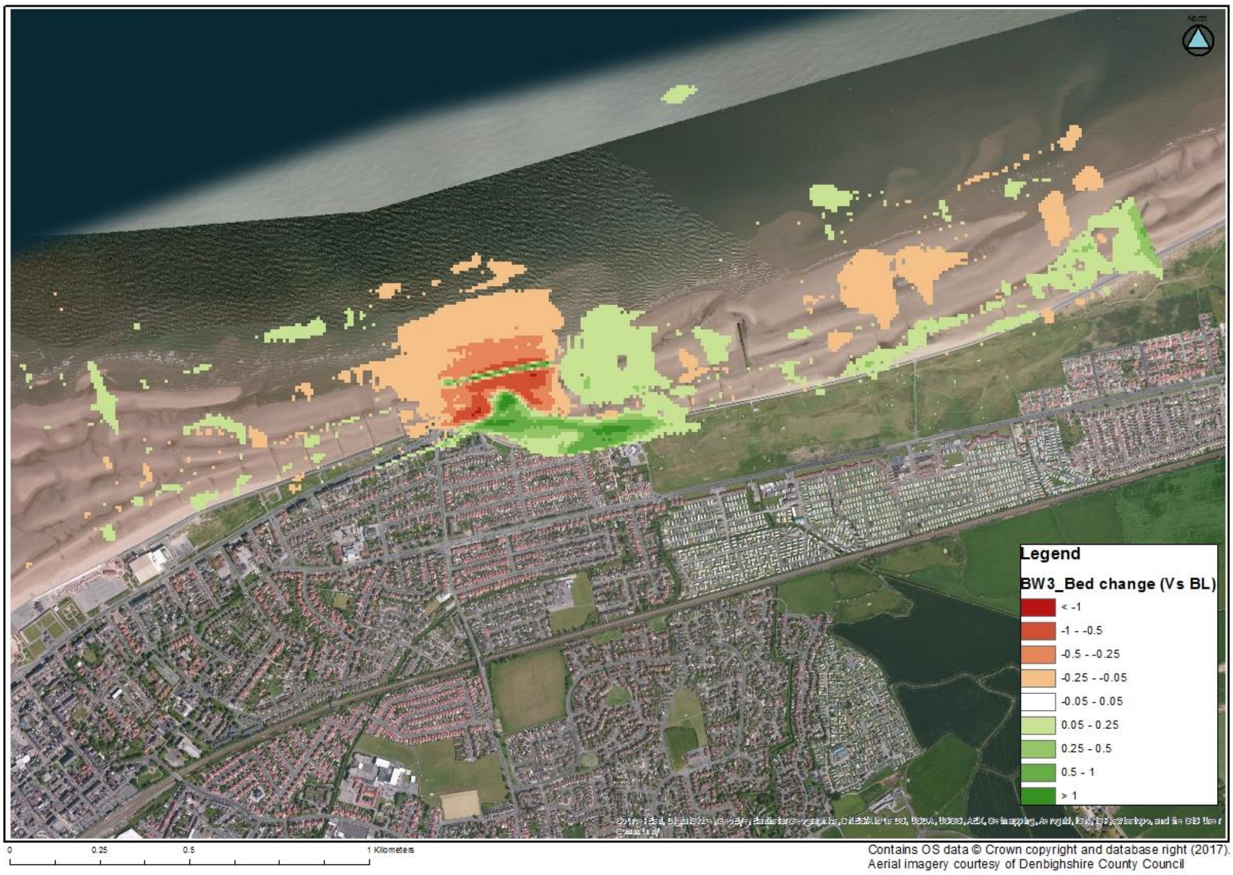


Figure 5-10: Bed level change for BW option 3 (compared to baseline) after 365 days of simulation

The simulation shows the development of a beach frontage in front of the breakwater extent with significant accumulation predicted on the exposed side. It is anticipated that the sediment stored here will continue to accumulate beyond the period simulated, forming an additional beach frontage, and allowing the longshore transport rate seaward of the breakwater to increase as a beach profile develops.

5.3 Detailed conceptual modelling

Baseline modelling of the undeveloped shoreline outlies that an average of 45,194 m^3/yr passes section DCC06, moving eastward as a direct result of longshore transport. Following construction, three separate longshore transport pathways governing the bypassing of sediment around the breakwater as denoted in Figure 5-11, and their role in the conveyance of sediment through the geomorphological feature is outlined below. This schematisation is discussed in greater detail in Section 4.1.

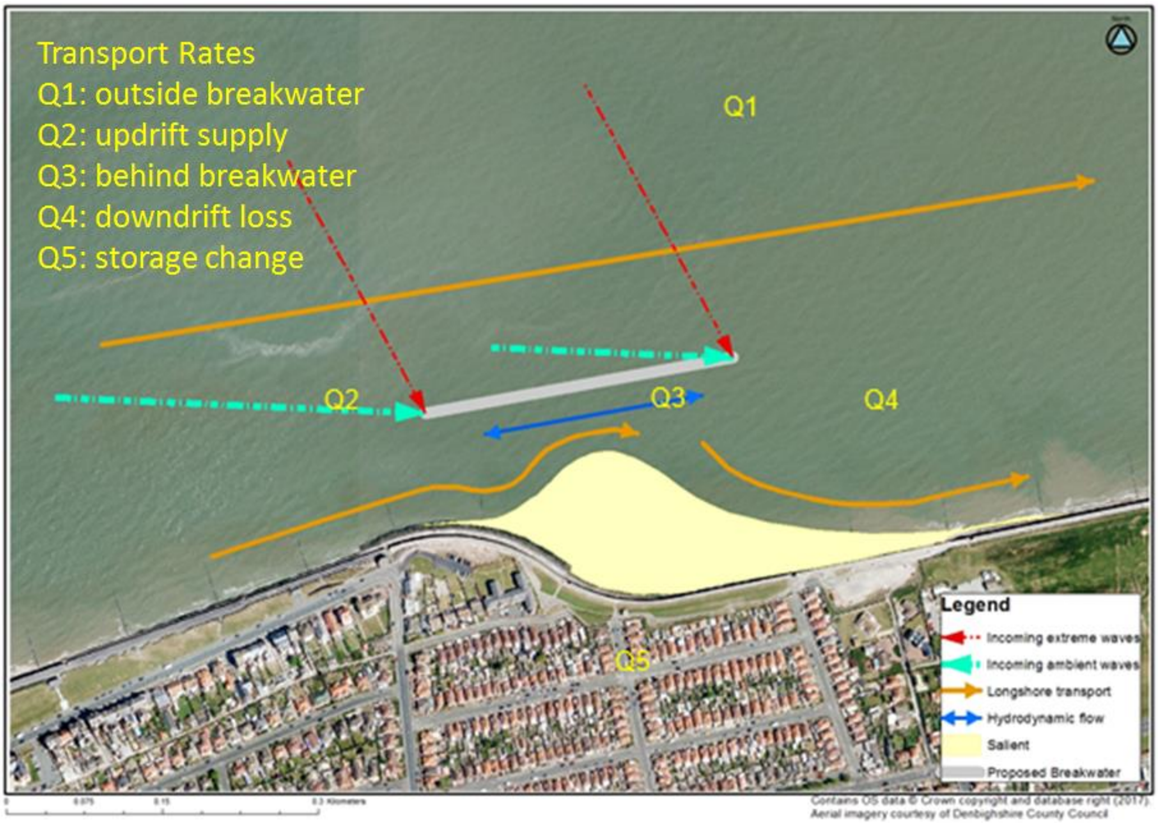


Figure 5-11: Conceptual model of breakwater bypassing

5.3.1 Q1: Breakwater Bypassing.

As the breakwater was conceived to be constricted by between 115 and 185m from the shoreline it was concluded that the seaward beach cross section would still be vulnerable to longshore currents and wave action. Subsequently the longshore transport for the cross section shoreward of the breakwater was calculated. The base of the breakwater was estimated to be at a level of -1.44mAOD (-1.26mAOD). Annual volumes of 18,574m^3 were calculated to be transported along this pathway.

5.3.2 Q2: Rounding the salient Apex

The salient in the lee of the breakwater forms because of wave refraction from the head of the breakwater modifying the wave height and direction, causing the dual equilibrium bay profiles at either side. The apex of the salient marks the watershed from the influence from one diffraction point to another, and therefore represents a sediment transport reversal. Therefore, the sediment bypassing the apex is transported along the salient by pathway Q4 and constitutes longshore transport.

To quantify this longshore transport, an equilibrium profile extended to depth of closure was devised at a point and an additional 10° further south from the western breakwater tip than the apex (calculated from Hsu & Silvester, discussed in Section 5.1.2). D-Wave outputs from section DCC06 were manually refracted around the breakwater apex to the calculation point on the salient and longshore transport calculated. The annual net transport north-westward at this location and so around the salient apex was 10,786m^3.

5.3.3 Q3: Hydrodynamic transport around apex

The output of the modelled data for a 28-day period was sampled at the crest of the apex to identify the total volumes of longshore transport at this location. An average total transport value of $2.78x10^{-7}$ $m^3/s/m$ was modelled to be transported eastward between aspects of the salient. This then, with the values output in Table 5-1 yields a hydrodynamic transport rate of 300 m^3/yr, 340 m^3/yr and 700 m^3/yr for breakwater 1,2 and 3 respectively.

5.3.4 Q4: Transport eastward of apex

On the eastern side of the salient, incoming waves undergo the same diffraction process as at the western side. Conceptually, this will result in a similar equilibrium profile with longshore sediment transport increasing exponentially with distance from the salient apex, until the longshore transport rate reaches an equilibrium with the down drift coastline, maintaining sediment supply downdraft by eroding the salient when necessary.

Longshore sediment transport mechanisms can account for 29,360m^3 of sediment bypassing the breakwater and salient in following full formation. Thus, an annual sediment deficit of 15,834m^3 is expected without the influence of other hydrodynamic processes. It is expected that this sediment is added to the salient volume on an annual basis. It is also expected that some of this will be lost as a result of reductions in the capacity of the salient structure in response to wave climate variation. This release will be in the form of pulses of sediment being transported eastward along the shoreline.

5.3.5 Q5: Growth and loss of sediment from salient

It is well documented that the salient formation in the lee of the breakwater will respond to variations in wave climate forcing. This growth, and subsequent loss, will account for an additional proportion of sediment throughput through the growth and attrition of sediment. The sediment deficit of 15,834m^3 can thus be divided to form an average weekly deficit which is added to the western updrift portion of the salient. On average 310m^3 is added to the salient weekly, when wave directions permit. When the wave climate constitutes a loss of sediment capacity within the apex it is predicted that this 310m^3 with an additional volume released from the reduction in salient capacity is passed downdrift. The sediment supply downdrift is then denoted by a steady supply of sediment punctuated by pulses of sediment, as sediment is released from the salient formation. Weekly pulses in sediment released longshore were estimated to be as high as 3,300m^3 (as estimated from the average hindcast year). Sediment was permitted to accumulate as salient supply increases and lost as the salient capacity decreases, allowing pulses of sediment to be transported downdrift.

5.3.6 Outcome of conceptual modelling

The analysis outlined in the conceptual modelling has indicated that, while the salient will allow the throughput of sediments (approximately 29,000m^3 per year), an additional volume of sediment will be released in an episodic fashion, and the salient expands and ablates with the shifting wave angles. This episodic ablation will likely occur during summer periods and during storm events, due to the incoming wave climate becoming shore normal and reducing the salient capacity (Figure 5-3).

The analysis also outlines the risk of salient closure and its impact on longshore transport rates. Both this and the episodic nature of longshore transport have potential to cause severe impacts downdrift and introduce a degree of uncertainty in management cost estimates (as tombolo formation will require a management response).

Key outcomes of the modelling and analysis of breakwaters include:

a. The required volumes and rates of sediment recharge volumes are large, due to the high potential for alongshore sediment transport. Material placed without constraint on East Rhyl beach will be rapidly transported eastward, and therefore any beach restoration associated with the revetment option should also include installation of groynes to slow the rate of sediment loss;

b. The original position of the offshore breakwater was determined likely to result in the shoreline attaching to the rock structure. This would effectively block alongshore flow, acting more like a groyne than a breakwater, with consequent downdrift erosion stresses likely to occur on the east side of the breakwater's wave shadow. The ability for the sediment feature to act as a sand source during periods of erosion stress would also be reduced, limiting its intended functionality;

c. The offshore breakwater needs to be located further offshore and westward to operate effectively. Relocation approximately 60m offshore from the original position is required;

6 Intervention evaluation

All options assessed in this analysis will result in measurable impacts to the longshore. A particular interest to this investigation is the total cost (construction and maintenance) of each intervention over a 100-year life span he potential impact of shoreline process modification on the surrounding avian populations (particularly the Little Tern (Sternula albifrons) community at Talcare) and the implications on coastal flood risk in Rhyl and at Splash Point. The modelling has been used to assess these primary concerns, along with addressing concerns about the adaptability of the sediment features proposed as part of intervention options

6.1 Option 4: Offshore breakwater

Three variations on the offshore breakwater were proposed to assess the viability of maintenance and the distance from closure. Breakwater options 1 and 2 were considered to be at a large risk of closure with increased sedimentation observed directly behind the breakwater. Breakwater option 3 was devised to be situated further offshore to allow increased throughput behind the breakwater and decrease the risk of tombolo formation

6.1.1 Breakwater options

The breakwater option that is considered most appropriate for implementation was option 3, located 185m from the shoreline (Figure 6-1). This was selected as it was deemed to represent the least risk of closure from sediment movements. Although construction further down the beach face will increase the cost of construction of the breakwater and the initial volume required for the salient (140,000m^3). Its position will also promote bypassing reducing perturbation and impact downdrift. The remaining breakwater positions (1 and 2) were deemed to be at a high risk of closure, given the calculated distance (less than 40m), and the modelling predicted sedimentation in the nearshore between the salient apex and the breakwater, leading to eventual tombolo formation.

Figure 6-1: Breakwater position 3

Breakwater option 3 was subsequently selected as the most suitable option, at least risk of closure from prevailing wave conditions, allowing minimal disturbance in longshore sediment transport rates.

6.1.2 Maintenance cost

Following construction, the maintenance of the breakwater is anticipated to be minimal and focused on post storm repair. The salient however will require maintenance to ensure a Tombolo does not form and the lee side of the feature is sufficiently nourished with sediment. This sediment nourishment can be sourced from the updrift side of the salient and movement to the lee side.

The position of breakwater option 3 creates a L/D (length/distance to shore) value of 1.62 which is denoted as a well developed salient to incipient Tombolo (Pope, 1986), therefore, there is risk of ad hoc management responses being required to disrupt or in response to tombolo formation. This management response is considered necessary to maintain a channel spacing between the salient and breakwater and maintain the current response of longshore transport. The residual risk of this occurrence is not presently quantifiable, due to the lack of similar structures on this coastline and the inability of models to effectively model longshore transport at appropriate timescales (Delft3D). The frequency of this response therefore cannot be reliably identified but is estimated at a one in 10-year event.

The rate of sediment loss is ambiguous due to the poor representation of wave diffraction within Delft3D. Subsequently, reliable estimation of an extreme loss rate during an abnormal year is not possible due to the high levels of uncertainty of the volumes of propagation of sediment through the shadow zone of the breakwater

6.1.3 Impact

The construction of the breakwater and salient complex will increase the variability along the frontage by modifying the mechanism responsible for the release of sediment. As discussed in section 5.3.6, this variability will supplement the existing longshore transport currents causing pulses of sediment to be released in response to variations in incoming wave direction. This variation and episodic manner is expected to be within the natural variability of the shoreline due to the movement onshore of cross shore bars as denoted by data collection. Therefore, this is not projected to have severe adverse impact on downdrift populations of *Sternula albifrons,* provided tombolo formation does not occur. If tombolo formation were to occur and be dispersed naturally (by a high-energy wave event) it would release a large volume of sediment (by bypassing the breakwater shadow zone) that would migrate eastward, longshore in the upper foreshore. This could have severe impact on ground nesting birds.

6.2 Option 5a: Revetment with beach face nourishment

The proposed revetment option causes minimal perturbation in shoreline process, however the artificial nourishment of sediments is expected to make an increased volume of sediments available for longshore transport and so increase the rate of longshore movement of sediments. Due to the high instability of the nourished sediments it is anticipated that the re-nourishment of the artificial beach fronting the revetment will be required regularly on an annual or bi-annual basis. The initial area of sediment required to nourish the initial modelled beach face (20,000m^3 to a level of 3.9mAOD) was calculated to be 99,000m^3.

6.2.1 Maintenance

The modelling performed in Delft3D showed a loss of 5,200 m^3/year from the nourished level over the simulated annual conditions. This in addition to the capital recharge quantities would likely increase the longshore and cross shore sediment transport in the vicinity of Splash Point and along the shoreline, as shown in the Delft 3D modelling.

6.2.2 Impact

The increased sediment available is anticipated to modify the cross-shore profile significantly, making more sediment available for longshore and cross shore transport and subsequently increasing the longshore transport rates in the vicinity of Splash Point.

It is anticipated that the inclusion of cross shore structures (groynes) will reduce this longshore transport rate and facilitate the retention of sediments in the vicinity of Splash Point and reduce their bleed rate from the nourished region, reducing the need for annual nourishment.

6.3 Option 5b: Revetment and nourishment with crosshore groynes

The inclusion of cross shore groynes in the modelling allowed a higher beach level to be maintained in front of Splash Point and reduce the attrition of maintained sediments when compared to the revetment and nourishment option. This option showed additional accretion of longshore sediments on the western sides of the groynes, increasing amenity value of the beach frontage here. The modelling showed the perturbation associated with groyne intervention

6.3.1 Maintenance

The maintenance of this option was considered significantly less than the other revetment option and the breakwater option due to the decrease in nourishment requirements and the lower degree of uncertainty. The Delft3D model was not considered reliable to estimate the required volumes of maintenance required to maintain the beach face at this location, due to the simulated accretion as groyne storage stabilises. The model also shows bed level increase in the region fronting the groyne as sediment is eroded from the nourished area and deposited in the lower foreshore. It is anticipated that a proportion of this sediment will be lost downdrift as in addition to the revetment and breakwater options, this option would require additional maintenance on the timescale of groyne lifespan (approximately 50 years for rock groynes).

6.3.2 Impact

This option produces the least perturbation in longshore impact in the long term, as once the groynes reach capacity the groyne system will be bypassed, and the contemporary longshore transport mechanisms will be maintained. This was further corroborated by delft3D model output, which showed a decline in bed level variability over the modelling period when compared to an uncontained nourishment option which significantly modified beach face.

6.4 Modelling conclusions

The modelling (both numeric and conceptual) was tasked with identifying the most suitable intervention to mitigate the flood risk at Splash Point, whilst also minimising the disturbance of sediment transport pathways and identifying potential areas of risk and uncertainty. The modelling was constrained by the scarcity of observational data, particularly beach profile observational data (and response to extreme transport events). However, the modelling identified the most appropriate option that is anticipated to have minimal impact to longshore sediment mechanisms and habitats, lowest capital and maintenance cost and also minimal risk and uncertainty. An option combining a rebuilt revetment with a nourishment regime and a set of four cross-shore groynes was considered to be most appropriate to mitigate the flood risk at Rhyl with minimal impact to shoreline sediment transport pathways and was considered to be at the lowest cost of the options simulated.

6.4.1 Option 4: Breakwater

A breakwater option was originally identified at PAR stage to be the most appropriate option to mitigate the risk from wave overtopping at Splash Point. When further investigation into the viability of the breakwater in this position it was identified to be at high risk of tombolo formation and closure, requiring immediate management response. The risk of closure was minimised by extending the breakwater a further 75m north and 75m west (breakwater option 3). This breakwater position was modelled conceptually and numerically and loss rates were calculated. However, the governing wave climate and constraints in the modelling performed (HAWI and poor representation of wave diffraction) yielded a high degree of uncertainty of the annual recharge volume required.

It was also determined that the variability between day to day and extreme wave directions would result in episodic pulses of sediment being transported longshore. Although this was anticipated to be within the natural range of variability of sediment supply (through onshore bar migration), it also yielded uncertainty in the response of the western salient arm to extreme events (and event driven tombolo formation associated with cross shore bar migration).

The modelling performed highlighted the uncertainty in the construction of the breakwater formation, particularly the risk of tombolo formation and its associated impact to longshore sediment regimes. This uncertainty and the associated cost of moving the breakwater further offshore, caused this option to be considered at a high risk and a high cost to implement. It was therefore not considered the preferred option to mitigate flood risk at Splash Point

6.4.2 Option 5a: Revetment and Recharge

The revetment option was devised to increase the crest level and width of the defences at Splash Point by rebuilding the rock armour defences. This reconditioned defence was then envisaged to be fronted by an additional nourished beach (approximately 20,000m^2). This option was considered less uncertain than the breakwater option in that the movement of sediments was more predictable. However, the addition of large sediment volumes (approximately 99,000 - 200, 000m^3) without retention methods to hold the sediment in their place of deposition, leaves the sediment vulnerable to incoming waves (both ambient and extreme) increasing longshore transport rates.

This option was deemed to have a high potential for impact of downdrift habitats by releasing large quantities of sediments for longshore transport. This method of transport is considered significantly different from the primary method of beach replenishment for this coast (cross shore bar migration). This is considered a significant impact on the habitat at Talacre. The exposure of sediments to large volumes of wave action also increase the cost of replenishment and nourishment of the frontage. On the basis of potential annual costs and the proposed impact to longshore habitats, this option was not considered the preferred option to mitigate flood risk at Splash Point.

6.4.3 Option 5b: Revetment and Recharge with Groynes

This option was similar to the option presented in Section 6.4.2 however this option was improved upon with the addition of a set of four cross shore groyne structures (ranging from 89m to 69 m in length). These additional features were designed to produce a stable groyne field with minimal loss down drift. This option improved upon Option 5a by minimising the release of sediments downdrift, increasing the potential for storage and reducing attrition rates, and reducing the potential for sediment losses downdrift

The addition of groynes, in theory will, allow annual nourishment volume and capital nourishment volumes to be decreased, and in turn reduce the potential for longshore dispersal and transport of sediments downdrift (although this was not represented appropriately in Delft3D model outputs.

This option was considered at less risk than the other two options presented, with lower levels of uncertainty surrounding the modification of coastal processes, a relatively low maintenance cost (through reduced annual nourishment volumes) and also a reasonable capital cost. This option was therefore considered the most appropriate to mitigate flood risk at Splash Point.

7 Evaluation of modelled of options

7.1 Summary

A coastal process assessment has been undertaken to refine the understanding of potential sediment management issues related to two coastal defence options for East Rhyl. Specific objectives were to:

- Refine estimates of sediment recharge volume and timing;
- Evaluate the effects of each option upon the physical distribution of sediment;
- Refine offshore breakwater position with regards to coastal stability; and
- Characterise impacts of the defence options on areas of environmental significance located downdrift (further east).

A layered evaluation was undertaken, combining review of existing literature, analysis of coastal monitoring and application of numerical modelling. Key findings of the evaluation include:

- The offshore breakwater needs to be located further offshore and westward to operate effectively. Relocation approximately 70m offshore from the original position is required;
- Recharge placed in conjunction with the revetment option will be rapidly transported eastward, unless controlled by secondary structures such as groynes;
- Options involving recharge will increase sediment supply to the downdrift coast. This effect will be dispersed by the intervening distance and effect of coastal protection works at Prestatyn. The sediment supply is volumetrically minor compared with existing year-to-year variation in beach volume occurring in the environmentally sensitive areas of Gronant and Talacre.

7.2 Coastal process analysis

Evaluation of active coastal processes was undertaken to support model selection, quantitative validation and interpretation. The evaluation included site visits, review of available literature and quantitative analysis of Denbighshire County Council coastal monitoring data.

East Rhyl has a tidally dominated coastline, with a relatively wide sandy shore that has been subject to progressive beach lowering over the 20th Century (see Figure 7-1). Wave conditions are low to moderate but are predominantly from the west-northwest. The high wave angle relative to the coast generates potentially high alongshore sediment transport, from west to east.

Figure 7-1: Rhyl Aerial Image, the difference between shore and nearshore ridge orientation

Coastal sediment transport is strongly modified by the formation of ridges and runnels in the intertidal zone, aligned in a direction that substantially reduces alongshore transport. Due to the low wave climate, which is comprised almost entirely of spilling breaker waves, these features are not characteristic of storm erosion-recovery cycles (i.e. storm bars), but behave more like coastal spits. The ridges are subject to frequent overwash, and therefore migrate landward and onshore, with a new spit being resolved each year, and taking 3-4 years to migrate onshore (Figure 7-2). There is some evidence of secondary geomorphic features developed through tidal flow within the runnels, particularly where they interact with coastal structures.

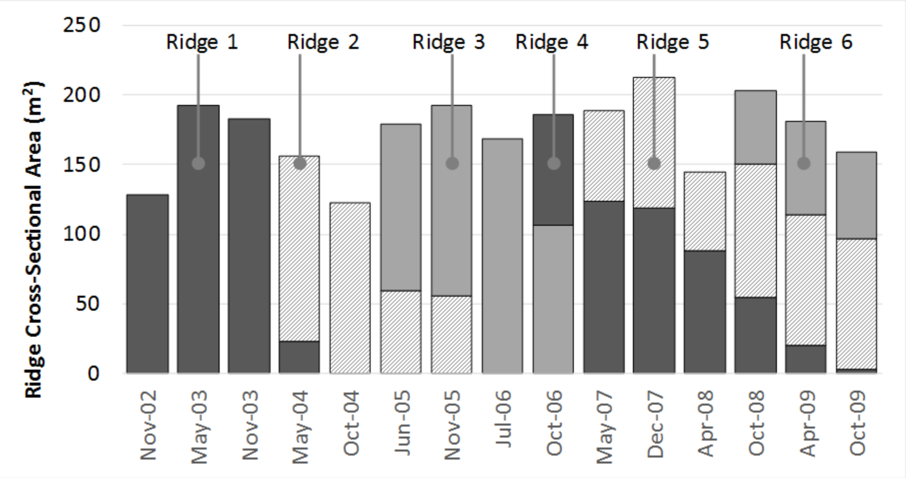


Figure 7-2: Cross-sectional Area of Beach Ridges, showing time sequence of onshore sediment delivery

Material that is deposited onshore due to ridge migration is subject to a greater alongshore stress due to the shoreline aspect, resulting in an approximate balance between the onshore supply and the alongshore transport. For the existing delivery rate, estimated at 60 m^3/m per year (mean supply over 2002-2009, derived from monitoring profile DCC07), this is equivalent to an alongshore transport rate of approximately 20,000m^3/yr from the section of coast between Splash Point and the beach access ramp. This transport rate corresponds to a beach level of approximately +2.5mAOD, and a higher beach, such as placed by a recharge scheme, will experience higher rates of alongshore sediment transport.

Long-term observations of beach lowering and narrowing of the intertidal zone along the Rhyl-Prestatyn shore suggest that there was a net tendency for erosion over the 20th Century. Much of this change is directly attributable to coastal works, including material excavation, a substantial training wall for the River Clwyd and coastal revetments. Modern observations from the Denbighshire County Council coastal monitoring programme since 2002 indicate a relative cessation of the historic erosion trend. However, due to the comparatively short duration of the monitoring program, it is not wholly certain that the coast has reached a degree of relative stability.

Analysis of coastal profiles from the east Rhyl site has indicated that the sandy material comprising the migratory ridges moves over a stable planar bed, including the occasionally exposed clay under-layer. The under-layer was not subject to measurable erosion during the monitoring period. Year-to-year variation in the volume of sediment in the ridges, and their relative movement, explains most of the previously reported volume changes on east Rhyl beach.

7.3 Regional transport modelling

Alongshore coastal sediment transport was assessed from Abergele to the Point of Ayr using the range of assessment techniques available within the Unibest coastal model (Figure 7-3). These techniques vary from bulk littoral transport formulae that are purely based on wave climate and shore aspect through to 1D modelling that has greater consideration of coastal profile structure, sediment size and spatial connectivity. In all cases, the modelling indicated a predominant west to east sediment transport, with a wide range of transport rates derived, from 2,500 m^3/yr to 115,000 m^3/yr. The highest estimated rate of transport was associated with the simplest bulk littoral transport rate, using the CERC formula. Previous application of this formula, based on a wave climate from further offshore, gave transport estimates of 330,000 m^3/yr to 465,000 m^3/yr (Halcrow 2010).

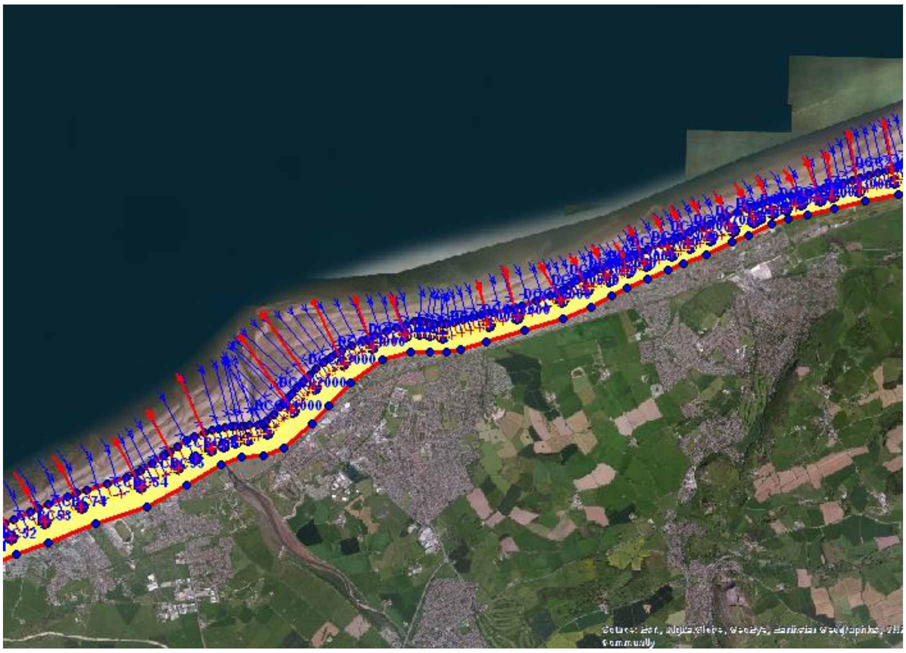


Figure 7-3:Illustration of Unibest profile density (blue lines), with comparison against measured profiles (red lines)

A key benefit of using the Unibest suite of assessment techniques is that it supports evaluation of the effect of physical attributes associated with each additional model refinement. In this case, most of the "additional physics" corresponds to morphological features that are present on the Rhyl foreshore. Consequently, there is a degree of confidence accepting the consequent reduction in projected alongshore sediment transport rates. The high rates of alongshore transport suggested by the simpler models are not supported by either the rates of erosion observed further updrift along the north Wales coast, or on the depositional features located further downdrift at Talacre and Gronant.

The best estimate range for mean littoral transport is 30,000 to 45,000 m^3/yr. This is based upon 1D modelling that accounts for variation of the profile grade, and truncation of the profile due to the existing revetment. However, the modelling is not capable of resolving the difference between the shore aspect and alignment of the intertidal ridges, and therefore can be expected to provide an overestimate of the alongshore transport rate. In effect, the modelling is consistent with the observational estimate of approximately 20,000 m_3/yr being delivered through onshore ridge migration, and subsequently removed by alongshore transport.

A higher resolution hydrodynamic and geomorphic model was applied to assess alongshore sediment transport for the defence options. The Delft3D modelling suite was used in both 2D and 3D modes.

7.4 Modelling of East Rhyl defence options

Two defence options were evaluated for the east Rhyl foreshore between Splash Point and the beach access ramp (to the east):

A rock offshore breakwater 350m long, was initially modelled for a location approximately 115m offshore and slightly east from Splash Point (Option 4). Two subsequent iterations were also modelled, first moved westward to ensure protection of Splash Point from the prevailing waves, then subsequently moved offshore to reduce the potential for the shoreline behind to connect to the breakwater.

The anticipated result of constructing an offshore breakwater is formation of a sediment body in the sheltered area behind the breakwater (Figure 7-5). This required assessment using the empirical model developed by Hsu & Silvester (1990). A volume of recharge is required to infill the expected feature, rather than cause near-field erosion if the feature were to draw material from the adjacent beach. The required volume of recharge was estimated as 156,000 m^3 for the breakwater option located furthest offshore.

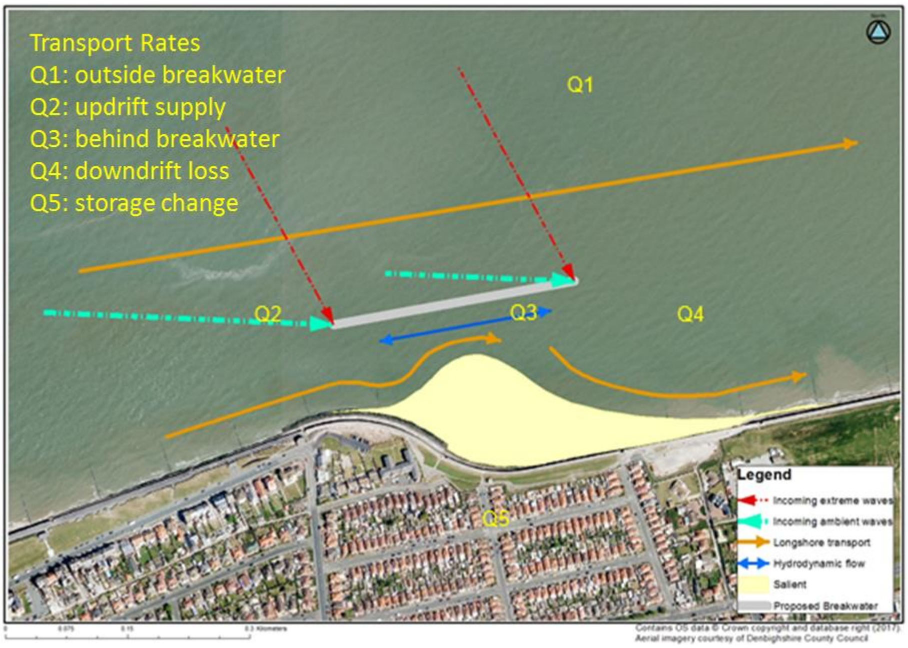


Figure 7-4 Transport Components Associated with the Offshore Breakwater Option and Associated Salient

A large volume of beach recharge was modelled, to investigate the recharge volume and rates potentially associated with revetment redesign. The “maximum” amount of sediment that could practically be placed on the beach (~200,000m^3) was modelled, with the understanding that the loss rate would progressively decline over time as the amount of “excess” fill on the beach reduced.

Sediment loss rates for the two options were determined using both the 1D modelling approaches used for regional transport modelling and higher resolution hydrodynamic and geomorphic modelling using the Delft3D modelling suite. As with the regional transport modelling, a layered assessment approach was used, including implementation of the high-resolution modelling in both 2D and 3D modes.

The 2D and 3D modelling replicated geomorphic attributes associated with the East Rhyl foreshore, including ridge and runnel migration. It also supported understanding of the sediment feature behind the offshore breakwater Figure 7-35) suggesting the need for locating the structure further offshore. However, the modelling also demonstrated relative biases and instabilities of each model (Figure 7-6), with the 2D mode causing higher rates of onshore sediment movement than are supported by observations. The 3D mode suggested slightly lower stability of the beach recharge for both options but created hydrodynamic features that were not considered realistic.

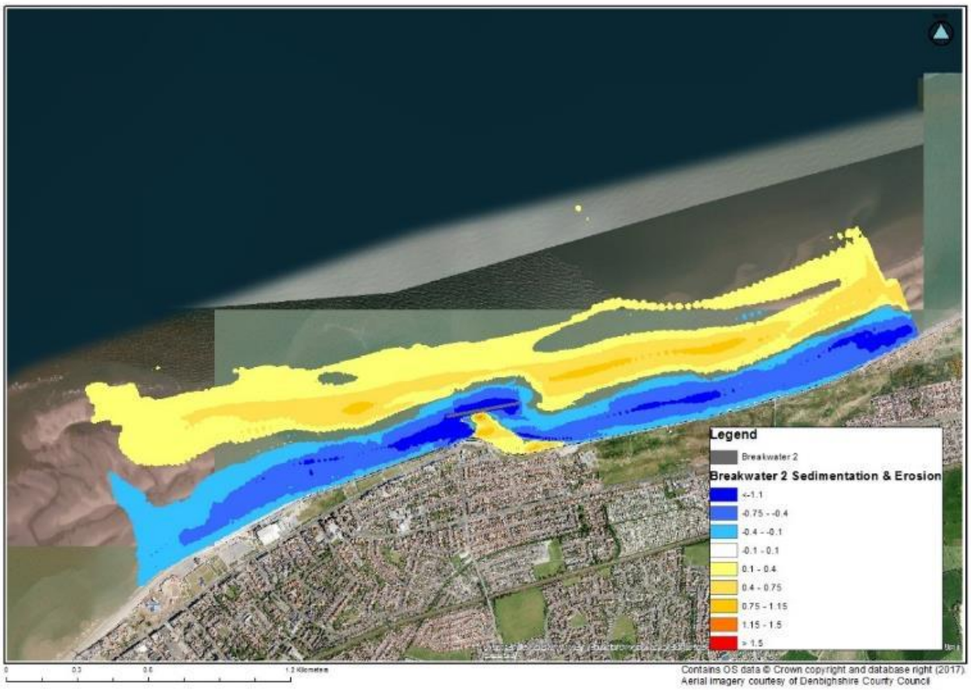
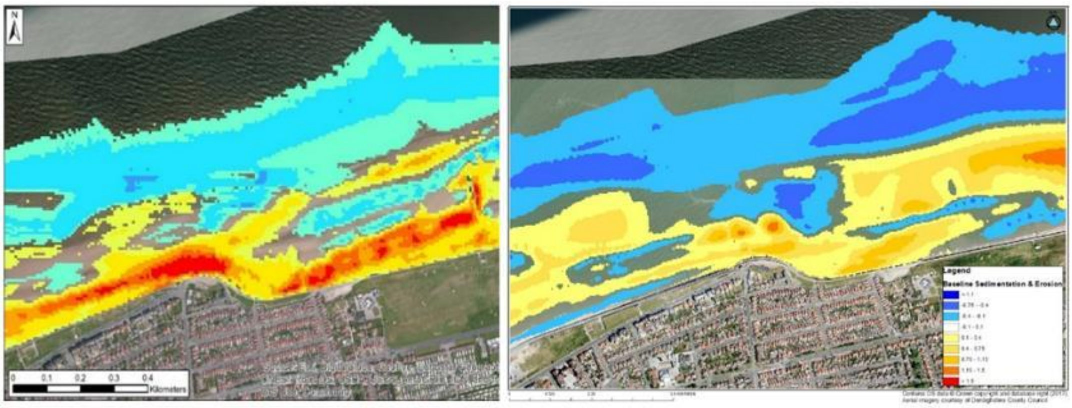


Figure 7-5 Sedimentation & erosion associated with offshore breakwater, showing salient



2D modelling simulates high rates of onshore sediment transport

Improved representation of shoreline processes in 3D modelling

Figure 7-6: Comparison of 2D and 3D model outcomes for existing case simulation

In all cases, the sediment size modelled was derived from the median particle size distribution of in situ sand. This represented fine-medium sand, with a median diameter of 0.26 mm. The effect of placing differently sized material will be to modify the required recharge rates, with coarser material typically requiring slightly less recharge (sediment with almost 50% larger mean diameter reduces the ongoing recharge rate by approximately 15%), but finer material may require a far higher rate of recharge (sediment with 40% smaller mean diameter increases the ongoing recharge rate by approximately 30%).

7.5 Key outcomes of the modelling

The required volumes and rates of sediment recharge volumes are large, due to the high potential for alongshore sediment transport. Material placed without constraint on East Rhyl beach will be rapidly transported eastward, and therefore any beach restoration associated with the revetment option should also include installation of groynes to slow the rate of sediment loss.

The original position of the offshore breakwater was determined likely to result in the shoreline attaching to the rock structure. This would effectively block alongshore flow, acting more like a groyne than a breakwater, with consequent downdrift erosion stresses likely to occur on the east side of the breakwater's wave shadow. The ability for the sediment feature to act as a sand source during periods of erosion stress would also be reduced, limiting its intended functionality.

The offshore breakwater needs to be located further offshore and westward to operate effectively. Relocation approximately 70m offshore from the original position is required.

Further to this analysis, the impracticality of maintaining a large volume recharge on the beach as part of the revetment option (Option 5a) was recognised. The option of using groynes to provide partial retention of sand on the east Rhyl beach (Option 5b) has been subsequently evaluated and included within cost-estimates. Comparison of the estimated recharge requirements (capital and ongoing) of the three options is summarised in Table 7-1 below. An upper limit allowance for ongoing recharge has been presented, to illustrate the uncertainty associated with modelled transport rates.

Table 7-1 Recharge estimates associated with defence options

Option	Capital Recharge Volume	Recommended Allowance for Ongoing Recharge	Upper Allowance for Ongoing Recharge
4 - Offshore Breakwater	156,000 m^3	5,000 m^3/yr *	15,000 m^3/yr
5a - Revetment Rebuild with recharge	200,000 m^3/yr (max) 99,000 recommended	10-30,000 m^3/yr	60,000 m^3/yr
5b - Revetment Rebuild, Recharge and Groynes	56,000m^3	7,000m^3/yr *	20,000m^3/yr
* Both the offshore breakwater and groynes have been designed for overall net stability. However, it is prudent to allow for potential ongoing loss.			

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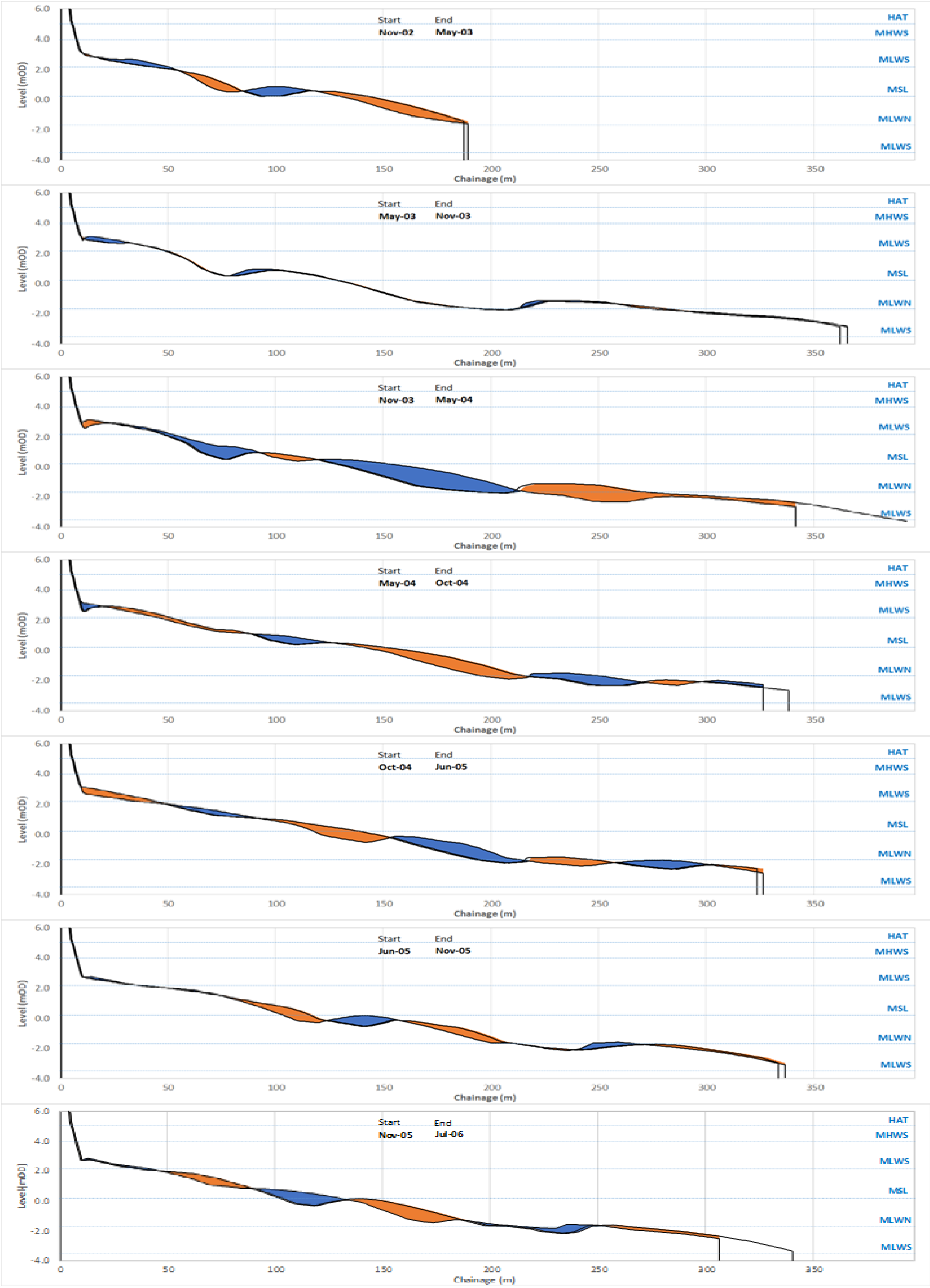
9 Appendix A: Beach Profile Time Sequences



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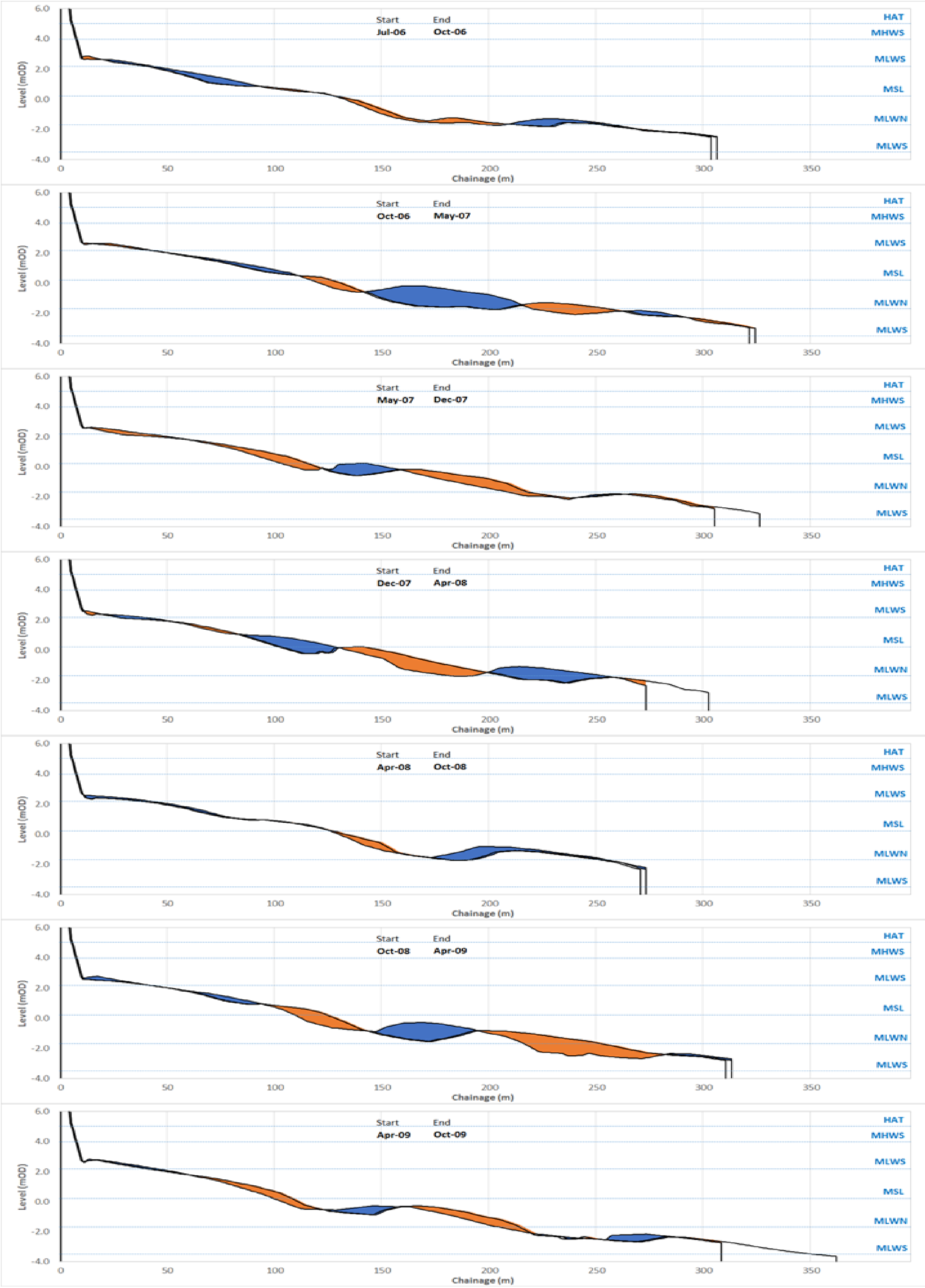
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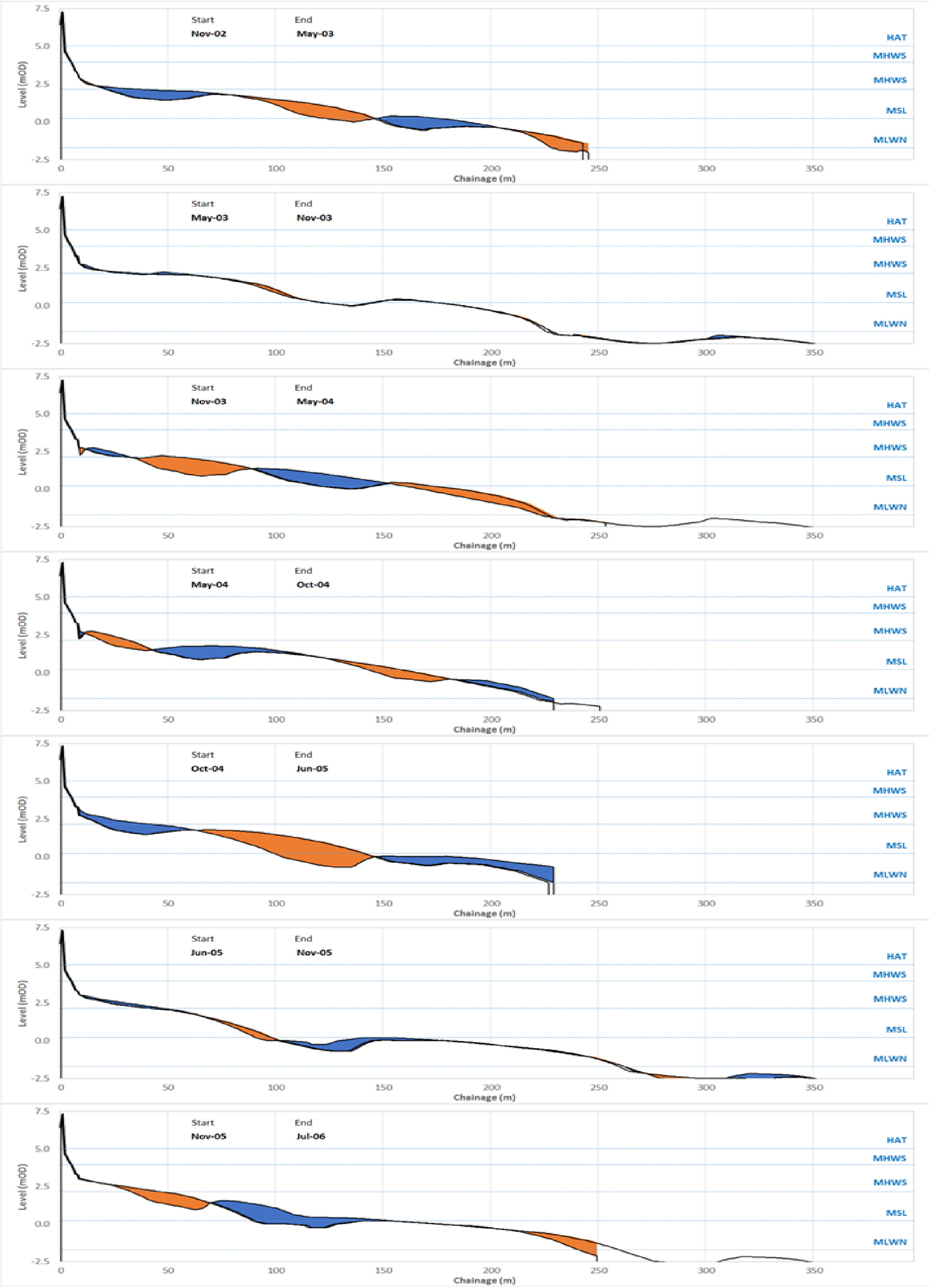
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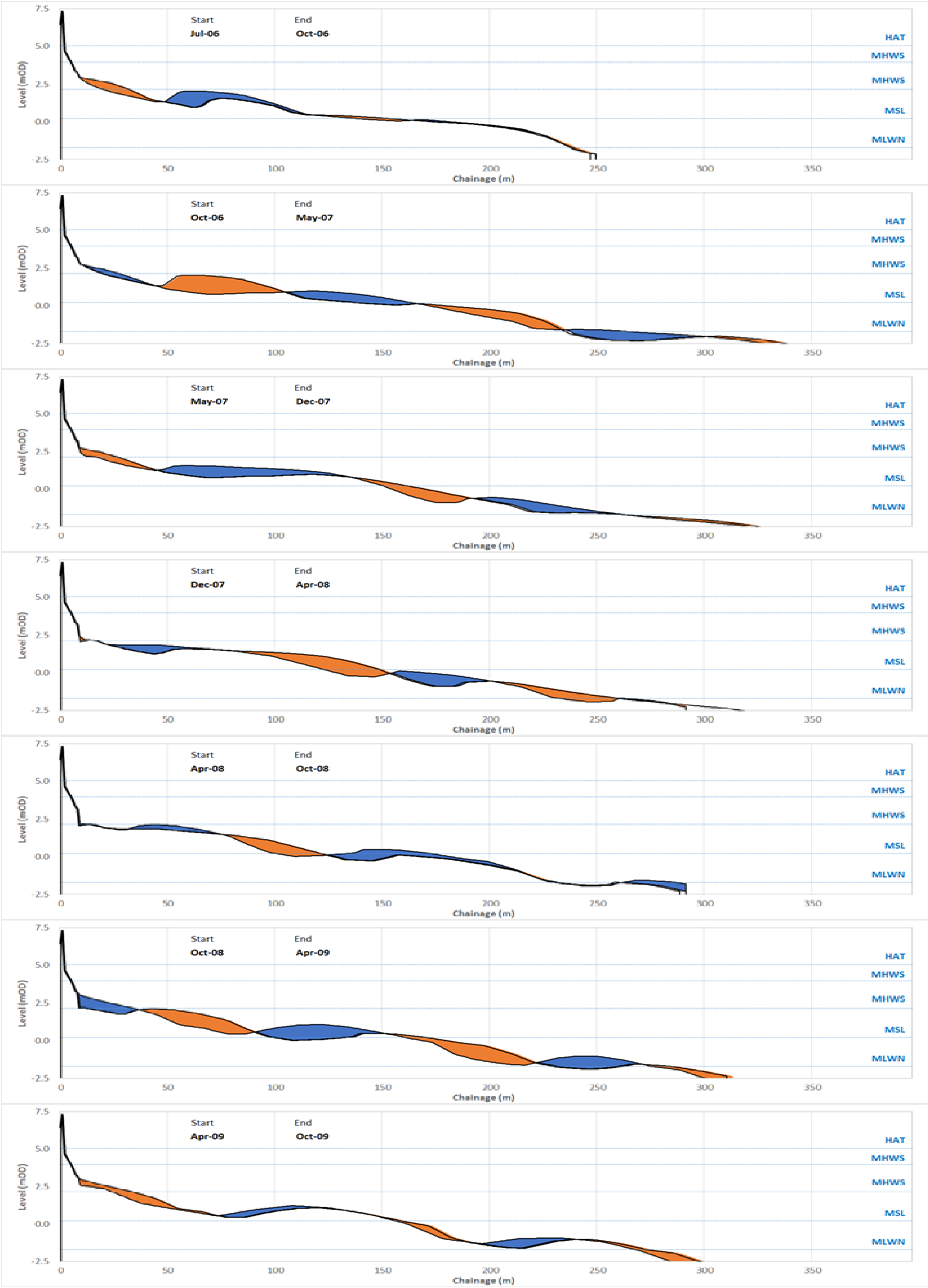
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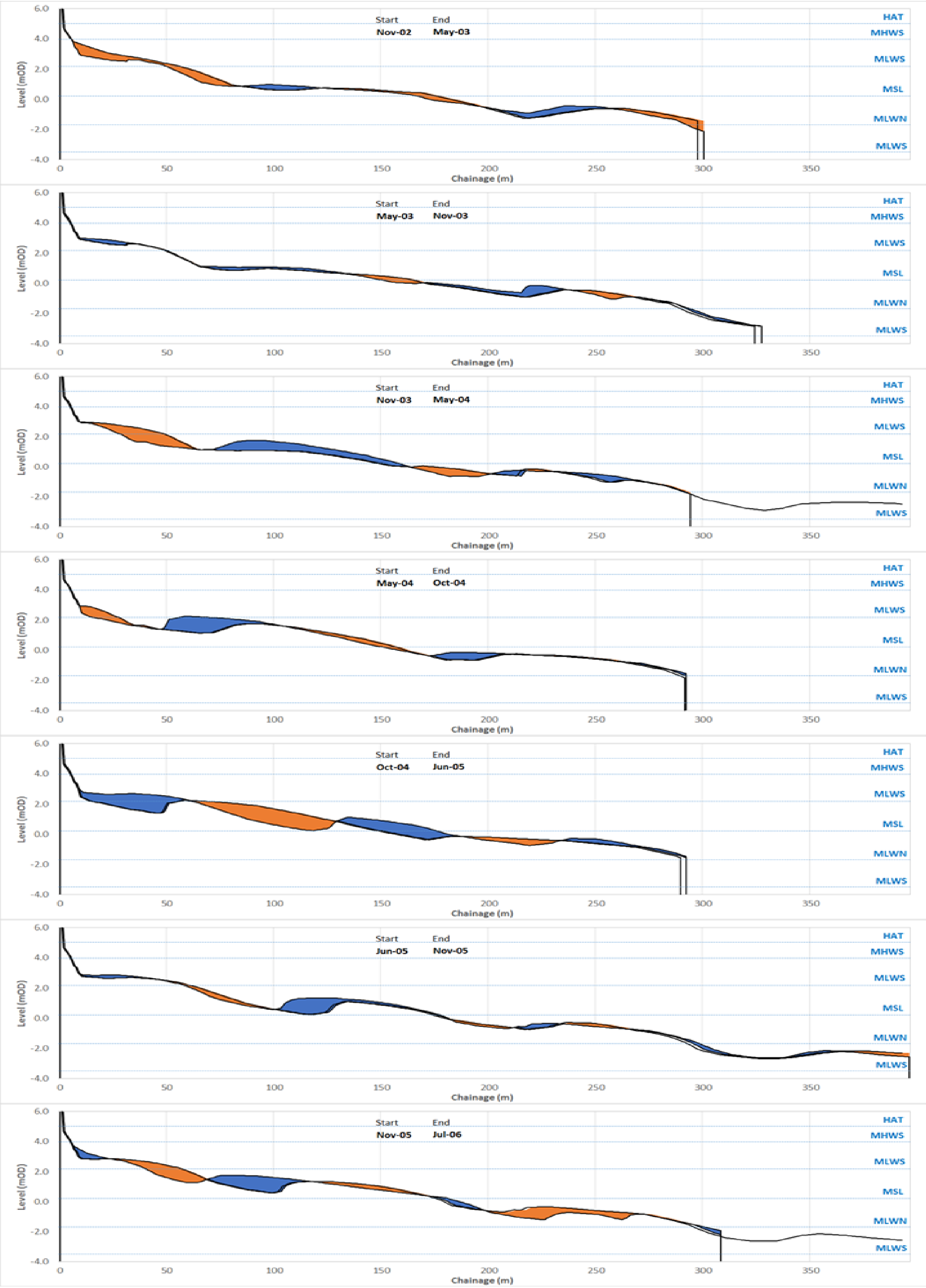
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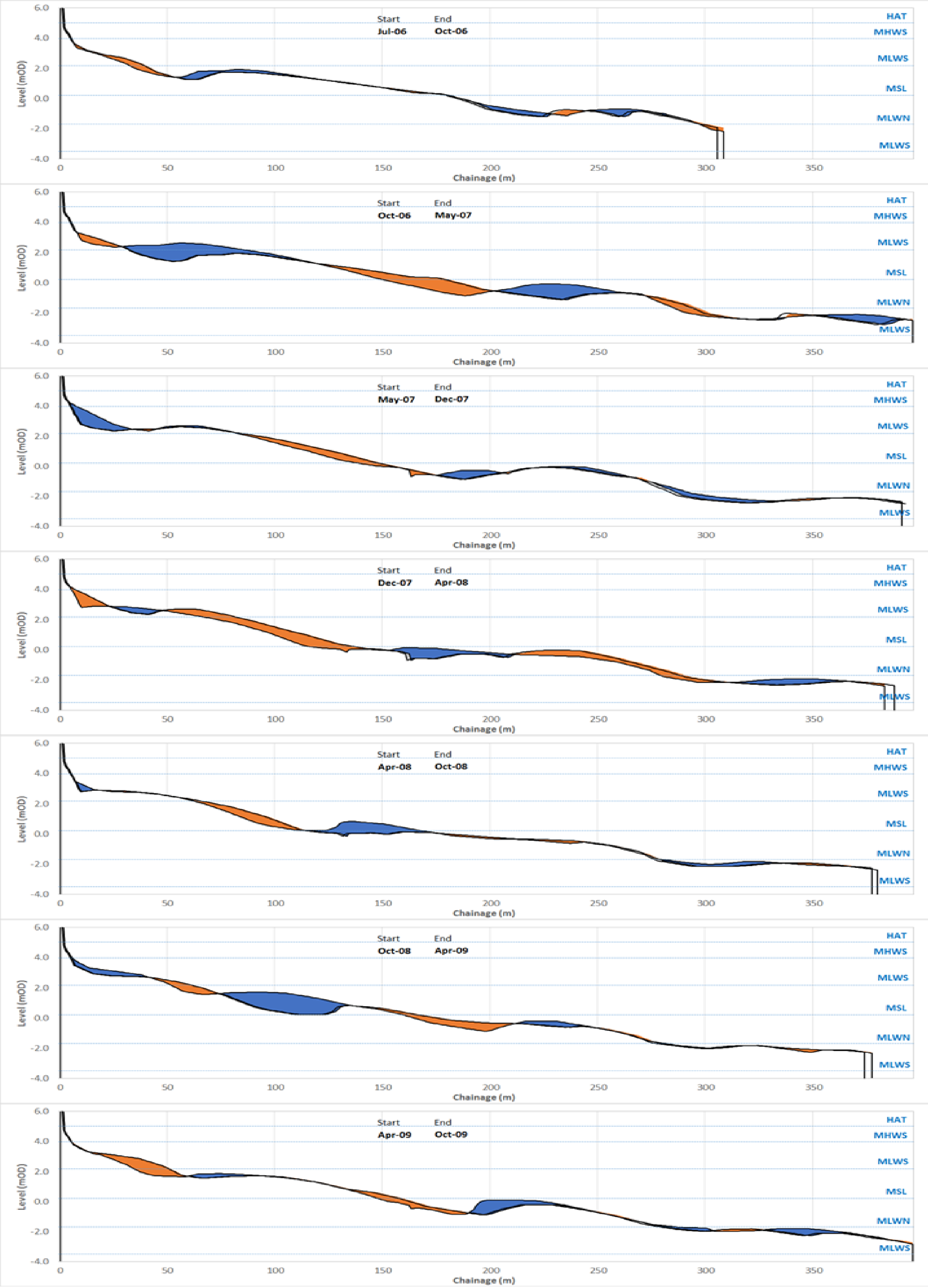
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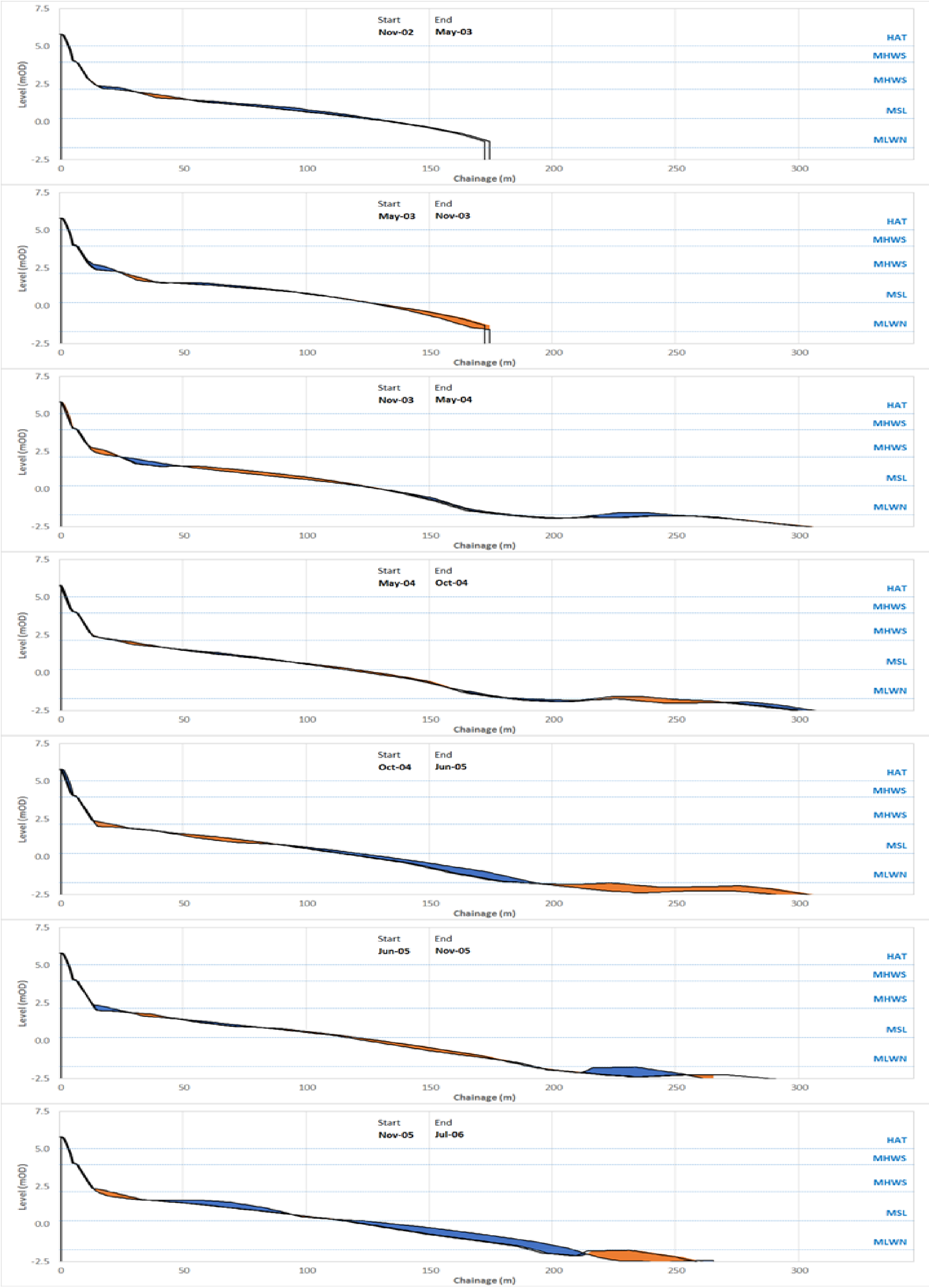
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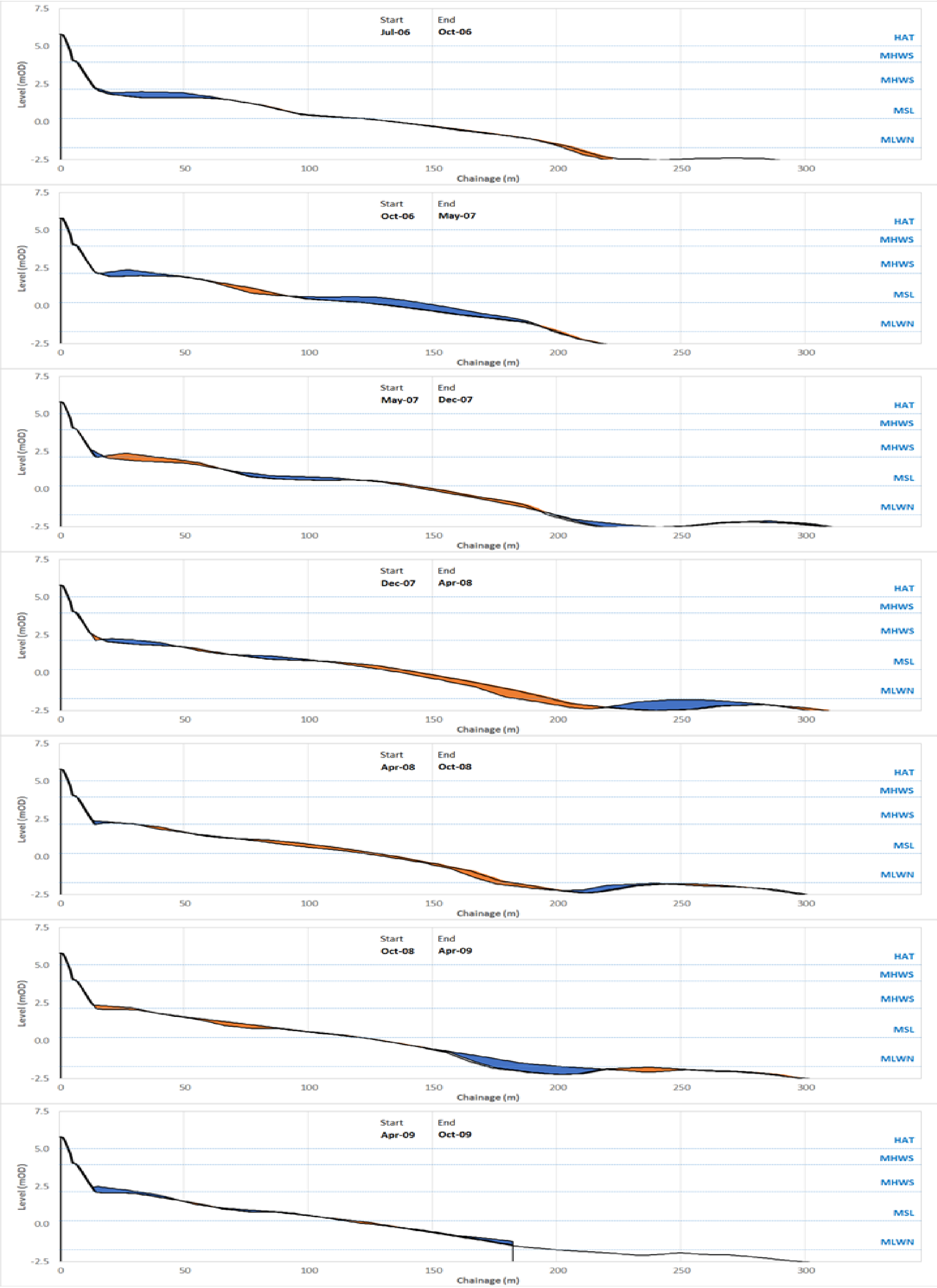
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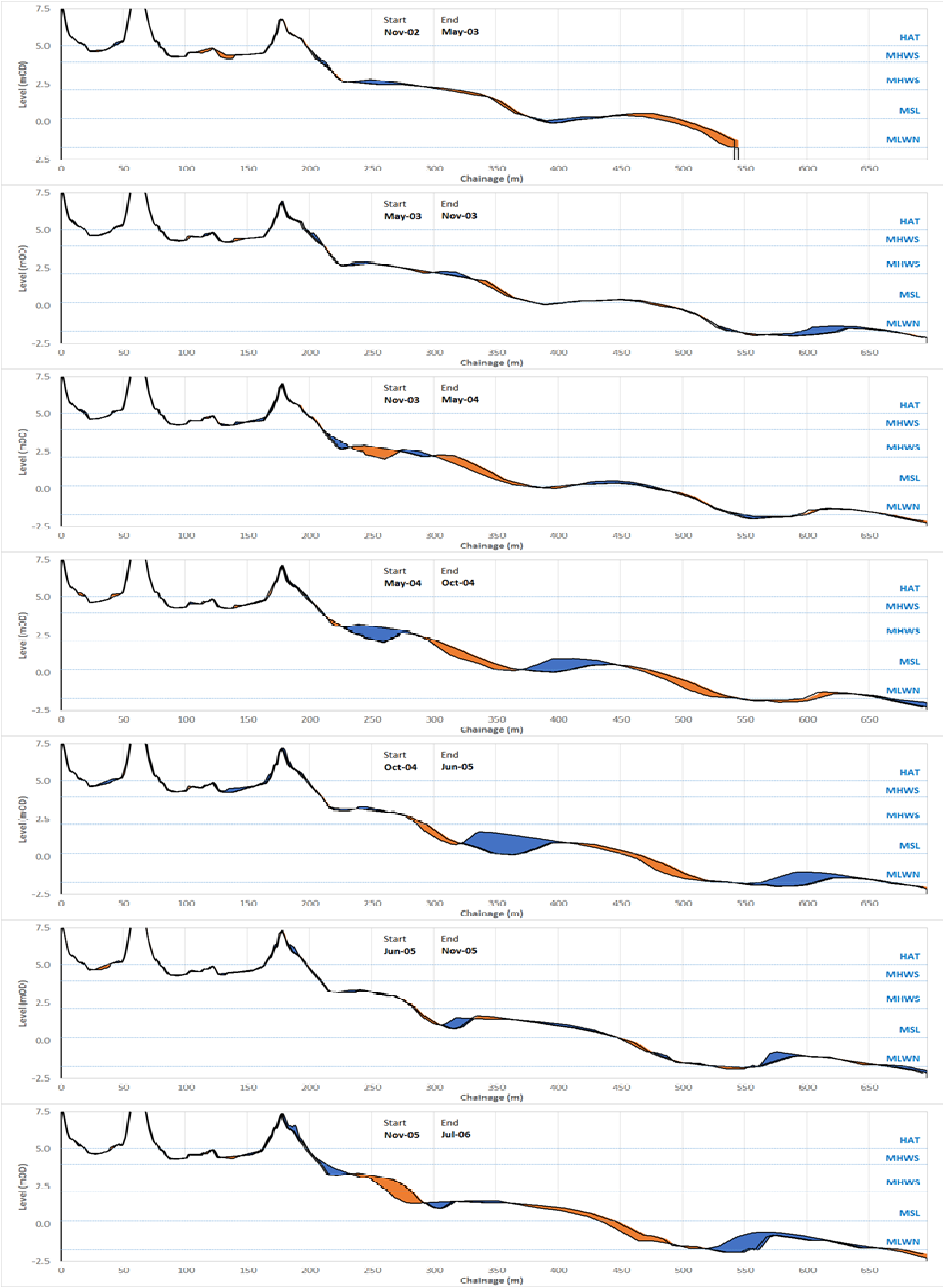
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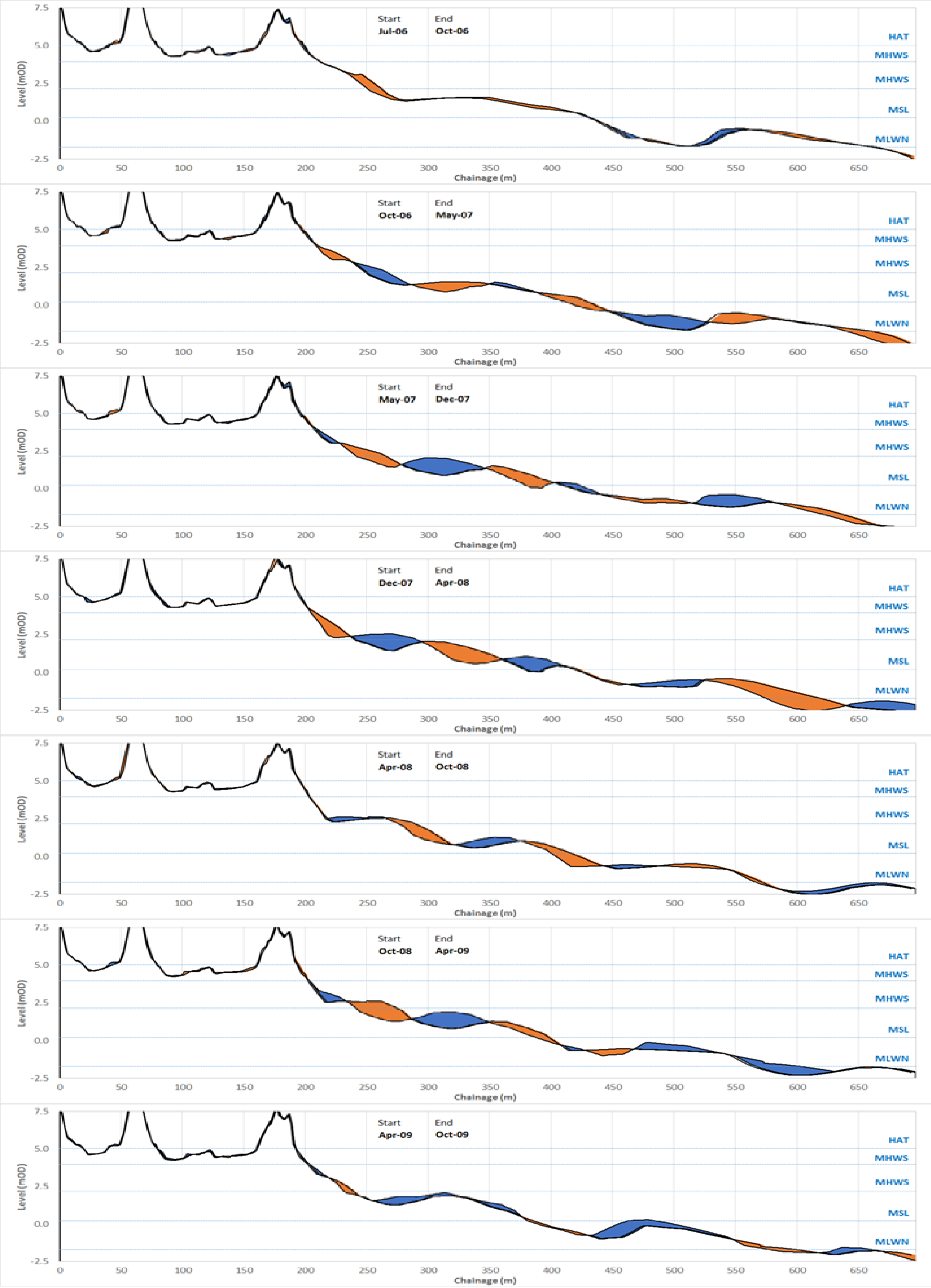

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Profile 24

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East Rhyl Coastal Defence Scheme

Water Framework Directive Assessment

Final Report

October 2018

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Revision Ref/Date	Amendments	Issued to
v0-1 / 9 October 2018	Internal review	Mark Cope
v1-1 / 16 October 2018	Client review	Balfour Beatty

Contract

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

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Environmental Consultant

Reviewed by .... David Revill BSc MSc CEnv MIES

Principal Environmental Consultant

Purpose

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Abbreviations

AOD	Above Ordnance Datum
BGL	Below Ground Level
CEMP	Construction Environmental Management Plan
DCC	Denbighshire County Council
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DrWPA	Drinking Water Protected Area
EQSD	Environmental Quality Standards Directive
GEP	Good Ecological Potential
GES	Good Ecological Status
HMWB	Heavily Modified Water Body
HTL	Hold The Line
INNS	Invasive Non-Native Species
LDP	Local Development Plan
MAGIC	Multi-Agency Geographic Information for the Countryside
MHWS	Mean High Water Spring
PU	Policy Unit
RBMP	River Basin Management Plan
SMP2	Shoreline Management Plan 2
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
WFD	Water Framework Directive

1 Introduction

1.1 Background

This Water Framework Directive (WFD) assessment has been prepared to inform the development and design of the East Rhyl Coastal Defence Scheme in Denbighshire, North Wales. It accompanies an application to Denbighshire County Council (DCC) for full planning permission for the proposed development.

The report has been prepared following a range of good practice guidance for WFD assessment:

- Guidance for assessing activities and projects for compliance with the Water Framework Directive, OGN72, Version 1.1, May 2017, Natural Resources Wales.
- Water Framework Directive assessment: estuarine and coastal waters – How to assess the impact of your activity in estuarine (transitional) and coastal waters for the Water Framework Directive (WFD), 9 November 2017, Environment Agency. Available at: https://www.gov.uk/guidance/water-framework-directive-assessment-estuarine-and-coastal-waters
- Advice Note 18: The Water Framework Directive, Version 1, June 2017. The Planning Inspectorate. Available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/uploads/2017/06/advice_note_18.pdf
- Local Authority services and the water environment: Advice note on the Water Framework Directive, Natural Resources Wales. Available at: https://naturalresources.wales/media/2627/wfd-docs-eng.pdf

It includes key elements of the Scoping Template provided within the Environment Agency Guidance (2017), which clearly sets out all potential risks to the WFD receptors associated with the proposed development. The Scoping Template has been modified to enable consideration of WFD groundwater waterbodies in addition to surface waterbodies. Data on the status of WFD waterbodies has been obtained from the Water Watch Wales website[1] and the Multi-Agency Geographic Information for the Countryside (MAGIC) website[2].

1.2 Project description

The proposed development seeks to improve the standard of coastal flood protection to the community of East Rhyl in Denbighshire, North Wales. The proposed defences comprise a new 600m section of rock revetment together with works to increase the height of a 550m long section of existing sea wall, located between Splash Point (NGR: SJ020825) and the western boundary of Rhyl Golf Course (NGR: SJ026825). Figure 1-1 shows the location of the proposed scheme between Splash Point and Rhyl Golf Club.

Rhyl is a seaside resort town located east of the Clwyd Estuary. The existing coastal flood defences, which comprise a concrete seawall, concrete stepped revetment and section of rock armour revetment around Splash Point, are subject to wave overtopping, which causes significant damage and disruption to adjacent residential and commercial properties, as well as Rhyl Promenade and the Wales Coast Path, which are important components of the local tourism industry. This became evident in 2013 when deep flooding of 130 residential properties occurred. As the risk of extensive coastal flooding grows due to climate change and associated sea level rise, it is increasingly important that the existing sea defences are upgraded to provide a higher standard of protection.

---

[1] Water Watch Wales website. Available at: http://waterwatchwales.naturalresourceswales.gov.uk/en/ [Accessed 4 July 2018]

[2] Multi-Agency Geographic Information for the Countryside (MAGIC) website. Available at: http://www.magic.gov.uk/ [Accessed 29 August 2018]

Figure 1-1: Scheme location

Rhyl Beach is a wide sandy beach with an extensive tidal range. It is a popular tourist destination and supports a range of recreational activities. Much of the beach is designated under the EU Bathing Waters Directive with the sub-tidal area designated as part of the Liverpool Bay Special Protection Area (SPA). The is located within a wider section of the North Wales coast that has undergone extensive modification. This has had a significant effect on natural coastal processes with widespread beach lowering occurring throughout the 20th century. Recent survey data[3] shows that onshore and longshore sediment transport processes are approximately balanced.

1.2.1 Proposed development

The proposed development will improve the standard of coastal flood protection and improve public access from Rhyl Promenade to the beach for both beach users and routine beach/flood defence maintenance activities.

[3] JBA Consulting (2018), East Rhyl Coastal Defence Scheme, Environmental Statement, Chapter 4; Coastal Hydrology and Hydromorphology

The proposed development will comprise the following activities:

- Removal of the existing 225m long section of rock armour around Splash Point and construction of a new 600m long section of rock armour revetment between Splash Point and the golf course. The new rock armour revetment will extend approximately 30m from the existing sea wall. The revetment will be formed of a double interlocking layer of 3-6 tonne rock armour, sloping from a crest of approximately 15mAOD, at a 1-in-3 gradient to a 5.5m wide toe.
- A 550m section of the existing seawall will be raised by approximately 0.5m. The existing upstand will be removed and replaced with a recurved upstand constructed from precast concrete units. The Promenade, located landward of the seawall, will be raised by 500mm so that views from the walkway out into Liverpool Bay are not obscured.
- Access to the beach will be maintained via three sets of precast concrete steps provided through the concrete upstand and rock armour revetment. These would be placed opposite Tynewydd Road, Hilton Drive, and Garford Road.

The majority of the proposed new rock revetment is located below current Mean High Water Spring (MHWS) tidal level.

A full and detailed description of the proposed development is provided in the Environmental Statement (ES)[4], which has been prepared to accompany the planning application for the scheme.

1.2.2 Construction methodology

The rock armour revetment will be constructed in 10m to 20m sections per tidal cycle. All site material (rock armour and precast concrete units) will be delivered to the site by road and onto the beach via a temporary slipway located immediately to the west of Splash Point. Temporary storage and sorting of rock will take place on the beach adjacent to where the rock will be placed in the revetment.

Construction of the rock revetment toe will require removal of the existing timber groynes within the footprint of the revetment (150m of groyne to be removed). The beach will then be excavated to 0mAOD along the revetment toe using an excavator. Excavated sand/shingle will be temporarily stockpiled next to the excavation. A geotextile membrane will then be laid directly over the excavated area, which will then be covered by a thin filter layer of stone. Graded rock armour will then be placed one-at-a-time onto the filter layer using an excavator with a grab attachment. Once the 10m to 20m section of revetment toe is complete, the previously excavated sand/shingle material will be reused to cover over the toe rock to the existing beach level. Construction of the remainder of the rock revetment section to the required crest level will then take place using the excavator positioned on the toe area. The works will progress in this fashion until revetment works are complete (25 months).

Construction of the access steps through the rock armour revetment would require excavation to the required foundation depth (-1mAOD). The foundations would be made using in-situ concrete pouring, which will be contained within a temporary sheet pile arrangement or through use of drag boxes.

Demolition of the upstand of the existing sea wall will take place in sections. All demolition waste will be removed from site and appropriately disposed of. In parallel with demolition of the old sea wall, the new precast upstand will be placed onto the concrete buttress using an excavator.

[4] JBA Consulting (2018) – East Rhyl Coastal Defence Scheme, Environmental Statement, October 2018

Construction of the scheme will take approximately 38 months to complete. Following completion of the works, the construction area, including affected areas of Rhyl Beach, will be reinstated to pre-construction conditions.

1.2.3 Breakdown of development aspects

Table 1-1 provides a breakdown of the individual components of the proposed scheme. These aspects will be assessed to determine whether they could cause or contribute to the deterioration in status of a waterbody or inhibit a waterbody from achieving its status objective.

Table 1-1: Breakdown of individual components of the proposed development

Component of the proposed development
Establishment, use and decommissioning of two temporary construction compounds. The main site compound will be located adjacent to the Pavilion Theatre with a smaller satellite compound adjacent to Garford Road. Establishment of site offices and welfare facilities, construction staff car parking, construction material delivery/storage areas, and waste storage facilities. Some vegetation clearance will be required to enable establishment of the main compound.
Temporary diversion of Wales Coast Path/National Cycle Route around construction area.
Establishment of temporary construction access route along Rhyl Promenade, between the main site compound and work area on the beach, including installation of temporary access ramp near Splash Point.
Permanent removal of 150m of existing timber groynes.
Temporary storage and sorting of rock armour on Rhyl Beach adjacent to works area.
Construction of concrete buttress for new seawall involving installation of formwork panels and in-situ concrete pouring.
Construction of rock revetment including excavation of revetment toe and temporary storage of excavated beach material, laying of new geotextile membrane, placement of rock armour blocks, and backfilling of excavated material.
Construction of new seawall upstand including demolition of existing concrete upstand (using either diamond track saw cutting or using a grinding or pinching excavator attachment) and installation of new pre-cast concrete wave return upstand. All demolition waste to be removed from site for appropriate disposal.
Construction of stepped access points through rock revetment requiring installation of temporary sheet pile cofferdam to create dry working area, excavation of foundation area to -1mAOD, in-situ concrete pouring to create foundation, and installation of the pre-cast step units.
Construction of new concrete pavement formed using a 150mm hydraulically bound sub-base and concrete slabs cast in-situ.
Re-grading and seeding of the grass bank landward of the Promenade and reinstatement of memorial benches.
Reinstatement of the construction area to pre-construction conditions including removal of temporary access ramp and re-establishment of beach to pre-construction levels (as necessary) using excavated beach material.
Operation of the completed flood defence scheme.
Periodic maintenance of the completed flood defence scheme.

1.3 Purpose of the report

1.3.1 Scope of this assessment

The WFD (2000/60/EC) is implemented in England and Wales by the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, which revoke and replace the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003. The framework for delivering requirements of the WFD is through River Basin Management Plans (RBMPs).

The Regulations require that Environmental Objectives are set for all surface (including river, lake, coastal and transitional waters) and groundwaters in England and Wales to enable them to achieve a Good status by a defined date. These Environmental Objectives are listed below:

- Prevent deterioration in the status of aquatic ecosystems, protect them and improve the ecological condition of waters;
- Aim to achieve at least Good status for all waterbodies by 2015. Where this is not possible and subject to the criteria set out in the Directive, aim to achieve Good status by 2021 or 2027;
- Meet the requirements of WFD Protected Areas;
- Promote sustainable use of water as a natural resource;
- Conserve habitats and species that depend directly on water;
- Progressively reduce or phase out the release of individual pollutants or groups of pollutants that present a significant threat to the aquatic environment;
- Progressively reduce the pollution of groundwater and prevent or limit the entry of pollutants; and
- Contribute to mitigating the effects of floods and droughts.

Surface waterbody status is made up of its ecological status and its chemical status. Ecological status is defined by a series of biological 'quality elements' and physico-chemical, hydromorphological, and chemical 'supporting elements' (which support the biological elements). Chemical status comprises a series of priority substances and other pollutants (listed in the Environmental Quality Standards Directive (EQSD)). These quality elements are taken from Annex V of the Directive.

The status of all relevant quality elements is classified according to five categories: 'High', 'Good', 'Moderate', 'Poor' and 'Bad'. The overall status of a waterbody is determined by the lowest elements status e.g., if all biological quality elements and supporting elements are at 'Good' status, except for one, which is at 'Moderate' status, then the ecological status is at 'Moderate' and the overall status is 'Moderate'. Published guidance requires that all quality elements need to be considered as part of a WFD assessment.

Groundwater waterbody status is defined by its 'quantitative status' and its 'chemical status'. Two classes are attributed to both quantitative and chemical status: 'Good' and 'Poor'. Both elements need to be at good status before the waterbody can be classified as 'Good'.

Under the WFD, Heavily Modified Waterbodies (HMWB) are bodies of water that are substantially changed in character due to physical alterations by human activity and cannot meet 'Good Ecological Status' (GES). Therefore, mitigation measures are set for the waterbody so that it achieves 'Good Ecological Potential' (GEP). This assessment therefore must consider whether the proposed scheme will conflict with the measures in place now or planned for the future, and whether this could affect the status of the hydromorphological quality elements (and ultimately the status of the waterbody).

1.3.2 Small non-reportable waterbodies

All waterbodies are protected under WFD. This includes stretches of water considered too small to be a formal WFD waterbody, such as ditches, small streams, and brackish lagoons. As such, deterioration of such water should be prevented. In the absence of any classification data relating to these waterbodies, it should be assumed that they are at 'Good' status. Therefore, any proposed development that could affect such a waterbody should be assessed to determine whether it could cause deterioration from good status.

1.3.3 Protected areas, priority habitats and invasive non-native species

Published guidance also states that the assessment must also consider the CC\potential impacts on the following:

- Protected areas – these are defined under Article 6 of the Directive and include the following:
  - Areas designated for the abstraction of water for human consumption (Drinking Water Protected Areas);
  - Areas designated for the protection of economically significant aquatic species (Freshwater Fish and Shellfish);
  - Bodies of water designated as recreational waters, including areas designated as Bathing Waters;
  - Nutrient-sensitive areas, including areas identified as Nitrate Vulnerable Zones under the Nitrates Directive or areas designated as sensitive under Urban Waste Water Treatment Directive (UWWTD); and
  - Areas designated for the protection of water-dependent habitats or species, including relevant Natura 2000 sites.
- Priority Habitats – these are "habitats of principal importance for the conservation of biodiversity", which are defined under Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 in England and Section 7 of the Environment (Wales) Act 2016 in Wales. Detailed assessment is required if a proposed development would significantly impact on a priority habitat that is critical to the ecological health of a waterbody i.e., directly impacts habitats that are critical to the individual biological quality elements.
- Invasive non-native species (INNS) – assessment of INNS is required if a development could cause the introduction or spread of INNS into a waterbody.

1.3.4 Approach to WFD Assessment

All new activities in the water environment need to the take account of the requirements of the WFD. For a project or activity to be compliant with the WFD, it should demonstrate that:

- There is no risk of it causing a deterioration in the status of any element; in addition, for groundwater, it will limit or prevent the input of pollutants;
- There is no risk of it preventing WFD protected areas from achieving their objectives;
- It will not jeopardise any waterbody from achieving good status/potential; and
- It will contribute to the protection, enhancement and restoration of waterbodies.

Therefore, this WFD assessment aims to determine whether the proposed development would have the potential to cause or contribute to the deterioration in status of a WFD waterbody or inhibit a waterbody from achieving its status objective. It also assesses the potential for the development to contribute to the objectives of the WFD.

The assessment identifies all activities that will take place as part of the proposed development, during both construction and operation, and where risks of an impact on the WFD quality elements might arise due to these activities.

This assessment follows published good practice guidance and has been undertaken following a staged approach:

- Stage 1: screening – to determine whether any activities associated with the proposed development do not require further consideration i.e., do not need to go through the scoping or impact assessment stages because there is no more than a low risk of a potential impact on a waterbody;
- Stage 2: scoping – identifies the potential risks associated with the proposed activities and the WFD receptors that are at risk i.e., those risks that need impact assessment; and
- Stage 3: impact assessment – a detailed assessment of the potential impacts of each activity, including consideration of ways to avoid or minimise impacts, and possible enhancement opportunities, to determine whether an activity may cause deterioration or jeopardise the waterbody from achieving good status.

This staged approach is summarised in Figure 1-2, which reproduces an assessment flow checklist taken from the Natural Resources Wales WFD guidance (2017). The NRW guidance also includes detailed screening criteria that can be used to determine whether a proposed activity is not likely to cause a deterioration in the status of a waterbody. This includes a list of activities that in general will not cause a deterioration, such as 'temporary' works that do not normally last more than six months and are not likely to have a residual impact on a waterbody. The guidance also lists other physical works and defines screening thresholds for each; these thresholds help to determine whether any activity presents a risk to a waterbody and any requirements for further assessment. However, these thresholds are for guidance only and expert judgement is required to determine if a proposed activity may have an impact on a waterbody.

A more detailed WFD assessment would be required if it cannot be concluded that the proposed development would not cause deterioration or inhibit the objective status of a waterbody. Further to this an in line with WFD requirements, there would be a need to apply the Article 4.7 test to seek approval for progression of the development if, after the full WFD assessment (including the implementation of mitigation measures), it cannot be determined that the development would not cause deterioration to a waterbody or prevent it from achieving its status objectives.

1.3.5 Cumulative and in-combination impacts

Good practice guidance published by NRW (2017) requires that the proposed development is also assessed for potential cumulative and in-combination impacts.

Cumulative impacts are multiple impacts on the same waterbody quality element that arise from the proposed development together with those from all developments that have been built and are operational.

In-combination impacts are those impacts that may arise from the proposed development in-combination with other plans and projects proposed/consented but not yet built and operational i.e., those developments that are separate from the baseline. These include:

- Activities started but not yet completed.
- Activities consented but not started.
- Ongoing activities subject to repeated authorisations (e.g. annual licenses).
- Application submitted but not yet determined.

Activities not requiring consent, but which have been approved by the relevant competent authority.

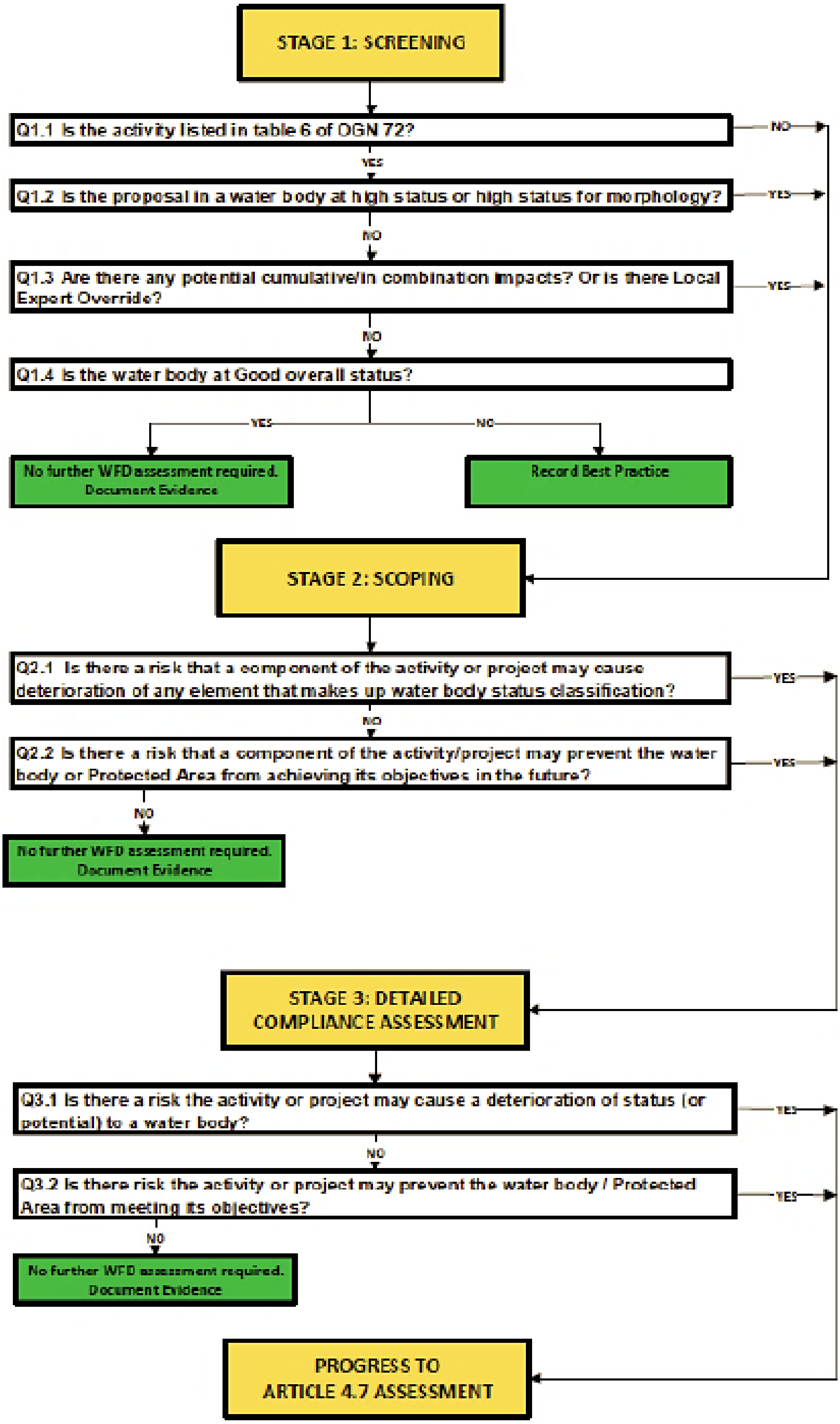

Figure 1-2: WFD assessment process flowchart (taken from Natural Resources Wales (2017) WFD guidance)

2 Baseline conditions

2.1 Relevant WFD waterbodies

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

2.2 North Wales coastal waterbody

The North Wales coastal waterbody encompasses a 45km stretch of the North Wales coast from Great Ormes Head to the Wales/England border, equating to an area of 146.25km^2. The waterbody is designated as a Heavily Modified Waterbody (HMWB) due to modification associated with coastal protection. As such, the specific objective of the RBMP for this waterbody is to achieve GEP and good chemical status by 2021.

The waterbody is currently assessed as having an overall status of 'Moderate', with 'Moderate' ecological potential, whilst its chemical status is currently 'Fail'. The quality elements that are contributing to the failing status of the waterbody include mercury (and it compounds) from an unknown source and Dissolved Inorganic Nitrogen (DIN) from dairy and beef farming and non-mains domestic sewage. Table 2-1 provides a summary of the current status of the WFD quality elements for the waterbody.

Table 2-1: WFD quality elements and status for North Wales coastal waterbody

Waterbody criteria		RBMP Cycle 2 (2015)
Ecological quality elements		
Phytoplankton		High
Invertebrates		Good
Physico-chemical supporting elements		
Flow		Pass
Dissolved Oxygen		High
Dissolved Inorganic Nitrogen		Moderate
Annex 8 Chemicals		High
Chemical quality elements		
Arsenic		Good
Copper		Good
Iron		Good
Zinc		Good
Annex 10 Chemicals	Benzo(a)pyrene	Good
	Cadmium	Good
	Fluoranthene	Good
	Hexachlorobenzene	Good
	Hexachlorobutadiene	Good
	Lead and its compounds	Good
	Mercury and its compounds	Fail
	Nickel and its compounds	Good

2.2.1 Supplementary ground investigation

As part of a Supplementary Ground Investigation[5] undertaken to inform the detailed design of the proposed scheme, four sediment samples (trial pits) were taken from the scheme area between the 23 and 25 April 2018. The trial pits (TP100 to TP103) were excavated to depths varying between 2.8m and 3.6m below ground level. Two of the sampling points (TP100 and TP103) comprised beach sands and two (TP101 and TP102) comprised intertidal flat deposits at the site. Laboratory testing and analysis of samples recovered was undertaken for a wide range of potential contaminants including:

- a range of metals and semi-metals;
- pH, cyanide, water soluble sulphates, asbestos and organic matter;
- a range of hydrocarbon analyses comprising:
  - Phenol
  - speciated Poly Aromatic Hydrocarbons (PAH's)
  - speciated Total Petroleum Hydrocarbons (TPH-CWG)
  - speciated Poly Chlorinated Biphenyls (PCB's)
  - a range of pesticides
- the Organotin compounds MBT, DBT & TBT; and
- a range of potential bacterial contaminants.

In all samples taken, with one exception, the concentration of each parameter was either below the limits of detection or below Cefas Action Level 1. The one exception to this was in relation to the sample of tidal flat deposits from TP101, where the concentration of cadmium (0.45mg/kg) slightly exceeded the Action Level 1 concentration of 0.40mg/kg. However, the result was well below the Action Level 2 concentration of 5.0mg/kg for cadmium. For all other samples taken, the concentration of cadmium was below the level of detection (<0.10mg/kg).

The current status of cadmium in the waterbody is 'Good', indicating that there is no known issue with cadmium contamination affecting waterbody status. The Supplementary Ground Investigation concluded that "Such a small exceedance is considered unlikely to be significant in relation to potential impacts on the marine environment."

2.2.2 Mitigation measures

For each HMWB, mitigation measures are set within the RBMP to ensure the hydromorphological characteristics of a waterbody are consistent with GEP.

For the North Wales coastal waterbody, a series of mitigation measures are identified. Many of these measures are related to the control of dredging activities and disposal of dredged materials; the proposed scheme will not affect these activities or decision-making relating to the control of these activities, and therefore these measures are not considered further. The following mitigation measures are relevant to the proposed scheme:

- Indirect mitigation
- Reduce sediment resuspension
- Manage disturbance
- Retain habitats
- Enhance ecology

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[5] Geotechnics (2018), East Rhyl Coastal Defence Scheme, Supplementary Ground Investigation Factual Report, July 2018.

- Realign flood defence
- Remove obsolete structure
- Remove or soften hard bank
- Preserve or restore habitats
- Bank rehabilitation

Typically, for a waterbody to be able to achieve GEP all of the mitigation measures must be in place and functioning. An assessment of the mitigation measures for the North Wales coastal waterbody (see Water Watch Wales website) identifies that the status of these mitigation measures is 'Good' and that the measures listed are 'not currently applicable – not required in this waterbody'. This indicates that the hydromorphological characteristics of the waterbody are consistent with GEP and that implementation of further mitigation measures is not required at this time.

2.3 Clwyd Permo-Triassic Sandstone groundwater body

The Clwyd Triassic Sandstone groundwater body spans a broad area along the North Wales Coast, from Llanddulas to Prestatyn, and south to Llysfasi. It encompasses an area of 237.32km^2 in size.

The waterbody has a quantitative status of 'Good' and a chemical status of 'Good', giving it an overall status of 'Good'.

2.4 Protected areas, priority habitats and invasive non-native species

The MAGIC website identifies that there are several WFD Protected Areas within 2km of the proposed scheme (see Figure 2-1). These comprise:

Within scheme area

- Clwyd Permo-Triassic Sandstone Drinking Water Protected Area.
- Rhyl East Bathing Water.

Within 500m of the scheme area

- Liverpool Bay Special Protection Area (SPA).
- Nitrate Vulnerable Zone (NVZ) 135.

Within 2km of the scheme area

- Rhyl Bathing Water.
- Marine Lake Bathing Water.

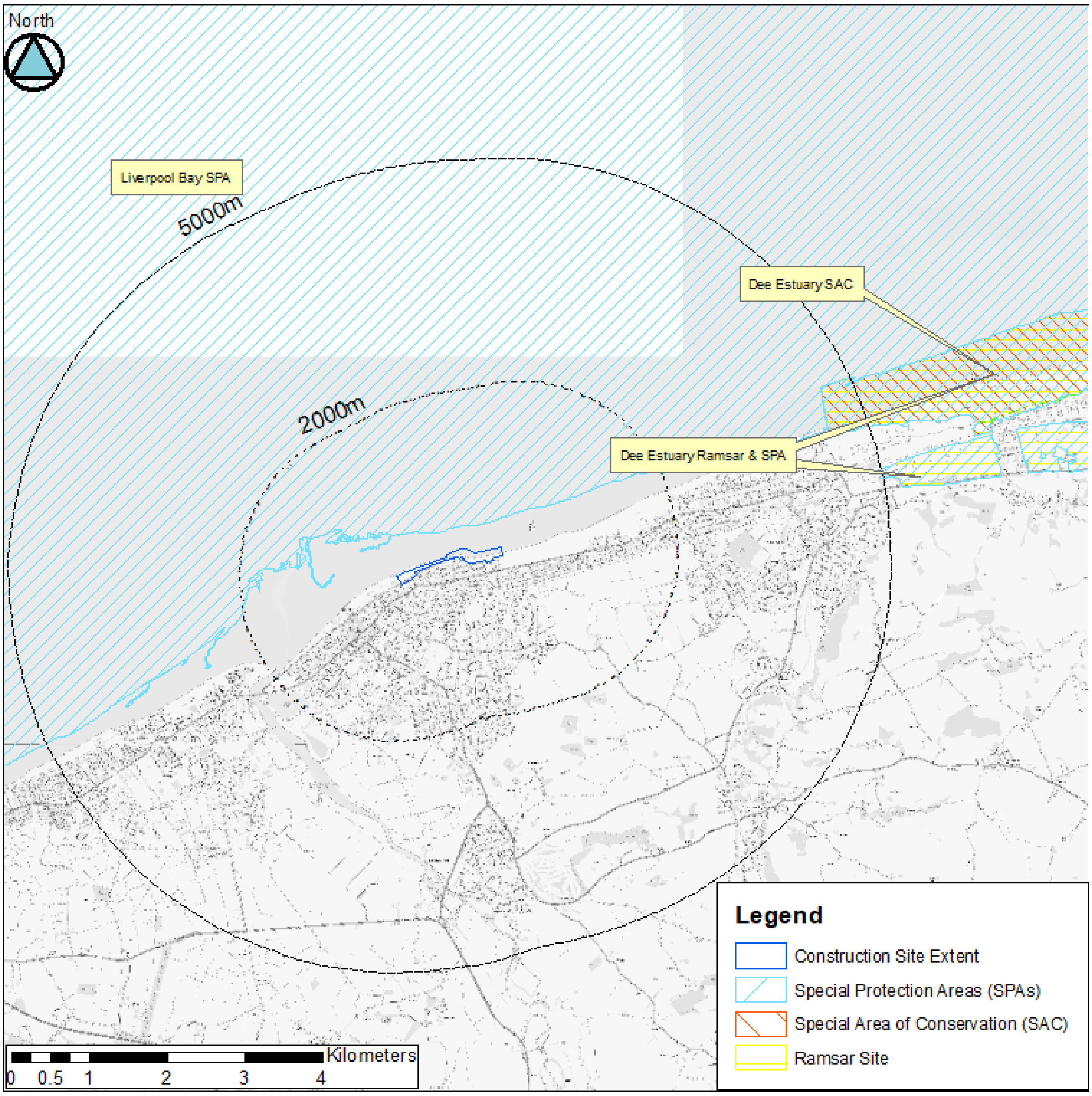

Figure 2-1: WFD Protected areas surrounding the site [Map derived and reproduced with permission of Denbighshire Council, © Crown Copyright Denbighshire, Wales. Contains Ordnance]

Survey data © crown copyright and database right 2018.

The following priority habitats (as defined by Section 7 of the Environment (Wales) Act 2016) are present within 500m of the proposed scheme:

- *Sabellaria alveolata* reef.
- Subtidal sands and gravels located approximately 300m to the north of the scheme area.

Anecdotal evidence indicates that the reef forming honeycomb worm *Sabellaria alveolata* has been recorded on one or more of the timber groynes present along the foreshore, with the next nearest record located approximately 150m to the north of the scheme area. However, this *Sabellaria alveoata* was not recorded in either of these locations during marine biotope and benthic invertebrate surveys undertaken in March 2017 and June 2018. A small amount of *Sabellaria alveoata* was found at the low tide mark during the survey carried out in June 2018. This had not been recorded before and had begun to form on a small area of cobbles. At the time of the survey it was badly damaged by storm action and it is likely that any Sabellaria reef here will be ephemeral.

The following WFD Higher Sensitivity Habitats are present within 500m of the proposed scheme:

- Mussel Beds (*Modiolus modiolus*, *Mytilus edulis* & others) (A1.22, A2.72, A5.62, A4.24, A3.361)

The ecology surveys of the scheme area undertaken in March 2017 and June 2018 did not identify the presence of this habitat and concluded that the habitat may be ephemeral, with the potential to return in the future.

The following WFD Lower Sensitivity Habitats are recorded within 500m of the proposed scheme:

- Intertidal Soft Sediment (Sand, Mud & Mixed A2.2, A2.3, A2.4) within and immediately adjacent to the scheme area.
- Small amounts of Rocky shore (Intertidal rock A1) within and immediately adjacent to the scheme area.

An Ecological Impact Assessment (EcIA) (see ES Chapter 5) of the proposed development confirmed that there are no historic records of INNS within 5km of the development site. However, the March 2017 survey of the scheme area identified the presence of the invasive barnacle *Austrominius modestus* on several of the timber groynes.

2.5 Assessment of other activities (plans and projects) requiring assessment for potential cumulative and in-combination impacts

The following plans and projects have been reviewed to identify the potential for cumulative or in combination impacts.

Welsh National Marine Plan

The Draft Welsh National Marine Plan ended its consultation period in March 2018. This is directly informed by High Level Marine Objectives set out in the Marine Policy Statement (2011)[6]. The Plan will guide decision-making on the sustainable use and management of the Welsh coastline.

The Plan sets out the following Plan Objectives that are relevant to the WFD:

- Plan Objective 6: Support enjoyment and stewardship of our coast and seas and their resources by encouraging equitable and safe access to the marine environment, whilst protecting and promoting valuable landscapes, seascapes and heritage assets.
- Plan Objective 7: Improve understanding and enable action supporting climate change adaptation and mitigation
- Plan Objective 8: Support the achievement and maintenance of Good Environmental Status (GES).
- Plan Objective 9: Protect, conserve, restore and enhance marine biodiversity to halt and reverse its decline.
- Plan Objective 10: Maintain and enhance the resilience of marine ecosystems and the benefits they provide in order to meet the needs of present and future generations.

The objectives of the draft Plan are consistent with those of the WFD and the policies it proposes seek to ensure clean, healthy, and biologically diverse seas. As such, there should be no cumulative or in-combination effects with the draft Marine Plan.

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[6] Welsh Government, 2015. The Welsh National Marine Plan Initial Draft. [Online] Available at: https://beta.gov.wales/sites/default/files/consultations/2018-02/draft-plan-en.pdf

Western Wales River Basin Management Plan (Natural Resources Wales, December 2015)

The measures contained within this plan aim to improve the ecological and chemical status of the waterbody. These measures are not likely to cause an adverse effect on the waterbody and may deliver significant benefits. As such, there would be no cumulative or in-combination effects with the proposed development.

Great Orme's Head to Scotland Shoreline Management Plan (SMP2) (North West England and North Wales Coastal Group, 2018)

The SMP2 sets out the long term (100 year) strategic policies to manage coastal flood and erosion risk in the strategy area, which encompasses Rhyl and the wider North Wales coastline. It informs decision-making at project level and coastal flood defence activities should be taken in-accordance with the overarching strategic policies as defined by the SMP2.

The scheme area is located within SPM2 policy units 4.1 and 4.2 (PU4.1 and PU4.2); the strategic policy to manage coastal flood and erosion risk is Hold the Line (HTL) for the next 100 years (to 2105) in both PUs. The policy states that maintaining and improving/raising the existing defences is required. This is justified in the SMP due to the commercial, residential and amenity assets, infrastructure, cycle routes and footpaths that are vulnerable to flooding. The proposed scheme is therefore consistent with the strategic flood risk management policies for this coastline.

Denbighshire Local Development Plan 2006-2021 (Denbighshire County Council, June 2013)

The adopted Local Plan includes policy provisions for the protection of the water environment in-accordance with national policy. This includes Policy VOE1, which protects important statutory and locally designated sites from adverse impacts from development, and VOE5, which seeks to safeguard protected species and nature conservation sites and requires development to integrate mitigation and enhancement measures.

In addition, the LDP includes policy provisions promoting other aspects of the Plan area and identifies Rhyl as an important local tourism/recreation centre that has the potential to contribute to the growth of the local economy. The LDP supports this through a range of policy provisions including Policy BSC11 (Recreation and Open Space), PSE1 (North Wales Coast Strategic Regeneration Area), PSE6 (Retail Economy), PSE12 (Chalet, static and touring caravan and camping sites), and PSE13 (Coastal Tourism Protection Zones), which identifies the importance of Rhyl as a major component of the local tourism industry.

Implementation of these and other associated environmental policies will deliver benefits to the water environment and support achievement of WFD objectives. In addition, permission for development allocated in the LDP should only be granted if these developments are in-accordance with these environmental policies; these developments should include adequate safeguards to ensure no adverse impact on the water environment and should support deliver of WFD objectives. As such, there will be no cumulative or in-combination effects with the proposed development.

Local development projects

A review of other local development projects has been undertaken to determine the potential for significant cumulative and in-combination effects (see ES Chapter 12). This included consultation with DCC and NRW to identify relevant projects. Whilst no significant cumulative or in-combination effects were identified, the assessment acknowledges that several of the projects have the potential to increase construction and/or tourism-related activities and could cause noise, dust and light disturbance, as well as affect coastal habitats.

3 Stage 1: screening assessment

Published guidance states that a WFD assessment is not required if an activity is assessed as being low risk, i.e., all criteria set out in stage 1 screening are met (see Figure 1-2) or where there is no (adverse) impact pathway to a WFD waterbody. Maintenance, repair, and changes to the operation of existing structures still in use for their original design purpose, where the design and the footprint of the structure remain the same, and the same or equivalent materials are used, can in most cases be screened out.

In relation to the Clwyd Permo-Triassic Sandstone groundwater body, no aspect of the proposed works would include abstraction of water, or excavation of land large enough to impact upon this groundwater body. No hazardous chemicals would be used during construction or operation of this structure, and no pathway would be created linking any construction materials to the groundwater waterbody. Therefore, no impact upon the quantitative or chemical status of the waterbody is anticipated and no further assessment upon this waterbody is undertaken.

The outcomes of the screening assessment in relation to the North Wales coastal waterbody are summarised in

Component of proposed development	Is the aspect low risk to North Wales coastal waterbody?
Establishment, use and decommissioning of two temporary construction compounds.	Yes – the site compounds are located landward of Rhyl Promenade and are located outside the waterbody. Minimal terrestrial vegetation removal will be required and no physical change to the coastline or coastal habitats will be undertaken. Establishment, use, and decommissioning of the compounds, which will contain all site welfare facilities, vehicle/plant parking, and waste storage/management facilities, will be managed in-accordance with approved method statements prepared following good construction practice and an approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes).
Temporary diversion of Wales Coast Path/National Cycle Route.	Yes – temporary diversion of the Wales Coast Path and National Cycle Route will not affect waterbody status.
Establishment of temporary construction access route.	Yes – a temporary haulage ramp will be constructed from the construction compound onto the beach over an area of existing rock armour at Splash Point; this ramp is required to facilitate construction plant and material access to the beach. The ramp will be orientated in line with the existing rock revetment (generally southwest to southeast), which is generally aligned to the direction of the localised longshore transport. A coastal hydrology and hydromorphology assessment (see ES Chapter 4) undertaken to inform the development of the scheme concluded that the ramp presents a minimal barrier to these transport processes. Therefore, given the very limited scale of the proposed works to establish the ramp, no impact on waterbody status is likely.
Permanent removal of 150m of existing timber groynes.	Yes – the existing timber groyne system within the footprint of the rock revetment and for 3m beyond the footprint would need to be removed. Seven groynes would be affected with a total of 150m of groyne removed. Removal would require excavation of beach material to groyne post formation level, which would be stored on the foreshore prior to reuse as backfill material in the excavated areas. The removal of each timber groyne (and backfilling) is scheduled to be completed within a single tidal cycle to reduce the risk of material mobilisation. The coastal hydrology and hydromorphology assessment (see ES Chapter 4) confirms that should entrainment of this material occur prior to backfilling, the amount of sediment entrained would be very slight in comparison to natural entrainment of subtidal and intertidal

	material (through onshore ridge migration) and would have a negligible impact on the existing sediment regime and nearshore turbidity. As such, no significant impact on waterbody status is likely.
Temporary storage and sorting of rock armour on Rhyl Beach.	Yes – construction of the rock armour revetment will require the temporary storage of rock in an area of beach adjacent to the revetment. Construction of the revetment will be undertaken in sections, with the rock required for each section generally stored and sorted in close proximity to the section being worked. The coastal hydrology and hydromorphology assessment (see ES Chapter 4) confirms that the temporary storage of rock material on the beach has the potential to create a layer of turbulent flows in the around of the rock pile, which could cause localised beach erosion. However, following removal of the rock, the beach profile will be reinstated using excavated beach materials and any effects on coastal processes will be temporary. As such, the impact to the sediment and hydrodynamic regimes from the presence of the rock piles is considered to be slight. In addition, storage of the rock has the potential to damage and disturb beach habitat within the footprint of the storage area; however, an EcIA undertaken to support the development of the scheme concludes that any impacts are very limited in scale and temporary in nature and will not significantly affect intertidal habitats or associated species. As such, these proposed works are not likely to have a significant effect on waterbody status.
Construction of concrete buttress.	Yes – construction of the concrete buttress will require in-situ concrete pouring. However, this work will take place between tidal cycles (at low tide and completed 3 hours before high tide) and so there would not be any opportunity for wet concrete to come into contact with the waterbody.
Construction of rock revetment including excavation of revetment toe and temporary storage of excavated beach material	No – this will require extensive intrusive works within, and immediately adjacent to, the waterbody that will result in a permanent change to a section of the beach. These works have the potential to conflict with several RBMP mitigation measures identified for the waterbody.
Construction of new seawall upstand including demolition of existing concrete upstand	Yes – these works will be undertaken outside the waterbody. Whilst the works have the potential to create significant volumes of dust, this can be effectively managed through implementation of good construction practice and an approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes). This includes use of a range of dust suppression techniques and management of associated surface runoff. As such, no impact on waterbody status is likely.
Construction of stepped access points through rock revetment	Yes – permanent access steps through the new rock armour will be constructed to enable continued public access to the beach. This will require limited excavation works, concrete pouring, and installation of pre-cast steps. Whilst these activities may present a contamination risk to the environment, they will be managed in-accordance with approved method statements prepared following good construction practice and an approved CEMP (approved via planning application and Marine Licence regimes). As such, these risks will be effectively managed. Given the very limited scale of the proposed works and use of good construction practice, no impact on waterbody status is likely.
Construction of concrete pavement	Yes – construction of the new Promenade surface will require significant excavation works and in-situ concrete pouring. However, this work will take place landward of the new seawall, which will provide a physical barrier between the works and waterbody. These works will be managed in-accordance with approved method statements prepared following good construction practice and an

	approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes). As such, no impact on waterbody status is likely.
Re-grading and seeding of the grass bank	Yes – these works are limited in scale and will take place landward of the new seawall, outside of the waterbody. As such, they will not affect waterbody status.
Reinstatement of the construction area to pre-construction conditions	Yes – following completion of the scheme, all areas affected by the construction works will be reinstated to pre-construction conditions. The majority of works at this stage will take place landward of the new seawall. No impacts on waterbody status are likely.
Operation of the completed flood defence scheme.	No – operation of the proposed scheme has the potential to impact on coastal habitats and adjacent sections of coastline due to changes in coastal process and/or associated with sea level rise due to climate change.
Periodic maintenance of the completed flood defence scheme.	Yes – maintenance activities associated with the proposed scheme are likely to be limited in extent to small-scale repair work. As such, these activities are not likely to impact on waterbody status.

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Table 3-1: Screening assessment

Component of proposed development	Is the aspect low risk to North Wales coastal waterbody?
Establishment, use and decommissioning of two temporary construction compounds.	Yes – the site compounds are located landward of Rhyl Promenade and are located outside the waterbody. Minimal terrestrial vegetation removal will be required and no physical change to the coastline or coastal habitats will be undertaken. Establishment, use, and decommissioning of the compounds, which will contain all site welfare facilities, vehicle/plant parking, and waste storage/management facilities, will be managed in-accordance with approved method statements prepared following good construction practice and an approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes).
Temporary diversion of Wales Coast Path/National Cycle Route.	Yes – temporary diversion of the Wales Coast Path and National Cycle Route will not affect waterbody status.
Establishment of temporary construction access route.	Yes – a temporary haulage ramp will be constructed from the construction compound onto the beach over an area of existing rock armour at Splash Point; this ramp is required to facilitate construction plant and material access to the beach. The ramp will be orientated in line with the existing rock revetment (generally southwest to southeast), which is generally aligned to the direction of the localised longshore transport. A coastal hydrology and hydromorphology assessment (see ES Chapter 4) undertaken to inform the development of the scheme concluded that the ramp presents a minimal barrier to these transport processes. Therefore, given the very limited scale of the proposed works to establish the ramp, no impact on waterbody status is likely.
Permanent removal of 150m of existing timber groynes.	Yes – the existing timber groyne system within the footprint of the rock revetment and for 3m beyond the footprint would need to be removed. Seven groynes would be affected with a total of 150m of groyne removed. Removal would require excavation of beach material to groyne post formation level, which would be stored on the foreshore prior to reuse as backfill material in the excavated areas. The removal of each timber groyne (and backfilling) is scheduled to be completed within a single tidal cycle to reduce the risk of material mobilisation. The coastal hydrology and hydromorphology assessment (see ES Chapter 4) confirms that should entrainment of this material occur

	prior to backfilling, the amount of sediment entrained would be very slight in comparison to natural entrainment of subtidal and intertidal material (through onshore ridge migration) and would have a negligible impact on the existing sediment regime and nearshore turbidity. As such, no significant impact on waterbody status is likely.
Temporary storage and sorting of rock armour on Rhyl Beach.	Yes – construction of the rock armour revetment will require the temporary storage of rock in an area of beach adjacent to the revetment. Construction of the revetment will be undertaken in sections, with the rock required for each section generally stored and sorted in close proximity to the section being worked. The coastal hydrology and hydromorphology assessment (see ES Chapter 4) confirms that the temporary storage of rock material on the beach has the potential to create a layer of turbulent flows in the around of the rock pile, which could cause localised beach erosion. However, following removal of the rock, the beach profile will be reinstated using excavated beach materials and any effects on coastal processes will be temporary. As such, the impact to the sediment and hydrodynamic regimes from the presence of the rock piles is considered to be slight. In addition, storage of the rock has the potential to damage and disturb beach habitat within the footprint of the storage area; however, an EcIA undertaken to support the development of the scheme concludes that any impacts are very limited in scale and temporary in nature and will not significantly affect intertidal habitats or associated species. As such, these proposed works are not likely to have a significant effect on waterbody status.
Construction of concrete buttress.	Yes – construction of the concrete buttress will require in-situ concrete pouring. However, this work will take place between tidal cycles (at low tide and completed 3 hours before high tide) and so there would not be any opportunity for wet concrete to come into contact with the waterbody.
Construction of rock revetment including excavation of revetment toe and temporary storage of excavated beach material	No – this will require extensive intrusive works within, and immediately adjacent to, the waterbody that will result in a permanent change to a section of the beach. These works have the potential to conflict with several RBMP mitigation measures identified for the waterbody.
Construction of new seawall upstand including demolition of existing concrete upstand	Yes – these works will be undertaken outside the waterbody. Whilst the works have the potential to create significant volumes of dust, this can be effectively managed through implementation of good construction practice and an approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes). This includes use of a range of dust suppression techniques and management of associated surface runoff. As such, no impact on waterbody status is likely.
Construction of stepped access points through rock revetment	Yes – permanent access steps through the new rock armour will be constructed to enable continued public access to the beach. This will require limited excavation works, concrete pouring, and installation of pre-cast steps. Whilst these activities may present a contamination risk to the environment, they will be managed in-accordance with approved method statements prepared following good construction practice and an approved CEMP (approved via planning application and Marine Licence regimes). As such, these risks will be effectively managed. Given the very limited scale of the proposed works and use of good construction practice, no impact on waterbody status is likely.
Construction of concrete pavement	Yes – construction of the new Promenade surface will require significant excavation works and in-situ concrete pouring. However, this work will take place landward of the new seawall, which will provide a physical barrier between the works and waterbody. These

	works will be managed in-accordance with approved method statements prepared following good construction practice and an approved Construction Environmental Management Plan (CEMP) (approved via planning application and Marine Licence regimes). As such, no impact on waterbody status is likely.
Re-grading and seeding of the grass bank	Yes – these works are limited in scale and will take place landward of the new seawall, outside of the waterbody. As such, they will not affect waterbody status.
Reinstatement of the construction area to pre-construction conditions	Yes – following completion of the scheme, all areas affected by the construction works will be reinstated to pre-construction conditions. The majority of works at this stage will take place landward of the new seawall. No impacts on waterbody status are likely.
Operation of the completed flood defence scheme.	No – operation of the proposed scheme has the potential to impact on coastal habitats and adjacent sections of coastline due to changes in coastal process and/or associated with sea level rise due to climate change.
Periodic maintenance of the completed flood defence scheme.	Yes – maintenance activities associated with the proposed scheme are likely to be limited in extent to small-scale repair work. As such, these activities are not likely to impact on waterbody status.

On the basis of the above screening assessment, potential risks to the North Wales Coastal Waterbody are limited to the following activities:

- Construction of rock armour revetment.
- Operation of the completed flood defence scheme.

These aspects will be taken forward to the next stage (Stage 2) of the assessment process, impact scoping, to further assess the potential for an adverse impact on the status on the North Wales coastal waterbody and its associated WFD objectives.

4 Stage 2: scoping assessment

The purpose of the Scoping Assessment is to identify whether aspects of the proposed development not screened out during Stage 1 could present a significant risk to any of the WFD quality element receptors. In doing so, it assesses whether these activities may cause deterioration in the status of a quality element or prevent the waterbody (or protected area) from achieving its WFD objectives in the future.

It utilises the Scoping Template provided within the Environment Agency guidance (2017), which comprises a series of scoping tables that aim to identify the need for a further, more-focussed impact assessment (Stage 3). Such a detailed impact assessment draws upon more in-depth evidence to determine whether the risks identified for each quality element could cause a deterioration in the status of a waterbody or prevent a waterbody from achieving its WFD objectives.

4.1 Hydromorphology

Table 4-1: Hydromorphology scoping assessment

Could any activity:	Yes/No	Hydromorphology risk issue(s)
Impact on the hydromorphology of a waterbody at High status?	No	The North Wales coastal waterbody is not at High status for its hydromorphological supporting elements.
Is in a waterbody that is heavily modified for the same use as the activity?	Yes	The North Wales coastal waterbody is a HMWB due to modifications associated with coastal protection.
Significantly impact the hydromorphology of any waterbody?	No	A detailed coastal hydromorphology assessment (see ES Chapter 4) has been undertaken to determine whether the proposed scheme could have a significant impact on coastal hydromorphology. The assessment considers potential impacts in relation to the storage of rock on Rhyl Beach, excavation of the rock revetment area, and as a result of operation of the completed scheme. It concludes that potential impacts are not likely to be significant. Excavation of the rock revetment toe will require the temporary storage of excavated materials on Rhyl Beach. This material will be excavated, stored, and returned to the excavated area as backfill within a single tidal cycle; as such, all works will be undertaken in dry conditions and the risk of entrainment of material will be significantly reduced. However, in a worst-case scenario, should all excavated materials (1,220m^3) be mobilised, the impact on the existing sediment regime and near shore turbidity is assessed as being slight. This risk is further mitigated by the presence of cohesive clay material within the tidal flat and fluvioglacial layers, which is more resistant to entrainment than the overlying beach sand. Operation of the finished flood defence scheme is not likely to significantly affect sediment supply or longshore drift processes. The primary sediment supply mechanism along this section of coastline is through the onshore movement of sand ridges, whilst sediment distribution continues to extend alongshore from Splash Point and then subsequently moved onshore through wave action. The presence of the rock revetment has the potential to retain sediment and thereby remove it from the longshore transport budget. However, the total footprint of the rock revetment is small in relation to the available intertidal area and therefore any impact on the sediment regime is likely to be no more than slight.

4.2 Physico-chemical

Table 4-2: Physico-chemical scoping assessment

Could any activity:	Yes/No	Physico-chemical risk issue(s)
Affect water clarity, temperature, salinity, oxygen levels, nutrients, or microbial patterns continuously?	No	Extensive earthworks are required adjacent to the existing defences to enable construction of the rock armour revetment. These works are temporary in nature. The rock armour will be installed in short sections. For each section, all excavated beach material will be temporarily stockpiled adjacent to the excavation and then returned to the excavated area once the rock armour is in place and before it is inundated by the incoming tide. Notwithstanding this, the impact of beach sediment mobilisation has been assessed (see ES Chapter 4). This assessment concludes that should all excavated beach material (1,220m^3) be available for entrainment, the effect on the sediment regime and near shore turbidity would be moderate at worst. However, this risk is mitigated by the phased approach to the excavations, significantly reducing the amount of material available for entrainment at any one time, and also by the presence of cohesive clay material within the excavated tidal flat and fluvioglacial layers, which is more resistant to entrainment than the overlaying beach sand. As such, the risk of a significant impact on water quality as a result of sediment is mobilisation is assessed as being low. No impacts on water quality are anticipated as a result of operation of the proposed scheme.
Is in a waterbody with a phytoplankton status of moderate, poor or bad?	No	The phytoplankton status of the waterbody is High.
Is in a waterbody with a history of harmful algae?	No	There is no evidence to indicate that the waterbody has a history of harmful algae.

4.3 Biology

4.3.1 Habitats

Table 4-3: Biology (habitats) scoping assessment

Is the footprint of any activity:	Yes/No	Biology (habitats) risk issue(s)
0.5km^2 or larger?	No	The area of works associated with construction of the rock armour revetment is significantly less (0.02km^2) than 0.5km^2.
1% or more of the waterbody's area?	No	Less than 0.02% of the waterbody area will be affected by the proposed works.
Within 500m of any higher sensitivity habitat?	Yes	The nearest higher sensitivity habitat (mussel bed) is located approximately 30m to the north of the proposed rock revetment, on Rhyl Beach. However, no evidence of this habitat was identified during ecology surveys of the beach area in March 2017 and June 2018, and it is possible that the habitat is ephemeral. Priority habitats within 500m include *Sabellaria alveolata* reef, which has historically been recorded on the timber groynes present along the foreshore (but was not recorded there during the 2017 and 2018 surveys – the nearest extent was located approximately 300m north of the

		proposed scheme area at the low tide mark), and subtidal sands and gravels located approximately 300m to the north of the scheme area. An EcIA of the proposed scheme (see ES Chapter 5) concludes that the proposals are not likely to have a significant impact on these habitats. No impact on subtidal habitats is anticipated, whilst in relation to *Sabellaria alveolata* reef, the potential for significant smothering is assessed as being low.
1% or more of any lower sensitivity habitat?	No	Rhyl Beach is classified as a WFD lower sensitivity habitat. However, this habitat extends along the entire North Wales coast from the Little Orme to the Dee Estuary. Therefore, the proposed scheme will result in temporary and permanent impacts on only a very small proportion of this habitat.
Impact on macrophyte or phytoplankton community diversity, condition, or distribution?	No	No adverse impacts on macrophyte or phytoplankton communities are anticipated. Construction of the rock armour has the potential to provide new habitat opportunities for a range of marine fauna and flora.
Impact on invertebrate community diversity, condition or distribution?	No	Within the footprint of the scheme (excavated rock revetment area), the invertebrate community is assessed as being relatively impoverished (see ES Chapter 5). However, species living in this area will be directly affected by the excavation of beach material and installation of the rock armour. Notwithstanding this, the significance of any impacts on the invertebrate community are very low given the abundance of similar adjacent habitats and likely rapid re-colonisation of the works area. As such, no adverse impacts on invertebrates are predicted; conversely, construction of the rock armour has the potential to provide new habitat opportunities for a range of marine fauna and flora.

4.3.2 Fish

Table 4-4: Biology (fish) scoping assessment

Could any activity:	Yes/No	Biology (fish) risk issue(s)
Impact on normal fish behaviour, such as movement, migration or spawning?	No	Impacts on fish foraging behaviour during construction (due to rock armour stockpiling reducing available sand foraging habitat) are not likely to be significant due to the abundance of similar habitat in the wider area. In addition, the risk of sediment mobilisation or chemical contamination affecting fish during construction is considered to be low. No significant impacts on fish are anticipated as a result of operation of the proposed scheme.
Could cause entrainment or impingement of fish?	No	Construction and operation of the proposed scheme does not include any aspects that could cause entrainment or impingement of fish.

4.4 Chemical

Table 4-5: Water quality (pollutants) scoping assessment

Could any activity use or release chemicals:	Yes/No	Water quality risk issue(s)
That are on the Environmental Quality Standards Directive (EQSD) list?	Yes	Beach sediment sampling[7] recorded a single sample (TP101) where the concentration of cadmium (0.45mg/kg) slightly exceeded the Action Level 1 concentration of 0.40mg/kg. However, the result was considerably less than the Action Level 2 concentration of 5.0mg/kg for cadmium (meaning the sediment would be considered unacceptable for uncontrolled disposal at sea without special handing and containment). For all other samples taken, the concentration of cadmium was below the level of detection (<0.10mg/kg).
That disturbs sediment with contaminants above Cefas Action Level 1?		

Table 4-6: Water quality (mixing zone) scoping assessment

If your activity has a mixing zone consider if:	Yes/No	Water quality risk issue(s)
The chemicals released are on the EQSD list?	No	The proposed scheme will not create a mixing zone.

4.5 WFD Protected Areas

Table 4-7: WFD Protected Areas scoping assessment

Is any activity:	Yes/No	Protected Area risk issue(s)
Within 2km of any WFD protected area?	Yes	There are several WFD Protected Areas within 2km of the proposed scheme. However, no significant impacts on these designated areas is anticipated. A Bathing Water Impact Assessment[8] undertaken to support the design of the proposed scheme concludes that the construction works are not likely to present a risk to bathing water quality. In addition, a EcIA (see ES Chapter 5) confirms that the proposed scheme is not likely to have a significant adverse effect on the features of the Liverpool Bay SPA. No impacts on the Clwyd Permo-Triassic Sandstone Drinking Water Protected Area or Nitrate Vulnerable Zone (NVZ) 135 are anticipated.

4.6 Invasive non-native species

Table 4-8: Invasive non-native species scoping assessment

Could any activity:	Yes/No	INNS risk issue(s)
Introduce or spread INNS?	No	There is the potential to contribute to the spread of the invasive barnacle *Austrominius modestus*, which has been identified on some of the timber groynes. However, risks associated with this species can be effectively managed through application of good construction practice and robust environmental management procedures, such as storing any affected timber groynes removed during construction above the high-water mark.

[7] Geotechnics (2018), East Rhyl Defence Scheme, Supplementary Ground Investigation Factual Report, July 2018.
[8] JBA Consulting (2018), East Rhyl Coastal Defence Scheme Bathing Water Impact Assessment, September 2018.

4.7 Scoping summary and requirement for impact assessment

The preceding sections provide the scoping assessment of the potential risks to WFD quality element receptors as a result of the proposed scheme. The outcomes of this work are summarised in Table 4-9.

Table 4-9: Scoping summary and further assessment

WFD receptor	Potential risk to WFD receptor?	Risk issue(s) for impact assessment
Hydromorphology	No	The proposed scheme is in a waterbody that is heavily modified for the same use as the activity (coastal protection). However, the most recent WFD status information for the waterbody (taken from the Water Watch Wales website) indicates that the status of mitigation measures is 'Good' and confirms that the identified measures are 'not currently applicable – not required in this waterbody'. In addition, detailed assessment of the potential impacts on coastal hydromorphology (see ES Chapter 4) has shown that construction and operation of the proposed scheme is not likely to have a significant effect on sediment supply or longshore drift processes. Therefore, no significant impacts on the hydromorphology quality elements are predicted.
Biology (habitats)	No	The proposed scheme will cause temporary and permanent impacts on beach habitats (WFD Lower Sensitivity Habitat), flora and fauna. However, these impacts are not likely to be significant given the availability of this habitat in the wider area. No impacts on designated sites or WFD Higher Sensitivity Habitats/Priority Habitats are anticipated. Conversely, construction of the rock armour has the potential to provide new habitat opportunities for a range of marine fauna and flora.
Biology (fish)	No	No impacts on fish as a result of construction or operation of the proposed scheme are anticipated.
Physico-chemical	No	The proposed scheme is not likely to have an adverse effect on physico-chemical conditions in the waterbody. Any potential risks to water quality during construction of the scheme will be carefully managed through implementation of good construction practice and closely monitored throughout construction.
Chemical	No	Sediment sampling identified a single sample where the concentration of cadmium slightly exceeded Cefas Action Level 1. In all other samples taken, cadmium concentrations were below detectable limits. A slight exceedance in a single sample is not likely to present a significant risk to the marine environment or the status of the North Wales coastal waterbody.
Invasive non-native species (INNS)	No	Whilst the invasive barnacle *Austrominius modestus* is present on some of the timber groynes, appropriate biosecurity good practise can be implemented throughout construction to effectively minimise the risk of its spread.
Protected Areas	No	However, no significant impacts on these designated areas is anticipated.

4.8 Discussion

4.8.1 Hydromorphology

Assessment undertaken at Stage 1 (screening) and Stage 2 (scoping) has identified that the proposed scheme is not likely to present a significant risk to hydromorphology of the North Wales coastal waterbody.

The temporary storage of rock material on the beach has the potential to create a layer of turbulent flows in the around of the rock pile, which could cause localised beach erosion. However, this is not likely to have more than a localised effect within the immediate vicinity of the rock pile. Following construction of the rock revetment the beach profile will be reinstated using excavated beach materials and no permanent effects are anticipated.

The primary sediment supply mechanism along the Rhyl coastline is the onshore movement of sand ridges, with sediment distributed along the coastline through longshore drift. The presence of the rock revetment has the potential to retain sediment and thereby remove it from the longshore transport budget. However, the total footprint of the rock revetment is very small in relation to the available intertidal area and therefore any impact on the sediment regime is likely to be very limited.

The Western Wales RBMP identifies a series of mitigation measures for the North Wales coastal waterbody. Many of these measures focus on the management of dredging activities; however, a number are relevant to the proposed scheme, particularly those that seek to improve the ecological value of defence structures and preserve or enhance habitats.

The Water Watch Wales website confirms that the measures listed for this waterbody are 'not currently applicable – not required in this waterbody' and that the mitigation measures are at 'Good' status. This means that the hydromorphological characteristics of the waterbody are consistent with GEP and that implementation of further mitigation measures is not required. This conclusion is supported by the 'reasons for failure' data, which identifies that the waterbody is failing to achieve its status objectives due to issues with DIN and mercury (and its compounds).

Notwithstanding this, the proposed scheme is not likely to conflict with the identified mitigation measures (should they be required in the future). The scheme is consistent with the SMP2 HTL policy for the relevant PUs, and so realignment of flood defences is not appropriate in this location. The scheme does support implementation of measures that seek to improve the ecological value of coastal habitats. Ecological surveys of the scheme area show that the upper beach habitats are relatively species poor (with an abundance of similar habitat in the wider area) and the proposed rock revetment has the potential to provide new habitat opportunities for a range of (rocky shore) fauna and flora. However, further ecological enhancements could be included in the design of the rock revetment to provide additional opportunities for rocky shore species to colonise.

4.8.2 Biology

The proposed scheme will cause both temporary and permanent impacts on beach habitat (these habitats are classified as a WFD Lower Sensitivity Habitat), flora and fauna. No impacts on designated sites (including the Liverpool Bay SPA, Section 7 Priority Habitats, or WFD Higher Sensitivity Habitats) are anticipated.

Construction of the rock armour revetment will require significant excavation of beach materials and the installation of rock armour; this will cause habitat damage and disturbance to the affected beach areas and the addition of a new habitat type (rock armour). Excavated beach material will be backfilled in the same area once the rock armour has been installed. The damage to this habitat will be largely temporary and no significant impacts on WFD Lower Sensitivity Habitat is anticipated, particularly given the abundance of this habitat type in the immediate vicinity of the scheme and likely rapid re-colonisation of the scheme area by marine fauna.

The addition of new rock armour habitat has the potential to provide an ecological benefit by providing opportunities for existing and new flora and fauna to colonise the scheme area, potentially increasing biodiversity. This includes providing new roosting opportunities for waterbirds and the rock armour may encourage establishment of WFD Higher Sensitivity Habitats, including mussel beds and polychaete reefs, which are already present in the wider area.

4.8.3 Water chemistry

Sediment sampling of beach material within the footprint of the rock revetment identified a single sample where the concentration of cadmium (0.45mg/kg) slightly exceeded Cefas Action Level 1 (0.40mg/kg). In all other samples taken, cadmium concentrations were below detectable limits (<0.10mg/kg). The waterbody is currently at 'Good' status for cadmium (and its compounds) and there are no reported issues with cadmium affecting the waterbody or adjacent/connected waterbodies.

The source of this cadmium is not known. Anthropogenic inputs of cadmium into the wider system may include fertiliser runoff from agricultural land or contaminated runoff from historic metal mining. Alternatively, cadmium may be the product of erosion of local/regional geology[9]. The exceedance was recorded in a tidal flat deposit at a depth of 1.0mbgl, where sediment disturbance is relatively limited, indicating that the source of cadmium could be historic.

A slight exceedance in a single sample is not likely to present a significant risk to the marine environment or to the status of the North Wales coastal waterbody. Notwithstanding this, the risk of cadmium mobilisation (if present) is further reduced by the scheme design and proposed construction methodology. All construction works on the beach will be undertaken in dry conditions. Excavated beach material will be backfilled within the same area within a single tidal cycle, reducing the risk of sediment (and cadmium) entrainment, whilst the presence of cohesive clay material within the excavated tidal flat and fluvioglacial layers, further reduces the risk of sediment mobilisation.

4.8.4 Protected Areas

The proposed scheme is located within Rhyl East Bathing Waters, designated under the Bathing Water Regulations 2013 (2013/1675), and the Clwyd Permo-Triassic Sandstone Drinking Water Protected Area (DrWPA), which encompasses the underlying groundwater body.

No impacts on the groundwater DrWPA are anticipated because the scheme does not include any significant abstraction of water or discharge to ground and does not require use of any hazardous chemicals.

No impacts on the designated bathing water are anticipated. There is no evidence of significant bacterial contamination of the beach and bathing water quality has been assessed as 'good' since 2014. The proposed scheme will not alter existing sewerage infrastructure or surface runoff patterns or result in the direct release of foul water/faecal matter into the bathing water.

Notwithstanding this, it is recommended that visual monitoring of the construction area is undertaken daily during the construction period to identify any signs of sewage debris, animal faeces, litter, and oil or tar that has been discharged into the area, particularly after storm or heavy rainfall events. If any such debris is identified, it should be removed from site to a suitable waste disposal facility. This will minimise the risk of bacterial contamination adversely affecting both users of the beach/bathing waters and construction personnel.

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[9] National Museum of Wales, Minerology of Wales, Mineral Database: Sphalerite, Available online at: https://museum.wales/mineralogy-of-wales/database/?mineral=84 [Accessed 15 October 2018]

5 Conclusion and recommendations

The proposed scheme is not likely to have a significant impact on any WFD receptors. No significant impact on existing coastal processes is predicted, whilst impacts on beach habitats, including damage and disturbance during construction, will be temporary in nature and will not be significant. Conversely, construction of the rock armour revetment may provide an ecological benefit. No impacts on WFD Protected Areas are likely.

The following recommendations are made to support the delivery of the proposed scheme and compliance with the requirements of the WFD:

- It is recommended that the proposed scheme seeks to contribute to any future requirement for additional mitigation measures. This should principally focus on opportunities to provide further ecological enhancement of the rock armour revetment.
- A Construction Environmental Management Plan (CEMP) should be prepared, which sets out the actions that will be implemented to control construction of the proposed scheme so as to avoid adverse impacts on the environment. The CEMP should form part of the construction contract. It should adhere to construction best practice for works on the coast so as to reduce the risk of environmental contamination during construction and include biosecurity procedures to prevent the spread of INNS (see below).
- It is recommended that a further ecology walkover survey of the scheme area is undertaken in-advance of construction to determine the continued presence of the invasive barnacle *Austrominius modestus* on any of the affected timber groynes. If found, appropriate biosecurity good practise should be implemented throughout construction to effectively minimise the risk of its spread. The measures to be adopted should be detailed in a CEMP to form part of the contract documents controlling the construction of the scheme.
- Visual monitoring of the construction area should be undertaken daily during the construction period to identify any signs of sewage debris or any other contaminated materials, which should be removed offsite for disposal. This will minimise the risk of bacterial contamination adversely affecting beach users and construction personnel.

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JBA Project Code: 2016s5126
Contract: East Rhyl Coastal Defence Scheme
Client: Denbighshire County Council / Balfour Beatty
Date: 24 September 2018
Authors: Ben Sullivan and David Revill
Subject: Bathing Water Impact Assessment

1 Introduction

Denbighshire County Council proposes to construct new coastal flood defence infrastructure at East Rhyl beach. The proposed defences comprise a new 600m section of rock revetment together with works to increase the height of a 550m long section of existing sea wall, located between Splash Point (NGR: SJ020825) and the western boundary of Rhyl Golf Course (NGR: SJ026825).

Rhyl is a seaside resort town located east of the Clwyd Estuary. The proposed flood defences are located on East Rhyl beach. The beach is designated under the EU Bathing Water Directive (2006/7/EC) as a bathing water and annual monitoring of bathing water quality at the beach is undertaken by Natural Resources Wales (NRW).

The purpose of this assessment is to determine whether the proposed scheme may have an impact on designated bathing water quality and public amenity. The findings of this assessment will be used to support the detailed design and construction of the flood defences and the production of the Environmental Statement (ES) prepared as part of the planning application for the proposed scheme.

The assessment seeks to identify any potential risks to bathing water quality during construction and operation of the scheme and requirements for any associated mitigation measures, i.e., controls on how the construction phase will be delivered.

2 Site location and description of the proposed development

Figure 2-1 shows the location of the proposed scheme between Splash Point and Rhyl Golf Club.

The scheme comprises removal of the existing 225m long section of rock armour around Splash Point and construction of a new 600m long section of rock armour revetment between Splash Point and the golf course. The new rock armour revetment will extend approximately 30m from the existing sea wall. In addition, a 550m section of the existing sea wall will be raised by approximately 0.5m. The existing upstand will be removed and replaced with a recurved upstand constructed from precast concrete units.

Access to the beach will be maintained via three sets of precast concrete steps provided through the concrete upstand and rock armour revetment.

Construction of the scheme will take approximately 38 months to complete.

The rock armour revetment would be constructed in 10m to 20m sections per tidal cycle. Temporary storage and sorting of rock will take place on the beach adjacent to where the rock will be placed in the revetment.

Construction of the rock revetment toe will require excavation of the beach to 0m Above Ordnance Datum (AOD) along the revetment toe using an excavator. Excavated sand/shingle will be temporarily stockpiled next to the excavation. A geotextile membrane will then be laid directly over the excavated area, which will then be covered by a thin filter layer of stone. Graded rock armour will then be placed one-at-a-time onto the filter layer using an excavator with a grab attachment. Once the 10m to 20m section of revetment toe is complete, the previously excavated sand/shingle material will be reused to cover over the toe rock to the existing beach level. Construction of the remainder of the rock revetment section to the required crest level will then take place using the excavator positioned on the toe area. The works will progress in this fashion until revetment works are complete (25 months).

Construction of the access steps through the rock armour revetment would require excavation to the required foundation depth (-1m AOD). The foundations would be made using in-situ concrete pouring, which will be contained within a temporary sheet pile arrangement or through use of drag boxes.

Demolition of the upstand of the existing sea wall will take place in sections. All demolition waste will be removed from site and appropriately disposed of. In parallel with demolition of the old sea wall, the new precast upstand will be placed onto the concrete buttress using an excavator.

Following completion of the works, the construction area will be reinstated to pre-construction conditions. A full description of the proposed scheme is provided in the Environmental Statement and the Design & Access Statement prepared for the planning application.

Figure 2-1: Scheme location

3 Designated bathing waters

The EU Bathing Water Directive (2006/7/EC) seeks to preserve, protect, and improve aquatic environmental quality and protect human health. The first Directive came into force in 1975 and was updated and expanded through new EU legislation adopted in 2006.

The Directive, which is transposed into law in England and Wales through the Bathing Water Regulations 2013 (2013/1675), requires Member States to designate bathing waters and monitor and assess water quality in these areas for concentrations of two faecal bacteria: Intestinal enterococci and Escherichia coli (E. coli).

In addition, Member States must inform the public about bathing water quality through the publication of annual bathing water profiles. Bathing water quality is classified using strict water quality standards and is given a rating of either:

- Excellent
- Good
- Sufficient
- Poor

In the UK, bathing waters are designated by each Local Authority. Monitoring of bathing water quality is undertaken by NRW; each year, water quality is tested at least six times within the bathing water season (15 May to 30 September) at each designated beach. The results are used to assess compliance with the Directive. Each local authority which controls a designated bathing water must display the water classifications provided by NRW. Beaches that are classified as 'Poor' must display advice against bathing together with information on the causes of pollution and mitigation measures that will be undertaken to improve water quality.

There are three designated bathing waters within 2km of the proposed scheme[1]:

- Rhyl East: The beach extends over 2.5km from the Clwyd Estuary to Splash Point. As such it overlaps with the western extent of the proposed flood defence scheme. The beach is gently sloping and predominantly sandy and displays a large tidal range. Water quality samples are taken from a point located opposite the car park to the west of The Rhyl Sun Centre (NGR SJ010820. The full Bathing Water Profile is available here: http://environment.data.gov.uk/wales/bathing-waters/profiles/profile.html?site=ukl1302-40650
- Rhyl: The bathing water is located 1km northeast of the River Clwyd. The water quality sample point is located towards the low water mark opposite the Rhyl Sea Life Centre (NGR: SJ002826), approximately 500m north west of the Rhyl East sampling site. The two bathing waters overlap and as a result, their physical characteristics are very similar, with a gently sloping beach and large inter-tidal area. The full Bathing Water Profile is available here: http://environment.data.gov.uk/wales/bathing-waters/profiles/profile.html?site=ukl1302-40600

[1] Natural Resources Wales, Bathing Water Quality website. Available at: https://naturalresources.wales/guidance-and-advice/environmental-topics/water-management-and-quality/water-quality/bathing-water-quality/?lang=en [Accessed 17 September 2018]

- Marine Lake: The bathing water is located immediately adjacent to the Clwyd Estuary in an offline marine lake. It is relatively isolated from the watercourse and is over 1km to the south west, and upstream of, the proposed flood defence scheme. Due to this, it is not considered further in this assessment. The full Bathing Water Profile is available here: http://environment.data.gov.uk/wales/bathing-waters/profiles/profile.html?site=ukl1302-40550

3.1 Water quality monitoring

The results of water quality monitoring at the designated bathing waters is shown in Table 3-1, together with details of the pressures affecting water quality at each beach–this information is taken from the Bathing Water Profile for each beach published by NRW.

Table 3-1: Bathing water quality monitoring results

Beach	Monitoring Results 2014	2015	2016	2017	Pressures on water quality affecting classification
Rhyl East	Good	Good	Good	Good	Bathing water is subject to short term pollution due to rainfall-induced surface runoff containing faecal material from agriculture, sewerage, and urban drainage. This includes intermittent discharges from combined sewers during overflow conditions, misconnections from domestic toilets, and diffuse runoff from extensive dairy, beef, and sheep farming in the catchment.
Rhyl	Sufficient	Sufficient	Sufficient	Sufficient	

At the time of writing, Rhyl East bathing exhibited an increased risk of reduced water quality due to heavy rainfall producing contaminated surface runoff, with elevated levels of Intestinal enterococci (73/100ml) recorded at the most recent monitoring event (21 August 2018); a water quality warning remained in place for the 24-hour period from the 11 September 2018. At Rhyl East and Rhyl bathing waters there were 27 warnings of a pollution risk during the 2017 bathing water season.

4 Impact assessment

4.1 Potential risks to bathing waters

Potential risks to bathing water quality associated with the proposed scheme comprise the following:

- Mobilisation of bacteria/faecal matter contained within beach sediment during excavation of the rock revetment toe and temporary storage of beach material.
- Direct discharges to bathing waters through foul water discharges from construction staff.

No risks associated with the operation or maintenance of the proposed flood defences have been identified.

Due to the extensive (38 month) construction period, the construction compound, which will provide all construction staff welfare facilities, will be connected to mains power, sewerage, and water for the duration of the construction works. Therefore, there will be no direct discharges of foul water to the beach.

4.2 Sediment sampling

As part of the Supplementary Ground Investigation[2] undertaken to inform the detailed design of the proposed scheme, four sediment samples (trial pits) were taken from the scheme area between the 23 and 25 April 2018. The trial pits (TP100 to TP103) were excavated to depths varying between 2.8m and 3.6m below ground level. Two of the sampling points (TP100 and TP103) comprised beach sands and two (TP101 and TP102) comprised intertidal flat deposits at the site. The sediment samples taken were analysed for the following bacterial parameters:

- Total coliforms
- Clostridium perfringens

The sampling locations are shown in Figure 4-1.

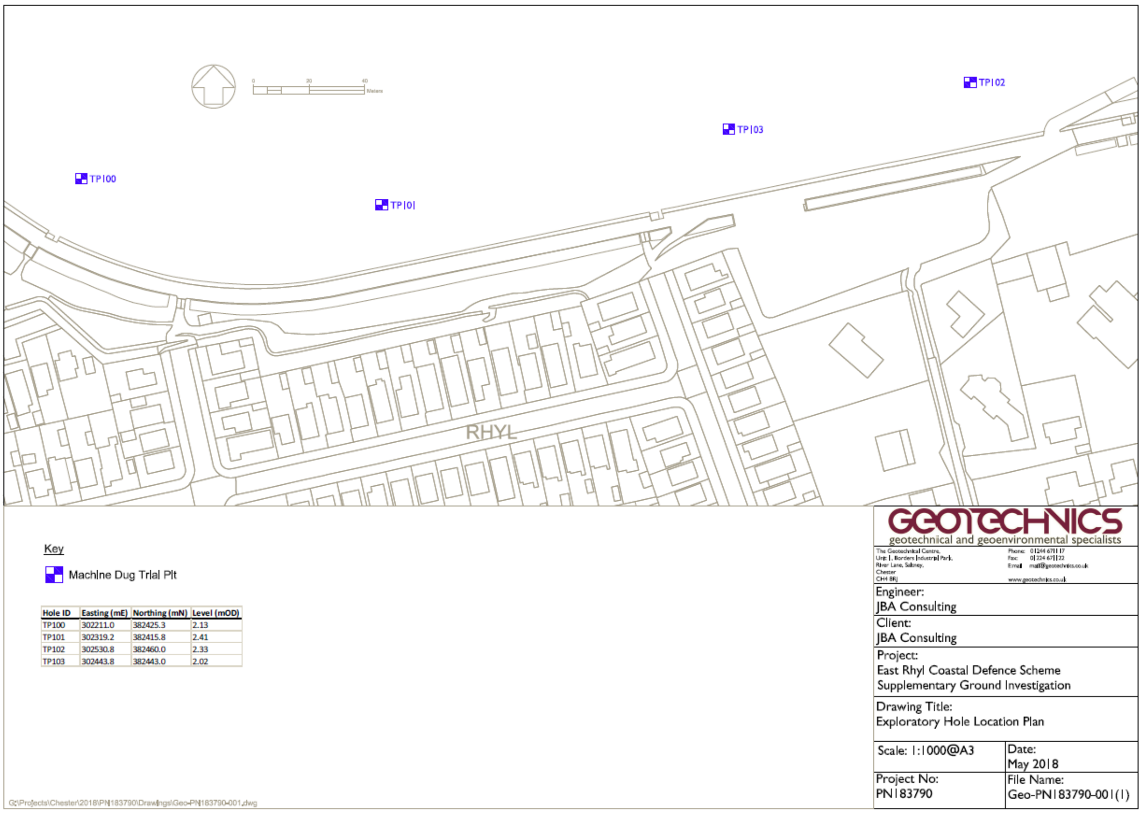

Figure 4-1: Location of sediment samples

[2] Geotechnics (2018), East Rhyl Coastal Defence Scheme, Supplementary Ground Investigation Factual Report, July 2018.

The results of the sediment sampling are shown in Table 4-1.

Table 4-1: Sediment sampling results

Parameter	Monitoring Results (cfu/g) TP100	TP101	TP102	TP103	Comments
Total coliforms	<10	<10	<10	<10	Below limits of detection.
C. perfringens	<10	<10	<10	<10	

In all samples taken, the concentration of both total coliforms and Clostridium perfringens were below the limits of detection (<10 colony forming units per gram [cfu/g]). No extant standards for bathing waters for either parameter is currently available; however, for total coliforms, the level recorded is significantly lower than the mandatory/imperative standard (10,000/100ml) established under the original Bathing Water Directive.

4.3 Discussion

Both East Rhyl and Rhyl bathing waters experience periodic issues with bathing water quality primarily due to contaminated surface runoff. The proposed flood defence scheme will not alter existing sewerage infrastructure or surface runoff patterns or result in the direct release of foul water/faecal matter into either bathing water.

Sediment sampling of the construction area shows that bacterial concentrations are below detectable limits. As such, the risk of mobilisation of significant bacterial concentrations due to the excavation work required to enable construction of the rock revetment toe is low. This risk is further minimised as the scale of excavation works will be limited to one or two 10m to 20m sections at any one time, with stockpiled excavated material returned to the excavated area before it is inundated by the incoming tide.

Notwithstanding this, it is recommended that visual monitoring of the construction area is undertaken daily during the construction period to identify any signs of sewage debris, animal faeces, litter, and oil or tar that has been discharged into the area, particularly after storm or heavy rainfall events. If any such debris is identified, it should be removed from site to a suitable waste disposal facility. Consideration should also be given to the requirement for any further mitigation as necessary to manage this risk. This will minimise the risk of bacterial contamination adversely affecting both users of the beach/bathing waters and construction personnel.

5 Conclusion

Due to the type and nature of the proposed scheme, no direct release of bacterial contaminants is anticipated. Ground investigation monitoring of beach sediment has not identified any significant contamination risk.

Monitoring of the works area should be undertaken throughout construction to identify the presence of any contaminated materials, which should then be removed from the site and disposed of appropriately.

As such, it is considered that the proposed scheme does not present a risk to bathing water quality or public amenity and any designated bathing waters.