Appendix 13.3

Coastal Study 2015 by Arup

Indaver

Resource Recovery Centre, Ringaskiddy, Co. Cork

Coastal erosion report

WM/REP/0001

Issue | 7 January 2016

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

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Executive summary

Indaver proposes to develop a resource recovery centre (including waste-to-energy facility) in Ringaskiddy in County Cork.

The proposed development will consist principally of a waste-to-energy facility (waste incinerator). In addition, the proposed development will include an upgrade of a section of the L2545 road, a connection to the national electrical grid, an increase in ground levels in part of the site and an amenity walkway along the eastern and part southern boundary of the site. Coastal protection measures are also proposed as part of the planning application and are discussed further in this report.

From 2008 to 2015 a series of studies were carried out to gain an understanding of the coastal erosion patterns in the area with a view to assessing if any coastal protection measures are needed. This report details the findings of the most recent study for which Arup was commissioned in 2014. This study involves an erosion study of the area and includes the following items;

- Assessment of the retreat rate based on historical information and the new surveys
- Numerical wave model and beach sediment transport
- Assessment of expected coastal retreat
- Appraisal of potential impacts of expected coastal retreat on the proposed Ringaskiddy Resource Recovery Centre
- Mitigation measures to minimise potential impacts

The construction of the Ringaskiddy Resource Recovery Centre including site development works will take circa 31 months. However, in view of the complexity of the development, licensing requirements and the need for the advance agreement of all conditions, Indaver is applying for a 10-year planning permission to commence and complete the construction phase.

In addition, permission is sought to operate the proposed development for an initial period of 30 years after commissioning with the option to extend the operating period for a further 30 year period, subject to obtaining a grant of permission for that extended period.

The maximum expected retreat rate was estimated following an assessment of historical and recent topographic surveys. From this assessment the expected maximum retreat rate is 0.5m/year. The recent surveys confirm that 0.5m is a good conservative estimate for the retreat

Applying this predicted rate of erosion gives an expected retreat of 50m in 100 years' time, 15m in 30 years' time and 20m in 40 years' time.

The study found that there would be no impact on the proposed development after 30 years. The study found that there could be a risk of an impact on a small section of the proposed development after 40 years however this would be confined only to the amenity walkway and a small section of a diverted gas pipeline outside of the security fence line. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

Wave modelling was carried out using the DHI MIKE 21 programme in order to predict the nearshore wave climate. The wave modelling output was then used to estimate wave run up onshore as well determining nearshore wave directions. From the nearshore wave directions the beach appears to be subject to a slightly oblique wave attack that drives sediment in a net northerly alongshore direction. Due to the presence of a rock outcrop towards the north it is likely that most of the sediment remains in the bay.

In addition to wave modelling, a sediment transport assessment was carried out. The assessment shows that the theoretical range of erosion of the beach is within the range of 10 to 30cm for the specified storm event and that local tidal currents are minimal at the site. There is a trend for sediment to move towards the north mainly due to wave-driven processes and the convex shape of the site, and with only a minor contribution from tidal currents on the flood flow. However, it is likely that the majority of this sediment remains in the coastal cell due to the presence of a rock outcrop to the north of the area and the low values of the currents observed in this particular sheltered site.

Coastal protection mitigation measures are not required for the waste-to-energy facility element of the development. However, given the concerns raised by An Bord Pleanála during the previous planning application in 2008 and given the low risk that the amenity walkway and a section of the diverted gas pipeline could be impacted in 40 years’ time, coastal protection measures have been included in this planning application as a precautionary measure so as to reduce the rate of erosion of the glacial till face.

Arup investigated a number of coastal protection options that could be applied to the Indaver site. Arup has recommended that the Indaver coastal boundary is monitored on an annual basis and the placement of approximately 1100m^3 of shingle of appropriate size and shape (rounded) above the foreshore on Gobby beach along the eastern boundary of the Indaver site. This will be a ‘soft’ solution which will potentially reduce erosion rates by limiting the exposure of the toe of the glacial till face to wave action.

The main aim of placing the material is to act as a proactive measure for the coastal area adjacent to the Indaver site only. The solution will have no negative impacts on the adjoining areas. However there will be benefits associated with the works as well as the provision of an environmentally friendly solution. The net coastal sediment transport goes from south to north according to wind conditions and swell; therefore the material is likely to move towards the north in the medium and long term. The Cork Harbour Special Protection Area (SPA) is located to the south west of the site and therefore the sacrificial material will not impact on the SPA.

It is proposed that the additional sacrificial material is placed during the construction period of the Indaver site. Thereafter, it is proposed that the placement of further additional sacrificial material is carried out if the cliff erosion rate is more than 0.5m per year measured over a period of six years, which would indicate some acceleration in the current erosion rate, or when the cliffs have retreated by approximately 3m, whichever is sooner. For this reason the coastal boundary of the Indaver site will be monitored for erosion on an annual basis.

Based on an assessment of existing topographic and site investigation information, as detailed in this report, it can be concluded that the sacrificial material will reduce the erosion rates as calculated for the existing scenario. The results show that with the application of the sacrificial material, there will continue to be no impact on the entire proposed development after 30 years. With the application of the sacrificial material, the diverted gas pipeline will not be impacted after 40 years. However, there is still a risk of an impact on the amenity walkway after 40 years. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

1 Introduction and history of coastal studies

Indaver proposes to develop a resource recovery centre (including waste-to-energy facility) in Ringaskiddy in County Cork.

The proposed development will consist principally of a waste-to-energy facility (waste incinerator). In addition, the proposed development will include an upgrade of a section of the L2545 road, a connection to the national electrical grid, an increase in ground levels in part of the site and an amenity walkway along the eastern and part southern boundary of the site. Coastal protection measures are also proposed as part of the planning application and are discussed further in this report.

The coastline along the eastern boundary of the Indaver site consists of a glacial till face adjoining Gobby Beach. The glacial till face is very shallow near the public car park to the north and steepens to the south to a maximum of 10-12m high. The glacial till face will be referred to as a cliff for the purposes of this report.

In November 2008, Arup carried out an assessment of coastal retreat and coastal flooding at the site of the proposed resource recovery centre. The coastline, which forms the eastern boundary of the site, was found to have eroded over the past 100 years at a varying rate, with the most significant erosion occurring along the south eastern boundary of the site. It was also noted that some accretion or increase by natural growth of sediment has occurred along a section of the beach to the north east of the site.

From 2008 to 2015 a series of studies were carried out to get an understanding of coastal erosion patterns in the area with a view to assess if any coastal protection measures were needed.

In May 2012, Arup carried out site investigations. The scope of works included an investigation of soil conditions at the base of the slope and of areas that will be exposed to erosion in the future, ground water levels in the coastal slope and sea water levels, and wave climate and the interaction with the beach and coastal slope along the eastern boundary of the site. From the investigations it was concluded that the sea is likely to frequently reach the base of the coastal slope at the site when extremely high water levels or extremely high waves are caused by storms. In addition it was noted that the slope is susceptible to erosion due to wave action and ground water seepage. It was recommended that the coastal evolution of the area be monitored and that a comprehensive topographical and bathymetric survey be carried out.

In 2014, Arup was commissioned by Indaver to provide consultancy services for the development of the Indaver site at Ringaskiddy. The services included:

- Topographic survey for the beach and cliffs at the eastern boundary of the Indaver site, in the area necessary to assess the coastal erosion processes which may have an impact on the proposed resource recovery centre
- Bathymetric survey in the nearshore area adjacent to the eastern boundary of the Indaver site, to be used as an input for the numerical wave model to assess the coastal erosion processes in the area

- Coastal erosion study which includes:
  - Assessment of the retreat rate based on historical information and the new surveys (see Section 2.2)
  - Numerical wave model and beach sediment transport
  - Assessment of expected coastal retreat
- Appraisal of potential impacts of expected coastal retreat on the proposed Ringaskiddy Resource Recovery Centre, and
- Mitigation measures to minimise potential impacts

The wave modelling was carried out using a spectral wave model (MIKE 21 SW), developed by the Danish Hydraulics Institute (DHI). The cross-shore sectional erosion modelling was carried out using the Coastal Engineering and Design Analysis System, SBEACH developed by Veri-Tech, Inc.

A wave run-up assessment was also carried out based on the methods described in the Eurotop Manual [8] and the CIRIA Rock Manual [1].

This report describes the coastal erosion study carried out in 2014 (dashed box above), and also proposes coastal management measures based on the findings.

An Bord Pleanála commissioned an independent marine hydrodynamic consultant (Aqua Vision BV) to carry out a review of the proposed marine works as detailed in the pre application consultation. This report also addresses the conclusions and recommendations of the independent review of the proposed works associated with the development as presented by An Bord Pleanála.

2 Assessment of historical retreat

2.1 Background

In the 2012 study carried out by Arup, the estimated future coastal retreat was based on historical data collected from various sources including the Geological Survey of Ireland (GSI) and the Ordnance Survey of Ireland (OSI). Rates identified from these historical datasets were extrapolated to give future retreat rates of up to 36 or 55m over 110 years (1897-2008) depending on the assumptions considered at the southern end of the cliff line at the site's eastern boundary.

The following data has been used for the aforementioned report:

S1) OS map, Cork Sheet 87, Ordnance Survey Ireland, 1844 edition, surveyed in 1841-42, scale 1:10560

S2) OS map, Cork Sheet 87-11 and 87-15, Ordnance Survey Ireland, 1898 edition, surveyed in 1896-97, scale 1:2500

S3) OS map, Cork Sheet 87-11 and 87-15, Ordnance Survey Ireland, 1932 edition, revised in 1929, scale 1:2500

S4) OS digital map, AutoCAD file, Ordnance Survey Ireland, 1997, scale 1:2500

S5) Survey at Ringaskiddy, Precise Control Ltd Land and Engineering Surveyors, 2000

S6) Survey at Spike Island and Ringaskiddy, Precise Control Ltd Land and Engineering Surveyors, 2001

S7) Beach Topographical Survey, Ringaskiddy, Precise Control Ltd Land and Engineering Surveyors, 2008

S8) Air Corps Aerial Photography courtesy of the Geological Survey of Ireland (GSI), 1952, scale 6 inches to 1 mile (approx.)

S9) AC1777 - Admiralty Chart, Port of Cork – Lower harbour and approaches, 1993 edition

Other data sources include:

S10) OS map, Cork Sheet 87, Ordnance Survey Ireland, 1902 edition, revised in 1896-97, scale 1:10560

S11) OS map, Cork Sheet 87, Ordnance Survey Ireland, 1934 edition, revised in 1928-29, scale 1:10560

S12) oblique aerial photograph (various years)

Historical data had been collected from various sources including the Geological Survey of Ireland (GSI), and the Ordnance Survey of Ireland (OSI).

The following data was used for the study of the coastline retreat:

- The 1897 OS map (S2)
- The 1929 OS map (S3)

- The 1997 OS map (S4)
- The 2000 Survey (S5)
- The 2001 Survey (S6)
- The 2008 Survey (S7)
- The 1952 Air Corps Aerial Photography (S8).

Historical OS maps (S2 and S3) were sourced from the Map Library in Trinity College Dublin. Each map consists of 4 separate sheets. These were first scanned and then digitally (raster) joined. The resulting images were imported in Autocad and the main features (coastlines, roads, Martello tower, field boundaries, etc.) were traced so they could be digitally projected on the more recent maps and surveys.

As discussed above, the rates identified from the historical datasets were extrapolated to give future retreat rates of up to 36 or 55m over 110 years (1897-2008) depending on the assumptions considered at the southern end of the cliff line at the site's eastern boundary. The level of uncertainty associated with this prediction was high due to a number of factors including the fact that there were large variations in the coastal retreat over the 110 year period, there were large gaps between surveys and the precision and accuracy of historical mapping cannot be quality checked to the same level as modern surveying/monitoring. Therefore retreat rates were also calculated from recent topographic surveys as discussed below

2.2 Recent topographic surveys

Following Arup's recommendations, periodic topographic surveys have been carried out in the area between 2008 and 2014.

The information obtained from these topographic surveys has been used to assess the coastal retreat since 2008 with a higher level of accuracy than the historical datasets. The topographic surveys used are as follows:

- 2008 Topographic survey
- 2010 Topographic survey
- 2014 Topographic survey

The results have been obtained for 8 equidistant sections on the site and the measured retreat is shown in Table 1 and Figure 2 below. Note that results for sections A1 and A2 are not shown as the topography in these areas is relatively low and cliffs are not present at these locations. The rates of retreat per year observed along the sections suggest that the erosion rate was lower during 2010-2014 when compared with the erosion rate from the full period monitored (2008-2014). However, the timescale is too short to be conclusive about the trend, since erosion appears to be related to the more energetic or episodic wave storm events. However, these are measured reliable values to be taken into account for reference and they indicate that there is no obvious accelerated erosion trend. It can also be inferred that the material that had eroded from the cliffs in the period 2008-2010 acted as a buffer to further retreat for the following period 2010-2014, and hence this may have contributed to the lower subsequent retreat rates (2010-2014).

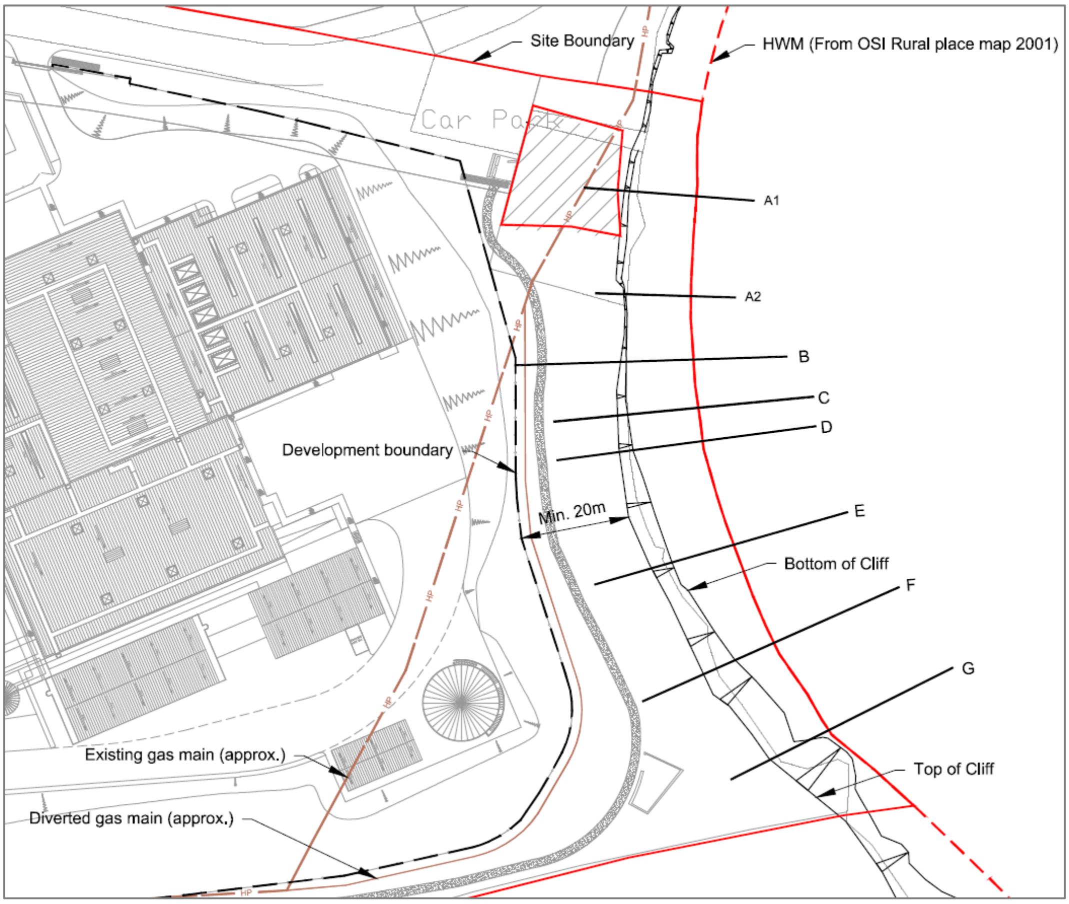

Figure 1: Plan of site showing section location. Note there is a minimum of 20m distance between the top of the cliff and the security fence proposed for the development

Table 1: Comparison of erosion rates based on topographical surveys

Sections	Retreat (m)					
	2010-2014	retreat per year 2010-2014	2008-2010	retreat per year 2008-2010	2008-2014	Average retreat per year 2008-2014
B	0.00	0.00	0.91	0.46	0.91	0.15
C	0.83	0.21	0.90	0.45	1.73	0.29
D	0.68	0.17	1.14	0.57	1.82	0.3
E	0.45	0.11	1.36	0.68	1.81	0.3
F	0.00	0.00	1.10	0.55	1.1	0.18
G	0.98	0.25	1.00	0.50	1.98	0.33

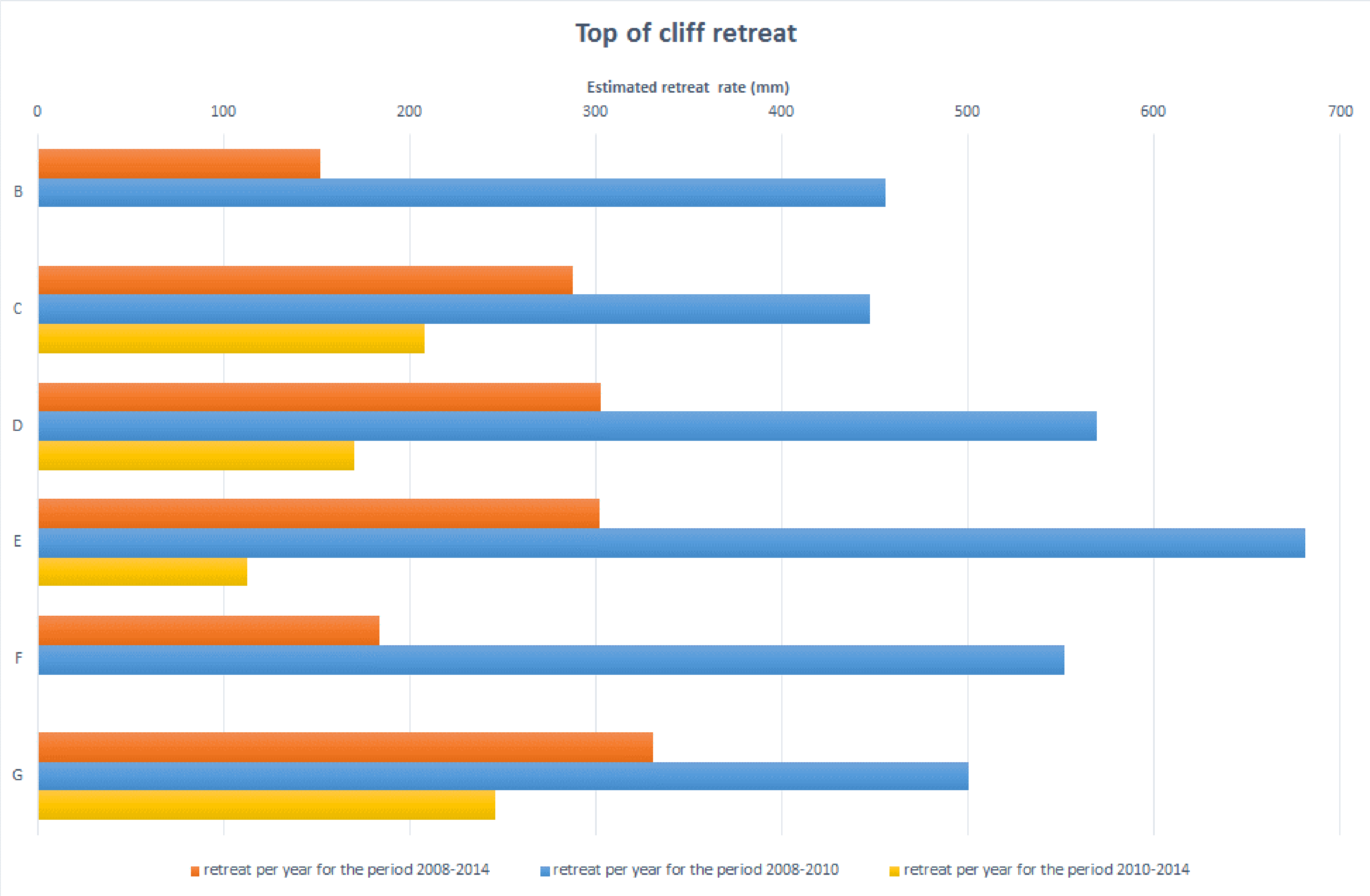

Figure 2: Rates of erosion based on topographical surveys for sections B, C, D, E, F and G.

2.3 Potential effects of erosion on the Indaver site

A conservative approach was subsequently used to calculate a maximum retreat line at the site based on the topographic survey data. The approach was based on observations and takes a conservative absolute maximum of any retreat observed within the site boundary over a six year period (2008-2014). Cliff erosion is likely to be the result of episodic events i.e. a similar event will most likely not occur in the following year and may not occur for a number of years. Therefore for the most accurate estimation of the erosion rate it is necessary to analyse data spanning the largest period available, which in this case is six years. This period of six years is still considered to be conservative to extrapolate an erosion rate.

The maximum localised retreat was measured at a particular location between sections D and F over the six year period and based on that the erosion rate was estimated as 0.47m per year. However, a conservative rate is estimated as 0.5m per year and is subsequently used to obtain the predicted retreat in 30 years and 40 years’ time (construction and operation period of proposed development).

Factors such as change in erosion pattern have not been taken into account for this assessment which is based on the recent cliff retreat measurements. However, this assessment includes the effects of sea level rise due to climate change during the measurement period. As the assessment does not take account of change in erosion patterns and potential accretion the resultant predicted retreat rate is a conservative estimate.

The maximum predicted retreat of 0.5m/year is then applied to the entire length of the top of the cliff line adjacent to the site. The topographic surveys carried out between 2008 and 2014 confirm the retreat rates found in the historical maps, surveys and aerial photographs (1897-2008) were within the correct range (36-55m over 100 years).

Applying this predicted rate of erosion gives an expected retreat of 50m in 100 years’ time, 15m in 30 years’ time and 20m in 40 years’ time. Refer to Appendix A which shows the estimated retreat lines.

Using this approach it is observed that a retreat of 50 m in 100 years would encroach beyond the security fence of the proposed development. The study found that there would be no impact on the proposed development after 30 years. The study found that there could be a risk of an impact on a small section of the proposed development after 40 years however this would be confined only to the amenity walkway and a small section of a diverted gas pipeline outside of the security fence line. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

3 Assessment of wave conditions

This section of the report addresses the recommendation by Aqua Vision BV to assess the coastal processes at the site.

3.1 Metocean conditions

3.1.1 Site location

The Indaver site is located at the eastern end of the Ringaskiddy Peninsula, which is situated approximately 2 kilometres south of Cobh. It is bounded to the north by the public road (L2545), to the east by a section of coastline within Cork Harbour and to the south and west by agricultural land. The coastal boundary of the Indaver site is a small area (approximately 150m in length) of a larger bay situated to the west of Cork Harbour located between Paddy's Point and Golden Rock. In larger context this particular area is less likely to erode due to both its sheltered protection by rock outcrops (Paddy's Point and Golden Rock) and its convex layout shape.

The eastern coastal boundary is formed by a glacial till slope. The toe of the slope varies from 3.0m Ordnance Datum Malin (ODM) at the northern end to 1.3m ODM at the southern end. The top of the slope varies from 3.5m ODM at the northern end to 11.6m ODM at the southern end. There are rock outcrops to the north and south of the site. Mean High Water Springs (MHWS) is 1.62m ODM (4.20m Chart Datum (CD)) at the site.

Figure 3: Indaver Site Aerial Photo - Source: Google Maps. - ©2014 Google

The site is sheltered from open sea waves but is fully exposed to wind generated waves from the second quadrant (from east to south) and a large proportion of wind generated waves from the first directional quadrant (from north to east).

Figure 4: Location of the site - Source: Google Maps. - ©2014 Google

3.1.2 Wind and wave data

3.1.2.1 Sources of data

Wind and wave data is used to define the boundary conditions of the nearshore model.

Wind data was sourced from Met Éireann for the nearby Roche's Point station which is located at Irish Grid reference W 82482 60071 and 'Irish national annex to the wind Eurocode (EN1991-1-4)' produced by Arup in 2009. The dataset covers 29 years from 1971 to 2000.

There was no wave data available within Cork Harbour.

3.1.2.2 Directional wind distribution

Directional analysis of the wind climate was carried out to characterise the metocean conditions of the waves arriving at the site location.

The site will only be affected by storm waves approaching from the first and second quadrants due to the position of the coastline bordering the east of the site (see Figure 5 below). For this reason, only wind and wave conditions from the first and second quadrant will be considered for this project (i.e. directions from north to south clockwise).

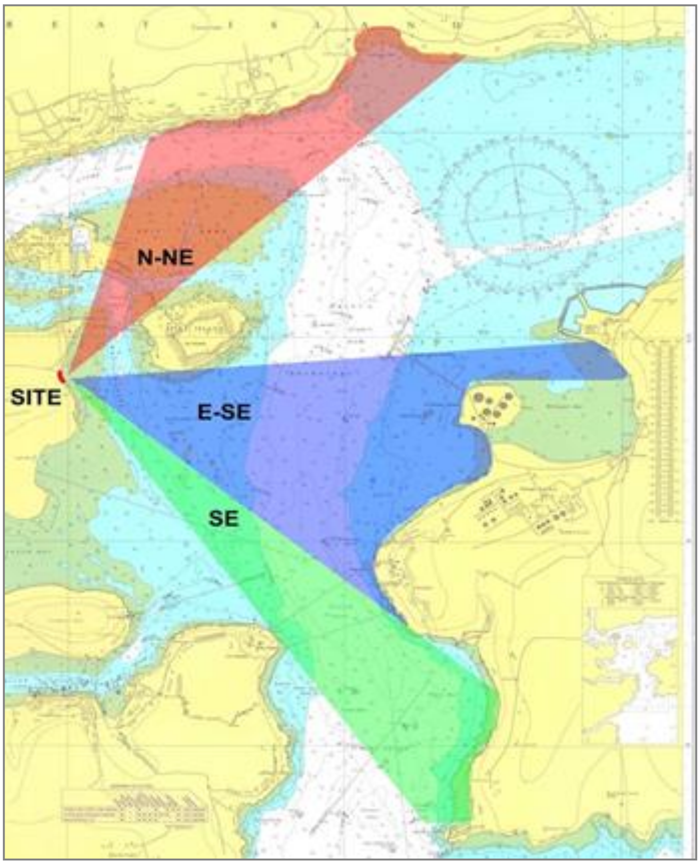

Figure 5: Wave fetch diagram

Figure 6 shows a full wind rose for Cork Airport for the period 1962 to 2010, which was obtained from the Met Éireann website (www.met.ie) [4]. The wind rose shows that the largest wind velocities and most frequent winds come from the South West. However, the largest wind velocities and most frequent winds, which could affect the wave climate at the site, come from the South. In addition to this the site can only be exposed to waves approaching from the first and second quadrant (N to S). For the site location, Figure 5 shows that the SE direction has the largest fetch length. However, the characteristics of the bathymetry for waves approaching from the East, make these waves lose less energy in the propagation process than those from the SE. For these reasons the wave conditions generated by winds from E, SE and S direction will all be assessed. The first sector (N to E) will not be considered in this assessment due to the fact that the shortest fetch length comes from the North, the site is protected by the presence of Spike Island, and winds coming from the NE are less frequent and intense. The MIKE21 SW wave model used in this project (Section 3.2) also takes into account the effect of waves generated to the E of Spike Island, which will reach the site by diffraction around the island.

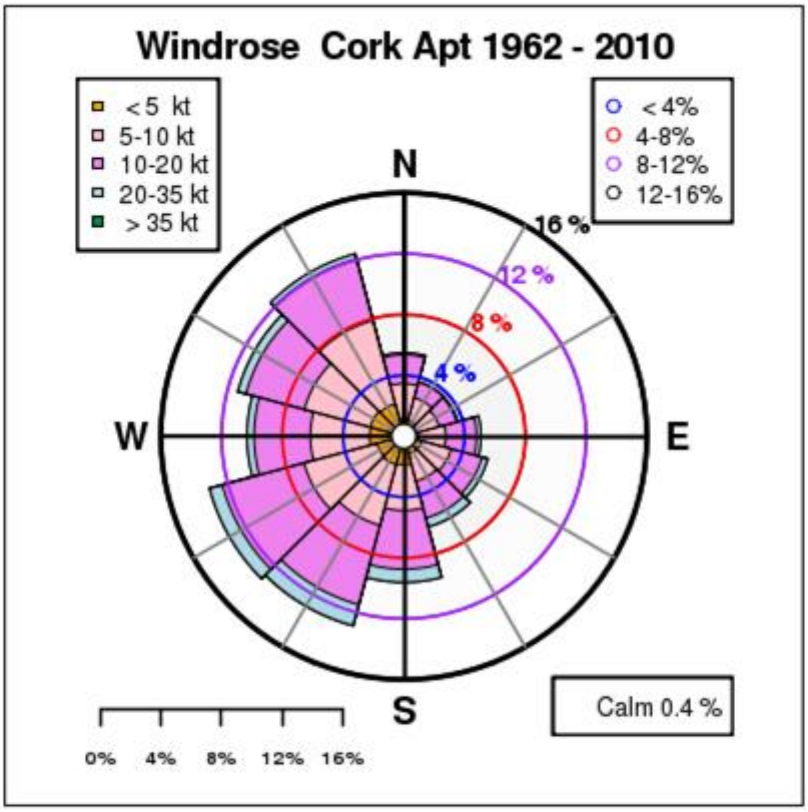

Figure 6: Wind rose for Cork Airport, Met Éireann

The site is exposed to open sea waves entering through the fairly narrow entrance to the harbour. However, the sheltered location of the site and the relatively long distance to the entrance support the assumption that the influence of the open sea wave action in relation to the locally wind generated waves is negligible. Wave modelling runs were performed to validate this assumption.

3.1.2.3 Wind regime

The following sources have been used:

- Wind data was gathered for Roche's Point including the mean monthly velocity. This value is used as a representative of mean events. The data was gathered from the Met Éireann website, (www.met.ie) [4].
- Wind speed for 10 minute duration at a height of 10m (V_w 10, 10m) for 50yr return period was obtained from the 'Irish national annex to the wind Eurocode (EN1991-1-4)' produced by Arup in 2009. This value is used as representative of extreme events.

3.1.2.4 Increased storminess

Change in 'storminess' may mean an increase or decrease in the intensity, severity or frequency of storms. Some research indicates that although the intensity of storms is increasing, their frequency is decreasing. In the context of maritime engineering, this may lead to increased or decreased surge, design wave height and wave loads, combining to change the structural loading regime on maritime structures. In addition, this issue may affect changes in cyclical fatigue loading and increased potential for scour.

In a number of global climate models it has been demonstrated that cyclones may change in frequency, tracked path and intensity. Studies in the North Atlantic Ocean have shown that wave heights have increased over the last few decades. These studies show a strong relationship between the North Atlantic Oscillation and interannual variability as great as 20% in the analysis of the ERA-40 global waves re-analysis. This identified significant trends in wave height, particularly in the Southern Ocean, the North Atlantic and the North Pacific. These trends are more pronounced in the high quartiles, indicating that the large wave events are increasing at a greater rate than the mean. However, it is noted that the results are far from conclusive and that more detailed investigations are required. This issue has been addressed by the reviewed climate change adaptation documents [2] and [7] in a number of different ways:

- Acknowledgement that storms may increase in intensity but no immediate action required.
- Recommendations for a sensitivity analysis either unstructured or structured (e.g. for England, DEFRA suggests an assessment based on increases to wave height and wind speed by +5 to +10%) outlined in Table 2.

For this study an increase of 10% of the present storm conditions has been assumed to assess the future scenario.

Table 2: Increased storminess scenarios

Parameter	**1990 – 2025**	**2025 – 2055**	**2055 – 2085**	**2085 - 2115**
Peak rainfall intensity (preferable for small catchments)	+5%	+10%	+20%	+30%
Peak river flow (preferably for larger catchments)	+10%	+20%		
Offshore wind speed	+5%		+10%	+10%
Extreme wave height	+5%		+10%	+10%

3.1.3 Sea level rise due to climate change

The Office of Public Works (OPW) “Planning System and Flood Risk Management Guidelines for Planning Authorities” [2] advise a precautionary approach with regard to climate change. The precautionary approach includes:

- Ensuring that the levels of structures designed to protect against flooding, such as flood defences, land-raising or raised floor levels are sufficient to cope with the effects of climate change over the lifetime of the development they are designed to protect
- Ensuring that structures to protect against flooding and the development are capable of adaptation to the effects of climate change when there is more certainty about the effects and still time for such adaptation to be effective.

Guidance by the OPW advises on future scenarios and allowances for climate change. It identifies two scenarios: the Mid-Range Future Scenario (MRFS); and the High-End Future Scenario (HEFS) with an allowance for mean sea level in 2100 for both of +0.5m and +1m respectively [7].

- The former (the MRFS) is intended to represent a 'likely' future scenario, based on the wide range of predictions available and with the allowances for increased flow, sea level rise, etc. within the bounds of widely accepted projections.
- The latter (the HEFS) is intended to represent a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictions available, and with the allowances for increased flow, sea level rise, etc. at the upper the bounds of widely accepted projections.

In addition to the element of sea level rise, the guidance also notes that this area of the country is subsiding due to Glacial Isostatic Adjustment (GIA). The rate of GIA is given as 0.5mm/year. Taking into account all the recommendations, wave model runs were carried out using an adopted climate change allowance estimate of 0.55m by 2100 i.e. the MRFS.

3.1.4 Design water levels

3.1.4.1 Tidal levels

The tidal range and associated levels have been derived from the United Kingdom Hydrographic Office Admiralty Chart Number 1777 Cork Harbour [10] for Cobh. Cobh and Ringaskiddy's gauges are both located close to the project site. All levels are referenced to CD, which is 2.58m above ODM. These levels are shown in Table 3.

Table 3: Tide levels at Cobh

	Tide level (m CD)	Tide level (m OD Malin)
HAT	4.60	2.02
MHWS	4.20	1.62
MHWN	3.20	0.62
MLWN	1.30	-1.28
MLWS	0.40	-2.18
LAT	-0.10	-2.68

3.1.4.2 Cases

A number of different extreme water levels were analysed and their relevance to the design cases in this report were assessed. The levels are based on tidal levels, climate change allowances and extreme water levels (comprising tidal and surge components) as noted in the ICPSS for this area [6]. This conservative approach has been adopted to account for the lack of an existing joint probability assessment. A joint probability assessment for surge and waves was not considered necessary for the study due to the fact that the extreme tidal levels will only occur for a few hours of the tidal cycle during Spring tide conditions. Therefore, a wide range of likely extreme events and their associated conditions provide a robust assessment of the extreme situations likely to happen at the site is shown.

The final water levels adopted for the wave modelling incorporated different scenarios of water levels: sea level rise for both the MRFS and HEFS, storm surge and extreme tidal water level combined with MHWS and the extreme water level for the 0.5% Annual Exceedance Probability (AEP) at prediction point Point C_2 within Cork Harbour as noted in the ICPSS [6]. The cases and combinations assessed are shown in Table 4.

Table 4: Cases and combinations assessed in the wave model

Direction	Case Number	Case	Water Levels					
			Design Year	Climate Change Allowance	Return Period	Extreme Water Level	Total Water Level	
			yr	m	yr	m OD Malin	m OD Malin	m CD
E	1.1	MHWS + MRFS	2100	0.55			2.17	4.75
SE	2.1	MHWS + MRFS	2100	0.55			2.17	4.75
	2.2	MHWS + MRFS	2100	0.55			2.17	4.75
	2.3	MHWS + HEFS	2100	1.05			2.67	5.25
	2.4	0.5% AEP + MRFS	2100	0.55	200	2.73	3.28	5.86
	2.5	0.5% AEP + HEFS	2100	1.05	200	2.73	3.78	6.36
	2.6	MLWS + MRFS	2100	0.55			-1.63	0.95
S	3.1	MHWS + MRFS	2100	0.55			2.17	4.75
	3.2	MHWS + MRFS	2100	0.55			2.17	4.75

3.2 Wave modelling methodology

3.2.1 Overview

A wave model was undertaken as part of this study with the aim of providing a more accurate estimation of the wave heights assessed previously using empirical formulae. The empirical formulae did not take into account variability of the bathymetry which is critical in the wave propagation process.

The methodology that underpins the computational wave modelling study is outlined in the following steps:

1. Set the wind climate conditions;
2. Set up the computational model (bathymetry, mesh configuration and boundaries);
3. Set up boundary conditions for the model;
4. Obtain the required outputs at the site location;

3.2.2 Software

The wave propagation model used was MIKE21 SW developed by DHI.

MIKE21 SW is a 3rd generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. The model includes the following physical phenomena:

- Wave growth by action of wind;
- Non-linear wave-wave interaction;
- Dissipation by white-capping;
- Dissipation by wave breaking;
- Dissipation due to bottom friction;
- Refraction due to depth variations:
- Wave-current interaction;
- Diffraction;
- Reflection;

A major application area for this model is the design of nearshore structures where accurate assessment of wave loads is of utmost importance for a safe and economic design.

When waves approach the coastline, they undergo a number of changes caused by the processes listed above, which affect their characteristics: wave steepness, height, propagation velocity and direction. In this study the MIKE21 SW model was used to propagate wind-generated waves from offshore to nearshore at the site location. As stated previously, the influence of open sea waves in relation to local wind generated waves is assumed to be negligible, and this case is also investigated for validation.

3.2.3 Bathymetric and topographic data

The different sources of data used in this study include the following:

- Topographic survey carried out by Precise Control Land & Engineering Surveyors in 2014
- Bathymetric survey carried out by Irish Hydrodata Ltd. in 2015
- UK Hydrographic Office Admiralty Chart number 5622.10

In order to determine how waves propagate to the site, it is necessary to gather all available bathymetric data in the harbour both nearshore and offshore from the site. The offshore bathymetry for the model was obtained from the UK Hydrographic Office Admiralty Chart number 5622.10: The Sound to Spike Island, scale 1:12,500, depths in metres reduced to Chart Datum (see Figure 7 below) [10].

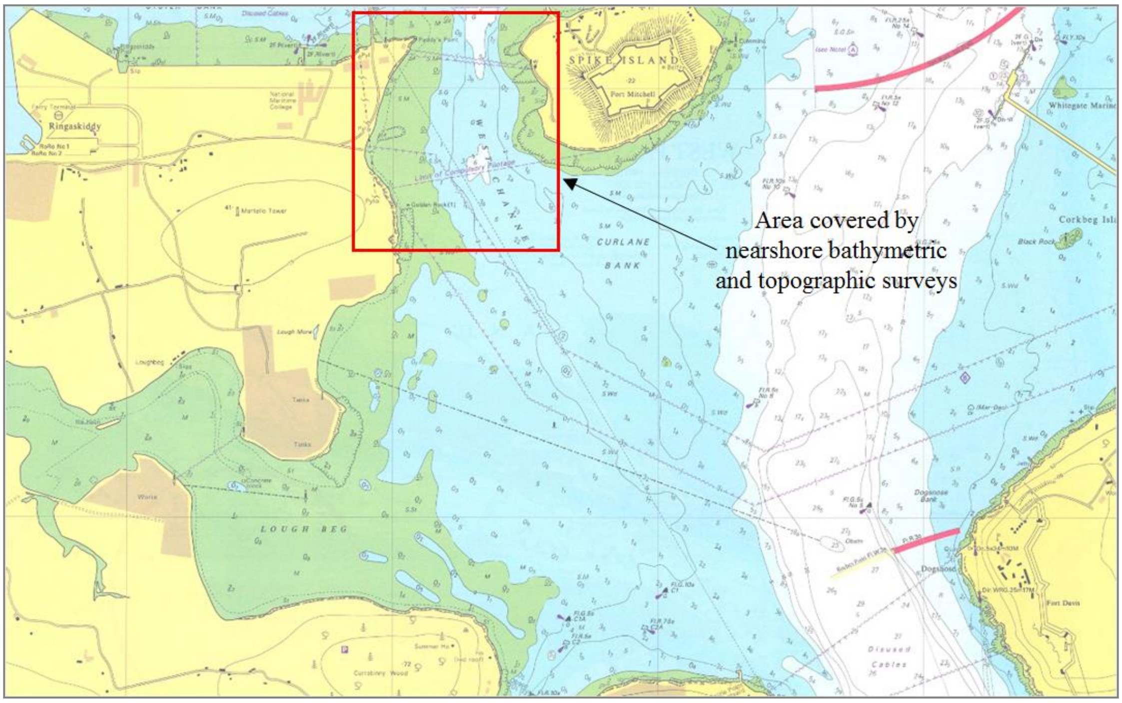

Figure 7: Snapshot of Admiralty Chart 5622.10 indicating the area covered by nearshore bathymetric and topographic surveys

Nearshore bathymetry was derived from a recent survey undertaken by Irish Hydrodata Ltd. in Jan 2015. On site topography was derived from a survey undertaken by Precise Control Land & Engineering Surveyors in November 2014.

3.2.4 Wave propagation

3.2.4.1 Model bathymetry

Figure 8 shows the digitized Admiralty Chart described in the previous section. The model bathymetry varies from roughly -28m CD to +9m CD and takes into account bathymetric features such as the Lough Beg to the south west and the Curlane bank south of Spike.

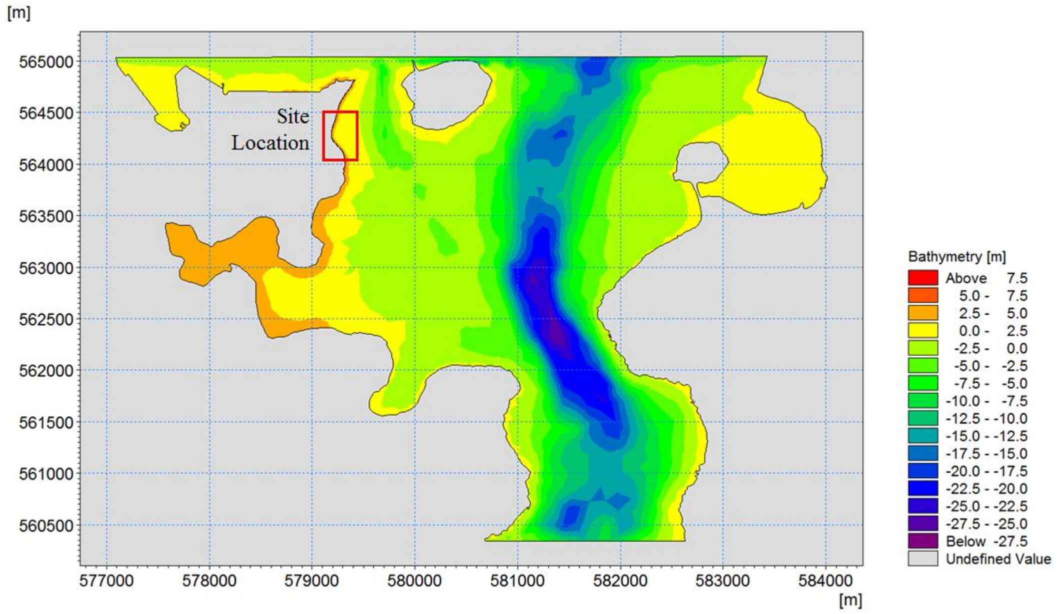

Figure 8: Bathymetric model derived from Admiralty Chart 5622.10 showing approximate site location

3.2.4.2 Computational mesh

The MIKE21 SW model uses a flexible mesh to calculate wave parameters within the computational domain. This mesh can be denser in the areas of interest. The mesh used in the model for Ringaskiddy is shown in Figure 9, Figure 10, and Figure 11.

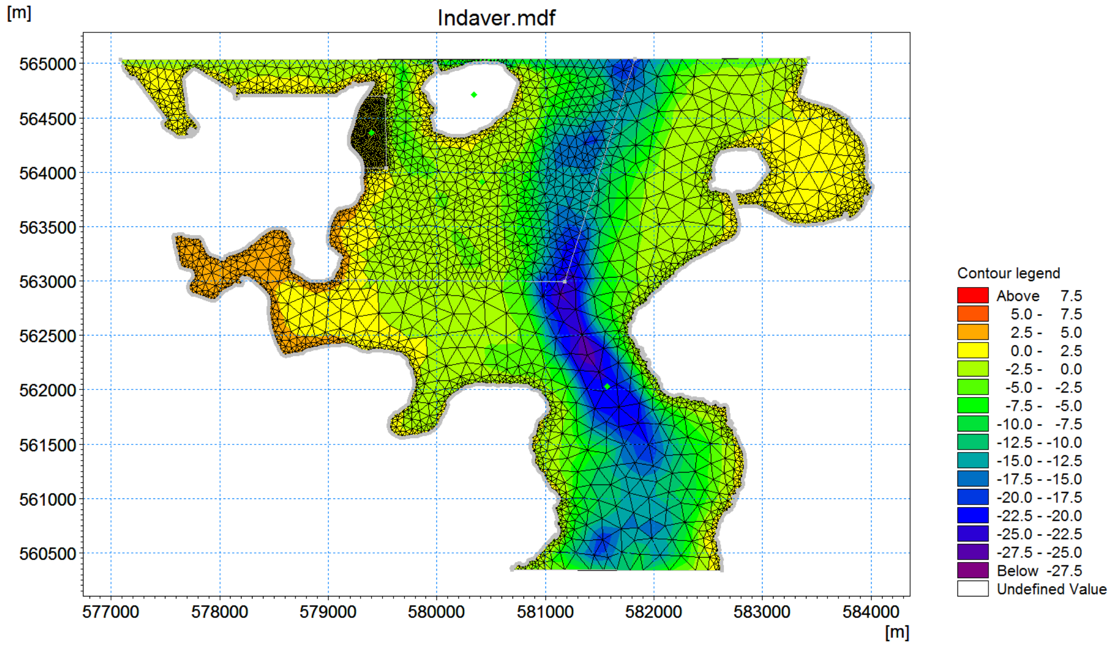

Figure 9: Bathymetry computational mesh in the MIKE21 SW model

Three different areas have been defined within the model for mesh generation. Each area had a different mesh size with a finer grid for the area of interest and coarser grid elsewhere. Figure 10 shows the bathymetry used in the model whereas the size of the mesh in the various model areas is shown in Figure 11. Table 5 below describes the different sized mesh used for each area.

Table 5: Mesh size for various areas in the computational domain

Section	Mesh Size
Nearshore	200 m^2
Intermediate	5,000 m^2
Offshore	20,000 m^2

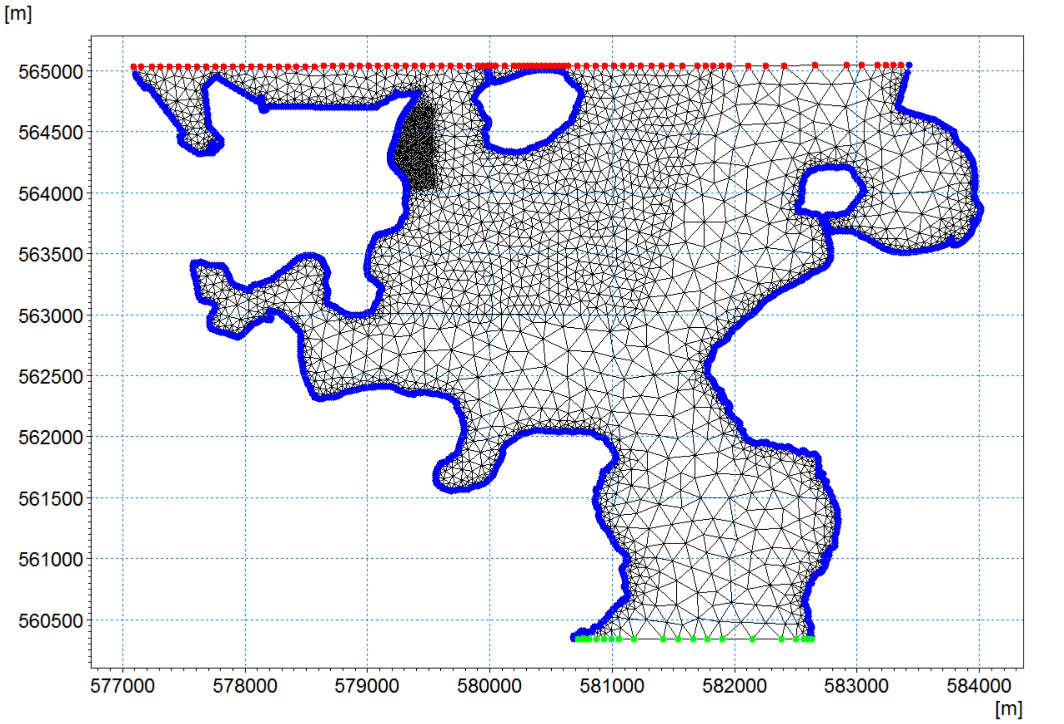

Figure 10: MIKE21 SW model mesh

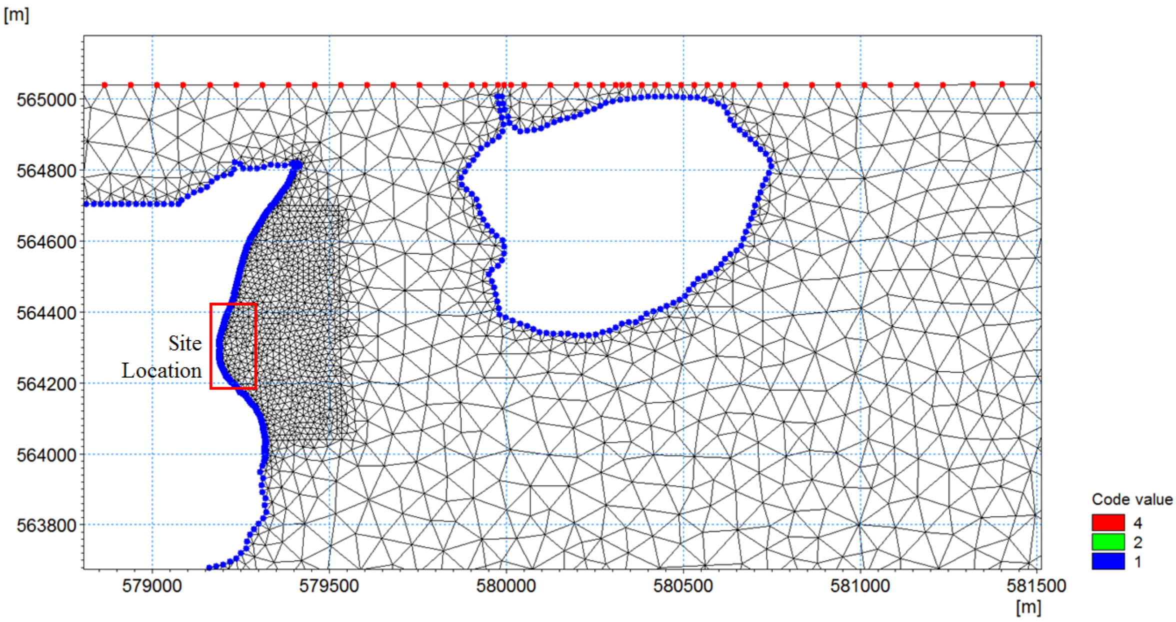

Figure 11: MIKE21 SW model mesh detail showing site location

3.2.4.3 MIKE21 SW model runs

The offshore waves were transformed over the domain, using a number of different input wind and wave conditions. The wind at Roche's Point was assumed to be acting along the entire computational domain (constant in time and space). The initial conditions of wave height, Hs, peak wave period, Tp, and direction of the offshore waves are provided as input data at the model boundaries.

The model was run as a fully spectral model. Two different situations were considered as follows: only considering wind generated waves, and considering both wind generated waves and waves from the open sea. The latter case was run in order to validate the assumption that open sea waves could be neglected in comparison with locally generated wind waves at the site. The model results showed that open sea waves entering the estuary are reduced in height by approximately 80% at the site (Cases 2.2 and 3.2). For this reason a unitary value for offshore waves was selected in order to see the relative importance in relation to locally generated winds, which proved to be negligible. Hence, the open sea waves were considered to be negligible in comparison with the locally wind generated waves in subsequent parts of the study. This conclusion was also supported by Arup's previous studies. Open sea waves coming from the S and SE direction were considered as these are the only open sea wave directions that can affect the site.

In relation to wind the same extreme wind speed is applied in cases where wind speed alone is considered regardless of direction. This was determined to be an appropriate assumption from analysis. However, this is a conservative assumption in that it takes the maximum statistically characterised wind speed and applies this to all likely directions. In addition, increased storminess as described in section 3.1.2.4 has also been factored into the wind speeds used in the model runs. As previously mentioned this is a conservative estimate.

A wide range of extreme wave events caused by extreme wave conditions in combination with different extreme water levels have been run in the Mike 21 model to assess the effects of such extreme wave conditions at the site. The aim was to obtain a wide range of extreme potential wave conditions nearshore, which will contribute to the natural erosion of the cliffs and beach.

Table 6 shows the model results for the various combinations of wind for extreme and mean conditions and offshore wave data and various water levels taking into account fluvial and tidal conditions as well as sea level rise for all the directions assessed. The nearshore wave results correspond to the values obtained at approximately the 3.6m CD contour (1.0m ODM), which is situated approximately 9.0m seaward of the bottom of the cliff. These values are a conservative estimate of nearshore wave conditions at the site. The resultant graphics of the different wave model cases are shown in Appendix B.

The model output line is located along the 1m CD contour immediately seaward of the site boundary and is located approximately 10m from the bottom of the cliffs. The output value is the maximum wave height along the 1m contour.

From Table 6 it can be seen that storms from both the East and South East produce the most unfavourable wave conditions at the site. Although the fetch length in the South East direction is the longest unobstructed length, the characteristics of the bathymetry aligned with the East direction result in less wave energy being dissipated in the wave propagation process. Hence Cases 1.1 and 2.1 show similar nearshore wave results. However, the SE direction is considered the most unfavourable for the following reasons:

- Winds from the SE direction are most frequent and have higher velocities than E direction
- Open sea swell waves will come from the S and SE direction and, (although smaller) will combine with waves generated by winds from the same direction.

Table 6: MIKE21 SW Results

Direction	Case Number	Case	Water Levels: Climate Change Allowance	Water Levels: Total Water Level		Wind Conditions: Case	Wind Conditions: Wind Velocity	Wind Conditions: Duration	Offshore Waves: Hs	Offshore Waves: Tp	Nearshore Wave Results: Hs	Nearshore Wave Results: Tp
			m	m OD Malin	m CD		ms-1	mins	m	s	m	m
E	1.1	MHWS + MRFS	0.55	2.17	4.75	50yr return period	28.3	10			1.0	3.9
SE	2.1	MHWS + MRFS	0.55	2.17	4.75	50yr return period	28.3	10			1.0	4.1
	2.2	MHWS + MRFS	0.55	2.17	4.75	mean wind speed	6.3	10	1.0	8	0.2	3.7
	2.3	MHWS + HEFS	1.05	2.67	5.25	50yr return period	28.3	10			1.3	4.2
	2.4	0.5% AEP + MRFS	0.55	3.28	5.86	50yr return period	28.3	10			1.6	4.2
	2.5	0.5% AEP + HEFS	1.05	3.78	6.36	50yr return period	28.3	10			1.7	4.1
	2.6	MLWS + MRFS	0.55	-1.63	0.95	50yr return period	28.3	10			0.0	0.0
S	3.1	MHWS + MRFS	0.55	2.17	4.75	50yr return period	28.3	10			0.8	4.1
	3.2	MHWS + MRFS	0.55	2.17	4.75	mean wind speed	6.3	10	1.0	8	0.2	7.2

Figure 12 and Figure 13 show the wave height distribution over the computational domain for Case 2.1 for a storm period equivalent of 50 year return period wind conditions, sea level rise for year 2100 and MHWS conditions. Case 2.1 can be used to provide an example of expected extreme wave conditions at the site.

Table 7: Nearshore wave conditions

Direction	Case Number	Case	Wind Conditions		Nearshore Wave Conditions	
			Velocity	Duration	Wave Height	Period
			ms^{-1}	min	m	s
SE	2.1	MHWS + MRFS	28.3	10	1.0	4.1

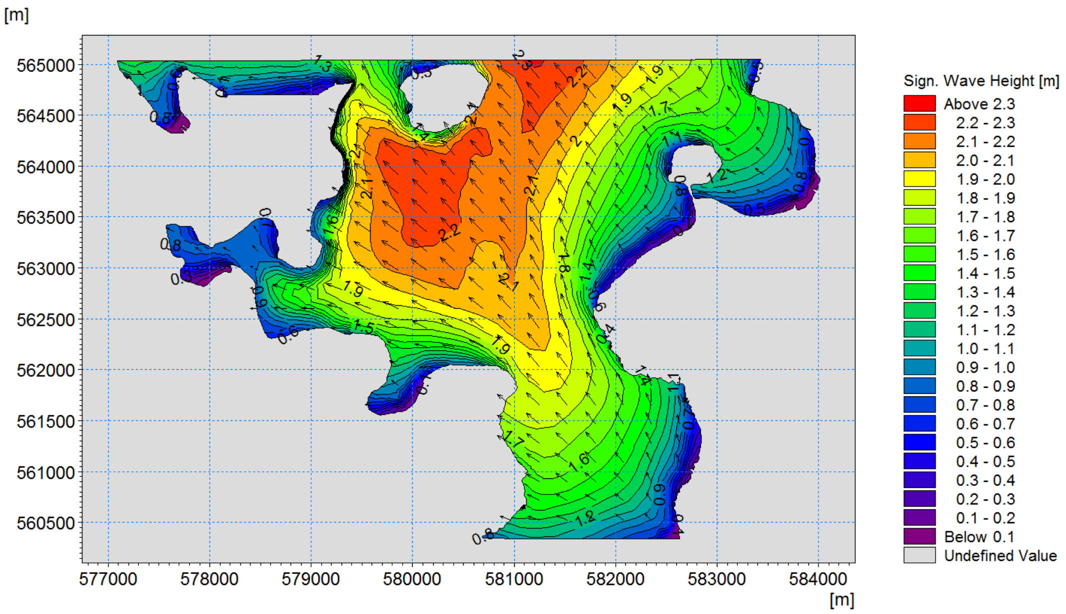

Figure 12: Offshore wave height distribution - Case 2.1 Waves from the SE

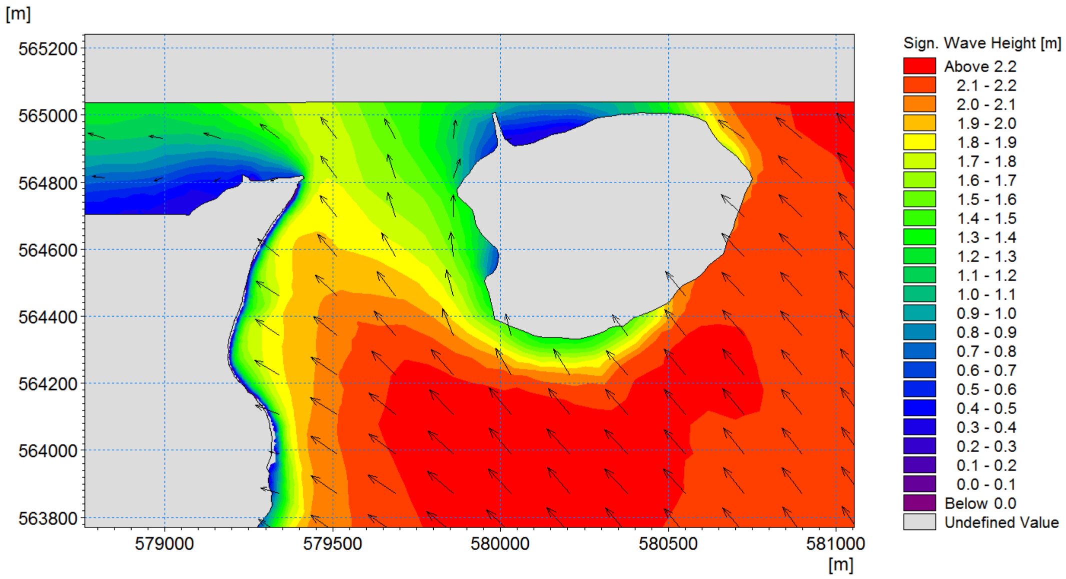

Figure 13: Nearshore wave height distribution - Case 2.1 Waves from the SE

3.2.5 Nearshore wave directions

The consideration of nearshore wave directions is a key element for the assessment of sediment transport within the coastal cell. Figure 14 to Figure 16 show the nearshore velocity component for Cases 1.1, 2.1 and 3.1 from the wave modelling output. The velocity component indicates the direction of the waves as the approach the shoreline. Generally speaking it is normal for waves to remain perpendicular to the nearshore bathymetry as can be seen in Figure 14. However, in Figure 15 and Figure 16 this is less apparent due to the local wind conditions forcing the waves from the SE and S respectively.

Table 8: Mean wave directions for all cases

Direction	Case Number	Mean wave direction (^{o} from S)
E	1.1	271
SE	2.1	279
	2.2	282
	2.3	285
	2.4	287
	2.5	287
	2.6	288
S	3.1	283
	3.2	286

The directions obtained from these design cases from the wave model (see Table 8) indicate that there is a slight tendency for waves to push sediment towards the northern extent of the site boundary since the beach is subject to oblique wave attack that drives sediment in a net northerly alongshore direction. Due to the presence of a rock outcrop towards the north it is likely that most of the sediment will remain in the bay as the rock will act as a natural barrier to the movement of sediment. Hence, the presence of the rock outcrops will likely reduce the potential for sediment to be lost from the coastal cell.

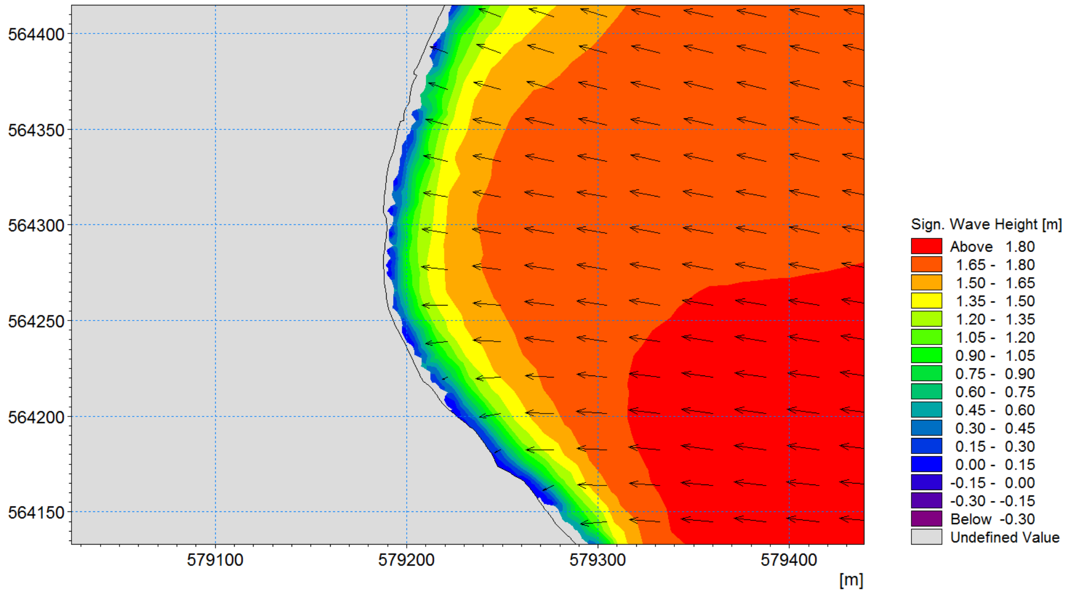

Figure 14: Case 1.1 (E direction) showing nearshore wave direction

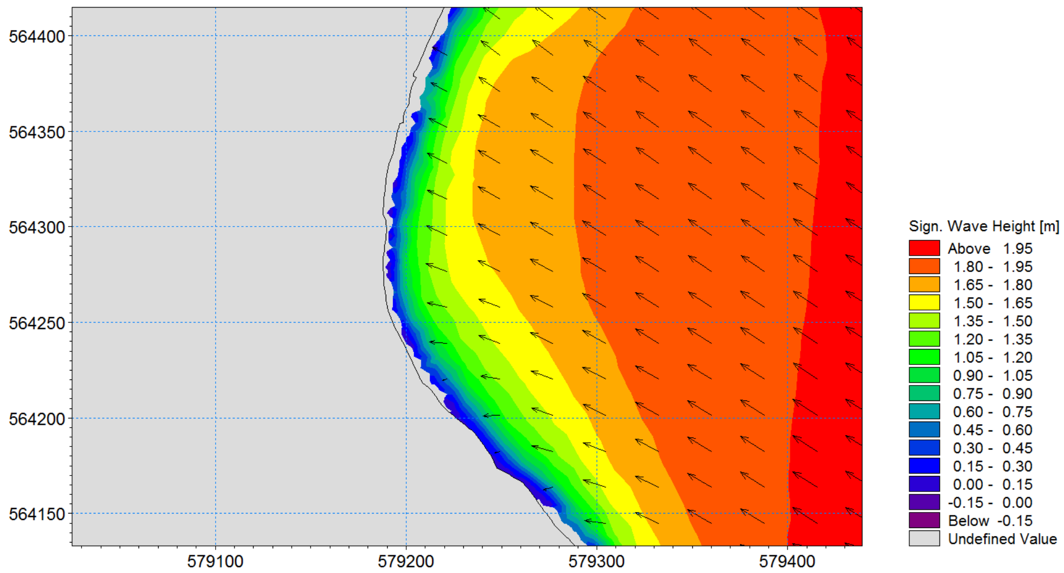

Figure 15: Case 2.1 (SE direction) showing nearshore wave direction

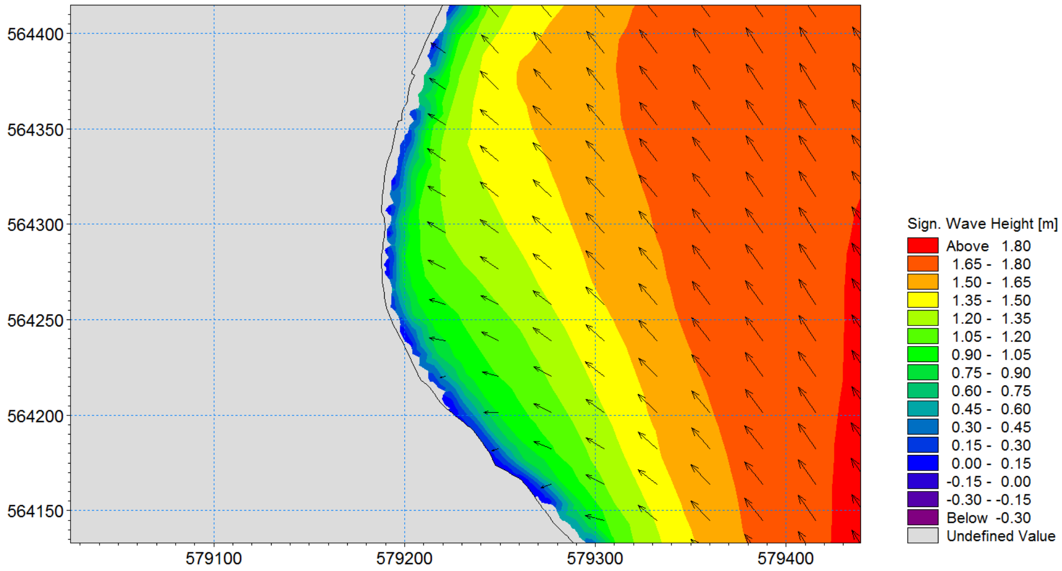

Figure 16: Case 3.1 (S direction) showing nearshore wave direction

3.2.6 Conclusions from the wave modelling

The following conclusions can be drawn from the modelling:

- The most unfavourable wind direction for the site is the SE. This direction has the longest fetch and it gives a wave height (Hs) in the same order as in the E direction. However, this direction may produce the largest Hs on site for the extreme return period considered and it may be combined with the swell open sea Hs of the same direction. The model used for this study was run as a fully spectral model. Model runs considering both wind and open sea swell waves showed that the reduction of the open sea wave energy is significant enough that a calculation of the most extreme wave conditions at the site can be based on local wind generated waves only. Joint probability figures for the combination of surge and waves were not available and therefore a conservative approach was taken by assuming that the extreme surge will only occur for a few hours of the tidal cycle during Spring tide conditions.

- The influence of mean wind conditions on wave conditions at the site is negligible.

- Hs values of 1m are obtained for a MHWS tidal level. MHWS occurs approximately twice per month with the highest portion of the tide lasting for less than three hours. For the maximum run-up to occur, a severe storm (50 yr wind conditions) is required within the harbour coinciding with MHWS.

- Case 2.1 gives an accurate reflection of expected extreme wave conditions at the site. This corresponds to an Hs value of 1.0m with an associated period of 4.1s. These values correspond to a tidal water level of MHWS with the MRFS (0.55m sea level rise).

- The beach appears to be subject to a slightly oblique wave attack that drives sediment in an alongshore direction rather than cross-shore. Due to the presence of a rock outcrop towards the north it is likely that most of the sediment will remain in the bay.

3.3 Wave run-up calculation

Breaking of waves on the beach results in a periodic wave 'uprush' above the still-water level known as run-up. This is not an inundation of water but can result in water intermittently reaching higher elevations on the beach. As described in the Arup "Coastal Recession Mechanisms Investigation" Report, 2012, the water may reach the toe of the cliff in storm conditions and this in turn may increase erosion rates of the cliffs. The wave run-up height ($R_{u2\%}$) is defined as the vertical difference between the highest point of wave run-up and the still water level (SWL). See Figure 17 below.

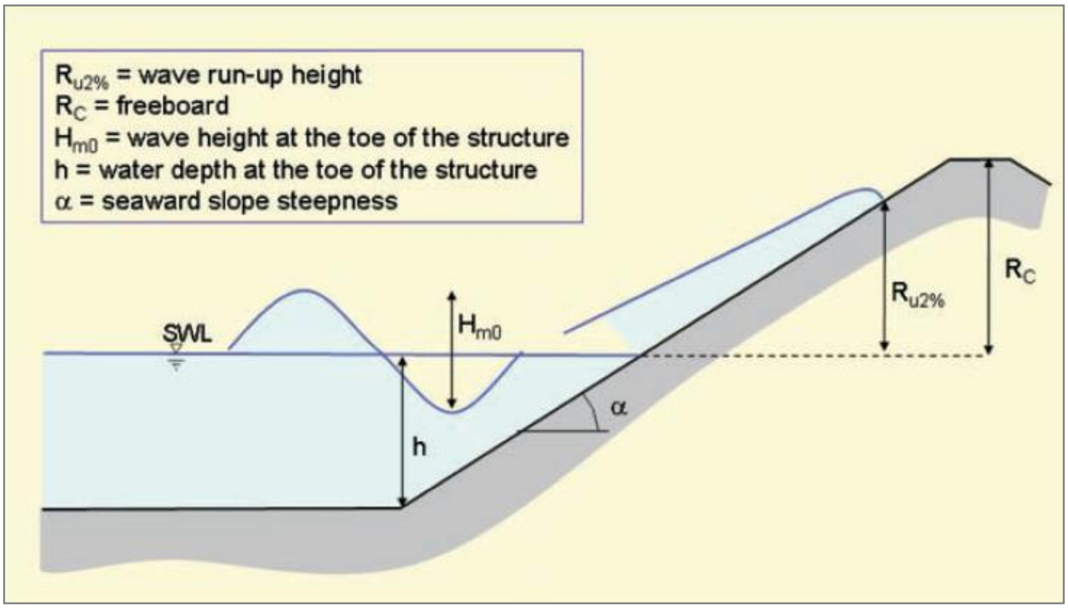

Figure 17: Definition of the wave run-up height Ru2% on a smooth slope, Eurotop Manual 2007

Calculations of wave run-up height were carried out for the cases as described in the previous section. The calculations were based on empirical formulae outlined in the Eurotop Manual [8] and CIRIA Rock Manual [1] as follows:

$$\frac{R_{u2\%}}{H_{m0}} = c_1 \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \xi_{m-1,0}$$

$$\text{with a maximum of } \frac{R_{u2\%}}{H_{m0}} = \gamma_f \cdot \gamma_\beta \left(c_2 - \frac{c_3}{\sqrt{\xi_{m-1,0}}} \right)$$

$R_{u2\%}$	wave run-up height exceeded by 2% of the incoming waves (m)
H_{m0}	significant wave height (m)
c_1, c_2, c_3	empirical coefficients
$\xi_{m-1,0}$	Iribarren number or Surf Similarity Parameter
γ_b	influence factor for berm
γ_f	influence factor for roughness
γ_β	influence factor for oblique wave

Table 9 shows the various input parameters used in the calculation of the wave run up.

Table 9: Wave run up calculation inputs

	Symbol	Inputs	Units
Still Water Level	SWL	6.36	m OD Malin
Slope angle	α	10.00	°
Berm Factor	γ_b	1	-
Roughness factor	γ_f	1	-
Oblique wave factor	γ_β	1	-
Coefficients	A	1.65	-
	B	4	-
	C	1.5	-
Gravity	g	9.81	m/s^2

The maximum wave run-up height was calculated for waves from the SE and is approximately 1.6m above SWL for the extreme scenario of the design wave storm and 1m sea level rise and MHWS. This corresponds to an approximate level of 5.86m CD for the HEFS. Table 10 summarises the wave run up height results for the various cases assessed. Note that cases 2.2, 2.6 and 3.2 from the wave modelling study were not considered in this analysis as the nearshore wave heights as shown in Table 6 were negligible. Note that the parameters used in the calculations were considered to be constant across the entire site which is a conservative estimate.

Table 10: Wave run up results for different cases

Direction	Case Number	Case	Water Levels		Nearshore Wave Results		Wave run up height	Total Water Level
					Hs	Tp	$R_{U2\%}$	
			m OD Malin	m CD	m	s	m	m CD
E	1.1	MHWS + MRFS	2.17	4.75	1.0	3.9	1.3	6.05
SE	2.1	MHWS + MRFS	2.17	4.75	1.0	4.1	1.4	6.15
	2.3	MHWS + HEFS	2.67	5.25	1.3	4.2	1.6	6.85
	2.4	0.5% AEP + MRFS	3.28	5.86	1.6	4.2	1.8	7.66
	2.5	0.5% AEP + HEFS	3.78	6.36	1.7	4.1	1.8	8.16
S	3.1	MHWS + MRFS	2.17	4.75	0.8	1	1.2	5.95

Figure 18 and Figure 19 below show the beach profile at section D in relation to the wave run up height for Cases 2.1 and 2.3 respectively. It can be seen that the run-up for the cases combining sea level rise with MHWS and the design storm results in a water level above the level of the toe of the cliff.

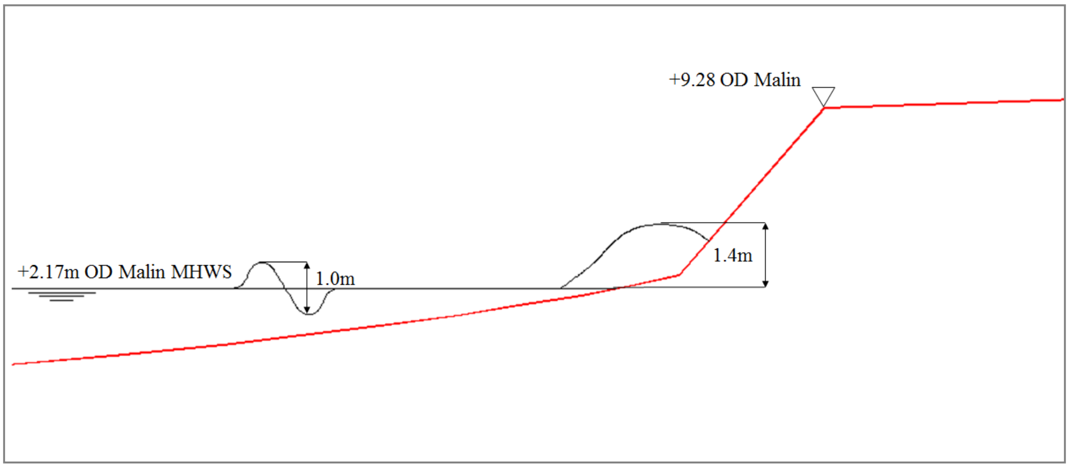

Figure 18: Beach profile for Section D showing wave run up heights for case 2.1

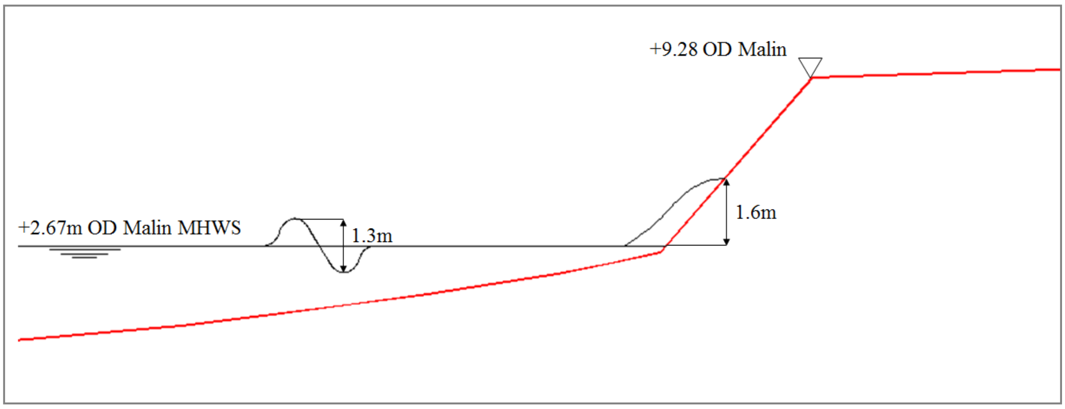

Figure 19: Beach profile for Section D showing wave run up heights for case 2.3

This estimation of wave run up does not include the set-up of the water level under breaking waves. Based on methods presented on the CIRIA Rock Manual [6], wave set up is estimated to be approximately 10% of the incoming wave height. For case 2.3 this corresponds to an additional 150mm.

4 Assessment of sediment transport

4.1 Beach evolution

The previous Arup study into the coastal recession at the site investigated movement of the High Water Mark (HWM) since 1897. It appears from the movement of the HWM on historical mapping that erosion of the beach has occurred along the south eastern boundary of the site. The cross sections assessed indicated the beach in this area to be steeper than the areas to the north.

The estimated wave action to the east of the site is sufficient to mobilise any fine sediment on the beach. Finer sediment from the glacial till overlying the rock on the beach may have been removed over time by wave action. Any fine sediment which has collected on the beach from the coastal slope is also likely to have been transported from the beach due to wave action. Grab samples taken from the beach at the base of the coastal slope in previous geotechnical surveys indicate that the material remaining on the beach is a large granular material (median grain size, d50 = 11.4mm). The removal of fine sediment by waves may be contributing to the granular make-up of the beach along the eastern boundary of the site.

Portions of the beach along the eastern boundary of the site are currently at the level of bedrock. The south eastern area of the beach appears to have undergone the biggest removal of overlying sediment and contains the most exposed bedrock. Moving northwards along the beach, patches of the overlying glacial till are visible through the gravel beach material.

The reduction of the beach level to bedrock along the south eastern boundary of the site may be due to more aggressive wave action. However, the higher elevation of bedrock in this area may also lead to it being exposed sooner than rock towards the north.

In the north eastern boundary of the site rock protection has also been installed to protect an electricity pylon. The rock armour may contribute to some slight alteration of the wave pattern on the beach, which could have an impact on the area to the south.

Large cobbles and boulders were noted at the base of the coastal slope along the south eastern boundary of the Indaver site. These may have been pushed up to the base of the slope due to wave action on the beach or have become exposed through the removal of sediment from the beach and base of the coastal slope.

The build-up of material on the beach (particularly towards the north eastern boundary of the site) may provide some minor protection to the coastal slope along the site. The material may help to reduce the coastal slope erosion as extreme water levels and wave run-up will reach the slope less frequently. The build-up of material to the north also shows that the beach is subject to oblique wave attack that drives sediment in an alongshore direction from south to north.

It is important to note that the beach's sand and shingle is likely to erode and partially recover during storms. The beach profile would also change seasonally. Accretion and erosion of the beach may occur along the Indaver site at the same time as sediment is removed from the base of the coastal slope.

Coastal slope erosion occurs due to ‘notching’ (localised removal of sediments) of the slope material by the sea water reaching the coastal slope. This may happen during storms combined with extreme high tides, but some notching may also happen at MHWS if the waves are large enough to create run-up. The erosion process has been explained in detail in the previous 2012 Arup report the main points of which will be covered in this section.

This section of the report also addresses the recommendation by Aqua Vision BV to assess the coastal processes at the site.

4.2 Sediment transport dynamics

As previously stated, the site is sheltered from the direct open sea swell waves which enter Cork Harbour from the south. The shape of the harbour and the location of the nearby Spike Island (to the North East) provide some shelter to the site from wind generated waves within the harbour.

The Indaver coastal area belongs to a physiographic unit formed by a coastline surrounded by two headlands. The stretch of coast under analysis is like a hollow between two rocky outcrops. These rocky outcrops have been found to have remained relatively stable through time and may contribute to keep the material relatively stable within this cell.

The beach also appears to be at or approaching ‘equilibrium’ shape as both the northern and southern extents are not likely to erode due to the presence of rock outcrops. Any further retreat that is likely to occur, is likely to occur towards the centre of the beach.

The beach is approximately described as a ‘shingle’ (i.e. gravel as described in the geotechnical investigation undertaken) type beach. The beach in Ringaskiddy has an upper slope of approximately 1:8 and a lower slope of 1:44. The d_{50} based on the 2012 SI figures is 11.4mm for the upper beach.

4.3 Influence of tidal currents

It is also beneficial for the assessment of the coastal erosion at the site to consider the potential effects of tidal currents on the local sediment regime. Figure 20 below show the flow plots for the ebb (outgoing) and flood (incoming) tides as well as expected current speeds. From the plots it is evident that there are substantial current speeds approaching 0.9m/s in the area between Haulbowline Island and Paddy’s Point. However, it can be seen that current speeds at or near the project site are very low in relation to the adjoining areas which is a factor which contributes to its stability (less than 0.1m/s for the ebb flow and less than 0.2m/s for the flood flow). These are relatively low current speeds and they are likely to cause very little movement of sediment in the local area.

From the model results it is inferred that there is a trend for sediment to move towards the north due to the higher current speeds on the flood flow and the convex shape of the site. However, it is likely that the majority of this sediment will remain in the coastal cell due to the presence of a rock outcrop to the north of the area and the low values of the currents observed in this particular sheltered site.

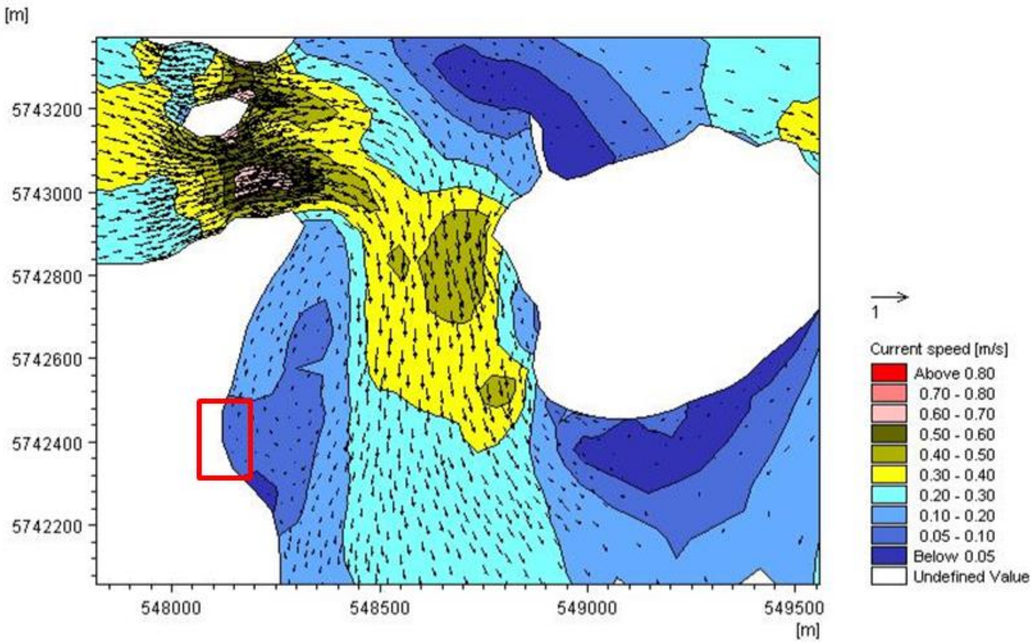

Figure 20: Ebb flow plot

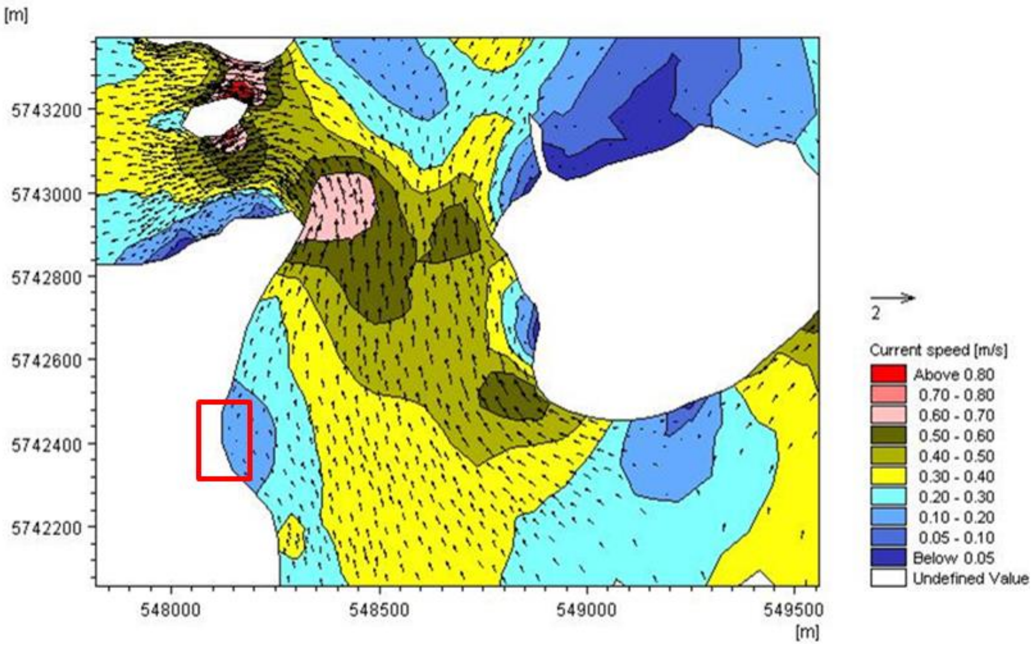

Figure 21: Flood flow plot

Given the low tidal currents predicted by the model, it is confirmed that the extreme wave action will be the key factor driving coastal erosion.

4.4 Sediment transport modelling

4.4.1 Introduction

The model used for sectional sediment transport modelling was the Coastal Engineering and Design Analysis System, SBEACH developed by Veri-Tech, Inc.

The Storm-induced BEAch CHange model (SBEACH) is a numerical simulation model of cross-shore beach, berm, and dune erosion produced by storm waves and water levels. The model is applied in beach fill project design and evaluation and in other studies of beach profile change. SBEACH operates in the CEDAS graphical user interface designed to facilitate data input, model setup and execution, and analysis of model results. The latest version allows simulation of dune erosion in the presence of a hard bottom.

This model is generally used for the estimation of erosion rates and assessment of sediment transport trends in dunes and beaches. SBEACH is intended to be used for grain sizes up to 1.0mm. Due to the larger sediment size on the beach in Ringaskiddy (50 to 100mm) the results need to be treated with caution. There is currently no other model available to model this shingle size and it was therefore decided to proceed with SBEACH to get a feeling of what would happen to the beach if it were made up of a smaller sediment.

4.4.2 Inputs for the profile

A section of coast derived from the Nov. 2014 topographic survey was input into the SBEACH model as a reach. Figure 22 shows a typical profile with MHWS conditions. Figure 23 shows the reach profile for section D. The profile is combined with various water levels as described in Section 4.4.4.

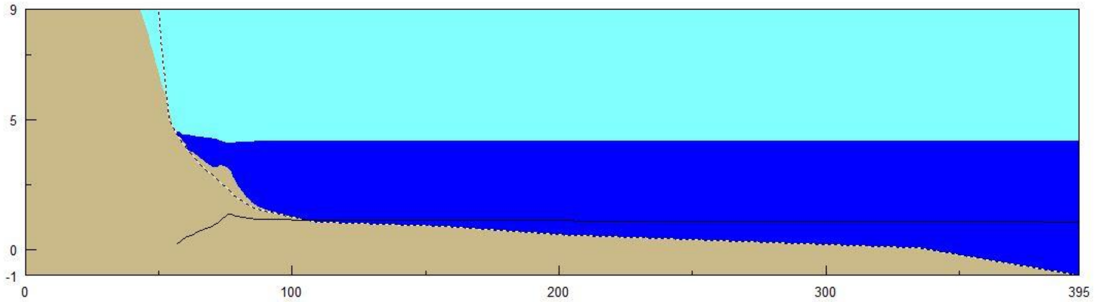

Figure 22: Typical profile with MHWS conditions

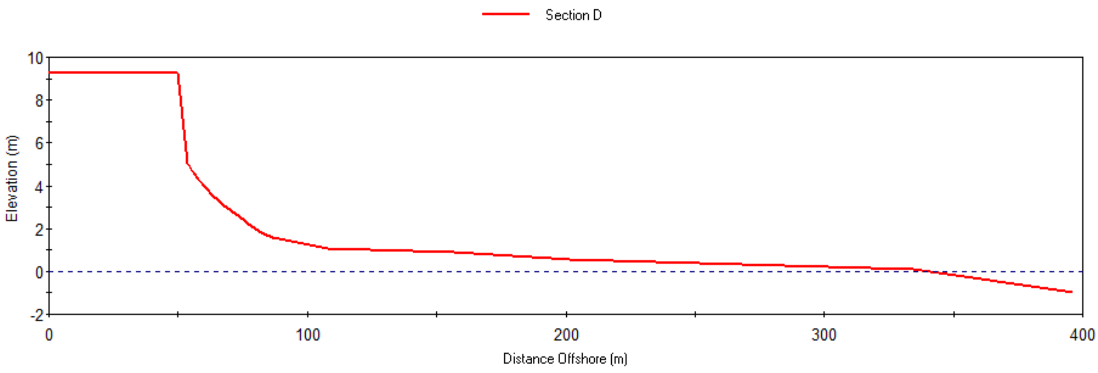

Figure 23: Reach for Section D derived from Nov. 2014 survey

4.4.3 Geology

In 2012, as part of the coastal recession investigation undertaken by Arup, a geotechnical investigation was carried out comprising 4 boreholes, 4 trial pits, five coastal slope scan lines, four groundwater monitoring standpipe installations, two variable head permeability tests and associated geotechnical laboratory testing.

This investigation was concentrated 10 – 15m inland of the coastal eastern boundary of the site in order to determine the ground conditions of the existing slope.

The ground conditions in the existing slope along the eastern coastal boundary of the Indaver site contribute to coastal erosion. A hard well-consolidated clay underlayer exists on the foreshore except where the bedrock is exposed. This beach clay underlayer is much more resistant to erosion than the cliff material but will still erode slowly due to wave stresses and sediment abrasion. Several factors affect the beach clay erosion rate, in particular the hardness of the clay, the strength of local wave and current motion on the clay surface, the presence of suspended sand, and the exposure time to overlying water and suspended sand.

At other sites that have a similar hard clay beach and soft clay cliff geology (such as parts of the East coast of England and the Great Lakes of North America), beach clay erosion rates are typically a few cm per year. Although the beach clay erosion is slow, it is irreversible. Unlike the overlying sand and gravel which can return to beaches after storms, the eroded beach clay will be carried offshore and will not return. The level of the beach clay layer is an important factor in determining the strength and frequency of wave attack at the cliff toe, and hence of the rate of cliff erosion [3], [5] and [9].

The following geotechnical findings were described in the Arup "Coastal Recession Mechanisms Investigation" Report, 2012 as conditions which contribute or have an impact on coastal erosion in the area:

- The ground conditions along the coastal slope face are variable. The slope comprises a profile of glacial till of clay/silt, clay and sand which makes the slope vulnerable to coastal erosion.
- The southern end of the slope is the most exposed to the sea and is the most resistant to erosion due to the presence of bedrock at the toe and the very stiff or stronger overburden. The slope at the southern end is near vertical and the slumped material has been removed by the sea water. Following the slope north, the bedrock falls to -1.11m ODM relative to a toe level of +2.70m ODM. The slope becomes more concave in shape and the slumped material remains at the base which indicates that the slope experiences less erosion. However, standard penetration tests indicate the soil at the toe of the slope is weaker (firm to stiff) and therefore will fail more easily when subjected to erosion from a combination of seawater, water seepages and weathering.
- The toe of the slope is most susceptible to erosion where the sand and silt lenses are exposed. Latterly and vertically discontinuous horizontal fissures, 50 – 100mm wide, were noted at the base of the slope. These fissures could represent sand or silt lenses in the glacial till that have been washed out by the seawater, water seepages and weathering.
- Weaker soil strata were identified higher up the slope at +6 to +9m ODM which represent softer sandy clay layers, sand and silt strata. Heavy windswept rain and freeze – thaw conditions can weaken exposed sand and silt layers and continuously erode the seaward face of the soil. Burrowing activity from insects will also contribute to loosening of the soil and promote erosion.

- The receding slope will intercept the water bearing sand and silt lenses (perched water tables) and will appear as water seepages on the slope face. These water seepages will contribute to the slope erosion. The groundwater table is confined in the bedrock by the overlying low permeability glacial till. It is unlikely that that the groundwater table in the bedrock will play a role in the erosion of the slope.
- The coastal slope erosion occurs when water from the sea reaches the base of the coastal slope during storm conditions and occasionally at MHWS. The removal of glacial till at the base of the slope undermines the overlying weakened material and causes the slope to slip and fail. The slumped debris at the base of the slope is eroded by sea water ingress, removing protection from the base of the slope and causing the process to begin again and the slope to recede. The coastal erosion process was assessed in the 2012 Arup report. Figure 24 below shows a typical cross section of the cliff area as described in the 2012 Arup report.

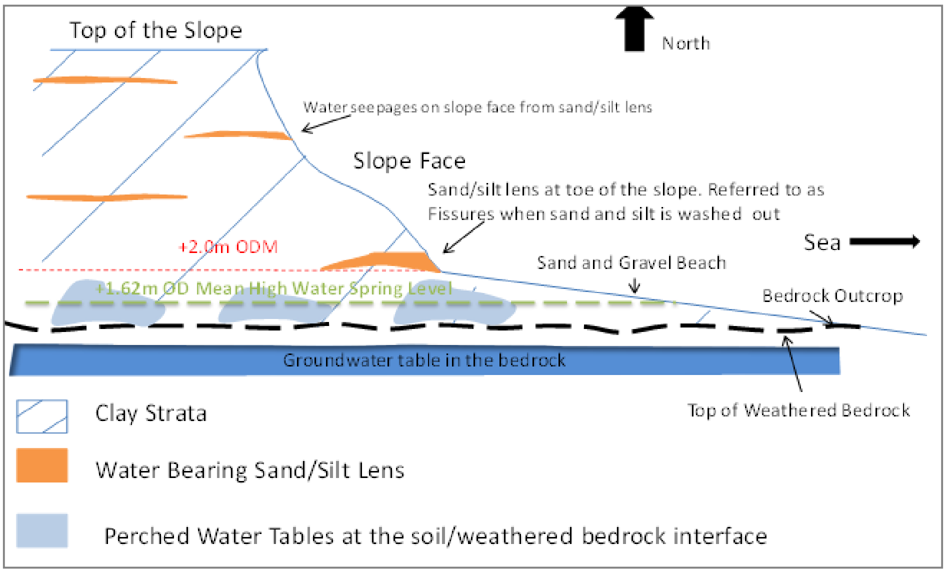

Figure 24: Sketch of Groundwater Regime in the Slope

4.4.4 Storm input to SBEACH

Input storm conditions are specified by values of the following parameters.

- Water level elevation
- Wave height and period
- Wave angle
- Wind speed and angle

The storm input was chosen to reflect a 3.3hr storm which can be assumed to be representative of a typical storm at MHWS. The calculation was carried out for a monochromatic wave in shallow water at a depth of 3.6m ODM at MHWS (deeper for MRFS and HEFS), which has been assumed to include the closure depth; therefore no significant sediment transport should occur beyond this point. The closure depth is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore area.

A number of calculations were carried out for various combinations of water elevations and wave height. Table 11 summarises the input conditions for the most severe scenarios. The MRFS scenarios include a 0.55m increase of water level due to climate change, while the HEFS scenarios include an increase of 1.05m. The extreme water levels as given in the ICPSS for the 1 in 200 year event (0.5% AEP) are also used.

The wave angle refers to angle at which the wave crest makes contact with the shoreline. The wave angle was set as 0 in a conservative approach i.e. all waves are parallel to the coast. The wind conditions used were the 50 year return period.

Separate storms were set up for the three different water levels, with and without wind conditions for the worst wind direction i.e. south east as identified from the wave modelling. Table 11 describes the various input parameters for the different cases analysed.

Table 11: SBEACH input conditions

Direction	**Case Number**	**Case**	**Water Levels**		**Wind Conditions**		**Wave conditions at closure depth**		
			Total Water Level		Velocity	Duration	Hs	Tp	h
			m OD Malin	m CD	ms^{-1}	hr	m	s	m
E	1.1	MHWS + MRFS	2.17	4.75	28.3	3.3	1.0	3.9	4.15
SE	2.1	MHWS + MRFS	2.17	4.75	28.3	3.3	1.0	4.1	4.15
	2.3	MHWS + HEFS	2.67	5.25	28.3	3.3	1.3	4.2	4.65
	2.4	0.5% AEP + MRFS	3.28	5.86	28.3	3.3	1.6	4.2	5.26
	2.5	0.5% AEP + HEFS	3.78	6.36	28.3	3.3	1.7	4.1	5.76
S	3.1	MHWS + MRFS	2.17	4.75	28.3	3.3	0.9	4.2	4.15

4.4.5 Model results

In addition to the cases mentioned in Table 11 an assessment was also carried out for MSL and MLWS. For all the cases shown water levels reach and exceed the toe of the cliff, whereas at MSL and MLWS the water will only reach the lower beach, and hence the rate of erosion during MSL and MLWS is substantially lower than during MHWS.

It is also evident that rates of erosion increase linearly with increased wave height. In all cases negligible erosion occurs during MLWS and MSL.

Note that the accuracy of the results in the cliffs area can only be treated as qualitative since the slope exceeds the maximum values that the software can take. Only values for the beach profile can be considered as suitable for the assessment. Figure 25 and Figure 26 show the model results for the MSL and case 2.3 respectively.

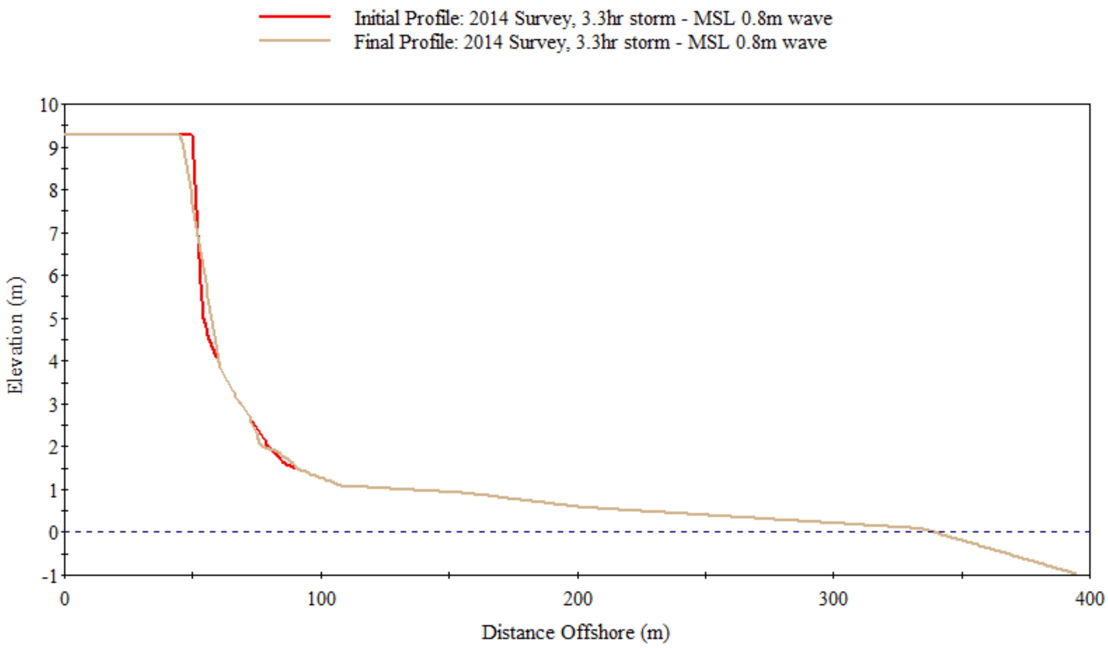

Figure 25: Erosion results for MSL case

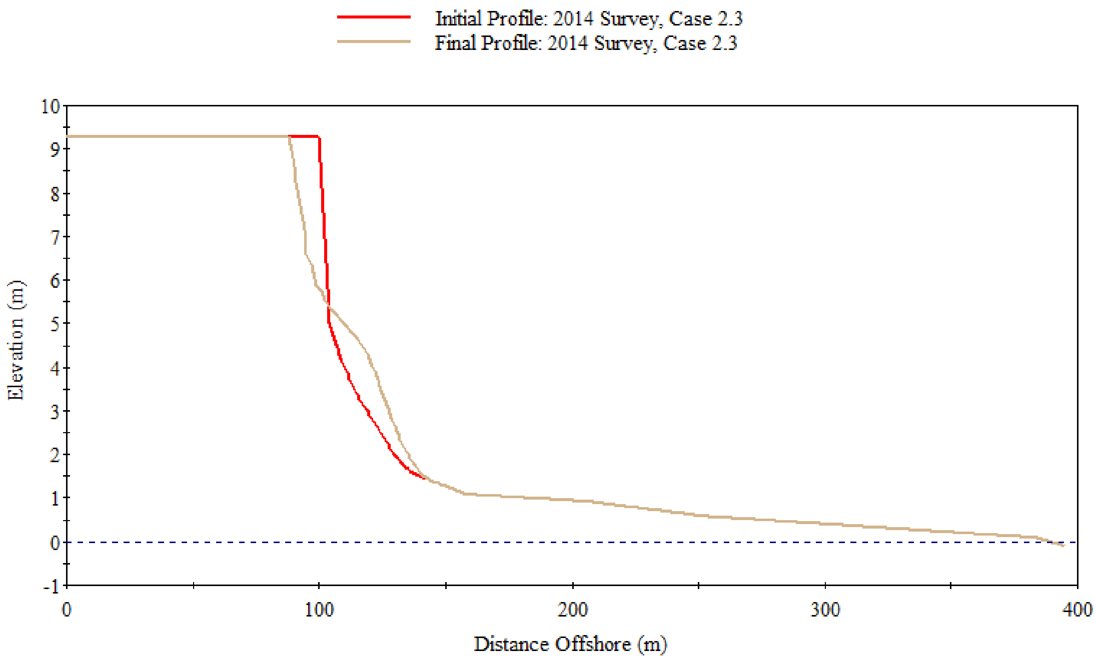

Figure 26: Erosion results for case 2.3

4.5 Conclusions

This basic sectional sediment transport assessment shows that even subjected to extreme events, the theoretical range of erosion of the beach is within the range of 10 to 30cm for the specified storm event, which is a relatively low rate.

The upper layer of the beach consists of consolidated clay overlain by small amounts of sand and shingle. The clay layer will erode slowly but irreversibly when exposed to wave stresses, especially when there is suspended sediment that can act as an abrading agent. The erosion rates depend on several factors, the hardness of the clay, the exposure time to water, the strength of local wave and current motion on the clay surface, the presence of suspended sand, and the exposure time.

A beach down cutting rate has been calculated on the assumption that the cliff and foreshore maintain the same shape relative to the mean sea level when affected by sea level rise [8], [10], [14]. Using this assumption, a beach down cutting rate in the order of up to a few centimetres has been estimated if no protective measures are undertaken

This mechanism also directly affects the exposure of the toe, which leads to stability failure and collapse as explained in section 4.3.3.

From the studies carried out it can be inferred that the erosion of the cliffs is influenced by wave action at the site. This mechanism of erosion is due to a combination of wave action and geotechnical conditions, which cause cliff collapse and retreat.

5 Recommended coastal management measures

As discussed above, the cause of erosion at the Indaver coastal boundary is due to a combination of both wave action and ground water seepage. From the wave modelling study the beach appears to be subject to a slightly oblique wave attack that drives sediment in a net northerly alongshore direction. Due to the presence of a rock outcrop towards the north it is likely that most of the sediment remains in the bay. This was confirmed by a further sediment transport assessment.

From an assessment of topographical surveys a conservative retreat rate of 0.5m/year has been applied in order to assess the potential impact of the retreat rate on the proposed development.

The study found that there would be no impact on the proposed development after 30 years. The study found that there could be a risk of an impact on a small section of the proposed development after 40 years however this would be confined only to the amenity walkway and a small section of a diverted gas pipeline outside of the security fence line. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

Coastal protection mitigation measures are not required for the waste-to-energy facility element of the development. However, given the concerns raised by An Bord Pleanála during the previous planning application in 2008 and given the low risk that the amenity walkway and a section of the diverted gas pipeline could be impacted in 40 years' time, coastal protection measures have been included in this planning application as a precautionary measure so as to reduce the rate of erosion of the glacial till face.

Arup investigated a number of coastal protection options that could be applied to the Indaver site in order to reduce the current retreat rate.

Based on the results from the numerical wave modelling it can be concluded that the location of the site is well protected and that the wave conditions in the nearshore area are sufficiently low to potentially allow for the use of an appropriate 'soft' coastal solution to protect the toe and base of the cliffs from wave action.

Taking into account the results of the various assessments a number of typical coastal engineering solutions that could be used at the Indaver site have been assessed. A summary of the advantages and disadvantages is given in Appendix C. The options range from 'hard' solutions such as breakwaters, revetments and sea walls to 'soft' solutions such as beach nourishment, replanting and the placement of sacrificial material (shingle).

In modern coastal engineering practice it is generally thought that the benefits of using 'soft' solutions (where possible) far outweigh the benefits of using 'hard' solutions. Also, 'soft' solutions have a degree of adaptability and dynamism compared to 'hard' solutions. Similarly there is evidence that certain 'hard' solutions can cause wave reflection and can in fact worsen the issue of erosion. For these reasons there is a trend in employing 'soft' solutions wherever possible.

Arup has recommended that the Indaver coastal boundary is monitored on an annual basis and the placement of approximately 1100m^3 of shingle of appropriate size and shape (rounded) above the foreshore on Gobby beach along the eastern boundary of the Indaver site. This will be a ‘soft’ solution which will potentially reduce erosion rates by limiting the exposure of the toe of the glacial till face to wave action.

The main aim of placing the material is to act as a proactive measure for the coastal area adjacent to the Indaver site only. The solution will have no negative impacts on the adjoining areas. However, there are benefits associated with the works as well as the provision of an environmentally friendly solution. The net coastal sediment transport goes from south to north according to wind conditions and swell; therefore the material is likely to move towards the north in the medium and long term. The Cork Harbour Special Protection Area (SPA) is located to the south west of the site and therefore the sacrificial material will not impact on the SPA.

It is proposed that the additional sacrificial material is placed during the construction period of the Indaver site. Thereafter, it is proposed that the placement of further additional sacrificial material is carried out if the cliff erosion rate exceeds 0.5m per year measured over a period of six years, which would indicate some acceleration in the current erosion rate, or when the cliffs have retreated by approximately 3m, whichever is sooner. For this reason the coastal boundary of the Indaver site will be monitored for erosion on an annual basis.

The following sections describe the recommended coastal management measures.

5.1 Proactive monitoring plan

The proposed measures comprise:

- Annual topographic surveys which will include 0m contour, top and bottom of cliff face monitoring and specified sections.
- An assessment of the retreat and reporting over the design life of the proposed development including the construction period (40 years).
- Proactive and reactive management of the beach comprising placement of imported shingle to areas of the beach where deemed necessary from beach monitoring data.

5.2 Sacrificial material

It is proposed that approximately 1100m^3 of sacrificial material comprising shingle of appropriate size and shape (rounded) is deposited in the area spanning from the car park at the northern end to the southern boundary of the Indaver site. This material would act as beach nourishment on the emerged beach above the foreshore i.e. above the high water mark. The purpose of the sacrificial material is to dissipate the wave energy at the site and protect the toe and lower area of the cliffs from direct wave action and hence reduce the rate of erosion. This solution protects the cliffs and provides extra material to the adjoining foreshore areas since the material can be transported within the coastal cell depending on the direction and severity of wave action in the area. The preliminary solution is shown in Appendix D.

The main advantages of this solution as outlined in Appendix C are as follows:

- Introduction of 'sacrificial material' to the area at the toe of the cliff would reduce erosion rates by increasing beach levels i.e. reducing nearshore water depth and wave heights
- Protects the cliff face from breaking waves
- Regarded as a very natural way of combating coastal erosion
- Less material than conventional beach nourishment needed
- The shingle can be placed within the Indaver site boundary
- It does not affect the current state of the cliffs (no need for re-shaping)
- It does not have any negative impact on the existing structures in the vicinity and adjoining areas (cliffs and beaches)
- It protects the site and also the adjoining areas to it, so it is beneficial for the entire coastline
- It enhances the amenity and recreational aspects of the area, providing additional beach area at high tide
- It enhances the visual appearance of the beach
- It provides an adaptive approach to the erosion and retreat issues of the coastline while working with nature
- Material is free to move in the coastal cell (bay) so it can help to promote the growth (accretion) of the beach
- Sacrificial material will protect the beach clay layer from further erosion
- The Cork Harbour Special Protection Area (SPA) is located to the south west of the site and therefore the sacrificial material will not impact on the SPA.

5.2.1 Stability of the new material

In normal conditions it is not expected that there will be significant movement of material for the following reasons:

- The material is designed to be placed above the High Water Mark, and hence it is not expected that the alongshore sediment drivers will have a big impact on these works.
- Local currents in this particular sheltered stretch of coast have been assessed to be low, and very low in comparison with the currents in the adjoining areas.
- Local mean wave climate.

- The sheltered location of the site and the protection that the rock outcrops offer.
- Previous experiences with beach nourishment above the foreshore in more exposed locations.

Hence, it is expected that the material will remain in place for the medium term and helps to lower the erosion rates within the site.

For the size of beach material that is proposed as beach nourishment there are no recognised methods to calculate the future distribution. In order to get an idea of the beneficial impact of placing this beach nourishment material Arup has carried out a volumetric assessment in order to estimate the expected reduction of erosion rates due to the presence of the sacrificial material. This assessment is based on a volumetric analysis of the existing topographic surveys (2008, 2010 and 2014). The following assumptions were made:

- The fine material that is eroded from the cliffs is lost and is not considered to be redistributed on the beach, which is likely to be close to reality as the general makeup of the cliff is clay. The loss of this material plays no significant role in the movement of shingle from the beach and as such will be discounted from the assessment.
- The eroded cliff material is partially made up of shingle material. The amount can be estimated from site investigation data.
- The proposed beach nourishment material will be eroded in the same way as the existing shingle on the beach as it will be of a similar make up and size. This is a conservative assumption and in reality a large percentage of the shingle material will remain at the site.
- A proportion of the erosion of the cliff is due to the effects of ground water seepage. However, it is difficult to estimate this proportion. We have assumed that 50% of the erosion is caused by ground water seepage and 50% by coastal erosion.
- Because of the assumptions made above a large factor of safety should be incorporated into any estimation of reduced erosion rates where the additional shingle material is considered. We have taken a factor of safety of 2.

The following sections describe the assessment methodology.

5.2.1.1 Assessment of topographic information

Similar to the assessment used in estimating the maximum retreat rate experienced at the site (Section 2.3), this assessment compares the topographic surveys from 2008, 2010 and 2014. The area of cliff eroded was assessed for sections B to G for the 2008 to 2014 and 2010 to 2014 periods (see Figure 27 below for section locations). The assessment only considers erosion of the cliff i.e. change in area above the toe of the cliff. As described previously Sections A1 and A2 were not considered for this assessment. Changes in beach level were not taken into account for the following reasons:

- The topographic surveys were undertaken at different times of year and it is possible that any changes in beach level that might be shown are due to seasonal variations of beach level.

– Based on the assumptions of the assessment when material is eroded from the cliffs it is considered to be removed from the site and therefore there should be no change in beach levels.

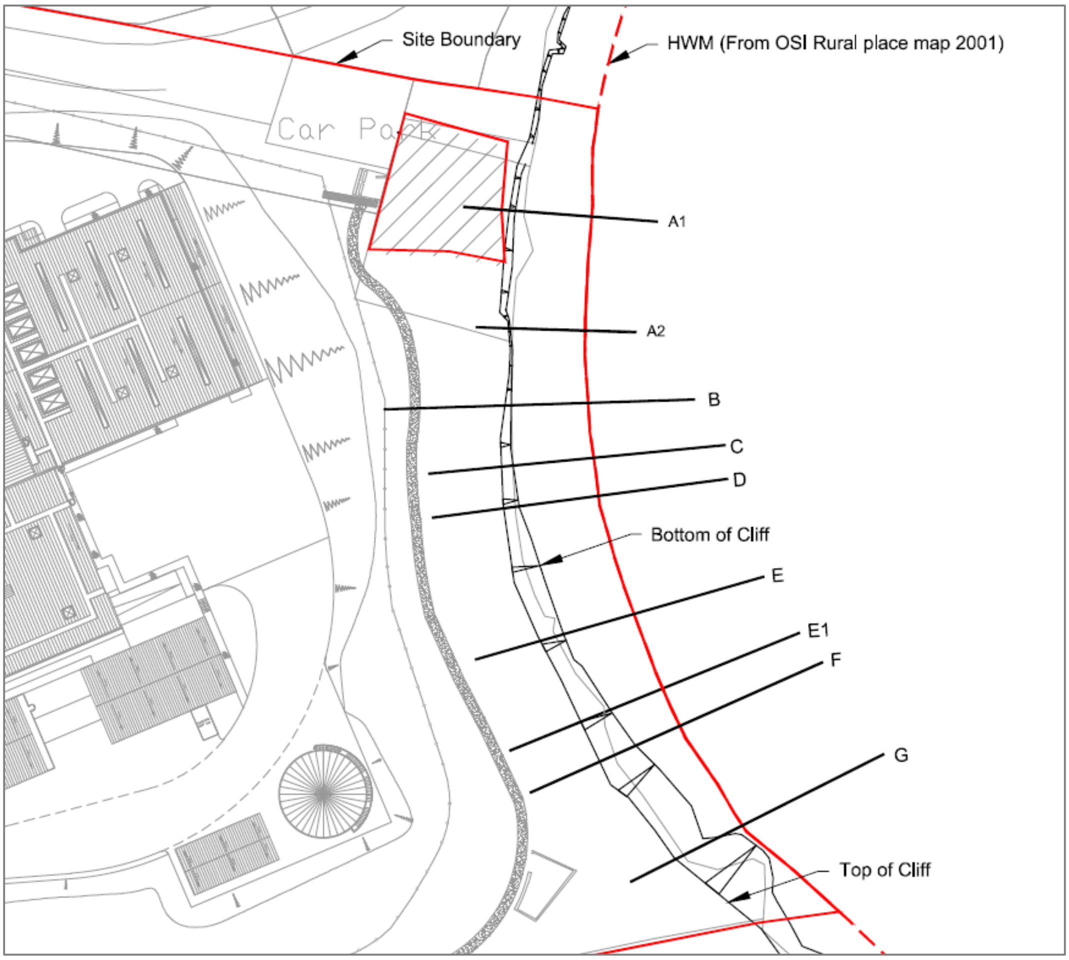

Figure 27: Plan of site showing section locations

Table 12: Comparison of erosion rates by area based on topographical surveys

Sections	**Area eroded 2008 - 2014** m²	**2008 - 2014 Retreat rate per year** m²/yr	**Area eroded 2010 - 2014** m²	**2010 - 2014 Retreat rate per year** m²/yr
B	1.3	0.2	0.0	0.0
C	6.2	1.0	2.2	0.6
D	5.9	1.0	7.5	1.9
E	7.7	1.3	0.8	0.2
E1	16.5	2.8	6.2	1.6
F	9.3	1.6	0.0	0.0
G	1.0	0.2	1.0	0.3

Table 12 above details the results of the comparison of the topographic surveys. It is important to note that these calculation differ from those given in Section 2.2 in that this calculation assesses the eroded sectional area (m²) as opposed to the eroded planar retreat (m). Again, a conservative approach was subsequently used to calculate the maximum eroded area at the site based on the topographic survey data. The approach was based on observations and takes a conservative absolute maximum of erosion within the site boundary over a six year period (2008-2014).

The point where maximum localised erosion of the cliff was measured for the six year period was found at section E1. The total area of cliff eroded at this location over the six year period was 16.5m^2. This corresponds to a rate of erosion of 2.8m^2 per year.

5.2.1.2 Assessment of SI information

The eroded cliff material consists of a combination of materials including gravels, clays and sands. In order to accurately assess the rate at which shingle material is eroded from the beach it is necessary to quantify the percentage of shingle contained in the eroded cliff material. The borehole logs and particle size distribution analyses from the 2012 site investigation (SI) were used to estimate the percentage of shingle contained in the eroded cliff material. The boreholes are located approximately 15m landward of the cliff edge. Table 13 below shows the percentage of shingle contained in four different boreholes as well as a number of random samples.

For the purposes of this assessment it has been assumed that shingle is defined as being any particle that is greater than 20mm. The boreholes contain a number of samples at different depths. The percentage of shingle in each borehole was calculated based on the depth of the samples and the thickness of the corresponding stratum. Total percentage of shingle in the boreholes varies from 11% to 39%. The average value of the percentage of shingle in the boreholes is 20%.

Table 13: Summary of 2012 SI results

Sample No.	Borehole No.	BH1	BH2	BH3	BH4	Random samples
Sample 1	Depth	1.2	3.2	1.2	4.5	10
	Thickness of stratum	*1.5*	*3.7*	*3.7*	*2*	*4*
	% shingle	8%	1%	6%	5%	20%
Sample 2	Depth	3.2	5.7	4.2	8.5	10
	Thickness of stratum	*4*	*4.6*	*1*	*4.6*	*4*
	% shingle	51%	17%	12%	15%	27%
Sample 3	Depth		7	6.2		8.7
	Thickness of stratum		*4.4*	*4.5*		*0.4*
	% shingle		12%	16%		23%
Sample 4	Depth			7.2		7.5
	Thickness of stratum			*4.5*		*0.3*
	% shingle			15%		16%
Sample 5	Depth					3.4
	Thickness of stratum					*0.9*
	% shingle					10%
	Total % per borehole	39%	11%	13%	12%	23%
	Total average	**20%**				

5.2.1.3 Estimation of reduced erosion rate

The basis of the assessment is that the sacrificial nourishment material will be removed from the site at a rate equal to the rate that eroded shingle material is removed from the beach. Using the information gathered from the assessment of topographic information and SI information the amount of time that the sacrificial material can be expected to remain on the beach can be estimated. In order to make this estimation a number of assumptions are needed as described earlier. Some of these assumptions are described in further detail below.

The proportion of cliff erosion due to ground water seepage has been estimated as 50% with the remaining 50% due to wave action. This considers cliff erosion due to wave action and cliff erosion due to ground water seepage to be two separate entities i.e. neither are influenced by each other. In reality both mechanisms of erosion are inherently linked. For example notching may occur at the toe of the cliff and ground water seepage may cause the section of material above the notched area to become unstable and eventually collapse. However, it is difficult to determine the exact relationship of these mechanisms so for the purpose of this assessment the mechanisms are assumed to be independent of each other.

In order to account for the uncertainties associated with the assumptions that have been made a factor of safety should be incorporated into any estimation of reduced erosion rates where the additional shingle material is considered. We have taken a factor of safety of 2. It is also assumed that the sacrificial material will have no effect on cliff erosion due to ground water seepage. Therefore only

50% of the cliff erosion will be affected by the placement of the sacrificial material.

The assumption that the sacrificial material will be removed from the site when it has been eroded is another conservative assumption. In actuality when the sacrificial material has been removed from the as constructed profile a percentage of the material will remain at the site on the beach. The material on the beach will continue to provide a protective function as it will increase beach levels locally which will affect the nearshore wave dynamics by decreasing water depth and causing waves to break further from the toe of the cliffs. For the purpose of this assessment it is assumed that the sacrificial material will only perform a protective function if it remains at the toe of the cliff.

Taking into account these assumptions and combining the results of the assessment of topographic information and SI information a reduced rate of erosion due to the placement of sacrificial material can be made. Table 14 below describes the various input parameters used in the estimation of the reduced erosion rate.

Table 14: Input parameters for reduced erosion rate estimation

Description	**Input**	**Units**
Length of beach to be nourished	150	m
Volume of nourishment material	1100	m^3
Retreat rate per year	2.8	m^2/yr
Max volume of retreat per year	420	m^3/yr
% Shingle based on SI	20%	
Max volume of shingle eroded per year	84	m^3/yr
Factor of safety	2	
No of years for nourishment material to be removed	6.5	yrs

From the topographic information 2.8m^2 per year is the maximum recorded area eroded for the cliffs as per Table 12. Over the length of the site this corresponds to a maximum eroded volume of 420m^3 per year. From the SI information 84m^3 of this is shingle. When compared with the proposed volume of sacrificial material and incorporating the factor of safety this corresponds to approximately 6.5 years i.e. the sacrificial material is expected to last a minimum of 6.5 years at the site.

From this the reduced rate of erosion due to the placement of sacrificial material can be estimated based on the fact that in the situation without the sacrificial material the maximum rate of erosion is 0.5m per year. See Table 15 below for the output parameters relating to the expected reduction in erosion rates calculation.

Table 15: Output parameters for reduced erosion rate estimation

Description	Input	Units
Initial erosion rate with nourishment	0.25	m/yr
Erosion rate without nourishment	0.50	m/yr
overall design life	40	yrs
No of years for nourishment material to be removed	6.5	yrs
Rate of erosion with nourishment in place	0.38	m/yr
Erosion with nourishment in place	2.4	m
Number of years for cliff to erode 3m with beach nourishment	7.6	yrs
Number of times nourishment is applied	5	
Erosion in 40 years (nourished once)	19.2	m
Erosion in 40 years (nourished x 5)	15.9	m
Reduced rate of erosion 40 years (nourished once)	0.48	m/yr
Reduced rate of erosion 40 years (nourished x 5)	0.40	m/yr

When the nourishment material is initially placed we know that erosion will only occur due to ground water seepage giving an erosion rate of 0.25m/yr. Over time the nourishment material will deteriorate and the erosion rate will begin to increase over the 6.5 year period that the nourishment is in place and may eventually return to the original erosion rate of 0.5m/yr. This gives an average erosion rate of 0.38m/yr over the 6.5 years that the nourishment is in place. Hence while the nourishment is in place the cliff will erode by approx. 2.4m.

If it is assumed that the nourishment material is placed on a once off basis it can be calculated that the reduced rate of erosion over a 40 year period will be 0.48m/yr. However, it is recommended that the material is replaced if the erosion rate exceeds 0.5m/yr over a six year period or if the cliffs erode more than 3m. If we consider that while the material is in place the cliffs will erode by 2.4m and that when the material has been removed the erosion rate will revert back to 0.5m/yr it will take a further 1.2 years for the cliff to erode by a total of 3m. Hence the sacrificial material is likely to be replenished every 7.7 years (6.5 years plus 1.2). From this it can be determined that over the 40 year design life the sacrificial material will be replenished 5 times. This corresponds to a reduced erosion rate of 0.40m/yr. Based on this reduced erosion rate the cliff line is expected to erode by a maximum of 15.9m over a 40 year period when the effects of the sacrificial material are considered.

5.2.2 Effects on the adjoining areas of the site

The sacrificial material will provide a beneficial solution for the site and the adjoining areas of the beach. As described above the sacrificial material will reduce the rate of erosion from 0.5m per year to 0.40m per year.

The stability of the material depends on the severity and frequency of storm events which occur. Some conclusions are as follow:

- Given the predominant south and south east wind and wave directions, the likely direction for the movement of the material due to extreme events would be from South to North.

- It is expected that the material placed will remain within the sediment cell delimited by the rock headlands, since these offer a partial barrier to sediment movement, and there is no evidence that mean wave conditions or currents can transport the material.
- The proposed size of the material (shingle) will be designed to ensure that it can remain in place within the beach. Potential seasonal movements of the material are expected; however, this effect is positive for the beach, since the material offers an additional protection for the emerged beach in storm conditions.
- The proposed material will most likely stay on the beach. However it is possible that the material will be moved from the beach to the foreshore but it is highly unlikely that the material will become suspended and move offshore or to adjoining coastal cells for the following reasons:
    - Local currents in this area are very low in comparison with the currents in the adjoining areas.
    - Local mean wave climate is relatively low in the nearshore area.
    - The sheltered location of the site and the protection that the rock outcrops offer.
    - Previous experience with beach nourishment above the foreshore in more exposed locations.
- The addition of the sacrificial material will increase the local amenity value of the area by providing a pathway which is accessible to members of the public during all states of tide.
- The final profile of the additional material is expected to adapt to the natural topography of the area.

5.2.3 Example

Arup has previously designed, supervised and monitored beach nourishment works at Greystones Co. Wicklow. The location of the proposed works is immediately north of Greystones Harbour extending to Bray Head at the North Beach. The placement of beach nourishment (10,000m^3 of shingle) was carried out by the contractor in April and May 2014 as recommended by Arup. This nourishment is helping to mitigate the retreat of the north beach in the northern area and erosion of the cliffs in the southern area at Greystones beach.

A continuous monitoring and observation of natural evolution has been carried out at Greystones beach since 2008, when a previous beach nourishment campaign was undertaken. The monitoring campaign is ongoing but early indications are that the additional material placed at the toe of the cliffs has been beneficial for the cliffs.

Figure 28: Completed beach nourishment works in the area between the revetment and the Gap Bridge. Site visit 25 May 2014

5.3 Conclusions

Coastal protection mitigation measures are not required for the waste-to-energy facility element of the development. However, given the concerns raised by An Bord Pleanála during the previous planning application in 2008 and given the low risk that the amenity walkway and a section of the diverted gas pipeline could be impacted in 40 years' time, coastal protection measures have been included in this planning application as a precautionary measure so as to reduce the rate of erosion of the glacial till face.

Arup has recommended that the Indaver coastal boundary is monitored on an annual basis and the placement of approximately 1100m^3 of sacrificial material (shingle of appropriate size and shape (rounded)) above the foreshore on Gobby beach along the eastern boundary of the Indaver site. This will be a 'soft' solution which will reduce erosion rates by increasing beach levels i.e. reducing near shore water depth and wave heights and will protect the glacial till face from breaking waves.

Based on the assessment of existing topographic and site investigation information, as detailed in the previous sections, it can be concluded that the sacrificial material will reduce the erosion rates as calculated for the existing scenario. Therefore the sacrificial material will help to ensure that the site is protected in the future.

The results show that with the application of the sacrificial material, there will continue to be no impact on the entire proposed development after 30 years. With the application of the sacrificial material, the diverted gas pipeline will not be impacted after 40 years. However, there is still a risk of an impact on the amenity walkway after 40 years. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

The main aim of placing the material is to act as a proactive measure for the coastal area adjacent to the Indaver site only. The solution will have no negative impacts on the adjoining areas. However, there will be benefits associated with the works as well as the provision of an environmentally friendly solution. The net coastal sediment transport goes from south to north according to wind conditions and swell, therefore the material is likely to move towards the north in the medium and long term. The Cork Harbour Special Protection Area (SPA) is located to the south west of the site therefore the sacrificial material will not impact on the SPA.

6 Conclusions and recommendations

6.1 Conclusions

The topographical beach surveys carried out between 2008 and 2010 have confirmed that the erosion rates found based on the topographical, survey and photographic evidence from the period 1897 to 2003 were within the correct range. Using the new surveys, a conservative retreat rate of 0.5m/year is established.

The proposed resource recovery centre has a design life of 25 to 30 years. In view of the complexity of the development, licensing requirements and the need for the advance agreement of all conditions, Indaver is applying for a 10-year planning permission to commence and complete the construction phase. In addition, permission is sought to operate the proposed development for an initial period of 30 years after commissioning with the option to extend the operating period for a further 30 year period, subject to obtaining a grant of permission for that extended period.

The waste to energy facility section of the proposed development has been located far enough away from the edge of the cliff to ensure that the waste to energy facility will not be impacted by the predicted retreat rates over the design life of the development.

The proposed development will not increase the current rate of retreat.

The study found that there would be no impact on the proposed development after 30 years. The study found that there could be a risk of an impact on a small section of the proposed development after 40 years however this would be confined only to the amenity walkway and a small section of a diverted gas pipeline outside of the security fence line. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission. It is noted that GNI confirmed that they were satisfied that the proposed gas diversion route was feasible.

Coastal protection mitigation measures are not required for the waste-to-energy facility element of the development. However, given the concerns raised by An Bord Pleanála during the previous planning application in 2008 and given the low risk that the amenity walkway and a section of the diverted gas pipeline could be impacted in 40 years' time, coastal protection measures have been included in this planning application as a precautionary measure so as to reduce the rate of erosion of the glacial till face.

Arup investigated a number of coastal protection options that could be applied to the Indaver site in order to reduce the current retreat rate

Based on the results from the numerical wave modelling it can be concluded that the location of the site is well protected and that the wave conditions in the nearshore area are sufficiently low to potentially allow for the use of an appropriate 'soft' coastal solution to protect the toe and base of the cliffs from wave action.

Taking into account the results of the various assessments a number of typical coastal engineering solutions that could be used at the Indaver site have been assessed. A summary of the advantages and disadvantages is given in Appendix C. The options range from ‘hard’ solutions such as breakwaters, revetments and sea walls to ‘soft’ solutions such as beach nourishment, replanting and the placement of sacrificial material (shingle).

In modern coastal engineering practice it is generally thought that the benefits of using ‘soft’ solutions (where possible) far outweigh the benefits of using ‘hard’ solutions. Also, ‘soft’ solutions have a degree of adaptability and dynamism compared to ‘hard’ solutions. Similarly there is evidence that certain ‘hard’ solutions can cause wave reflection and can in fact worsen the issue of erosion. For these reasons there is a trend in employing ‘soft’ solutions wherever possible

Erosion rates are low and there are no signs of potential accelerated erosion processes in the future potential scenarios assessed, other than natural variation and the possible acceleration of sea level rise due to climate change. The existence of the beach bedrock may also limit the maximum coastline and cliff retreat if the overlying beach sediment is eroded to bedrock level. Arup recommends that the erosion tendency and status of the beach and cliffs are monitored in future in order to identify any changes in erosion rates by way of a proactive monitoring plan.

Nearshore currents are also low and it is not believed that they have a major influence on local sediment dynamics in comparison with the extreme wave events.

Arup has recommended that the Indaver coastal boundary is monitored on an annual basis and the placement of approximately 1100m^3 of shingle (of appropriate size and shape (rounded) above the foreshore on Gobby beach along the eastern boundary of the Indaver site. This will be a ‘soft’ solution which will reduce erosion rates by increasing beach levels i.e. reducing near shore water depth and wave heights and will protect the glacial till face from breaking waves.

The main aim of placing the material is to act as a proactive measure for the coastal area adjacent to the Indaver site only. The solution will have no negative impacts on the adjoining areas. However there will be benefits associated with the works as well as the provision of an environmentally friendly solution. The net coastal sediment transport goes from south to north according to wind conditions and swell; therefore the material is likely to move towards the north in the medium and long term. The Cork Harbour Special Protection Area (SPA) is located to the south west of the site and therefore the sacrificial material will not impact on the SPA.

It is proposed that the additional sacrificial material is placed during the construction period of the Indaver site. Thereafter, it is proposed that the placement of further additional sacrificial material is carried out if the cliff erosion rate is more than 0.5m per year measured over a period of six years, which would indicate some acceleration in the current erosion rate, or when the cliffs have retreated by approximately 3m, whichever is sooner. For this reason the coastal boundary of the Indaver site will be monitored for erosion on an annual basis.

The results show that with the application of the sacrificial material and the annual monitoring, there will continue to be no impact on the entire proposed development after 30 years. With the application of the sacrificial material, the diverted gas pipeline will not be impacted after 40 years. With the application of the sacrificial material, there is still a risk of an impact on the amenity walkway after 40 years. The waste-to-energy section of the proposed development will not be impacted by coastal erosion for the entire duration of the planning permission.

The proposed material will most likely stay on the beach. However it is possible that the material will be moved from the beach to the foreshore but it is highly unlikely that the material will become suspended and move offshore or to adjoining coastal cells for the following reasons:

- Local currents in this area are very low in comparison with the currents in the adjoining areas.
- Local mean wave climate is relatively low in the nearshore area.
- The sheltered location of the site and the protection that the rock outcrops offer.
- Previous experience with beach nourishment above the foreshore in more exposed locations.

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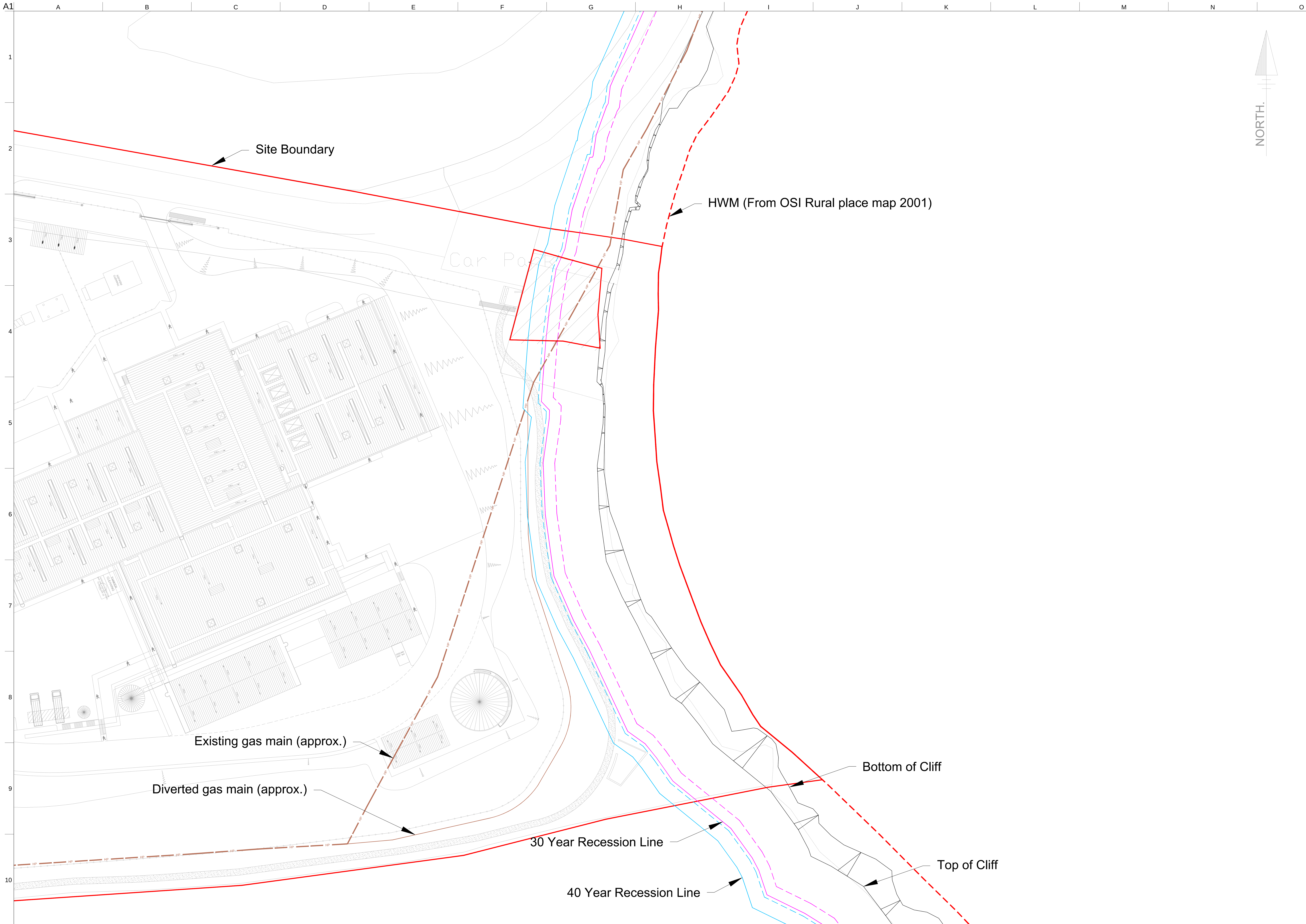
Appendix A

Estimated retreat lines

A1



Notes:

1. Information shown on this drawing is to be considered indicative only.
2. All dimensions are shown in metres unless noted otherwise.
3. All levels are shown in metres above ordnance datum.
4. All levels shown are based on most recent Bathymetric and Topographical Survey.
5. Material type and dimensions are assumed based on visual inspection and site investigation works.

Legend:

- Site boundary
- High water mark
- 30 year recession line
- 30 year recession line with nourishment
- 40 year recession line
- 40 year recession line with nourishment

Issue	Date	By	Chkd	Appd
PL01	21/12/15	JR	SL	JA
	Issued for Planning			

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Job Title: Ringaskiddy Resource Recovery Centre

Coastal Study
Estimated Retreat Lines

Scale at A1: 1:500
Discipline: Civil
Job No: 238129-00
Drawing Status: For Planning
Drawing No: C-000-060
Issue: PL01

Do not scale

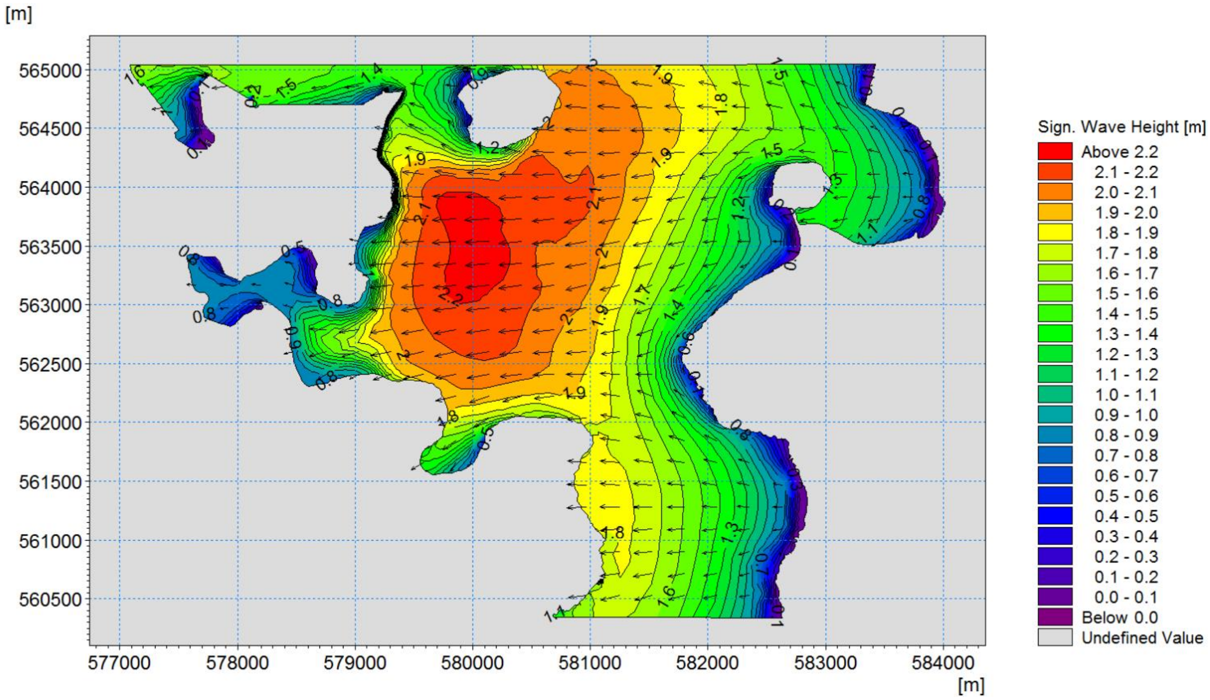
\\globalarup\europe\Cork\Jobs\238000\238129-00\4. Internal\4-02 Drawings\4-02-9 Maritime\Appendix A Drawing C-000-060_I02.dwg

Appendix B

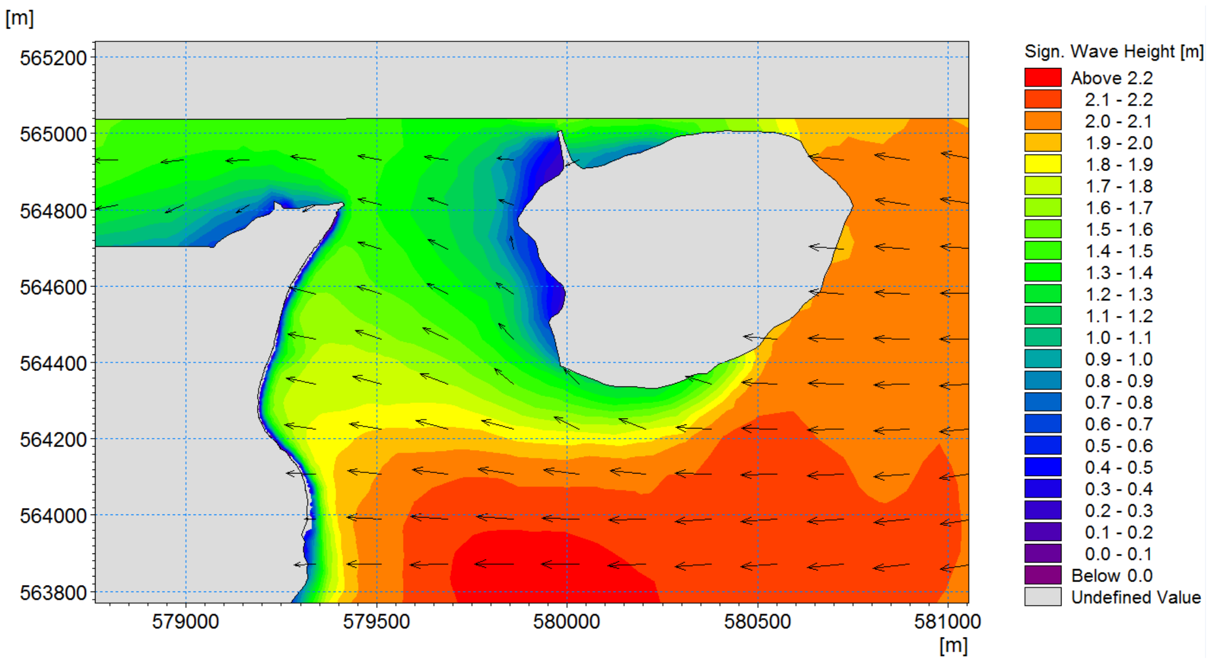
Wave Modelling Results

B1 Wave Modelling Results

B1.1 Case no. 1.1 results

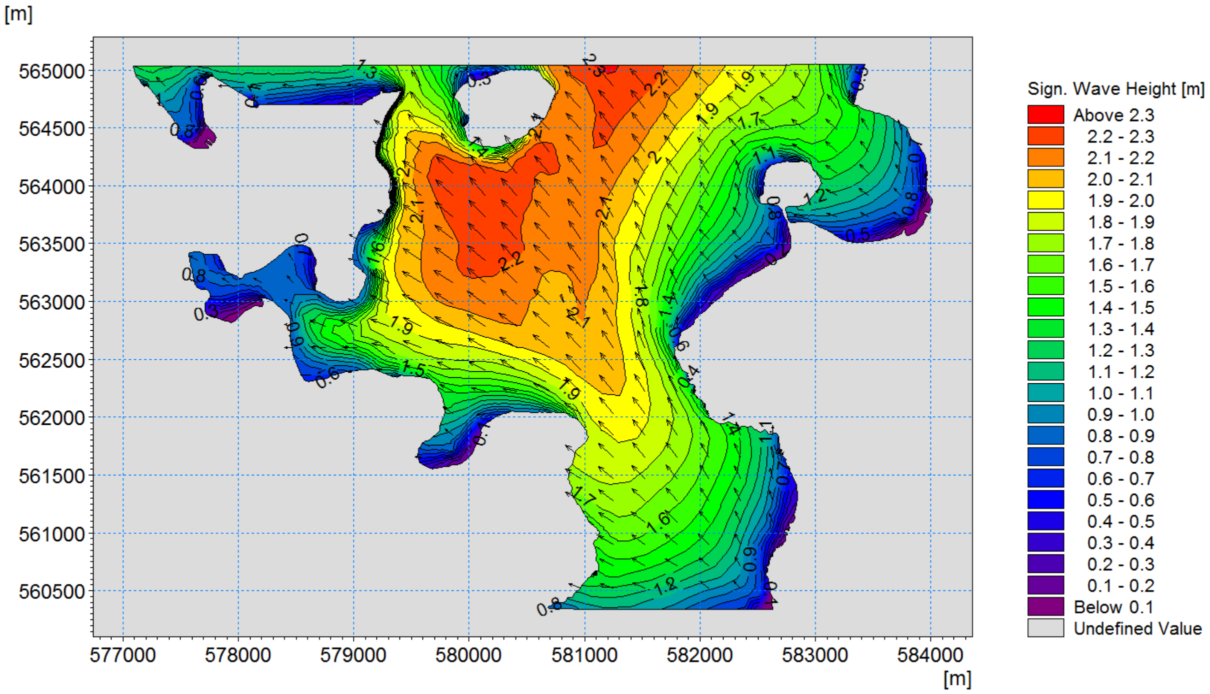


Offshore wave height distribution

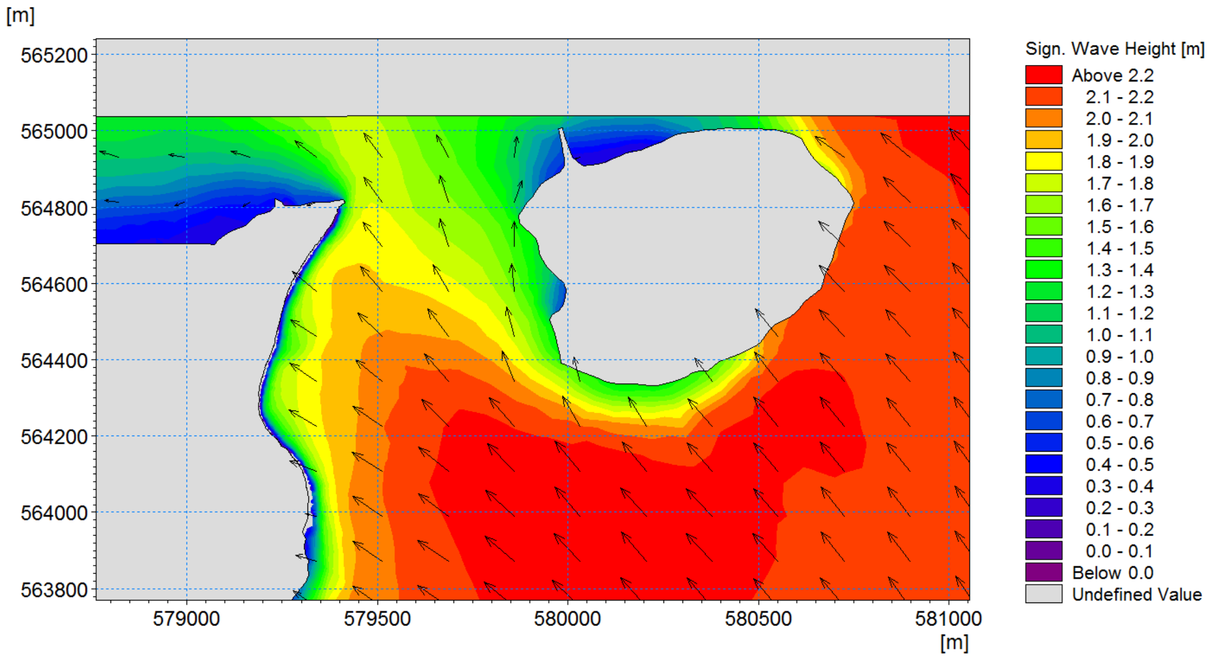


Nearshore wave height distribution

B1.2 Case no. 2.1 results

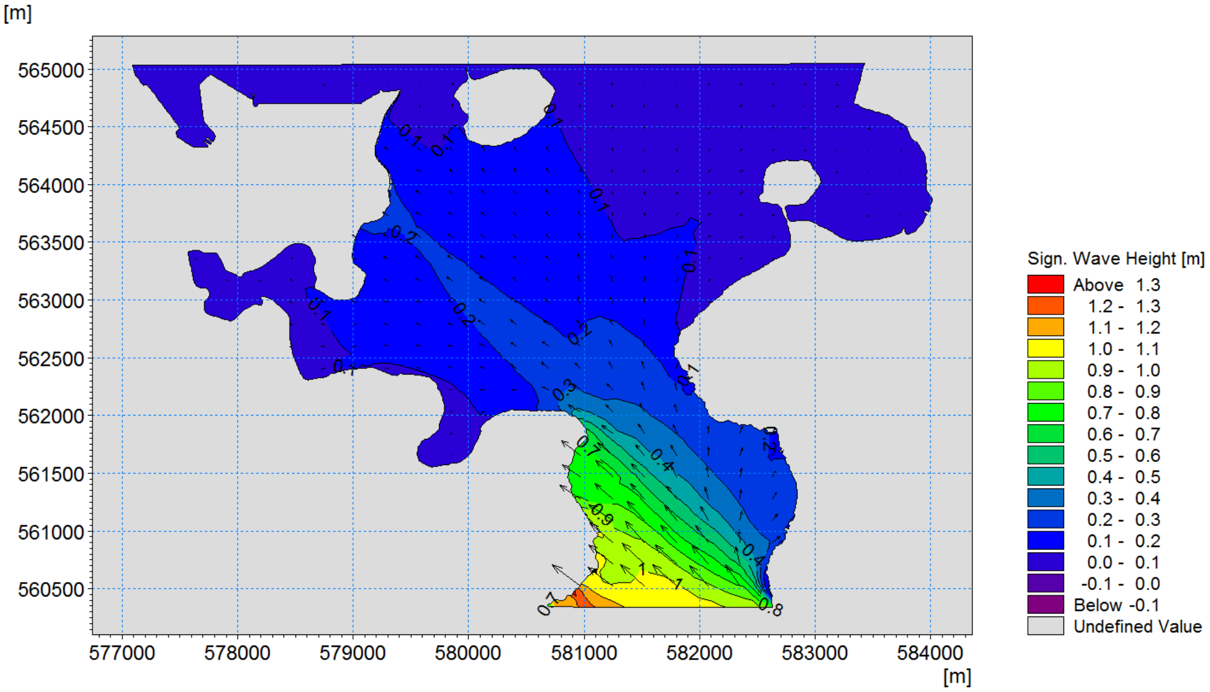


Offshore wave height distribution

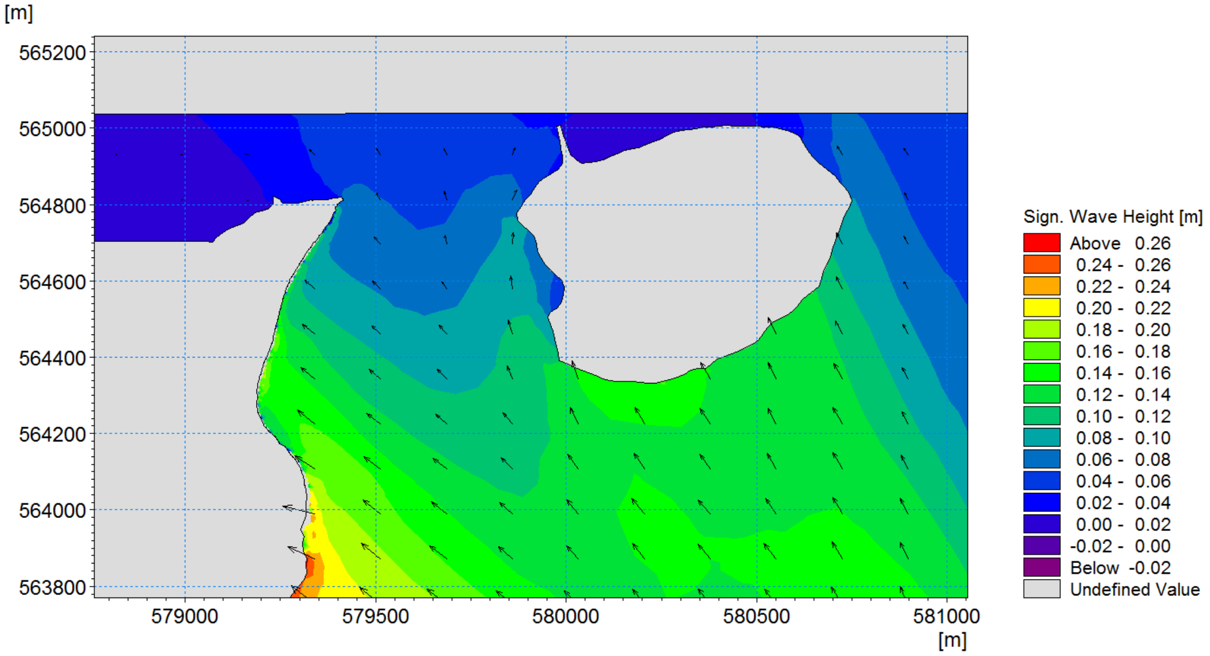


Nearshore wave height distribution

B1.3 Case no. 2.2 results



Offshore wave height distribution



Nearshore wave height distribution

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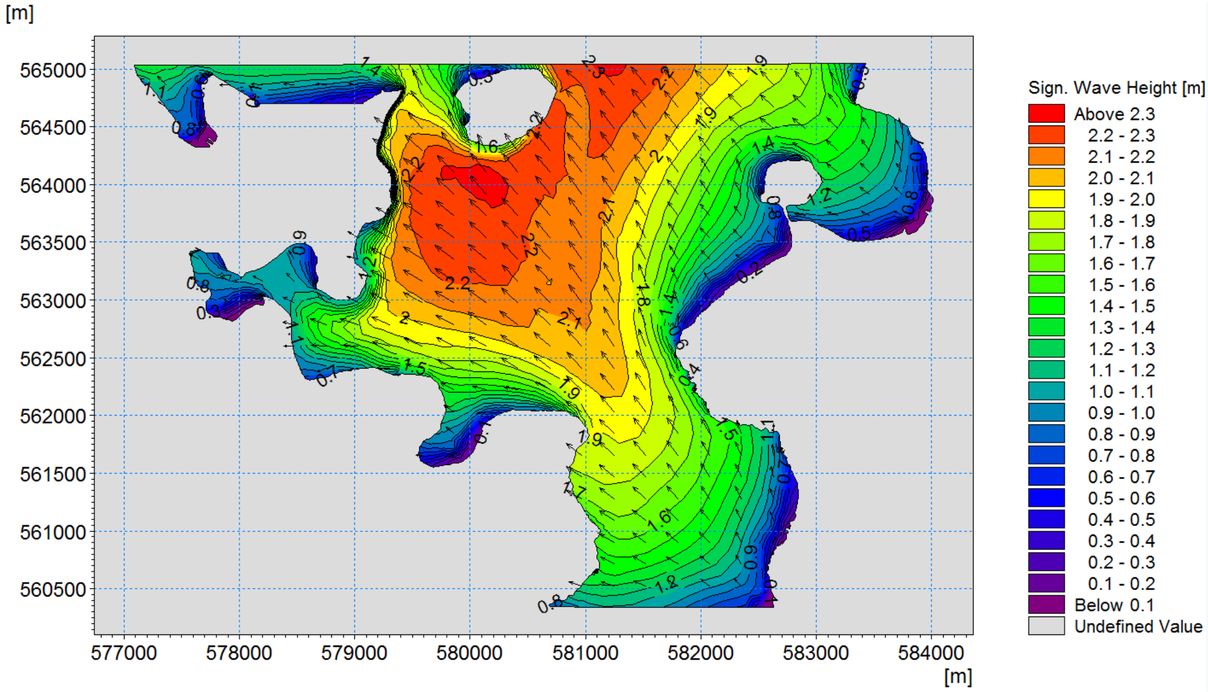
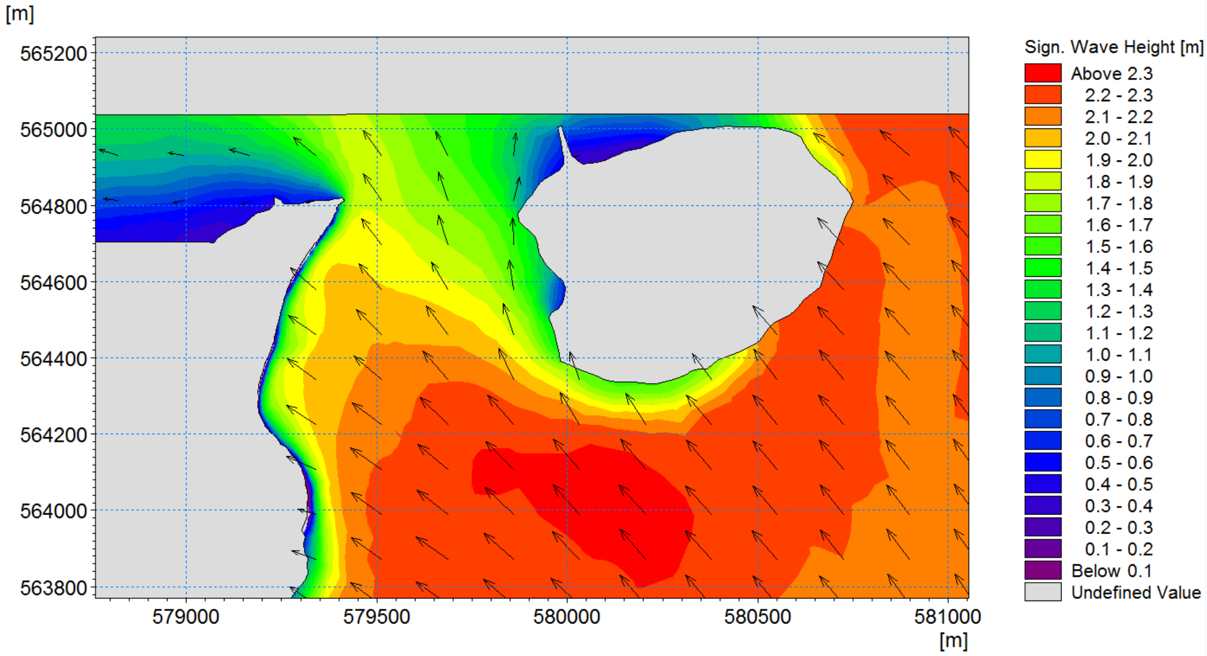
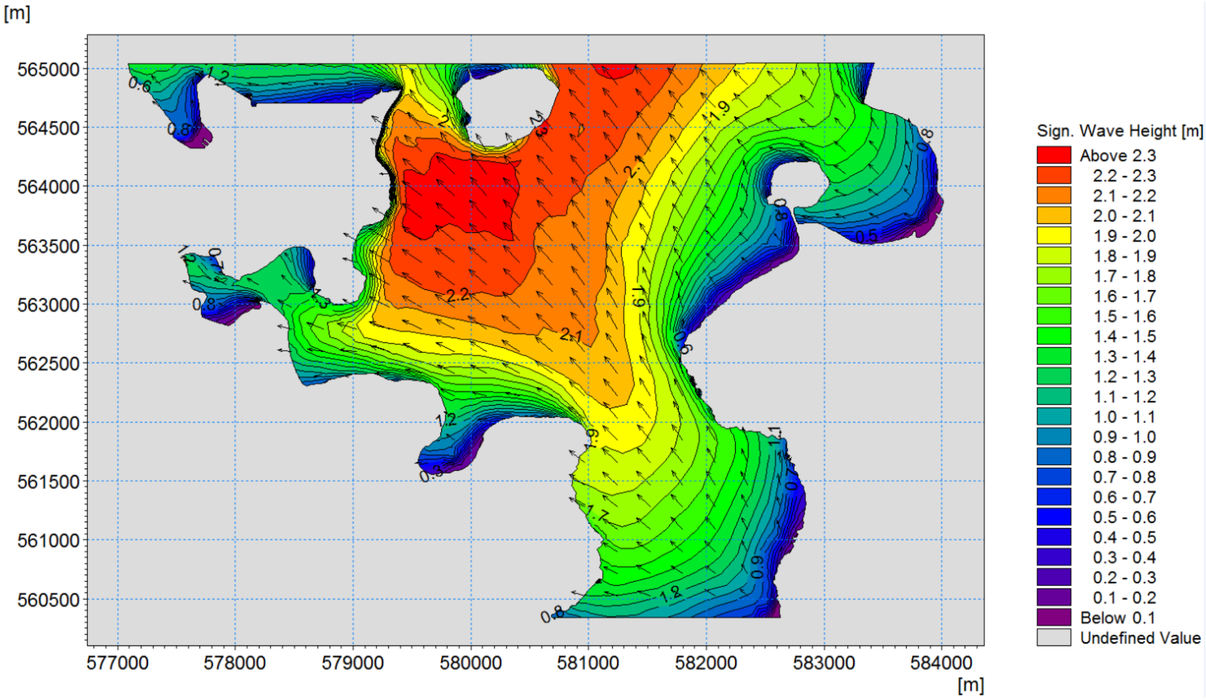


Offshore wave height distribution

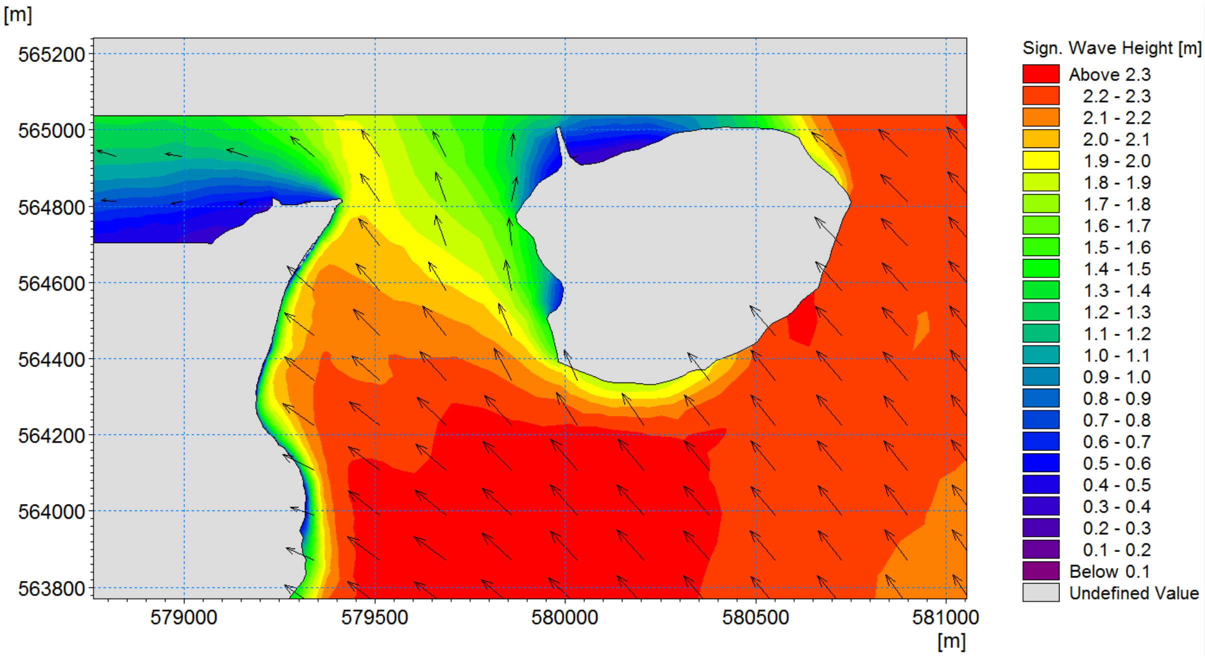


Nearshore wave height distribution

B1.5 Case no. 2.4 results

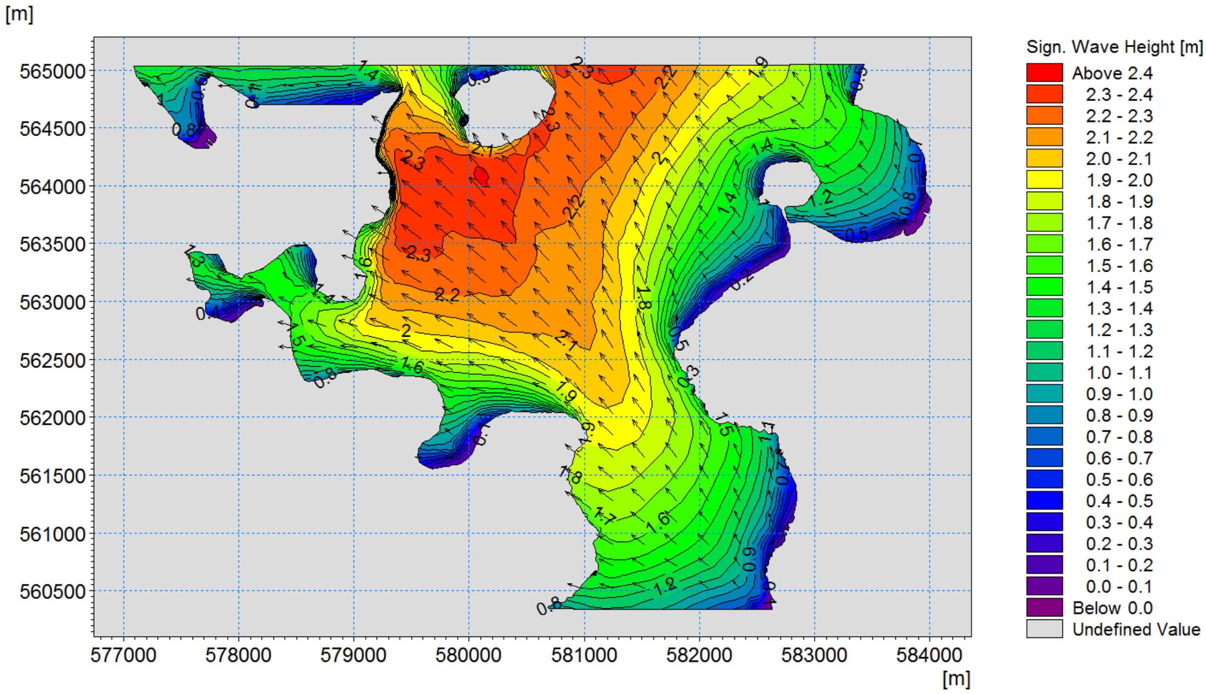


Offshore wave height distribution

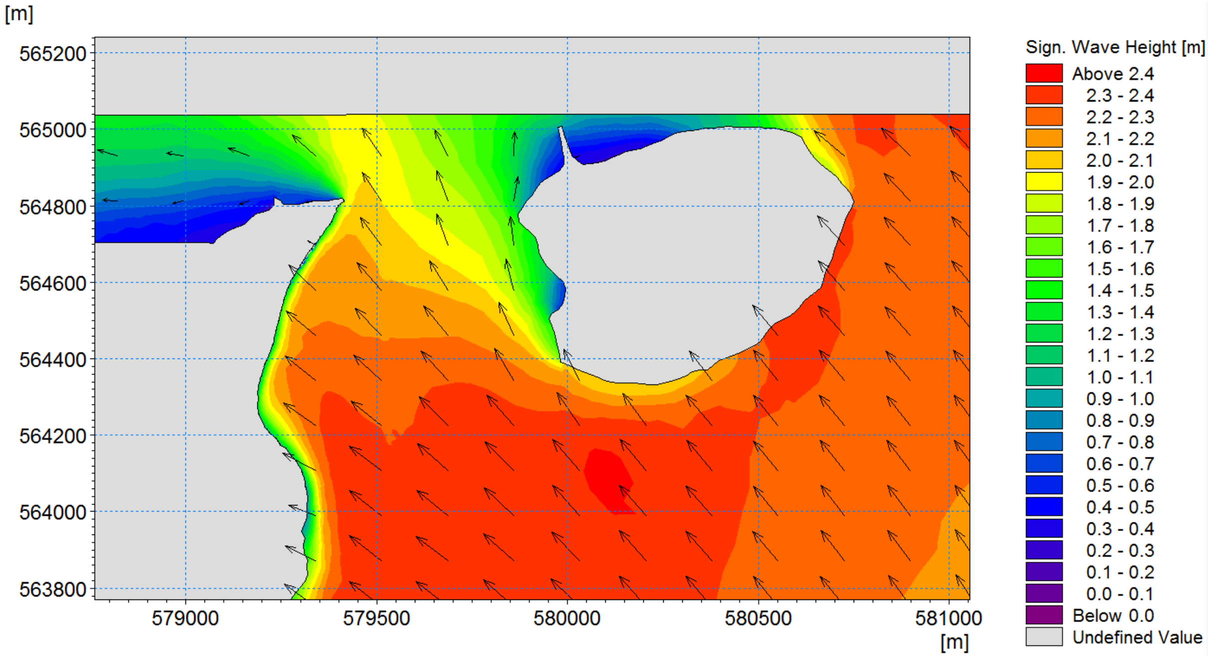


Nearshore wave height distribution

B1.6 Case no. 2.5 results

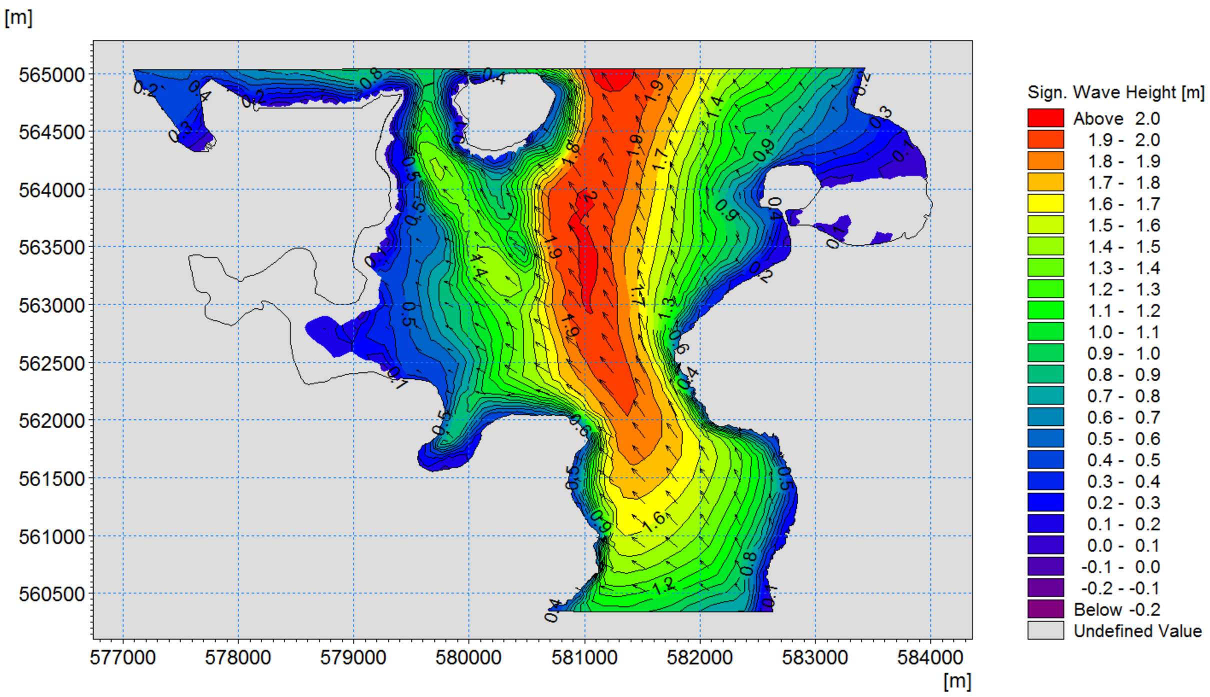


Offshore wave height distribution

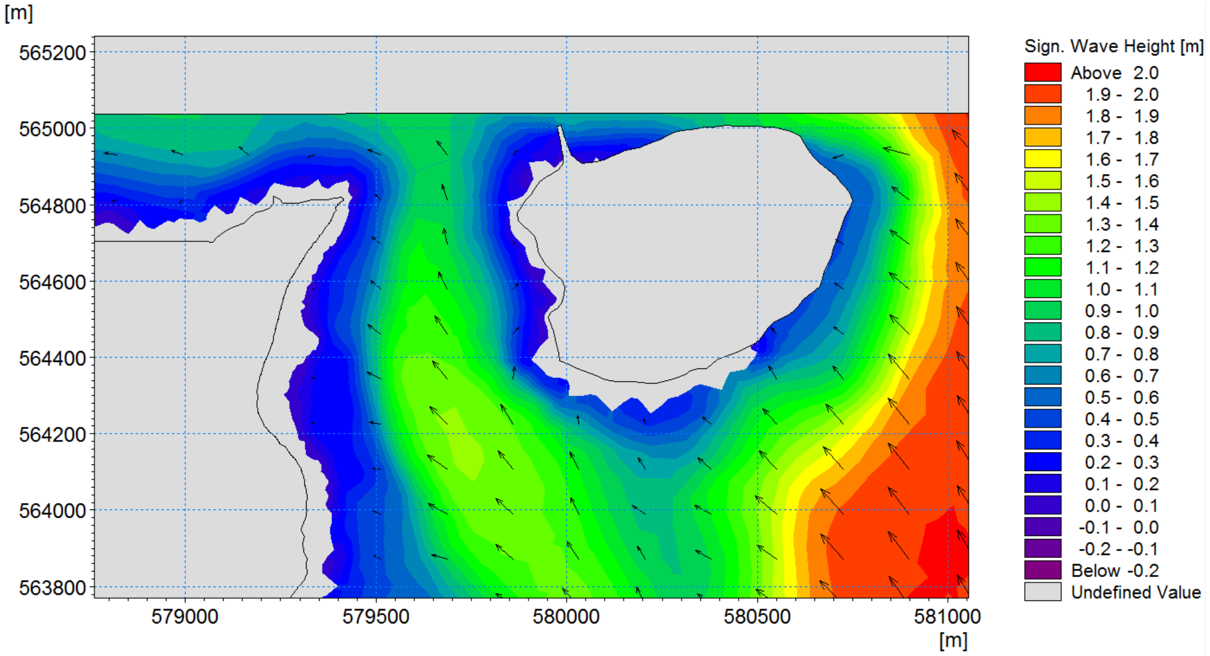


Nearshore wave height distribution

B1.7 Case no. 2.6 results

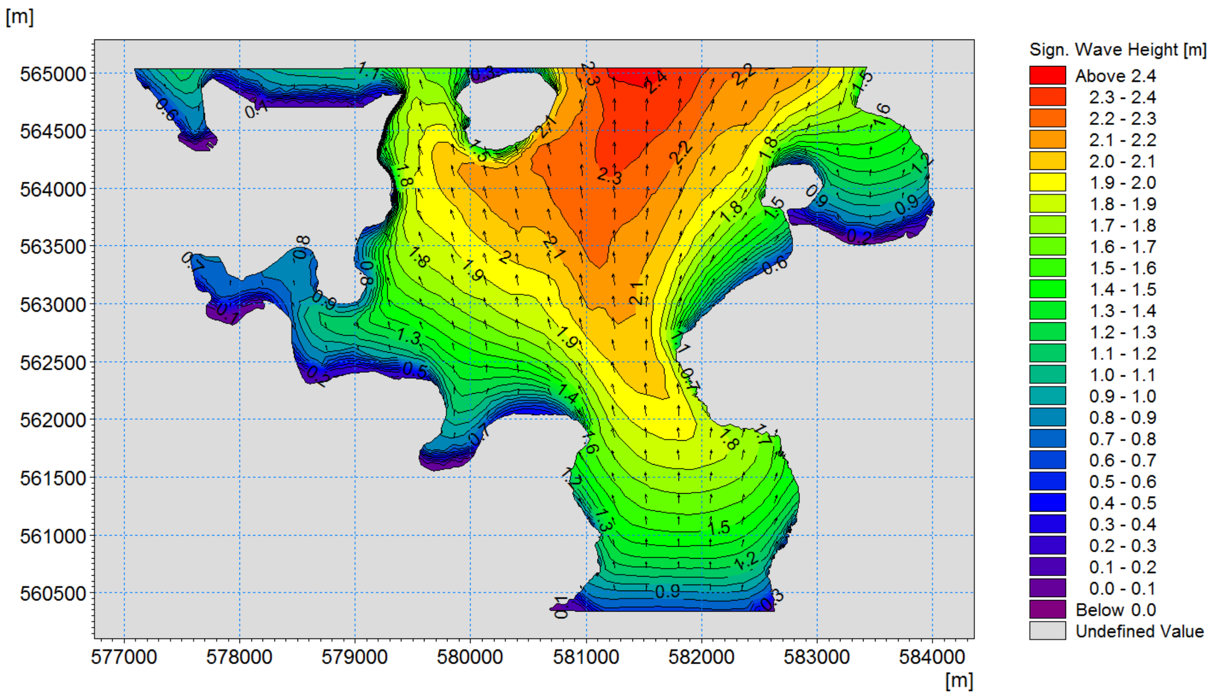


Offshore wave height distribution

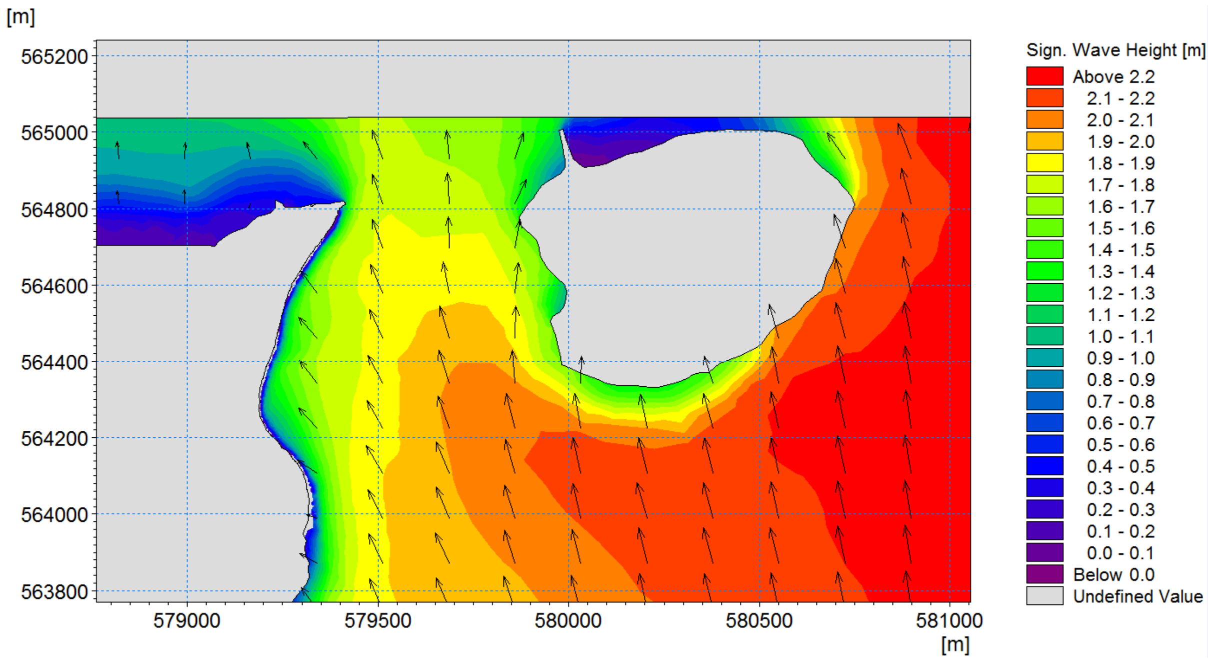


Nearshore wave height distribution

B1.8 Case no. 3.1 results

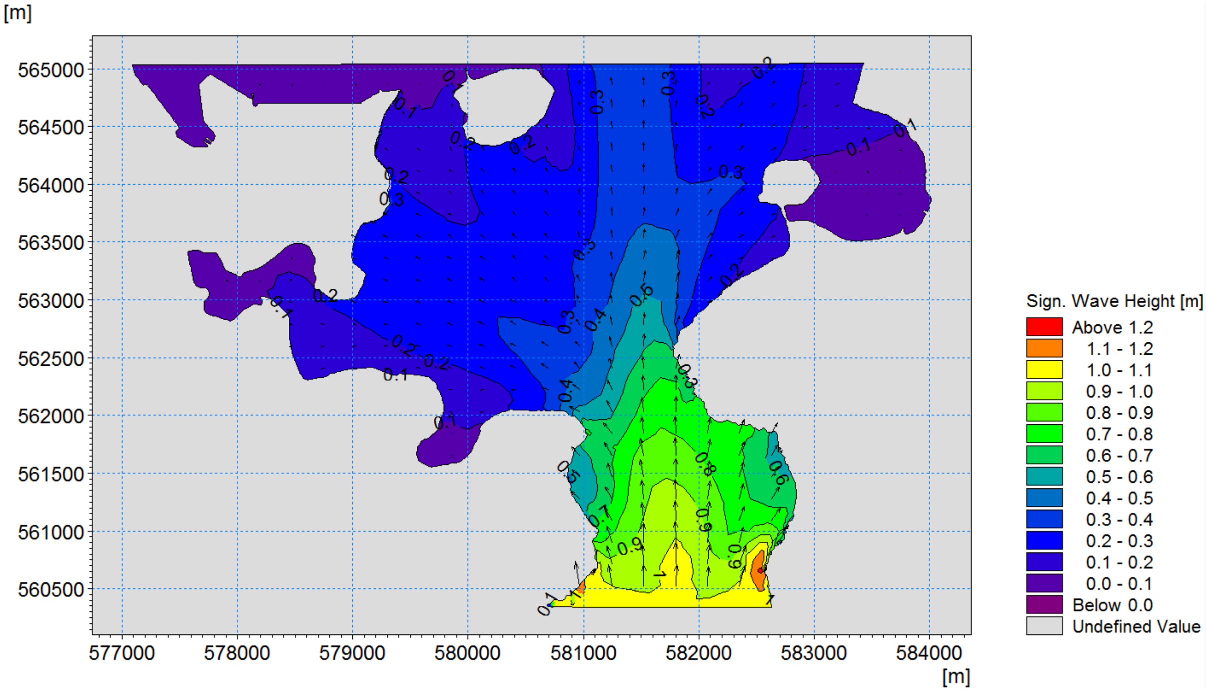


Offshore wave height distribution

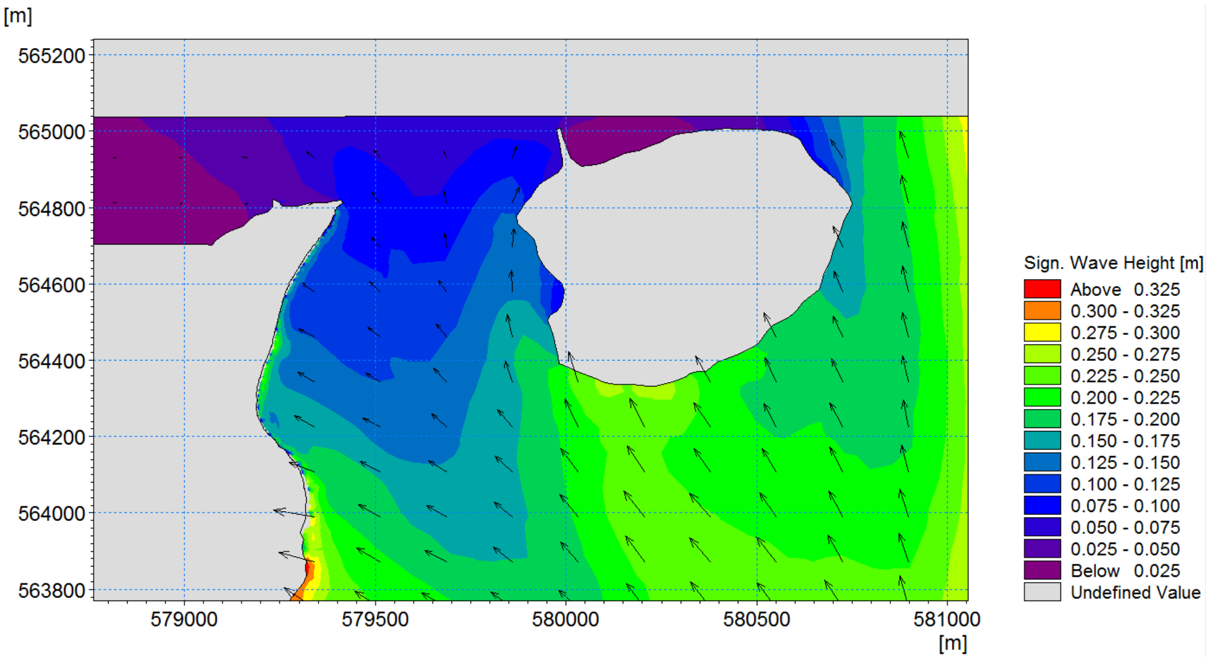


Nearshore wave height distribution

B1.9 Case no. 3.2 results



Offshore wave height distribution



Nearshore wave height distribution

Appendix C

Coastal engineering solutions

Solution	Technique	Advantages	Disadvantages	Licensing
Detached Breakwaters	Intermittent structures made of a loose material core which is covered with a resistant outer skin composed of rocks or concrete units. It is constructed in the wave breaking zone.	Dissipate wave energy further seaward than under natural conditions. Encourage beach build-up at the shoreline in the lee of the structure.	Requires construction outside of the Indaver site boundary. May pose as a hazard to vessels navigating the waters, however, it is envisaged the breakwaters would not be a hazard to ships in this case.	Foreshore licence needed
Sills	Un-segmented, structures parallel to the shore, always or occasionally submerged, usually built of rock and designed to hold beach material on their landward side.	They alter the cross shore sediment transport, preventing offshore loss of sediment resulting in a perched beach behind the sill. They also absorb some of the wave energy reaching the cliff.	Requires construction outside of the Indaver site boundary. May cause some scour of the beach immediately to the seaward. Risk to small craft users and swimmers due to submerged structure. May trap sand that would have deposited at other beaches.	Foreshore licence needed
Groynes	Narrow structures built usually at right angles to the shoreline which can be made of timber piles, rock, sheet pilling and concrete. They extend across the beach but rarely below the low water mark	Hold back sediment that would otherwise move along the beach under the action of waves and long-shore currents. Results in the accumulation of sand on the updrift side of the groyne to protect the coastline	Requires construction outside of the Indaver site boundary. Can increase the erosion along the down drift shoreline.	Foreshore licence needed
Revetments	Revetments are a means of protecting soft cliffs and slopes from wave impact forces. The most common methods are with rock armour or gabions.	Depending on size and location, it may not require construction outside of the Indaver site. Reduce wave impact energy on the cliff or coastal slope.	Depending on size, and location it may require construction outside of the Indaver site. Visually intrusive and may be hazardous to beach users if the rocks are very large. Requires beach access for construction.	Foreshore licence likely not to be needed
Sea Walls	Vertical or near vertical walls, usually built at the high water mark between the shore and the land from concrete or stone.	It can be constructed within the Indaver site boundary. They can reflect or absorb the wave impact energy and prevent erosion.	Visually intrusive and may prevent access to the beach or sea. Prevent normal development of the shoreline and may hamper strand line flora and fauna.	Foreshore licence likely not to be needed
Bulkheads	Vertical retaining walls with either cantilevered or anchored sheet piles or gravity structures.	Can be constructed within the Indaver site boundary. Reduce land erosion and loss to the sea by preventing soil from sliding seaward.	They commonly cause a change to the beach profile, normally resulting in sediment deposits along the shore where the bulkheads end.	Foreshore licence likely not to be needed
Cliff Strengthening	Applied above the tidal zone for soft rock or glacial till cliffs, techniques include the provision of drainage lines within the cliff face to minimize moisture or planting suitable vegetation on the cliff face.	Can be constructed within the Indaver site boundary.	Can have an impact on the ecology or land use at the cliff top (not expected for Indaver site).	

Solution	Technique	Advantages	Disadvantages	Licensing
		Reduce mass failure of cliff face by increasing the material strength or decreasing the strain forces put on them.	Can have an impact on shoreline sediment budgets. However, considering the short length of the cliff at the Indaver site this would only be minor.	
Beach Nourishment	Artificially adding material to the beach in order to overcome a deficit in the sediment budget.	Protects the cliff face from breaking waves.	Long-term maintenance effort usually required.	Foreshore licence needed
		Regarded as a very natural way of combating coastal erosion.	Cause of the erosion is not eliminated as beach material is sacrificed with time.	
			Requires construction outside of the Indaver site boundary	
Sacrificial beach material (shingle) at the toe of the cliffs	Artificially adding material to the beach above the foreshore in order to protect the toe of the cliff from wave action	Protects the cliff face from breaking waves.	Long-term maintenance effort usually required.	Foreshore licence likely not to be needed
		Regarded as a very natural way of combating coastal erosion.	Cause of the erosion is not eliminated as beach material is sacrificed with time.	
		Less material than conventional beach nourishment needed		
		It can be constructed within the Indaver site boundary.		
Planting	On cliffs, grass, bushes and trees protect the cliff slope against surface erosion by rain and melt-water.	Landslides on the cliff slope are reduced by the presence of planting.	In isolation they are generally not sufficiently effective.	Foreshore licence likely not to be needed
		It can be constructed within the Indaver site boundary.	Vegetation may fail due to environmental conditions	
			May be successful in low energy environment but not for example on the open coast.	

Appendix D

Plan and section drawings of proposed solution

A1

Notes:

1. Information shown on this drawing is to be considered indicative only.
2. All dimensions are shown in metres unless noted otherwise.
3. All levels are shown in metres above ordnance datum.
4. All levels shown are based on most recent Bathymetric and Topographical Survey.
5. Material type and dimensions are assumed based on visual inspection and site investigation works.

Legend:

- Sacrificial material
- Site boundary
- High water mark
- Top/ bottom of cliff

Issue	Date	By	Chkd	Appd
PL01	21/12/15	JR	SL	SL
	Issued for Planning			

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Client: INDAVER

Job Title: Ringaskiddy Resource Recovery Centre

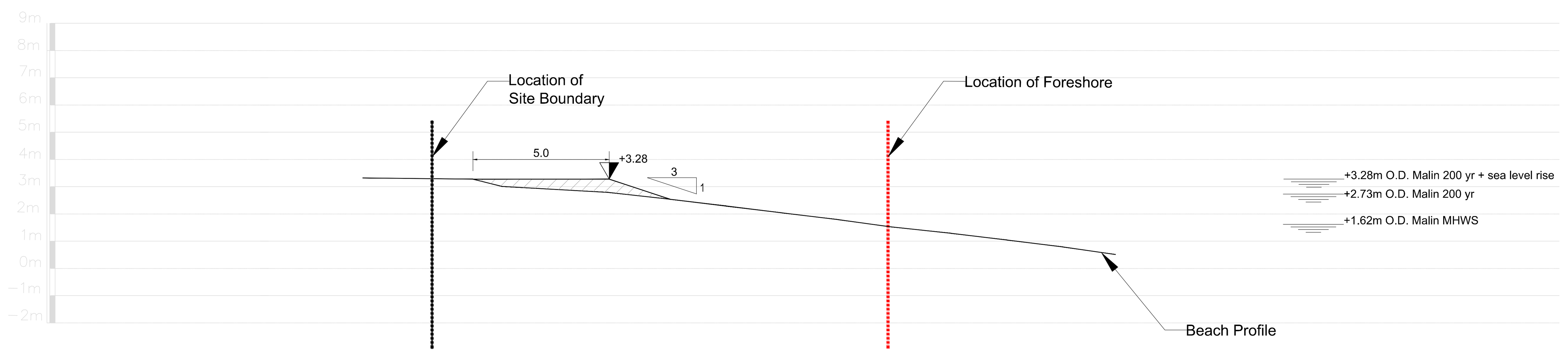
Coastal Study
Proposed Solution Plan

Scale at A1: 1:500
Discipline: Civil
Job No: 238129-00
Drawing Status: For Planning
Drawing No: C-000-061
Issue: PL01

Do not scale

\\global\europe\Cork\Jobs\238000\238129-00\4. Internal\4-02 Drawings\4-02-9 Maritime\Appendix D Drawing 061, 062, 063_I02.dwg

A1



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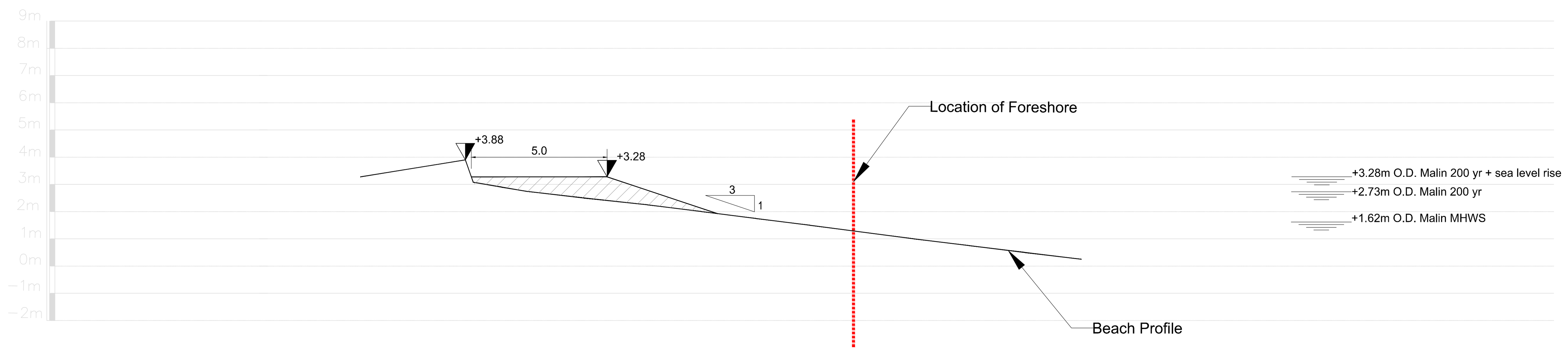

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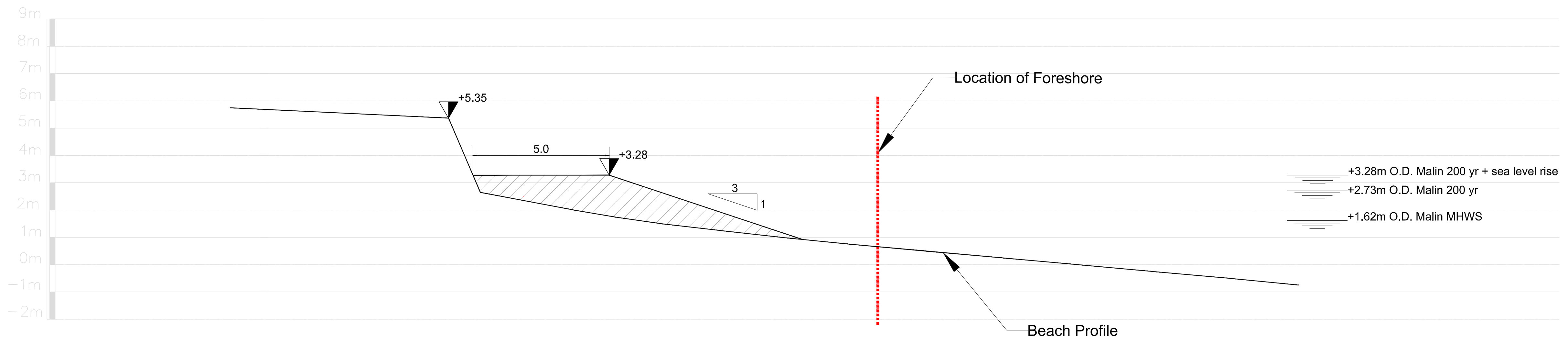

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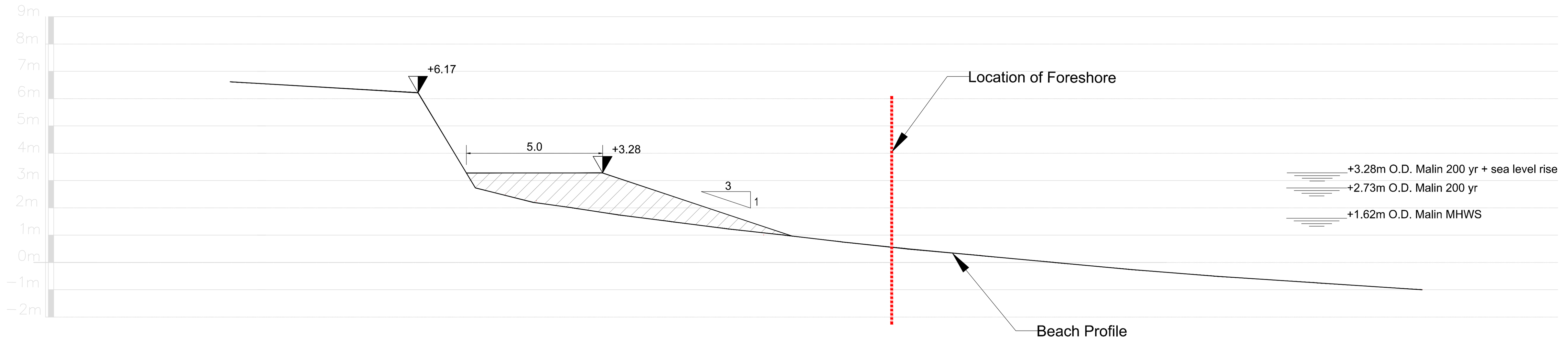

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Issue	Date	By	Chkd	Appd
PL01	21/12/15	JR	SL	SL
	Issued for Planning			

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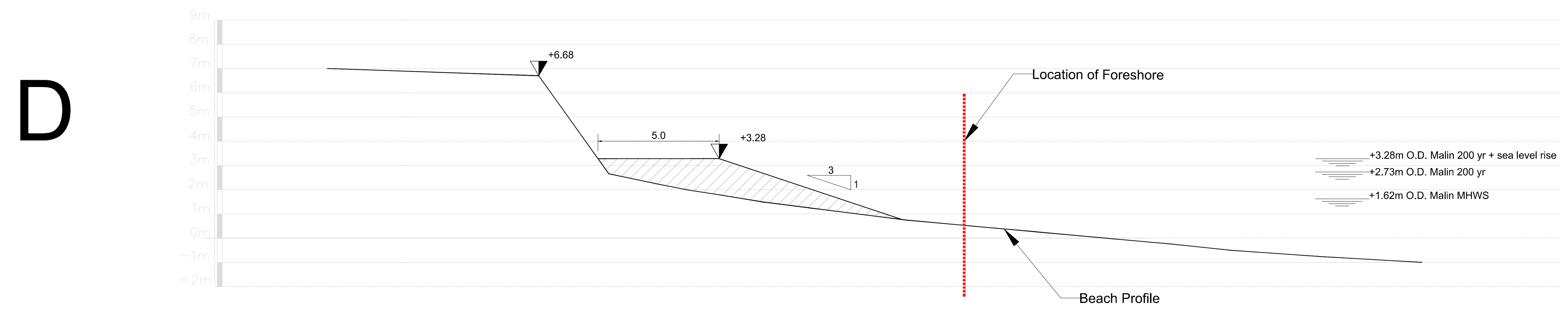
Client
INDAVER

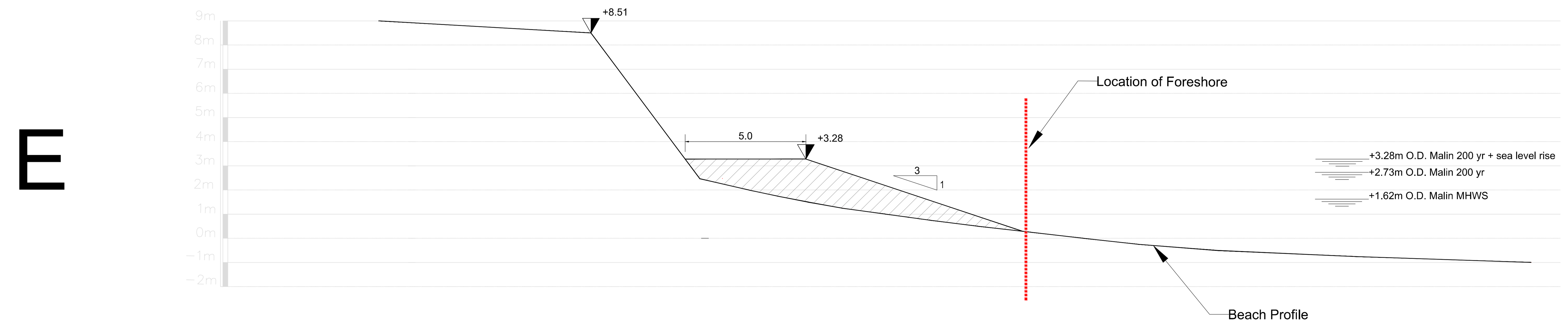
Job Title
Ringaskiddy Resource Recovery Centre

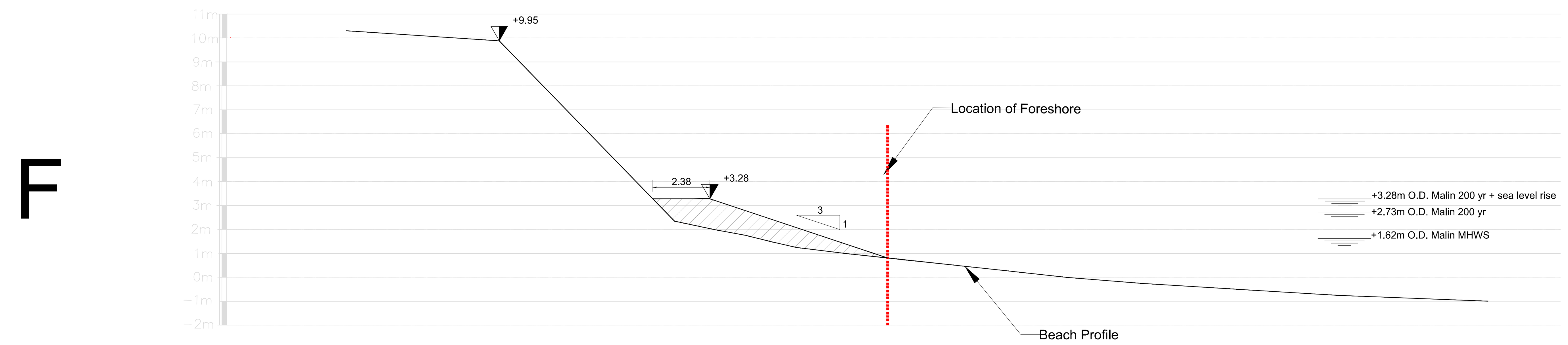
Coastal Study
Sacrificial Material
Section Details

Scale at A1 1:150
Discipline Civil
Job No 238129-00
Drawing Status For Planning
Drawing No C-000-062
Issue PL01

Do not scale







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5. Material type and dimensions are assumed based on visual inspection and site investigation works.

Issue	Date	By	Chkd	Appd
PL01	21/12/15	JR	SL	SL
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Job Title
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Coastal Study
Sacrificial Material
Section Details

Scale at A1: 1:150
Discipline: Civil
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Drawing No: C-000-063
Issue: PL01

Do not scale