Coastal Processes at the Burrow, Portrane

Erosion and Climate Assessment Report

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1 INTRODUCTION

Until recently, the coastline of the natural sandy spit of the Burrow at Portrane was considered to be dynamically stable; moving about a fixed position in response to prevailing weather conditions. However, with global climate driving an increase in prevailing weather conditions, sea level conditions and the frequency and magnitude of extreme storm events, the sandy dune system illustrated in Figure 1.1 is now at an increased risk from coastal erosion.

Between 2013 and present, the coastline around the Burrow was subject to extensive episodes of acute coastal erosion with the dune line in some regions retreating landward by more than 20 metres to create an immediate structural risk to a number of private residential properties. In context of historical coastal change at Portrane these episodes of erosion were until recently unprecedented in extent and magnitude.

In response to this risk Fingal County Council have engaged RPS to characterise the recent storm events, assess the future threat of coastal erosion and consider a range of protection measures that could be implemented to mitigate such risks.

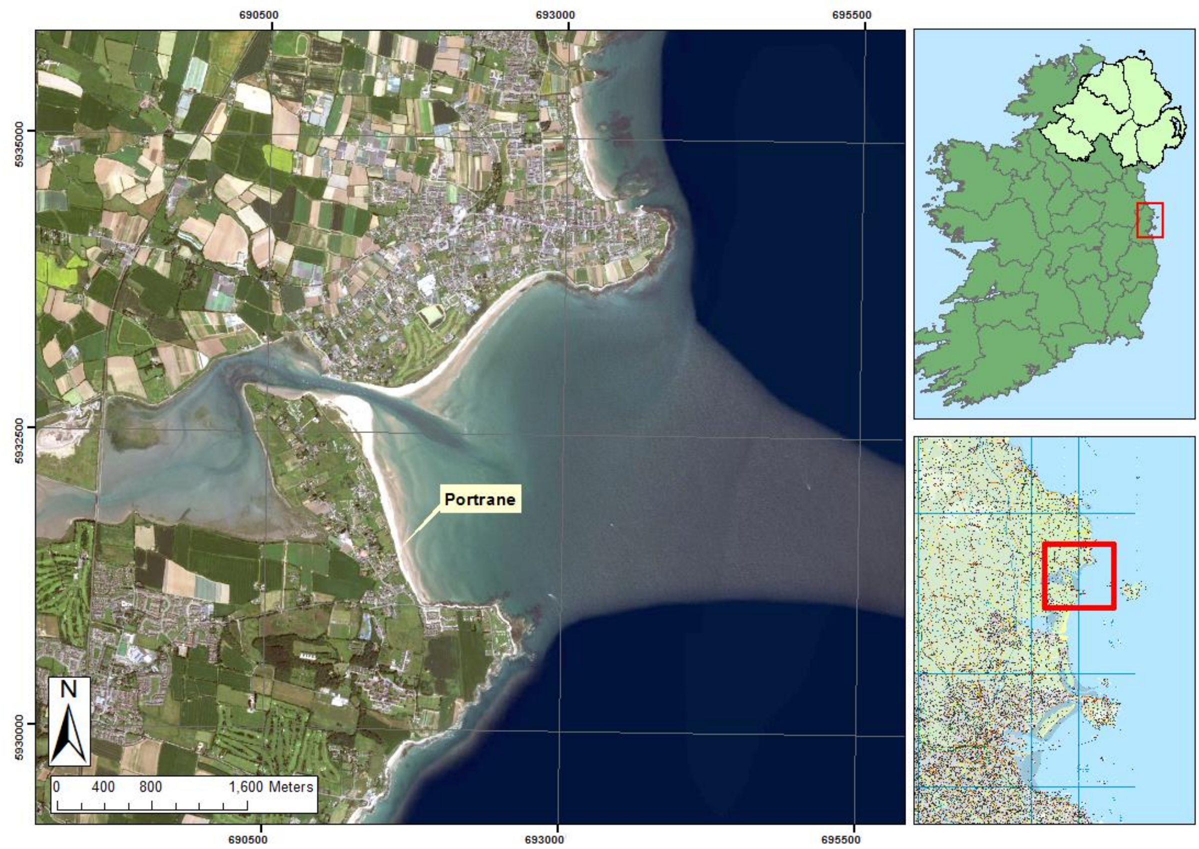

Figure 1.1: Location and extent of the sand spit currently threatened by coastal erosion along the Burrow at Portrane.

1.1 SITE BACKGROUND

The Burrow at Portrane is a natural sandy spit that separates the environmentally sensitive Rogerstown estuary from the Irish Sea. In previous years, a wide and flat sandy beach together with an extensive dune system created an effective natural buffer against incident wave energy and erosive processes. In recent years acute erosion driven by climate change has exacerbated the loss of sand during increasingly frequent extreme waves and storm surges and has increased the threat of further coastal erosion along the majority of the Burrow.

Since the late 1950’s no hard engineering measures have been implemented to mitigate the threat of coastal erosion along the Burrow due to the potential of such measures impacting the qualifying interests of the Rogerstown Estuary SAC and Rogerstown Estuary SPA which includes white and grey dune systems amongst other features. Instead, a programme of soft engineering works have been implemented over the last number of years including dune re-profiling, sand trap fencing and the planting of marram grass. However, the continued depletion of sand in the area has reduced beach levels to the extent that large energetic waves have been able to propagate landward, rendering these soft engineering measures ineffective and thus resulting in significant coastal erosion.

A preliminary assessment of the flood risk which was previously undertaken by RPS also found that owing to the low lying nature of much of the sandy spit at the study site, the dune system along the Burrow provides an essential buffer against coastal flooding. Therefore it is believed that the current threat of coastal erosion not only presents an immediate structural risk to assets and infrastructure properties along the frontage, but it also presents a very significant flood risk to the Burrow if the dune system was to be breached.

2 PREVIOUS EROSION PROJECTIONS

The previous coastal erosion risk management study undertaken by RPS in 2013 for the Portrane Rush areas found that that based on historical information from between 1843 and 2013 the coastline at Portrane was dynamically stable, shifting about a mean position in response to prevailing weather conditions.

Based on this assumption RPS estimated future coastal erosion using the Historical Trend Analysis Rule (HTAR) that relates the rate of shoreline retreat to the rate of sea level rise. The HTAR equation is presented below:

$$\mathbf{R_2= (R_1/S_1). * S_2}$$

Where:

S_1=historical sea-level rise rate (m/yr)
S_2= future sea level rise rate (m/yr)
R_1= historical retreat rate (m/yr)
R_2= future retreat rate (m/yr)

The HTAR is a common approach used to assess shoreline retreat over specific periods of time. However this method assumes that sea level rise is the dominant driver of coastal recession and that other factors that determine coastal recession such as the inshore wave climate or storminess remain constant.

RPS used a range of geo-referenced ordnance survey maps and ortho-photographs to digitise the position of the vegetation line along the coastline of the Burrow between 1843 and 2013. Using the information illustrated in Figure 2.1 RPS used the HTAR approach to estimate the position of the vegetation line by 2100 using climate change guidelines issued by the Office of Public Works. The two climate change scenarios investigated were the Mid-range Future Scenario (MRFS) and the High-End Future Scenario (HEFS) whereby sea level is expected to rise by 500mm and 1000mm by 2100 respectively. Using these projections the HTAR assessment found that:

- Under the MRFS the 2013 vegetation line was estimated to retreat by between 8 – 24 metres by 2100, putting at least 1 property at risk of structural failure.
- Under the HEFS the 2013 vegetation line was estimated to retreat by up to 48 metres by 2100, putting approximately 11 properties at risk of structural failure.
- Under both scenarios there would be a significant loss of the intertidal zone that would likely impact recreational users of the beach area.

The position of the projected vegetation line by 2100 under the MRFS and HEFS climate change scenarios and the properties likely to be at risk based on the 2013 study are illustrated in Figure 2.2 to Figure 2.4 on the following pages.

Since this assessment was undertaken in 2013, Ireland and the UK have experienced a dramatic increase in extreme weather events which has resulted in unprecedented coastal conditions at many coastal locations in both countries. One of the most significant of the storm events in relation to east coast of Ireland was Storm Emma. This particular storm event which occurred in early May, together with the resultant coastal conditions at Portrane are discussed in more detail in Section 3.

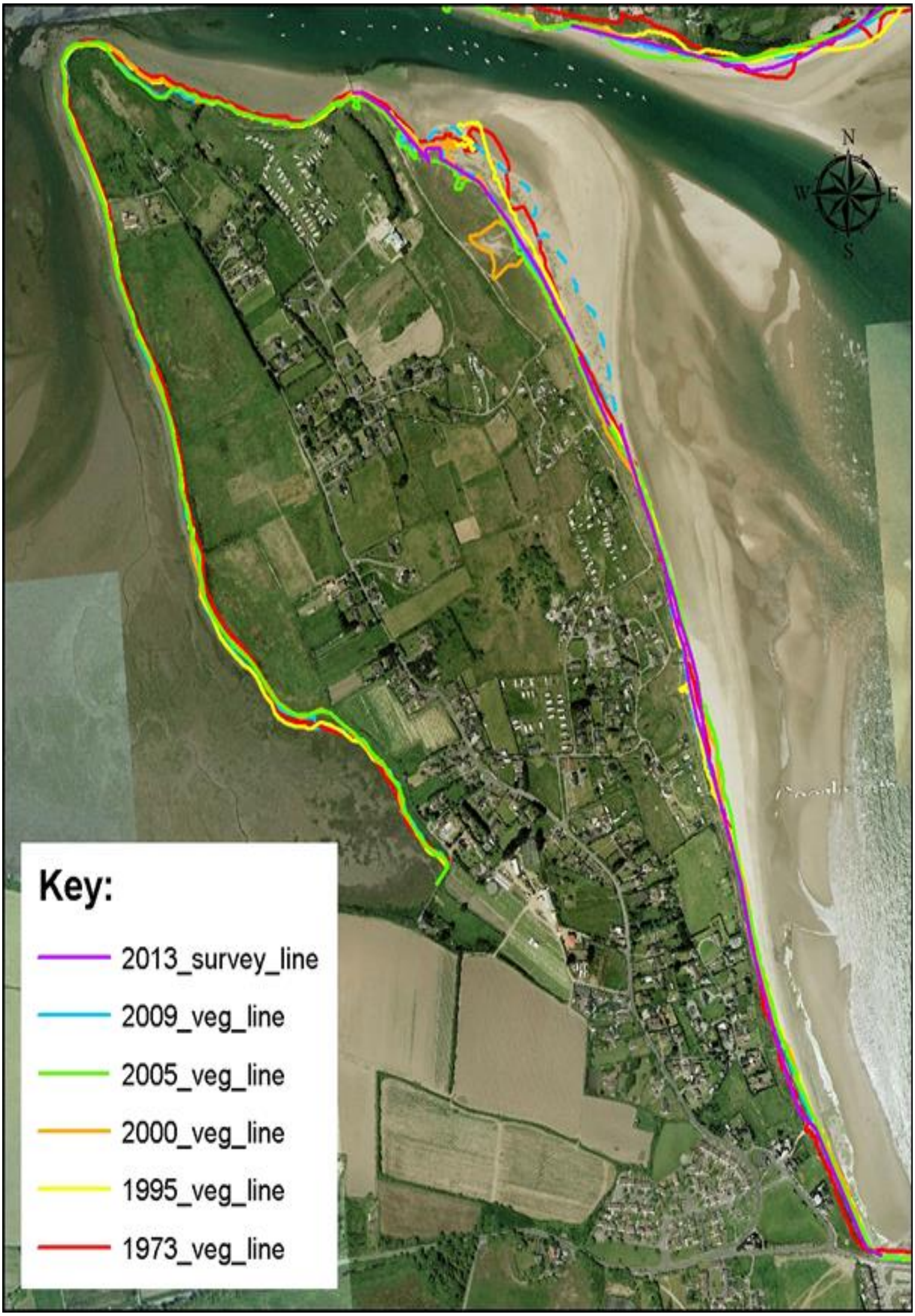

Figure 2.1: Portrane - vegetation lines from OS aerial photos superimposed on a 2009 photograph.

Figure 2.2: Position of the 2013 vegetation line and the 2100 MRFS and HEFS erosion lines.

Figure 2.3: Properties identified as being at risk by 2100 along the Burrow (Zone 2).

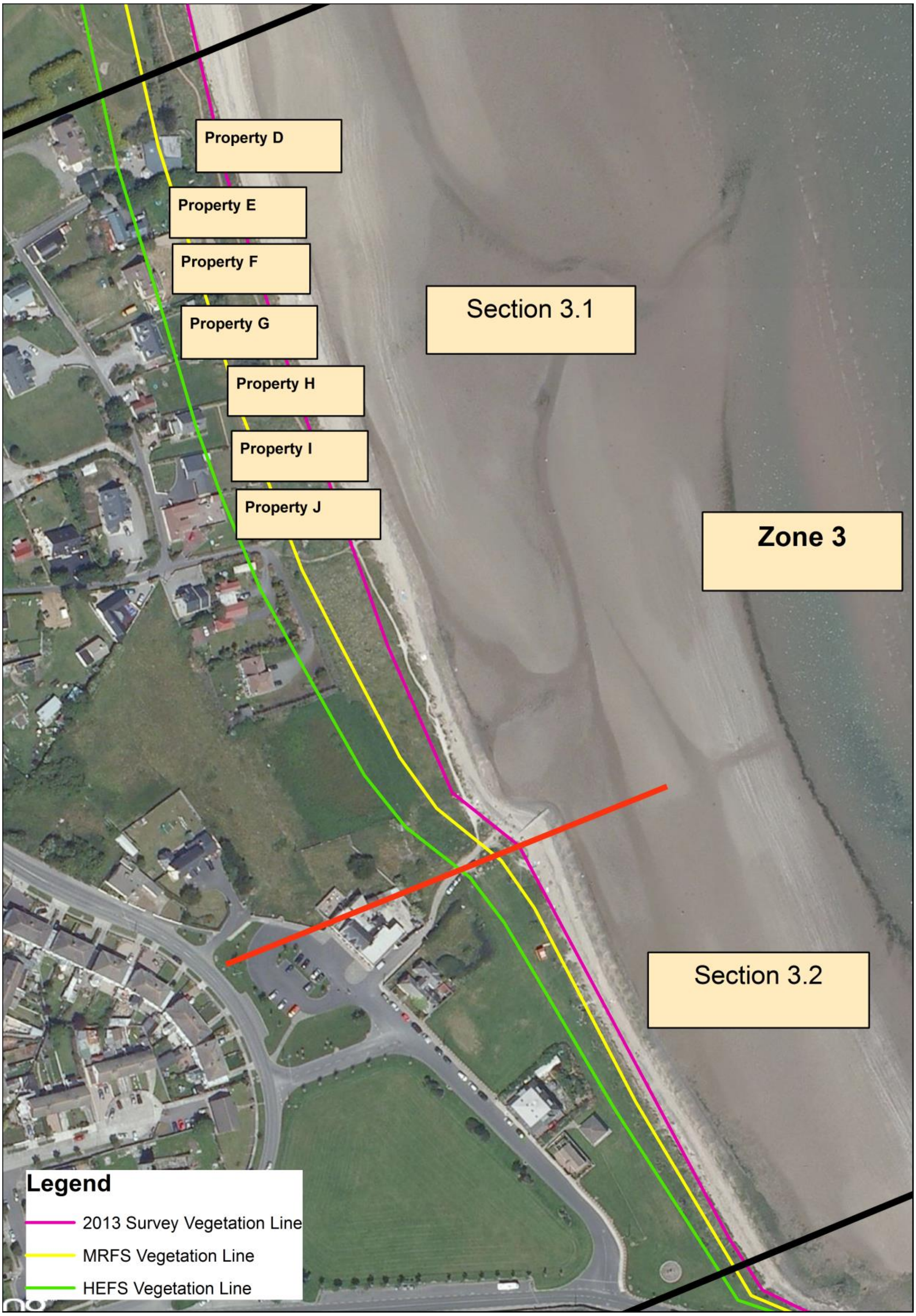

Figure 2.4: Properties identified as being at risk by 2100 along the Burrow (Zone 3).

3 STORM EVENTS OF WINTER 2017/2018

Between late 2017 and early 2018, Ireland and the United Kingdom experienced 10 individual named storm events; this is 5 more events compared to the same period in 2016/17. Naming storms is a decision made jointly by forecasters in both Met Eireann and the UK Met Office in response to wind storm events that have potential to result in significant land-based impact or to severe wind events that give rise to orange or red status weather warnings. The 10 individual storm events of the 2017/2018 season are summarised in Table 3.1 below.

Table 3.1 Summary of UK/ROI storm events 2017/18.

Storm Name	Date of impact on UK and/or Ireland	Description
Aileen	12 - 13 September 2017	Many areas of England and Wales experienced winds between 55 – 65 mph with the max gusts in excess if 80mph
Ex-Hurricane Ophelia	16 - 17 October 2017	Ex-Hurricane Ophelia impacted the UK and Ireland on Monday 16 October and Tuesday 17 October, bringing gusts of up to 90mph
Brian	21 October 2017	Brought strong gusts across the UK & Ireland coinciding with highs tides. Impacts were most significant in Ireland and Wales with flash flooding in a number of Irish cities
Caroline	07 December 2017	Brought gusts of up to 93mph in regions of the UK
Dylan	30 - 31 December 2017	Low pressure system that brought strong winds to Ireland and southern Scotland
Eleanor	2 - 3 January 2018	Brought gusts of up to 90mph in regions of the UK and Ireland
Fionn	16 January 2018	Strong winds affected the ROI, especially across western counties, with the highest gust of 75 mph at Galway
David	18 January 2018	Brought strong winds to eastern parts of the UK before strengthening further as it crossed the North Sea and impacted northern Europe
Georgina	24 January 2018	A low pressure system that moved eastwards across northern Scotland and the North Sea later in the afternoon. Gusts up to 85mph were recorded
Emma	01 March 2018	This weather system pushed up from the south and brought strong winds and gusts in excess of 60 mph in from the east. This event resulted in significant erosion along the east coast of Ireland

3.1 ANALYSES OF STORM EMMA

The nearest long term recorded offshore wave dataset to Portrane can be found at the M2 wave buoy in the Irish Sea. As illustrated in Figure 3.1 the M2 wave buoy is approximately 45km to the east of Portrane at the offshore point 53.48°N, 5.42°W. This device records various wave parameters including significant wave height, direction and wave period and covers the period between 2001 - 2018. To expand this dataset RPS supplemented this information with an additional five year dataset from 1996 – 2001 that was taken from the European Centre for Medium Range Forecasts (ECMWF) wave model.

As a result RPS were able to analyse the recent storm events that resulted in erosion to the Burrow in context of a 22 year offshore wave dataset. It should be noted that as the analyses presented in the following sections of this report have been based on wave data from the M2 wave buoy and tide gauge data from Howth harbour, results should only be considered as indicative of the conditions that would have been observed at Portrane.

Figure 3.1: Location of the M2 wave buoy in relation to Portrane.

An assessment of this data found that despite greater gust speeds being recorded during previous storm events, it was during Storm Emma that the highest offshore waves were recorded at the M2 buoy. During Storm Emma on 02/03/2018 at 06:00am an offshore significant wave height of 6.25m with a corresponding wave period of 7.85s was recorded from 70°. This event was then followed by a succession of smaller offshore waves from the east between 17/03/2018 – 18/03/2018. The M2 wave buoy recorded significant wave heights of 4.20m and 4.22m from the east during this period.

To put Storm Emma and the subsequent unnamed storms into context Table 3.2 overleaf lists the 5 most extreme wave events from the easterly sector recorded at the M2 buoy between 1996 and 2018. As can be seen from this Table, aside from being the most extreme easterly storm event ever recorded by the M2 buoy, the wave recorded during the 02/03/2018 was also *c.*35% greater than the next largest wave event which was recorded back in 30/12/2009.

Table 3.2: The 5 most extreme easterly wave events recorded at the M2 buoy between 1996 – 2018 (based on data recorded by M2 buoy and ECMWF wave data).

Rank	Date	Significant Wave Height [m]	Wave Period [s]	Wave Direction [°N]
1	02/03/2018 06:00	6.25	7.85	70
2	30/12/2009 12:00	4.60	7.00	70
3	17/03/2018 15:00	4.22	6.68	69
4	27/10/2004 23:00	4.20	7.41	110
5	10/12/2002 18:00	4.20	7.22	70

The wave climate at the M2 buoy during the previous 4 winter seasons is illustrated in Figure 3.3 overleaf (it should be noted that the gaps in this data is a result of the M2 wave buoy being offline due to either maintenance or damage). It will be seen from this Figure that in general the 2017/2018 wave climate was no more arduous than previous winter periods except for two notable periods in mid-October and then again in early to mid-March.

During the event in mid-October a significant wave height of 6.64m was recorded at the M2 buoy, however this wave originated from 180°N and would have been unlikely to have directly impacted the coastline at the Burrow. As discussed previously the succession of wave events in early to mid-March all originated from the easterly sector and would have therefore propagated directly towards the coastline at the Burrow to result in very energetic inshore wave conditions.

Figure 3.2 below illustrates all of the offshore wave data at the M2 wave buoy between 1996 and 2018. It can be seen from this figure there has been a notable upward trend in the magnitude and frequency of extreme wave events, particularly within the last decade. It also appears that there is an increased frequency of extreme events.

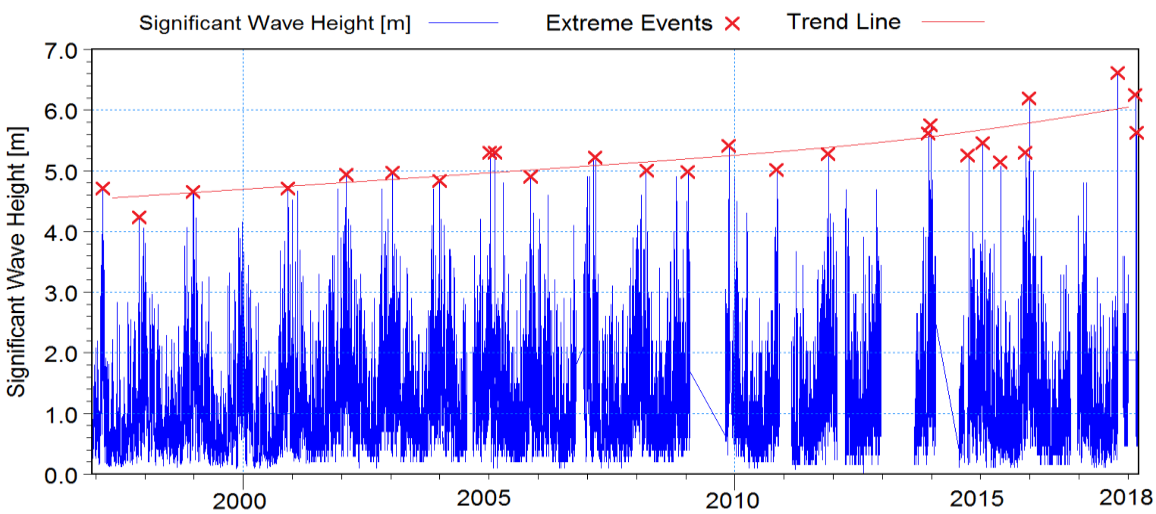

Figure 3.2: Significant wave heights from all wave directions at the M2 buoy between 1996 and 2018.

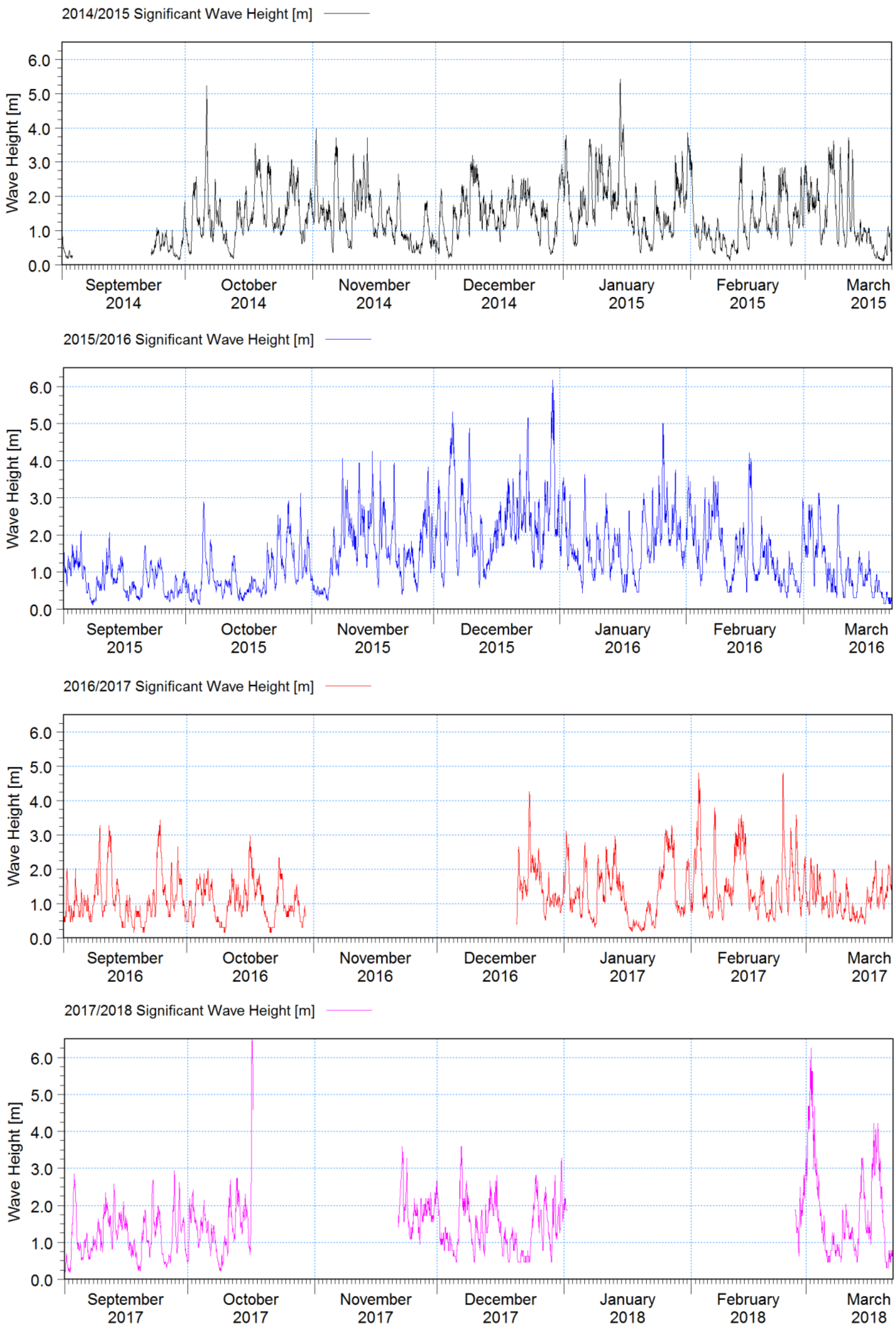

Figure 3.3: Winter wave climate at the M2 buoy from 2014/2015 to 2017/2018.

3.2 EVIDENCE OF CLIMATE CHANGE

In the recent years since RPS issued the Coastal Erosion Risk Management Study for Portrane in 2013 both Ireland and the UK have experienced a succession of extreme weather events that when considered together as a group point towards an accelerated change in the current climate. Some evidence of this acceleration in climate change includes but is not limited to the following:

- Ex-hurricane Ophelia that hit Ireland in late 2017 was only downgraded from a hurricane to an extra-tropical cyclone just some hours before it made landfall. Historical records only show one hurricane reaching Ireland whilst still at hurricane strength: Hurricane Debbie in 1961.
- Storm Emma in early 2018 seen exceptionally high wave energy events from the east couple with significant surge activity to result in some of the most arduous conditions experienced along the east coast of Ireland and the UK. The significant wave height recorded at the M2 buoy during this event was 35% greater than the next greatest easterly wave recorded by the buoy.
- A notable increase in the frequency and magnitude of extreme storm events since 2013 (see Figure 3.2);
- An analysis of the extreme offshore conditions (see Section 3.4) indicated that extreme offshore wave heights increased by *c.*14% between 2013 to present.

3.3 IMPACT OF CLIMATE CHANGE

As discussed above it is highly likely that the change in the offshore wave conditions observed at the M2 buoy is a direct result of climate change. Furthermore, the changes observed are actually in line with numerous predictions that were outlined in the fifth assessment report on climate change which was issued by the Intergovernmental Panel on Climate Change (IPCC 2014). The main predicted changes in this report that relate to the coastal environment include:

- An increased frequency of more extreme storms and cyclones in the 21st Century
- A likely strengthening in future cyclones caused by increased sea surface temperatures. This is expected to result in more intense events with higher wind speeds and heavier rainfall.
- Some regions are likely to experience an increase in average wind speed throughout the year caused by stronger prevailing winds.

Other studies aside from the IPCC have also investigated the potential impact of future climate change. Some of the main findings from a selection of these relevant studies are presented below.

- It is expected that the effect of just a 10% increase in wind speeds in the coastal environment results in an order of magnitude increase in other coastal processes. A 10% increase in wind speed is predicted to result in about a 26% increase in wave heights
    - This could potentially increase longshore sediment transport rates by between 40% and 100% (Theron, 2007).
    - These impacts could affect shorelines in areas previously weakened by erosion such as the Burrow at Portrane

- Hurricanes from the Atlantic are much more likely to be supported and sustained by the warmer seas. This will mean that future tropical cyclones are more prone to hit Western Europe, and will do so earlier in the season, thereby increasing the frequency and impact of hurricane force winds. (Haarsma *et al.,* 2013).

- Evidence indicates that severe tropical cyclone type storms will become more common across western Europe during early autumn and that many of these storms may re-intensify to become hurricanes as they approach Europe. (Baatesen *et al,.* 2015)

- The UKCP09 Sea level rise projections are likely to be increased by up to 20% based on an updated analysis as part of the UKCP18 project thus indicating climate change is occurring much more rapidly than initially anticipated.

- By the end of this century, a 100-year coastal flood event could become an annual risk under high-end warming. (Vousdoukas *et al*., 2017)

In general, the overwhelming consensus of the recent scientific literature is that climate change is occurring much more rapidly than initially anticipated in some of the early IPCC reports. Furthermore, the majority of these studies indicate the effects of climate change will increase the frequency and magnitude of extreme coastal conditions and will thus have a detrimental impact on many coastal communities.

The impact of climate change on the extreme offshore wave climate at Portrane is discussed in more detail in Section 3.4 overleaf.

3.4 EXTREME EVENT ANALYSIS

To assess the change in the wave climate since the Coastal Erosion Risk Management study originally undertaken in 2013 and present, RPS undertook an extreme event analysis (EVA) of the offshore wave dataset for the easterly sector and all wave directions (omni-directional) for the period between 1996 – 2013 and 1996 – 2018. This dataset was five years longer than the original dataset and contained significantly more extreme wave and storm events than the dataset that was available for the 2013 study.

The EVA was performed by fitting a theoretical probability distribution to the dataset and using a peak over threshold model to select the largest events. A Truncated Gumbel probability distribution was then fitted to the dataset using a Jackknife re-sampling technique to derive a series of return period waves heights for the east sector for the two time periods.

The output from this analysis is illustrated in Figure 3.4 and Figure 3.5 overleaf for the periods between 1996 – 2013 and 1996 – 2018 and summarised in Table 3.3 and Table 3.4 below. It will be seen that based on this analysis a 1 in 200 year return period event from the easterly sector increased by *c.*10% between 2013 and 2018 from *c.*5.99m to *c.*6.61m. These results indicate that a 1 in 200 year return period event increased by *c.* 14%.

Using this information is was found that Storm Emma could have equated to a *c.* 1 in 125 year event.

Table 3.3: Extreme Easterly significant wave heights between 1996 – 2013 and 1996 – 2018 at the M2 buoy.

Return Period [Years]	Significant Wave Height [m]	
	1996-2013	1996 - 2018
2	2.74	3.38
5	3.49	4.13
10	3.98	4.62
20	4.46	5.09
50	5.07	5.70
100	5.53	6.15
200	5.99	6.61

Table 3.4: Extreme Omni-Directional significant wave heights between 1996 – 2013 and 1996 – 2018 at the M2 buoy.

Return Period [Years]	Significant Wave Height [m]	
	1996-2013	1996 - 2018
2	4.66	5.14
5	5.22	5.82
10	5.59	6.27
20	5.59	6.71
50	5.94	7.26
100	6.40	7.68
200	7.08	8.10

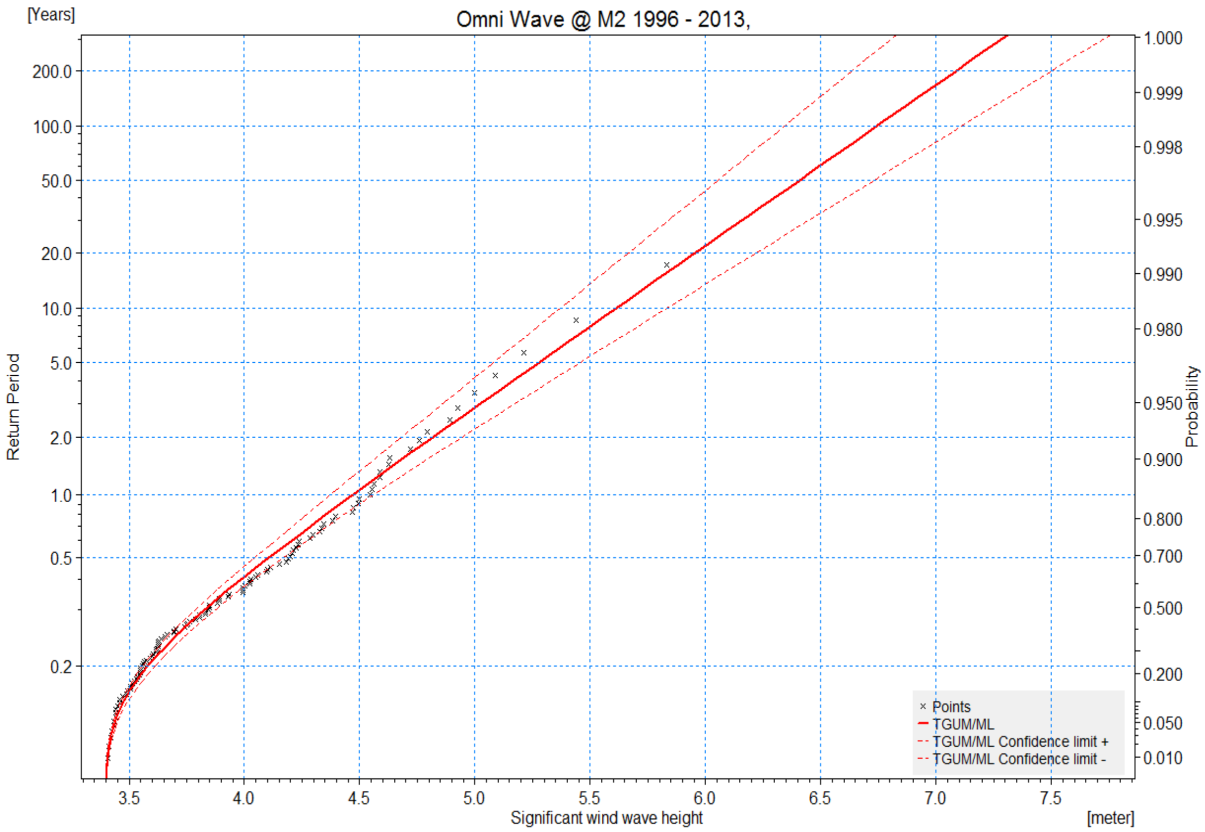

Figure 3.4: Extreme event analysis of offshore waves from all directions between 1996 and 2013.

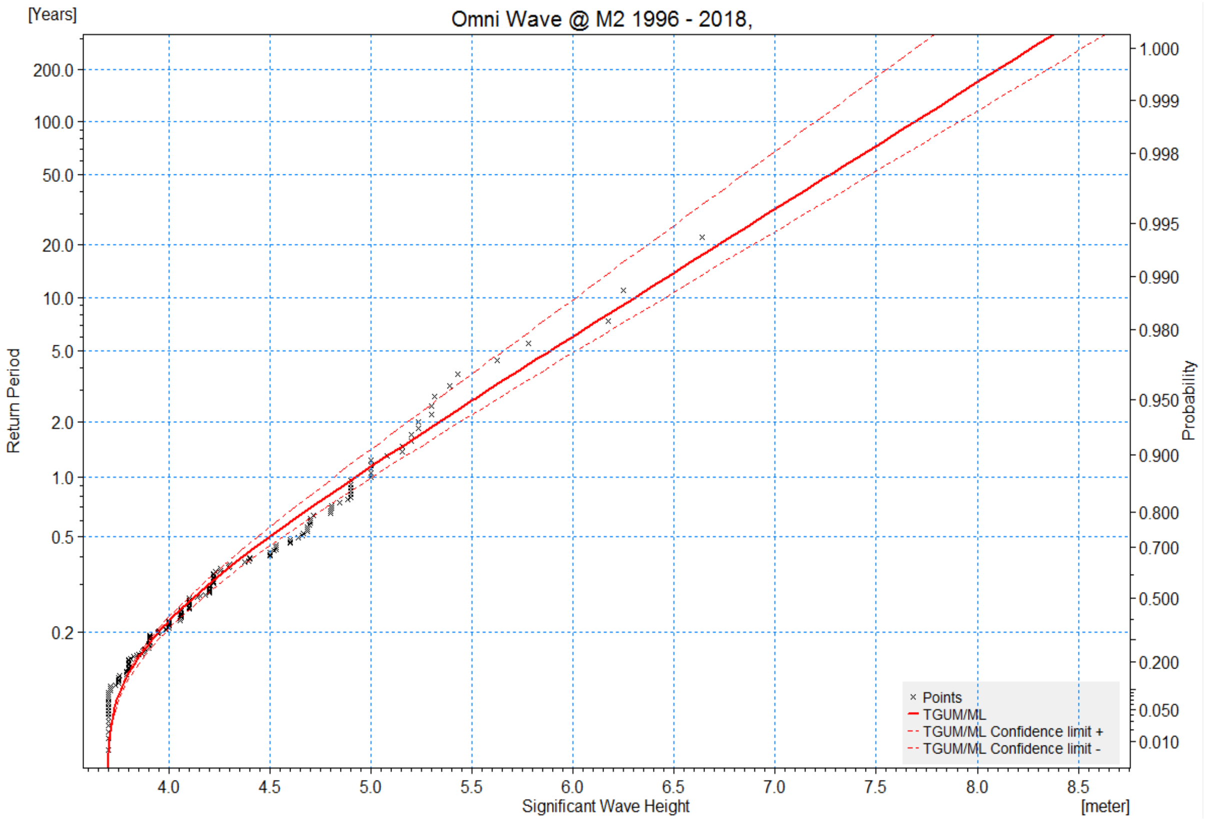

Figure 3.5: Extreme event analysis of offshore waves from all directions between 1996 and 2018.

3.5 JOINT PROBABILITY ANALYSIS

As an extreme offshore wave event may occur at low water and therefore result in much less severe inshore conditions it is important to consider the joint probability return period of an event, i.e. the probability of an extreme wave event occurring simultaneously with an extreme high tide. Therefore to fully characterise Storm Emma and the subsequent succession of smaller events RPS undertook a joint probability analysis of the offshore wave heights recorded at the M2 wave buoy & the inshore water levels recorded at the Howth tide gauge.

The joint probability analysis was undertaken using the procedures and techniques recommended in the DEFRA/EA report FD2308, "Joint Probability: Dependence Mapping and Best Practice". The correlation factors between wave heights & water levels used for this analysis were based on the research and analysis undertaken by RPS for the ICPSS which established the correlation factors for waves with water levels along the east coast of Ireland as 0.25 for storms from the east sector. The results from this analysis are presented in Table 3.5 below and Figure 3.6 overleaf.

Table 3.5: Joint Exceedance vales for waves and water levels for the Easterly Sector.

Value of first variable: Water Level (MSL) - Portane (ICPSS pt. 15)	Joint exceedence return period (years)							
	2	5	10	20	50	100	200	1000
	Value of second variable: Significant Wave Height (m)							
1.92	2.45	3.23	3.82	4.36	5.06	5.53	5.99	7.05
2.03	1.96	2.68	3.31	3.89	4.59	5.12	5.63	6.83
2.15	1.24	2.04	2.59	3.19	3.97	4.50	5.03	6.23
2.25	0.73	1.51	2.11	2.65	3.47	4.03	4.56	5.77
2.36	0.25	0.96	1.59	2.17	2.91	3.54	4.09	5.31
2.48	-	0.33	0.87	1.48	2.25	2.80	3.43	4.70
2.58	-	-	0.39	0.93	1.75	2.31	2.87	4.23
2.69	-	-	-	0.45	1.19	1.82	2.37	3.75
2.81	-	-	-	-	0.53	1.08	1.72	3.04
2.91	-	-	-	-	0.06	0.59	1.15	2.51
3.01	-	-	-	-	-	0.12	0.65	2.03
3.14	-	-	-	-	-	-	0.03	1.32
3.24	-	-	-	-	-	-	-	0.80
3.33	-	-	-	-	-	-	-	0.32
3.56	-	-	-	-	-	-	-	0.00

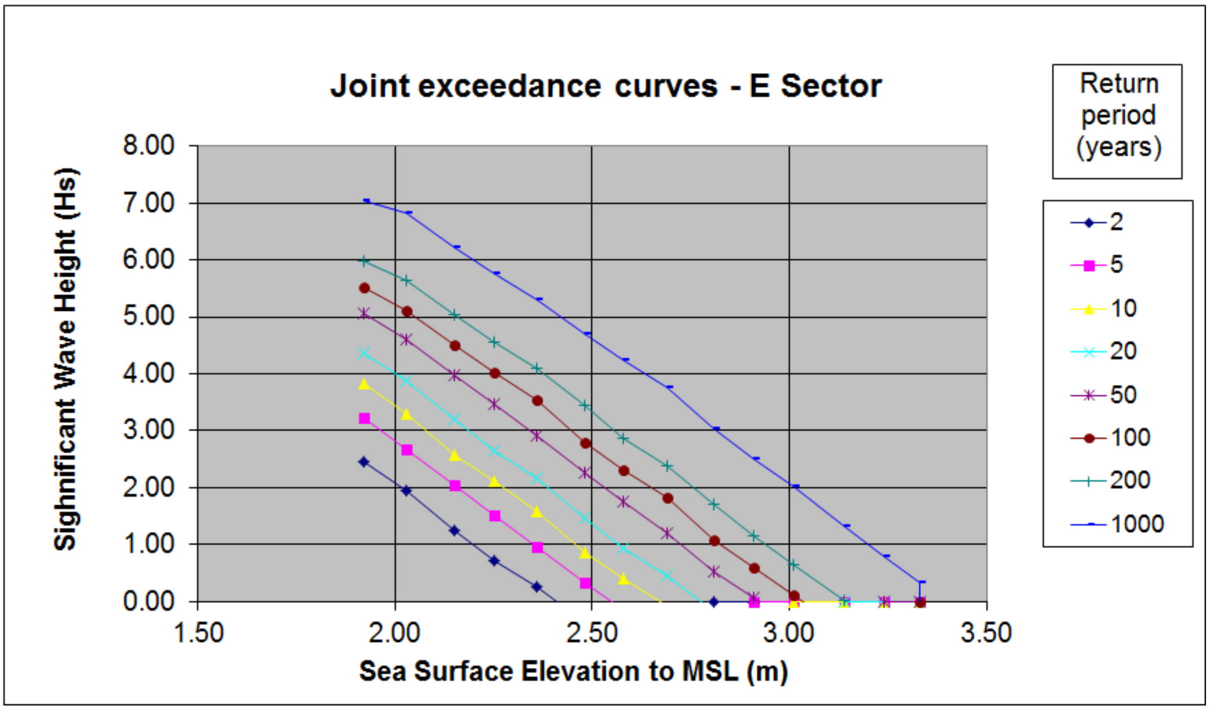

Figure 3.6: Joint Exceedance curves for waves and water levels for the Easterly Sector.

Wave parameters recorded at the M2 buoy during Storm Emma and the succession of smaller events together with the corresponding tide levels as recorded by the Howth tide gauge are illustrated in Figure 3.7 overleaf. It may be seen from this figure that the peak wave event of 6.25m actually occurred just after low water and thus had a very low joint probability return period. If this event had corresponded with the next high tide it would have had a joint probability return period of *c.* 1 in 200 years. However approximately 6 hours later a high spring tide of 2.09m coincided with a significant wave height of 4.84m to result in a joint probability return period event of *c*. 1 in 75 years.

The wave events which followed in mid-March occurred during standard spring tides and thus could not be analysed using the Joint Probability output which is based on extreme water levels.

Furthermore it should be noted that as the beach levels at Portrane have been significantly depleted of sediment material together with the fact that the beaches in this area are particularly flat, even minor storm waves that occur during standard high tides have the potential to cause notable erosion along the Burrow at Portrane.

Finally, an analyses of the inshore wave climate using the MIKE 21 Spectral Wave model has demonstrated that owing to the depth limited nature of the incident waves at this site, the waves that can be expected along the frontage of the Burrow during 1 in 200 return period events do not differ significantly to those during 1 in 50 year events. That is to say that it is reasonable to expect similar size waves to attack the dune system at the Burrow during a range of return period conditions.

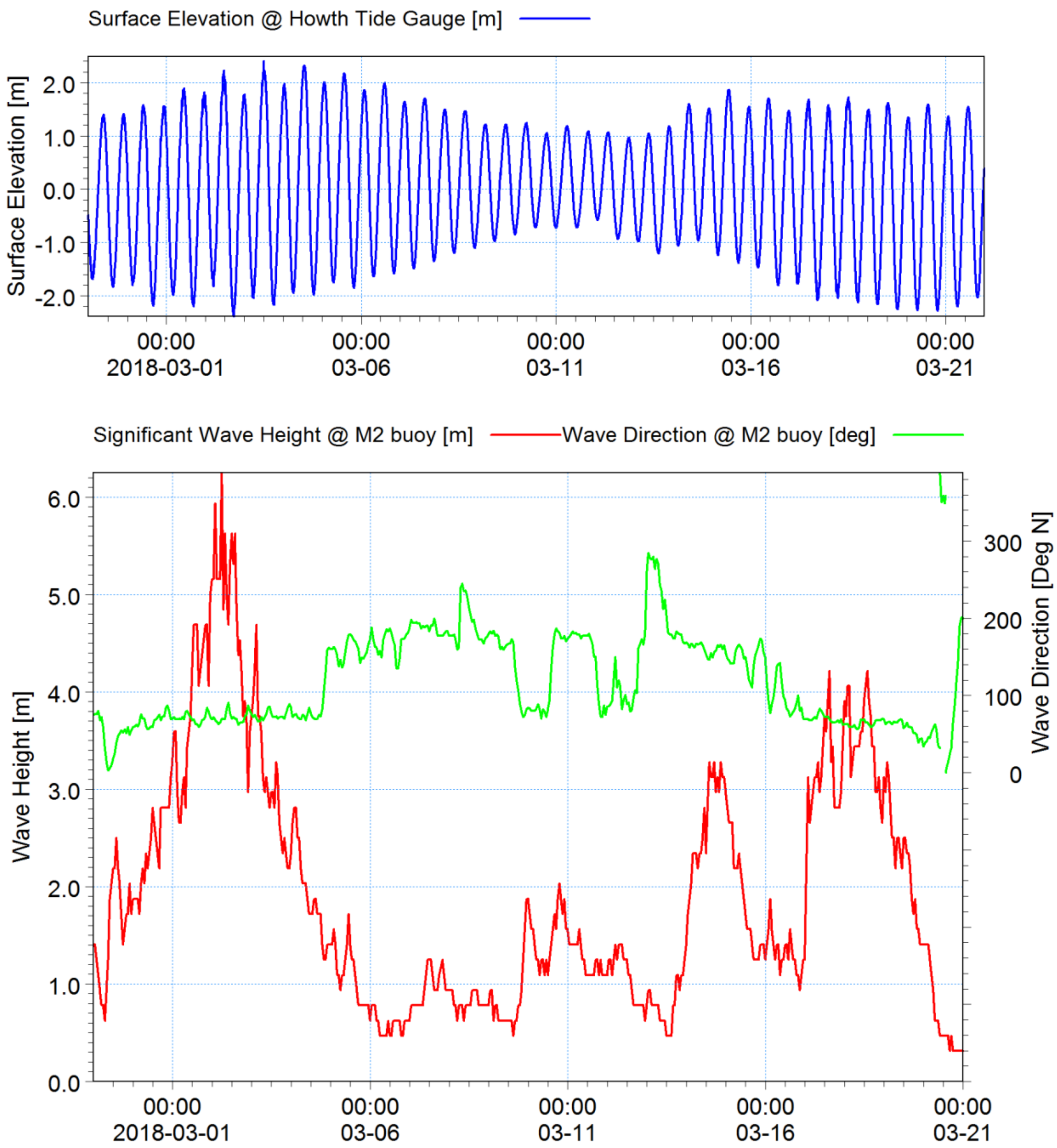

Figure 3.7: Wave climate at M2 buoy and water levels at Howth tide gauge during storm Emma.

4 EXTENT OF THE RECENT COASTAL EROSION

In April 2018 RPS gathered aerial drone footage to assess the damage to the dune system along the Burrow following the storm events of early 2018. Photogrammetric techniques were also used to create up-to-date geo-referenced orthophotography of the study area and to estimate the vertical level of the beach and the dune system.

It will be seen from Figure 4.1 to Figure 4.6 that the majority of the southern extent along the Burrow was significantly affected by coastal erosion during this period. It is believed that the seaward sandbags that can be seen in Figure 4.1 and Figure 4.3 represents where the toe of the dune would have been prior to these extreme storm events. The extent and magnitude of the erosion during this succession of extreme storm events was such that Residential property D discussed in Section 2 can be seen right on the edge of the over-steepened dune face. Based upon the site visit in 2018, it was estimated that the corner of this property is actually less than 0.5m from the edge of the dune and is therefore in imminent danger of structural failure. As can be seen from Figure 4.2 the boundary of the neighbouring property, residential property E, is also dangerously close to the edge of the dune.

The fact that the magnitude of erosion gradually reduces the further north along the Burrow indicates that much of this recent erosion could be attributed directly to easterly & north easterly storm events. This can be seen in Figure 4.6 which illustrates erosion along the southern extent of the Burrow in relation to the last geo-referenced position of the vegetation line in 2013.

It will be seen from Figure 4.6 that the coastline in this area has already retreated by approximately 10m which is halfway towards the erosion line projected for the 2100 MRFS climate change scenario and has in localised regions exceeded this area. The extent of erosion at three representative chainages between 2008 and 2018 is illustrated in Figure 4.7.

Figure 4.1: Residential property D is now perched on the edge an over-steepened dune.

Figure 4.2: The severely eroded dune system and debris in front of residential property E.

Figure 4.3: Extent and magnitude of dune erosion along the mid section of the Burrow.

Figure 4.4 Extent and magnitude of dune erosion along the mid-section of the Burrow – looking north.

Figure 4.5: Aerial view of the threatened residential properties along the southern section of the Burrow.

Figure 4.6: The 2018 and 2013 vegetation line in relation to the 2100 MRFS & HEFS vegetation line.

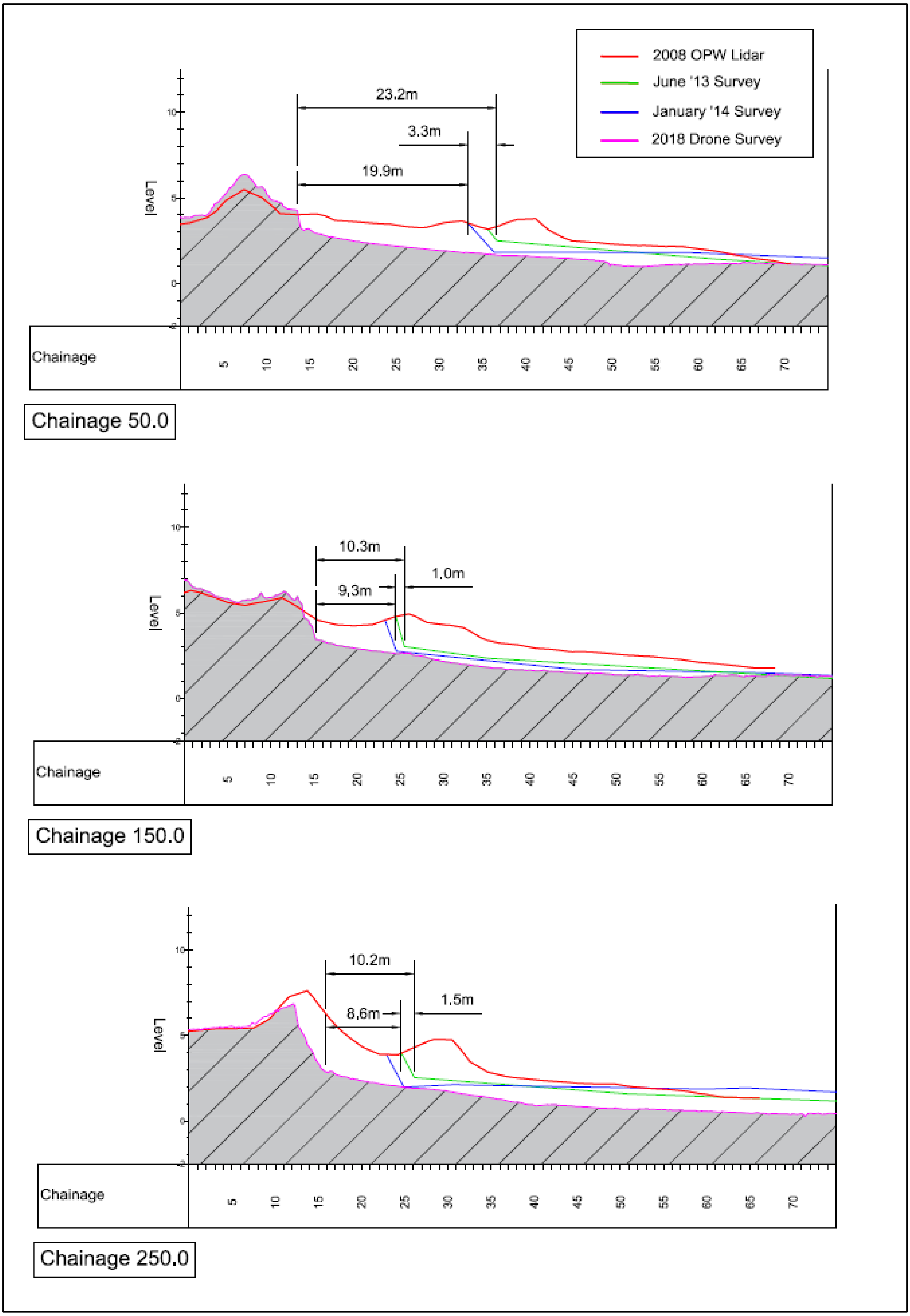

Figure 4.7: Extent of erosion between 2008 – 2018 at representative chainages 50m, 150m and 250m.

5 ASSESSMENT OF FUTURE COASTAL EROSION

5.1 SPECTRAL WAVE MODELLING

RPS used the updated offshore wave information that was derived as part of the Extreme Event Analysis and the Joint Probability Analysis detailed in Sections 3.4 and 3.5 to develop offshore boundary conditions for a series of joint probability return period events. RPS then used these boundary conditions in conjunction with the MIKE 21 Spectral Wave model to derive the inshore wave climate at Portrane for extreme storms with return periods ranging from 1 in 10 to 1 in 200 years. Representative outputs from these simulations are presented in Figure 5.1 and Figure 5.2 for the joint 1 in 50 and 1 in 200 return period scenarios respectively.

It will be seen from these Figures that despite notably different offshore wave conditions for each return period event, the inshore wave conditions across much of beach at Portrane are relatively similar under each set of conditions. This can be attributed to the fact that much of the incident waves that approach the Burrow are in fact depth limited. Thus, it should be noted that any decrease in beach levels or increase in water levels are likely to have a significant impact on the magnitude of waves that can impact the dune system along the Burrow.

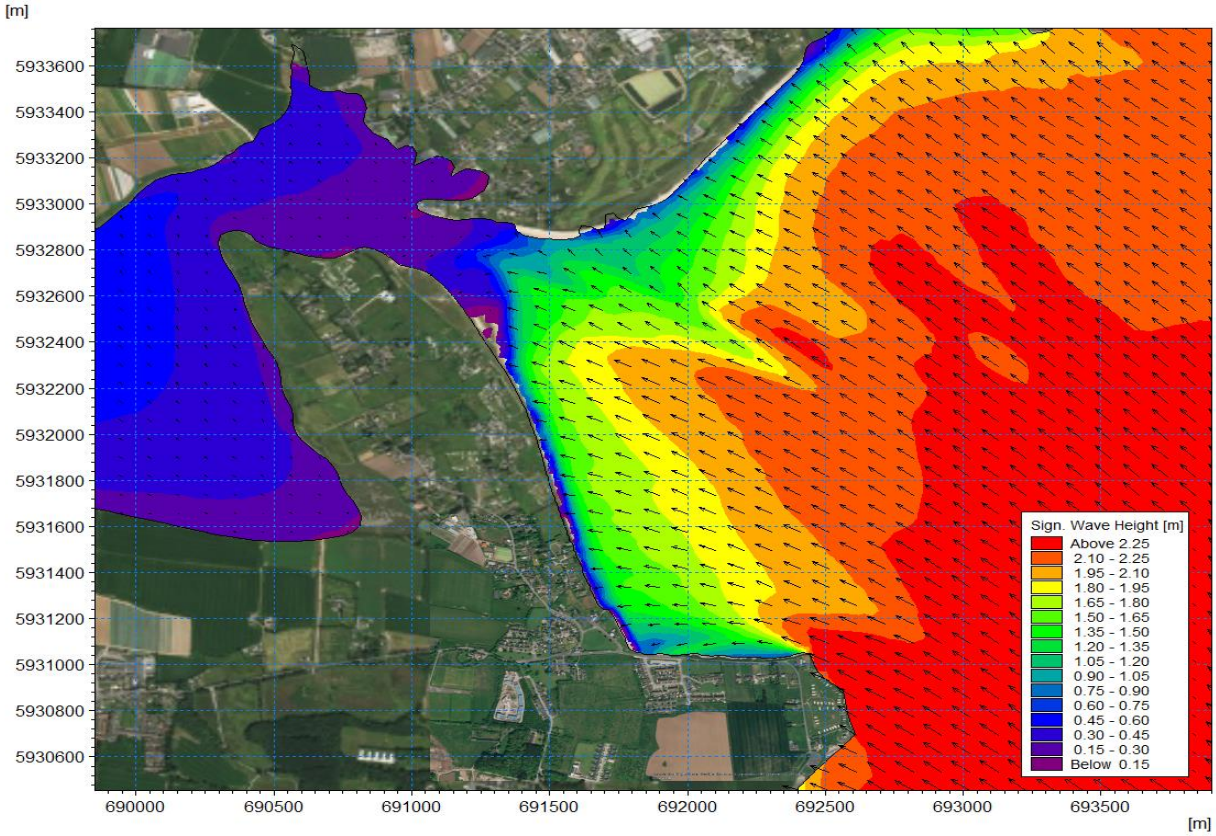

Figure 5.1: Significant wave height and mean wave direction during a joint probability 1 in 50 year return period storm event from the South East.

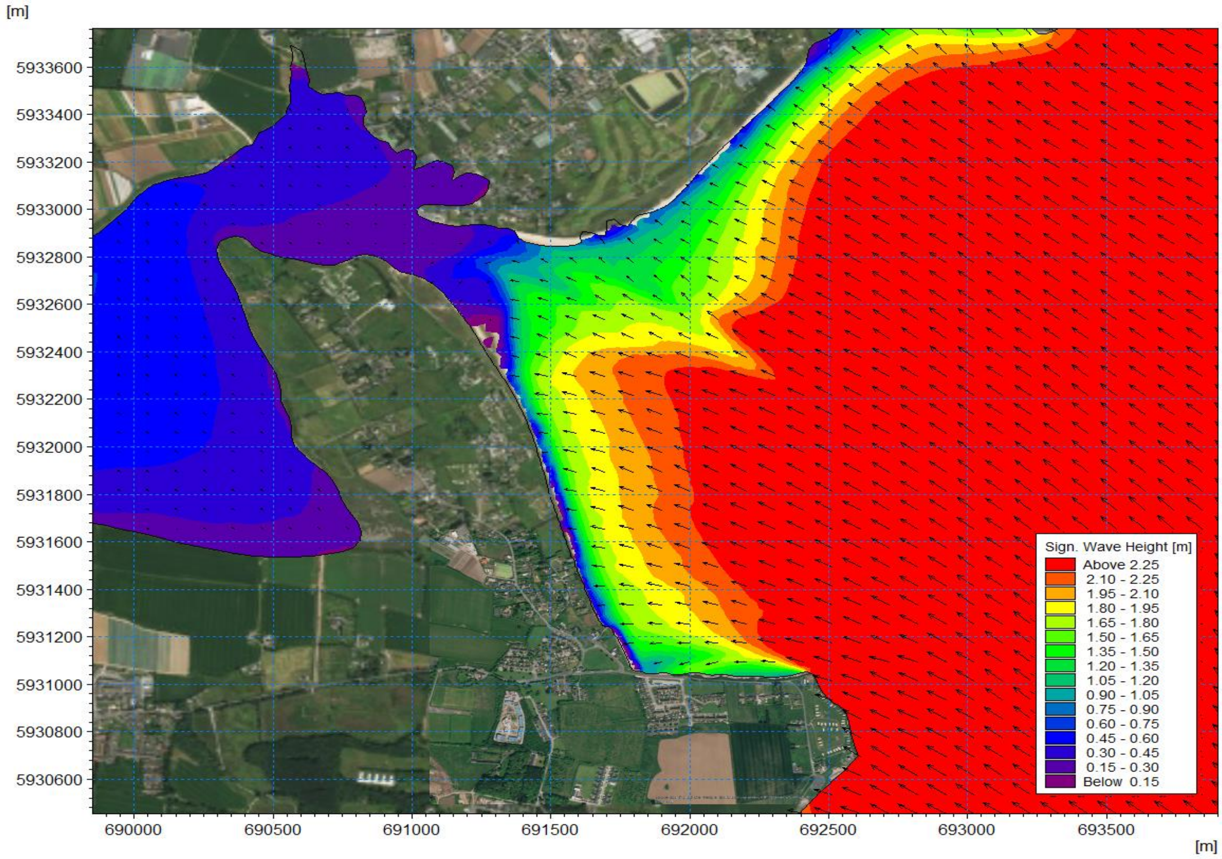

Figure 5.2: Significant wave height and mean wave direction during a joint probability 1 in 200 year return period storm event from the South East.

5.2 MORHPLOGICAL MODELLING

Using results from the spectral wave modelling detailed in the previous Section, RPS have undertaken an analysis of the morphological response of the dune system along the Burrow over a 100 year period. This morphological modelling also accounted for the effect of climate change by including a Sea Level Rise of +0.75m which is halfway between the OPW's recommended guidelines for the Medium Range Future Scenario (MRFS) and High End Future Scenario (HEFS) whereby sea level is expected to rise by +0.50m and +1.00m respectively.

The morphological modelling of the beach and dune erosion was undertaken using the XBeach model which was developed by Deltares, an independent institute for applied research in the field of water and subsurface. XBeach is a 2D morphological model developed to assess the natural response to time-varying storm conditions, including dune erosion, over wash and breaching. The model computes the propagation of waves, the non-stationary shallow water equations, sediment transport and bed update. XBeach also uses avalanching to compute dune erosion and cross-shore transport.

XBeach has been validated with a series of analytical, laboratory and field test cases showing toperform well in different situations including dune erosion, over wash and breaching, modelled using a standard set of parameter settings. More detail about this modelling system can be found in the XBeach manual (Roelvink *et al.,* 2009). For the purposes of this study, the XBeach morphological model was calibrated using data from the M2 Wave Buoy for Storm Emma and the corresponding extent of coastal retreat that was estimated to have occurred as a result of this particular event.

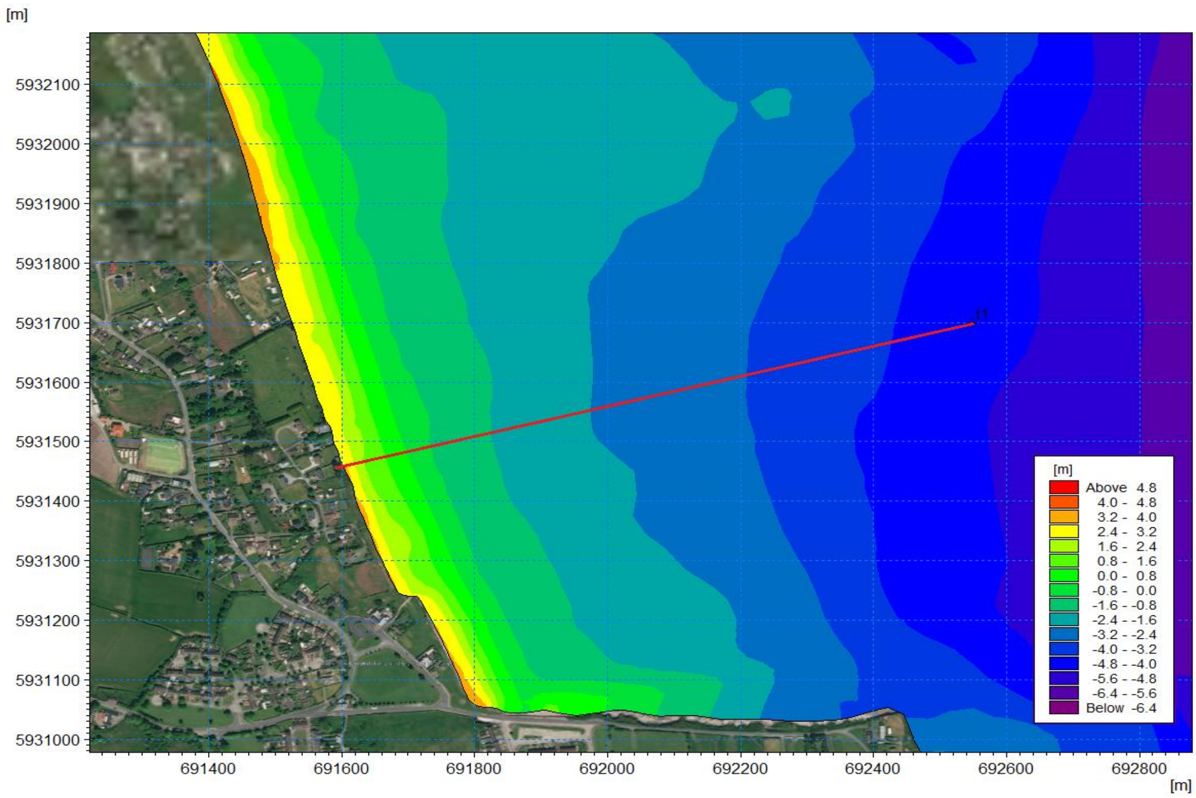

Figure 5.3: Location of the typical cross section profile that was constructed from the 2018 model bathymetry and used in the XBeach morphological modelling simulations.

5.3 MODELLING APPROACH

In order to estimate the extent of coastal erosion along the Burrow over the next 100 years it was necessary to construct a pseudo combination of storm events that are statistically likely to occur over this period. For example, during a 100 year period it is reasonable to expect one 1 in 100 year storm event, two 1 in 50 year events, five 1 in 20 year events and so on. For the purposes of this modelling exercise, RPS randomly arranged the following combination of extreme wave events with each extreme storm event lasting for approximately 3 days:

- 10x 1 in 10 year events
- 5x 1 in 20 year events
- 2x 1 in 50 year events
- 1x 1 in 100 year events
- 1x 1 in 200 year events

Due to the computationally demanding nature of the XBeach modelling system RPS only simulated extreme storm events that would result in erosive conditions at the shoreline and excluded calm conditions that would be typical of summer months during which the beach would gradually accrete sediment and facilitate the recovery of the dune system. Therefore to offset this natural recovery RPS did not include any extreme storm event that had a return period of less than 1 in 10 years in the morphological modelling assessment.

As it is not possible to predict the exact number, magnitude and order of extreme storm events that will occur over the next 100 years, this approach of using a random combination of the above extreme events was considered the most suitable method to estimate the potential extent of coastal erosion by 2118. As such, it should be noted that the actual extent and rate of erosion by 2118 will be subject to prevailing weather conditions and future climate change and could therefore differ significantly to the findings presented in this report.

5.4 EROSION MODELLING RESULTS

Using XBeach to model two individual extreme events in order to calibrate the modelling system it was found that:

- The face of the dune across the 2018 beach profile could retreat by *c.* 8.5m and 12.2m during a 1 in 50 and 1 in 200 year joint probability event respectively.

Using XBeach to assess and quantify the extent of erosion in response to a pseudo combination of extreme storm events that could be statistically expected to occur over a 100 year period it was found that:

- The existing vegetation line could retreat landward at a rate of ≥ 0.86m per year.
- Based on this rate of retreat, the existing vegetation line could be expected to retreat by ≥ 86m.
- Under this scenario which accounted for climate change by including a sea level rise of +0.75m, approximately ≥ 52 properties could be immediate risk from coastal erosion.

A commonly used method to estimate shoreline retreat along relatively flat sandy beach areas like Portrane is the Bruun Rule (Bruun, 1962) which relates the slope of an active coastal profile to the expected future sea level rise. Using this approach for Portrane whereby the beach is at a relatively flat slope of at *c.* 1 in 80, it can be estimated that for a sea level rise of *c.* +0.75m, the shoreline at Portrane could be expected to retreat by approximately 60m (i.e. +0.75 / (1/80)) by 2118. This calculation is considered to be comparable with the findings from the XBeach modelling assessment.

The evolution of the dune profile that was modelled over a 100 year period using the XBeach system is illustrated in Figure 5.4 below. The estimated extent of erosion by 2118 and the properties at risk along the Burrow is illustrated in Figure 5.5 overleaf.

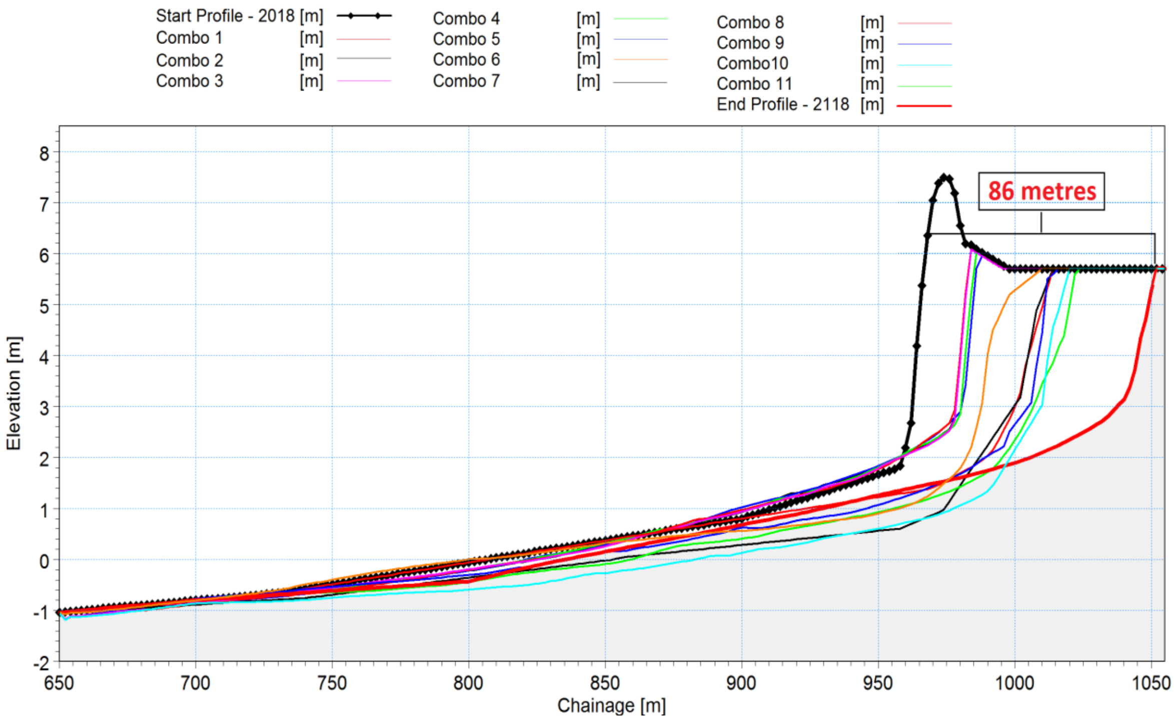

Figure 5.4: The evolution of the beach dune profile at Portrane following the first 11 storm combination events and the final position of the profile by 2118.

Figure 5.5: Extent of coastal erosion and properties at risk along the Burrow by 2118.

6 COASTAL FLOODING & EROSION RISK MANAGEMENT OPTIONS

6.1 BACKGROUND

In the previous Section of this report it was demonstrated that, subject to future climate change and prevailing weather conditions, the existing dune system along the Burrow could retreat by a further *c.*86m by 2118 thus placing up to 52 properties at risk from erosion. It is therefore imperative that Fingal County Council develop a sustainable and effective Coastal Flooding and Erosion Risk Management (CFERM) option in partnership with all relevant stakeholders without delay.

In other regions affected by coastal erosion and/or flooding, commonly adopted CFERM options can include:

- **Do Nothing:** Under this scenario the relevant authority commits no further investment to either flooding or erosion protection works, regardless if any defences or commitments have existed previously.

- **Hold the Line:** This option involves building or maintaining existing defences to maintain the position of the shoreline in order to protect the assets in the hinterland. The method or type of defence may change throughout the lifetime of this option in order to achieve this result.

- **Managed realignment:** As opposed to working against nature, this option involves working with nature by managing coastal processes in certain areas and providing the coastline enough space to dynamically respond to prevailing weather conditions and/or climate change. This policy often involves relocating important assets and/or rebuilding important infrastructure. In circumstances whereby private residential property is affected it may be necessary for relevant authorities to institute relocation and/or buy-back programs to help with relocation costs or compensate property owners when their property becomes uninhabitable.

  Whilst the overall emphasis of this policy promotes retreat, soft engineering techniques such as dune stabilisation and sand trap fencing etc. may also be used to manage the realignment for a limited period of time when appropriate. However, hard engineering techniques such as the construction of revetment structures or repeated beach renourishment campaigns are generally not permitted.

Each of these options in context of the threat of coastal erosion at Portrane and the Burrow are described in further detail in the following Section of this report.

6.2 HOLD THE LINE

Given the nature of the acute erosion at Portrane whereby the shoreline can retreat by a significant distances during a single storm event it unlikely that any measures other than hard engineering techniques would provide the required level of protection against future coastal erosion over the next 100 years.

Some of the most common hard defence options that can be used to manage coastal erosion include:

- Seawalls
- Revetments
- Groynes
- Detached breakwaters
- Headlands/modified breakwaters

Based on RPS' specialist knowledge of coastal engineering and experience of the issues faced at Portrane, the two most feasible of these options from a financial, technical and environmental perspective is the revetment option and modified groyne together with a beach renourishment option. Both of these options are discussed in more detail below.

6.2.1 Hold the Line Option 1 – Revetment Structure

Revetment structures are sloping structures designed to absorb wave energy, reduce wave reflection and run up. Most often revetments are constructed using appropriately sized rock armour; however specialised concrete blocks such as ECAB units can also be used as an effective alternative. In both instances, the units/rock comprising the revetment are relatively large, with the weight being determined by the incident wave regime and are usually built with at least one primary layer placed on top of a graded under layer. The toe of the armour will usually extend *c.*1m beyond the lowest recorded beach level whilst the crest is usually constructed well above the mean high water spring tide level.

When designed and constructed correctly revetment structures are considered to be extremely effective in absorbing wave energy and thus managing the threat of coastal erosion. In most instances revetments are considered relatively cheap solutions due to the availability of rock. Revetment structures are also much more flexible than other defences such as sea walls as they can be modified when affected by factors such as sea level rise as a result of climate change.

As revetment structures are most commonly constructed in front of dune systems they can interfere with and disrupt the natural beach-dune interaction and thereby reduce the amount of sand material available for natural beach recovery following arduous storm events. Over the long-term, this can result in a "coastal squeeze" whereby the width of the beach is reduced, thus facilitating the propagation of larger, more energetic waves closer inshore.

Based on an assessment of the coastal erosion threat along the Burrow, it was found that if revetment structures were used to Hold the Line at Portrane, approximately 1250m of the shoreline would need to be protected by a suitably designed revetment structure. Based on cost estimates for various coastal protection structures as prepared by the Environment Agency (2015), it is envisaged that this structure would cost approximately €3-4million euros to construct.

Based on this high level assessment of potential options, the extent of revetment structure that would likely be needed to mitigate the risk of erosion and Hold the Line at Portrane is presented in Figure 6.1 overleaf. The actual extent and design of this revetment structure would be subject to further detailed design.

It should be noted that as sea levels continue to rise and the frequency & magnitude of extreme storm events increase due to climate change, it may be necessary to consolidate the toe and crest of the revetment structure after a period of *c*. 50 years. Furthermore, depending on future climate change and the prevailing weather conditions, it may be necessary to adopt an alternative CFERM option such as managed retreat or Long-term Withdrawal; both of these options are discussed in further detail in the following Sections of this report.

Figure 6.1: Layout and extent of a typical revetment structure (shown in green) that could be constructed along the Burrow to protect against erosion.

6.2.2 Hold the Line Option 2 – Fish tail groynes and beach renourishment

An alternative option that could be implemented to Hold the Line along the Burrow would involve constructing a series of beach control structures such as rock armour fish-tail groynes and renourishing the upper beach profile with suitable material.

Shore attached fish-tail groynes are used extensively throughout the UK and the rest of Europe and are highly effective in reducing both the cross-shore and longshore elements of a sediment transport regime. Therefore, given that significant volumes of beach material can be removed from the beach at Portrane during extreme storm events via cross-shore transport, whilst smaller more continuous volumes are lost to the longshore transport during regular conditions, fish-tail groynes are considered to be a particularly effective option for Portrane. Furthermore, the “fish-tail” section of these groyne structures would act as partial nearshore breakwaters, thus dissipating a portion of the incident wave energy and reducing erosion along the shoreline.

By following the construction of these groynes with a beach renourishment campaign it would be possible to increase the effectiveness of the existing dune system which acts as a natural buffer against incident wave energy. Renourishing the upper beach profile would also reduce available water depths and limit the size of incident waves.

Unlike revetment structures, fish-tail groynes do not completely cut off the natural beach dune interaction and still allow the dune system to feed sand onto the beach following arduous storm activity. From this perspective, fish-tail groynes are considered more sustainable than revetment structures. Furthermore, under the right conditions fish-tail groynes may retain or actually facilitate the creation of embryo dune or salt marsh habitat.

In order to provide effective protection against future coastal erosion it is envisaged that approximately four shore connected fish-tail groynes 150m in length should be constructed at 300m spacing’s along the southern and mid-section of the Burrow. Each of these groyne structures would be constructed using suitably sized rock armour and would be finished with a 75m “tail” that would splay approximately 135^{o}. The construction of these groynes would then be followed by renourishing the beach with *c.*250,000m^3 of material to increase the height of the beach profile along the southern and mid-section of the Burrow by up to 2.5m.

Preliminary estimates indicate that this option would cost approximately €4.5 - 5.5 million to construct the fish tail groynes and a further €1 million to renourish the upper beach profile. Thus this option would cost approximately €5.5 – 6.5m million in total, subject to detailed design and the availability of renourishment material. A high level indication of this scheme is illustrated in Figure 6.2 overleaf.

As this option is not only designed to mitigate the threat of erosion, but also to retain sediment and encourage deposition along the upper beach profile, this option is likely to be much more technically effective in maintaining beach levels over the long-term (subject to prevailing weather conditions). If this CFERM policy is adopted, relevant authorities should be prepared to commit to at least three future maintenance nourishment campaigns to maintain beach levels and the dune system at Portrane. The source of re-nourishment material would be the subject of a more detailed study; however it may be possible to recycle dredge material from maintenance dredging applications which are regularly submitted to the Environmental Protection Agency (EPA).

Figure 6.2: Layout and extent of a series of fish-tail groynes and beach renourishment areas that could be implemented along the Burrow to protect against erosion.

6.3 MANAGED RE-ALIGNMENT

Managed realignment generally involves setting back the line of the existing vegetation line or dune system to a new position inland. This policy allows the shoreline to dynamically respond to the prevailing weather conditions, coastal processes and climate change without the intervention of expensive hard engineering options. However, as the existing shoreline erodes it may be necessary to demolish or relocate existing property or infrastructure. In some circumstances, adopting a policy of managed realignment can promote the creation of intertidal habitat which if managed correctly can be highly effective at attenuating incident wave energy and reducing erosion.

From an environmental and financial perspective, managed realignment is often considered to be a more sustainable option relative to Hold the Line as this option can facilitate the creation of new habitat and reduce impacts to the existing natural environment. However it should be noted that most examples of managed realignment throughout the UK have been developed and implemented primarily to manage the risk of coastal flooding as opposed to erosion. This is a particularly relevant point for the Burrow which is a dynamic sand spit of finite width.

In most instances, managed re-alignment is implemented at sites that are not constrained by the availability of land or space in the hinterland. It is therefore important to acknowledge that adopting a policy of managed realignment for the Burrow would essentially only delay the existing issue of coastal erosion for future generations and that the relevant authorities would eventually have to decide whether to adopt an alternative, more sustainable long term CFERM option.

At Portrane it would be possible to manage the re-alignment along the Burrow by constructing buried longstops to protect key assets or infrastructure. This would effectively create a coastal buffer and give the relevant authorities time to develop a longer term strategy.

The cost of implementing this policy would depend on the number of assets or infrastructure considered critical and would therefore be subject to a detailed analysis which is beyond the scope of this report. However, it is envisaged that the cost of a buried long stop could range between €2,000 and €3,500 per metre, subject to further detailed design.

6.4 LONG-TERM WITHDRAWAL FROM THE BURROW

This option would involve actively planning to withdraw from the Burrow over the long term and allowing the dune system and beach area to respond naturally to the prevailing weather conditions and future climate change. In order not to exacerbate the existing issues it would be imperative to prevent further development along the Burrow area.

Importantly, this option would involve no active intervention to mitigate the threat of coastal erosion and flooding but would instead involve relevant authorities instituting relocation and/or buy-back/buyout programmes to help with relocation costs or compensating property owners when their property becomes uninhabitable. Such buy back or compensation schemes should be voluntary and could be implemented when existing home owners choose to vacate their properties or properties become available.

Several case studies in America have found that a policy of long term withdrawal can often be a much more environmentally, financially sustainable option relative to Hold the Line. Furthermore, if implemented correctly, a policy of long-term withdrawal could present a unique opportunity to facilitate the creation of a prime nature reserve comprised of expansive wetland and/or saltmarsh habitat similar to that of the Medmerry Nature Reserve in West Sussex England. For example, it is estimated that the Medmerry scheme resulted in a direct economic benefit of around £90m due to the lower maintenance costs, whilst the local economy has received a significant boost from an increase in green tourism and the recreational benefits stemming from the scheme.

Based on a preliminary analysis of the vector mapping for the Burrow and Portrane area, it is estimated that approximately 350 properties or buildings could be affected by this policy of long-term withdrawal. It should be noted that this number excludes temporary buildings such as caravans and holidays homes and has been based on best available vector mapping data that lacks land registry information. As such, the number of affected properties or buildings may vary significantly. An indicative area that would likely be affected by a policy of Long-term withdrawal is illustrated in Figure 6.3 overleaf. It should be noted that the actual size and extent of this area would be subject to extensive discussions between all relevant stakeholders and further studies.

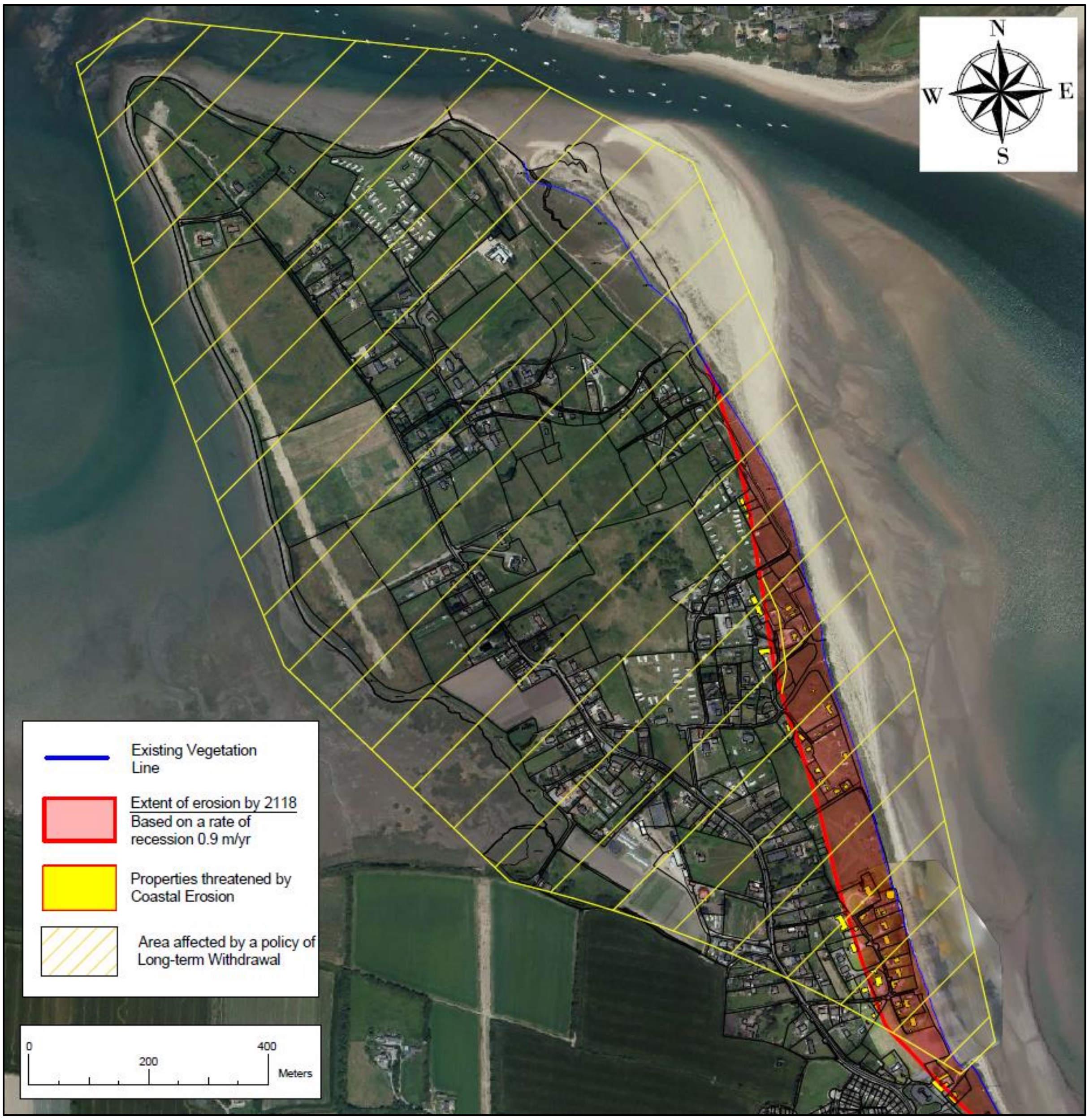

Figure 6.3: Indicative extent of area that could potentially be affected by a policy of Long-term withdrawal.

7 ECONOMIC ASSESSMENT

Economic Appraisal is a technique that can be used to aid and improve decision making about investment in policies, plans or schemes to alleviate flood or erosion risk. The appraisal process involves quantifying, as far as is possible, the benefits that would accrue by the avoidance of erosion, discounting the accumulated benefits over the lifespan of the alleviation scheme, and hence determining the present value of the benefit. This present value is then compared with the discounted capital cost of providing the defence works and the scheme's effectiveness computed in relation to the baseline "Do Nothing" option.

7.1 METHODOLOGY FOR ASSESSMENT OF LOSSES

As part of the economic risk assessment a monetary loss is assigned to certain receptors at risk. This loss represents the costs to the nation if the flood or erosion events being considered were to occur. In general, monetary values are assigned to any assets at risk such as properties, land and recreational assets. However given the scope of this study, only properties and land have been assigned monetary loss values for this economic assessment.

The total loss to the Portrane/Burrow area is used to quantify the economic risk and provide the amount of potential benefit that would occur if an erosion risk management measure is put in place which would prevent the loss from occurring.

The loss assessment methodology for the study follows the guidance in "The Benefits of Flood and Coastal Defence: A Manual of Assessment Techniques" (Flood Hazard Research Centre, Middlesex University, UK, 2005). This document is often referred to as the Multi Coloured Manual (MCM).The methodology contained in the Multi Coloured Manual was developed by Middlesex Polytechnic Flood Hazard Research Centre and is applied throughout the UK and Ireland as an appropriate methodology for assessing flood and coastal defence schemes protecting assets.

7.2 LOSS OF PROPERTIES DUE TO EROSION

At this stage of the economic assessment RPS only considered the monetary loss occurred by the property and land due to erosion alone. The extent of land and the number of properties that was estimated to be threatened by coastal erosion by 2118 was assessed and described in Section 5 of this report.

In brief, it was found that approximately 52 properties and *c.* 23 hectares of land could be lost to coastal erosion by 2118. A safety margin of 2 years was allowed to represent a set-back from the cliff edge, as per MCM guidelines.

The average market value (unadjusted for erosion) for residential property along the Burrow was calculated at as approximately €344,500 as part of a previous study undertaken by RPS in 2013. The value of land assets behind the existing vegetation is difficult to quantify in terms of current Market Value (MV), however a recent report from Sherry FitzGerald Research found the average price of land to be *c.* €9,500/ac, this value was therefore used for the purposes of this economic assessment.

7.3 CALCULATING THE NET PRESENT VALUE AND COST OF SCHEMES

The economic benefit derived from a coastal defence scheme is the difference in present value losses before and after the measure is put in place. Therefore, in order to calculate the net present value of benefits, the scheme options need to be compared with the "Do Nothing" scenario in terms of the amount of mitigation they provide. The options that were assessed as part of this economic assessment were:

- **Baseline - Do Nothing**
  - Under this scenario the relevant authority commits no further investment to either flooding or erosion protection works, regardless if any defences or commitments have existed previously.
- **Option 1 - Hold the Line, Construction of a revetment structure (see Section 6.2.1)**
  - Under this scenario it is envisaged that a 1250m revetment structure would be constructed at an initial capital cost of *c.* €3,000,000.
  - It has been assumed that approximately 10% of the initial capital costs could have to be re-spent every 25 years in order to maintain this defence.
- **Option 2 - Hold the Line, Construction of Fish tail groynes and beach renourishment (see Section 6.2.2)**
  - Under this scenario it is envisaged that approximately four fish tail groynes would be constructed along the Burrow at an initial capital cost of *c.* €4,500,000.
  - It has been assumed that approximately 10% of the initial capital costs could have to be re-spent every 25 years in order to maintain this defence.
  - This option should be complimented by a renourishment programme that would likely need to be repeated at least every 25 years. Each renourishment campaign is likely to cost *c.* €1,000,000.

It should be noted that the other options presented in Section 6 of this report, i.e. Managed re-alignment and Long term Withdrawal from the Burrow were not assessed as part of this economic appraisal as each of these options would require a high level of detailed designed and future planning which is beyond the scope of this study.

Each of the two options above has a design life *c.* 100 years and are therefore expected to delay erosion by 100 years. The damages incurred at each year over the 100 year period must be discounted back to present day costs; this is known as present value damage (PvD). For the purposes of this type of analysis OPW guidelines specify a Discount Rate of 4% for use in determining the present value of the benefit. However, research undertaken by the HM Treasury (2008) as part of the Stern Review suggests using a lower discount rate of 2.14% to account for the intergenerational wealth transfer of long term projects that span between 76 – 125 years. RPS have therefore undertaken a Benefit Cost Assessment of each option using both discount rates.

The net present value (NPV) is the sum of the discounted benefits of an option less the sum of the discounted costs. In order to present the benefit analysis clearly the Flood and Coastal Defence Project Appraisal Guidance's (FCDPAG3) spreadsheets, developed by the UK Ministry of Agriculture Fisheries and Food (MAFF) were used for the calculations.

7.4 ECONOMIC APPRAISAL OUTPUT

The summary output from the economic appraisals that used the 4% and 2.14% discount rates are presented in Figure 7.1 and Figure 7.2 respectively. It will be seen from these figures that when a discount rate of 4% is used, neither Option 1 or Option 2 has a positive Benefit Cost Ratio (BCR) of >1.0.

However, when a lower discount rate of 2.14% is used to account for the intergenerational wealth transfer of long term projects Option 1 was found to result in a BCR of > 1.0. The BCR for Options 1 and 2 using the lower discount rate of 2.14% was 1.44 and 0.81 respectively.

Project Summary Sheet

Client/Authority			Prepared (date)	
Fingal County Coucil			Printed	16/05/2018
Project name			Prepared by	KC
Rogerstown Coastal Erosion Assessment			Checked by	AKB
Project reference	IBE_xx		Checked date	
Base date for estimates (year 0)	May-2018			
Scaling factor (e.g. £m, £k, £)	€	(used for all costs, losses and benefits)		
Principle land use band	C	(A to E)		
Discount rate	4.00%			
Costs and benefits of options				

	Costs and benefits €				
	Option 1 (do nothing)	**Option 2 Revetment & Maintenance**	**Option 3 Groynes and Nourishment**		
PV costs PVc	-	3,804,700.71	6,324,488.97	-	-
PV damage PVd	3,374,751.60	62,641.92	62,772.61	-	-
PV damage avoided		3,312,109.67	3,311,978.98		
PV assets Pva	-	-	-	-	-
PV asset protection benefits		-	-		
Total PV benefits PVb		3,312,109.67	3,311,978.98		
Net Present Value NPV		- 492,591.04	- 3,012,509.99		
Average benefit/cost ratio		0.87	0.52		
Incremental benefit/cost ratio			- 0.00		
		Highest b/c	-		

Brief description of options:

Option 1 (do nothing)	Do nothing
Option 2 Revetment & Maintenance	Hard Defences + Dune Management
Option 3 Groynes and Nourishment	Groynes and Nourishment

Notes:

1) Benefits will normally be expressed either in terms of damage avoided or asset values protected. Care is needed to avoid double counting

2) PV damage avoided is calculated as PV damage (No Project) - PV damage (Option)
PV asset protection benefits are calculated as PVa (Option) - PVa (No Project)
PV benefits calculated as PV damage avoided + PV asset protection benefits

3) Incremental benefit/cost ratio is calculated as:
(PVb(current option) - PVb(previous option))/(PVc(current option) - PVc(previous option))

Figure 7.1: Summary output from the Economic Assessment for each option using a discount rate of 4.0%

Project Summary Sheet

Client/Authority		Prepared (date)	
Fingal County Coucil		Printed	16/05/2018
Project name		Prepared by	KC
Rogerstown Coastal Erosion Assessment		Checked by	AKB
Project reference	IBE_xx	Checked date	
Base date for estimates (year 0)	May-2018		
Scaling factor (e.g. £m, £k, £)	€	(used for all costs, losses and benefits)	
Principle land use band	C	(A to E)	
Discount rate	2.14%		

Costs and benefits of options

	Costs and benefits €				
	Option 1 (do nothing)	**Option 2 Revetment & Maintenance**	**Option 3 Groynes and Nourishment**		
PV costs PVc	-	4,010,474.41	7,153,299.70	-	-
PV damage PVd	6,510,436.30	743,989.83	748,905.49	-	-
PV damage avoided		5,766,446.47	5,761,530.81		
PV assets Pva	-	-	-	-	-
PV asset protection benefits		-	-		
Total PV benefits PVb		5,766,446.47	5,761,530.81		
Net Present Value NPV		1,755,972.07	- 1,391,768.89		
Average benefit/cost ratio		1.44	0.81		
Incremental benefit/cost ratio			- 0.00		
		Highest b/c	-		

Brief description of options:

Option 1 (do nothing)	Do nothing
Option 2 Revetment & Maintenance	Hard Defences + Dune Management
Option 3 Groynes and Nourishment	Groynes and Nourishment

Notes:

1) Benefits will normally be expressed either in terms of damage avoided or asset values protected. Care is needed to avoid double counting

2) PV damage avoided is calculated as PV damage (No Project) - PV damage (Option)
   PV asset protection benefits are calculated as PVa (Option) - PVa (No Project)
   PV benefits calculated as PV damage avoided + PV asset protection benefits

3) Incremental benefit/cost ratio is calculated as:
   (PVb(current option) - PVb(previous option))/(PVc(current option) - PVc(previous option))

Figure 7.2: Summary output from the Economic Assessment for each option using a discount rate of 2.14%.

7.5 ECONOMIC BENEFIT OF THE DUNE AS A FLOOD DEFENCE

A previous preliminary flood assessment undertaken by RPS in 2014 found that due to the low lying nature of the spit at Portrane, much of the Burrow would actually be at risk of flooding during an extreme storm event if the existing dune system was breached as a result of coastal erosion.

Using the information from this preliminary assessment together with the extent of predicted erosion by 2118, RPS found that if the area of dune illustrated in Figure 7.3 was to retreat by approximately 39m (i.e. in *c.* 43years time based on a rate of retreat of 0.90m/year) an additional 23 properties would be at risk from coastal flooding during a 1 in 200 year flood event. These additional 23 properties are illustrated in Figure 7.3 overleaf.

As both Hold the Line options detailed in the previous Sections of this report would effectively mitigate this risk of coastal flooding, RPS repeated the Benefit Cost Assessment with this added benefit using both the 4% and 2.14% discount rates.

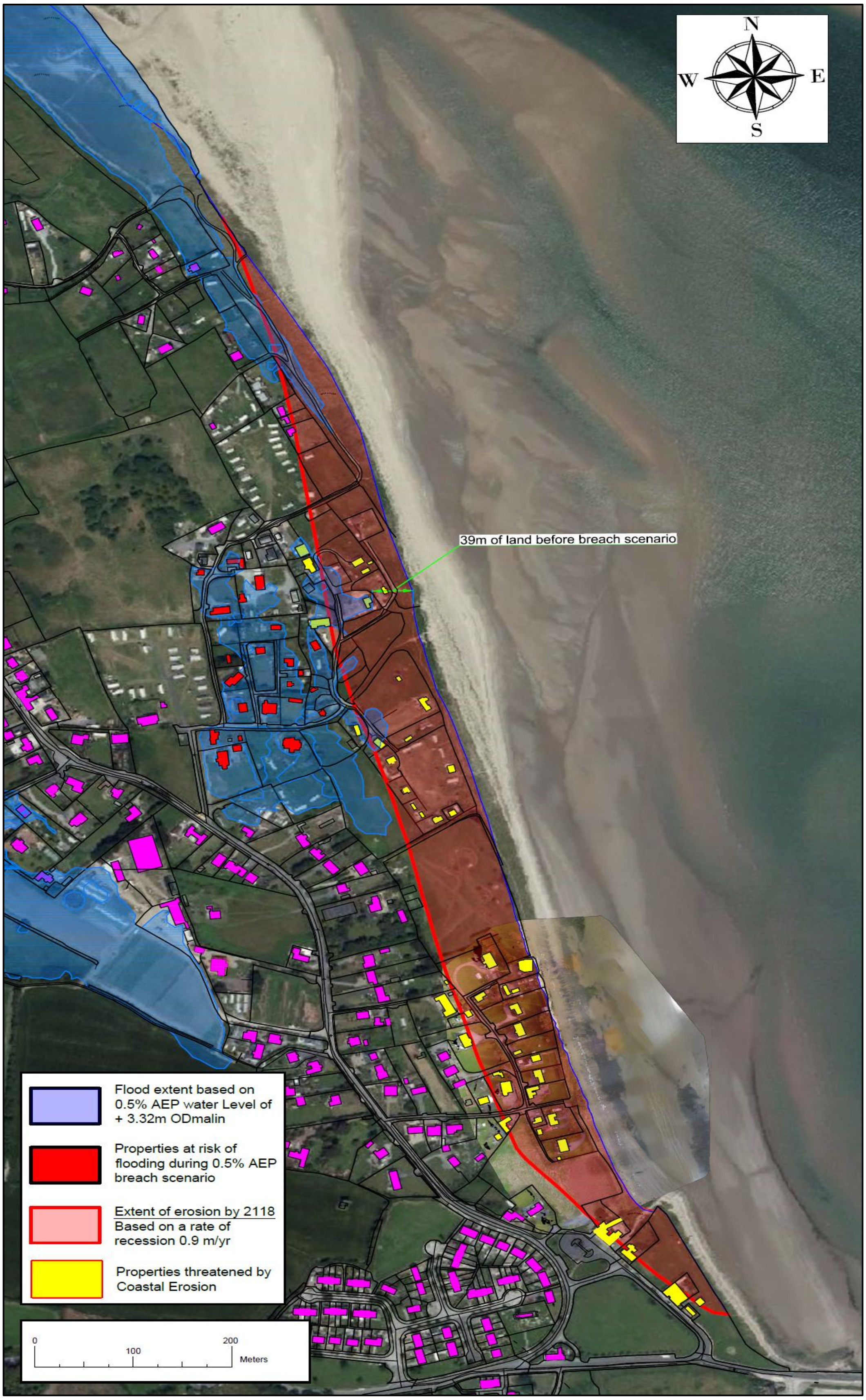

Figure 7.3: Extent of coastal erosion along the Burrow and properties at risk from erosion and flooding under a 0.5% AEP flood/breach event by 2118.

The summary output from the economic appraisals with the additional benefit of flood protection accounted are presented in Figure 7.1 and Figure 7.2 for the 4% and 2.14% discount rate assessments respectively. It will be seen from these Figures that both Hold the Line options have a BCR of > 1.0 when a discount rate of 2.14% was used, but that only Option 1 results in a BCR of >1.0 when a discount rate of 4.00% was used.

Project Summary Sheet

Client/Authority			Prepared (date)	
Fingal County Coucil			Printed	16/05/2018
Project name			Prepared by	KC
Rogerstown Coastal Erosion Assessment			Checked by	AKB
Project reference	IBE_xx		Checked date	
Base date for estimates (year 0)	May-2018			
Scaling factor (e.g. £m, £k, £)	€	(used for all costs, losses and benefits)		
Principle land use band	C	(A to E)		
Discount rate	4.00%			

Costs and benefits of options

	Costs and benefits €				
	Option 1 (do nothing)	**Option 2 Revetment & Maintenance**	**Option 3 Groynes and Nourishment**		
PV costs PVc	-	3,804,700.71	6,324,488.97	-	-
PV damage PVd	5,091,144.97	96,626.58	96,757.27	-	-
PV damage avoided		4,994,518.39	4,994,387.70		
PV assets Pva	-	-	-	-	-
PV asset protection benefits		-	-		
Total PV benefits PVb		4,994,518.39	4,994,387.70		
Net Present Value NPV		1,189,817.68	- 1,330,101.27		
Average benefit/cost ratio		1.31	0.79		
Incremental benefit/cost ratio			- 0.00		
		Highest b/c	-		

Brief description of options:

Option 1 (do nothing)	Do nothing
Option 2 Revetment & Maintenance	Hard Defences + Dune Management
Option 3 Groynes and Nourishment	Groynes and Nourishment

Notes:

1) Benefits will normally be expressed either in terms of damage avoided or asset values protected. Care is needed to avoid double counting

2) PV damage avoided is calculated as PV damage (No Project) - PV damage (Option)
   PV asset protection benefits are calculated as PVa (Option) - PVa (No Project)
   PV benefits calculated as PV damage avoided + PV asset protection benefits

3) Incremental benefit/cost ratio is calculated as:
   (PVb(current option) - PVb(previous option))/(PVc(current option) - PVc(previous option))

Figure 7.4: Summary output from the Economic Assessment for each option using a discount rate of 4.0% with the added benefit from flood protection included.

Project Summary Sheet

Client/Authority		Prepared (date)	
Fingal County Coucil		Printed	16/05/2018
Project name		Prepared by	KC
Rogerstown Coastal Erosion Assessment		Checked by	AKB
Project reference	IBE_xx	Checked date	
Base date for estimates (year 0)	May-2018		
Scaling factor (e.g. £m, £k, £)	€	(used for all costs, losses and benefits)	
Principle land use band	C	(A to E)	
Discount rate	2.14%		

Costs and benefits of options

	Costs and benefits €				
	Option 1 (do nothing)	**Option 2 Revetment & Maintenance**	**Option 3 Groynes and Nourishment**		
PV costs PVc	-	4,010,474.41	7,153,299.70	-	-
PV damage PVd	9,980,031.23	1,161,525.34	1,166,441.01	-	-
PV damage avoided		8,818,505.89	8,813,590.23		
PV assets Pva	-	-	-	-	-
PV asset protection benefits		-	-		
Total PV benefits PVb		8,818,505.89	8,813,590.23		
Net Present Value NPV		4,808,031.48	1,660,290.53		
Average benefit/cost ratio		2.20	1.23		
Incremental benefit/cost ratio			- 0.00		
		Highest b/c	-		

Brief description of options:

Option 1 (do nothing)	Do nothing
Option 2 Revetment & Maintenance	Hard Defences + Dune Management
Option 3 Groynes and Nourishment	Groynes and Nourishment

Notes:
1) Benefits will normally be expressed either in terms of damage avoided or asset values protected. Care is needed to avoid double counting
2) PV damage avoided is calculated as PV damage (No Project) - PV damage (Option)
PV asset protection benefits are calculated as PVa (Option) - PVa (No Project)
PV benefits calculated as PV damage avoided + PV asset protection benefits
3) Incremental benefit/cost ratio is calculated as:
(PVb(current option) - PVb(previous option))/(PVc(current option) - PVc(previous option))

Figure 7.5: Summary output from the Economic Assessment for each option using a discount rate of 2.14% with the added benefit from flood protection included.

7.6 ECONOMIC ASSESSMENT SUMMARY

In summary, both options of Hold the Line were found to have a Benefit Cost Ratio of more than 1 when a discount rate of 2.14% was used and when the added benefit of flood protection was included. However, only Option 1 had a BCR of > 1.0 when a discount rate of 4% was used.

It should be noted that this benefit cost assessment was considered to be conservative as other benefits such as recreation, cultural heritage and those related to other national/public infrastructure were omitted from the assessment. Based is this it is therefore likely that both Hold the Line options would be economically viable regardless of the discount used.

Table 7.1: Summary of Benefit Cost assessment of both Hold the Line options.

Benefit Summary	Discount Rate	Option 1 - Revetment and Maintenance	Option 2 - Groynes and renourishment
Erosion Only	4	0.87	0.52
	2.14	1.44	0.81
Erosion and Flooding	4	1.31	0.79
	2.14	2.20	1.23

8 ENVIRONEMNTAL DESIGNATIONS

As discussed in the original Coastal Erosion Risk Management study undertaken by RPS in 2013, the main limitation to any hard engineered coastal management strategy for the Burrow being progressed is due to the potential for a Hard Engineering option to negatively impact the environmentally sensitive Rogerstown estuary which has been designated as a Special Area of Conservation (SAC) and Special Protection Area (SPA). The extent of these environmentally designated areas in relation to the Burrow is illustrated in Figure 8.1 below.

Given the any of the CFERM options have the potential to interact with the qualifying interests of Rogerstown Estuary SAC and Rogerstown Estuary SPA, it is important to understand and consider the specific qualifying features and conservation objectives of the nearby SPA and SAC. These qualifying features and conservation objectives are described in further detail in the following Sections of this report.

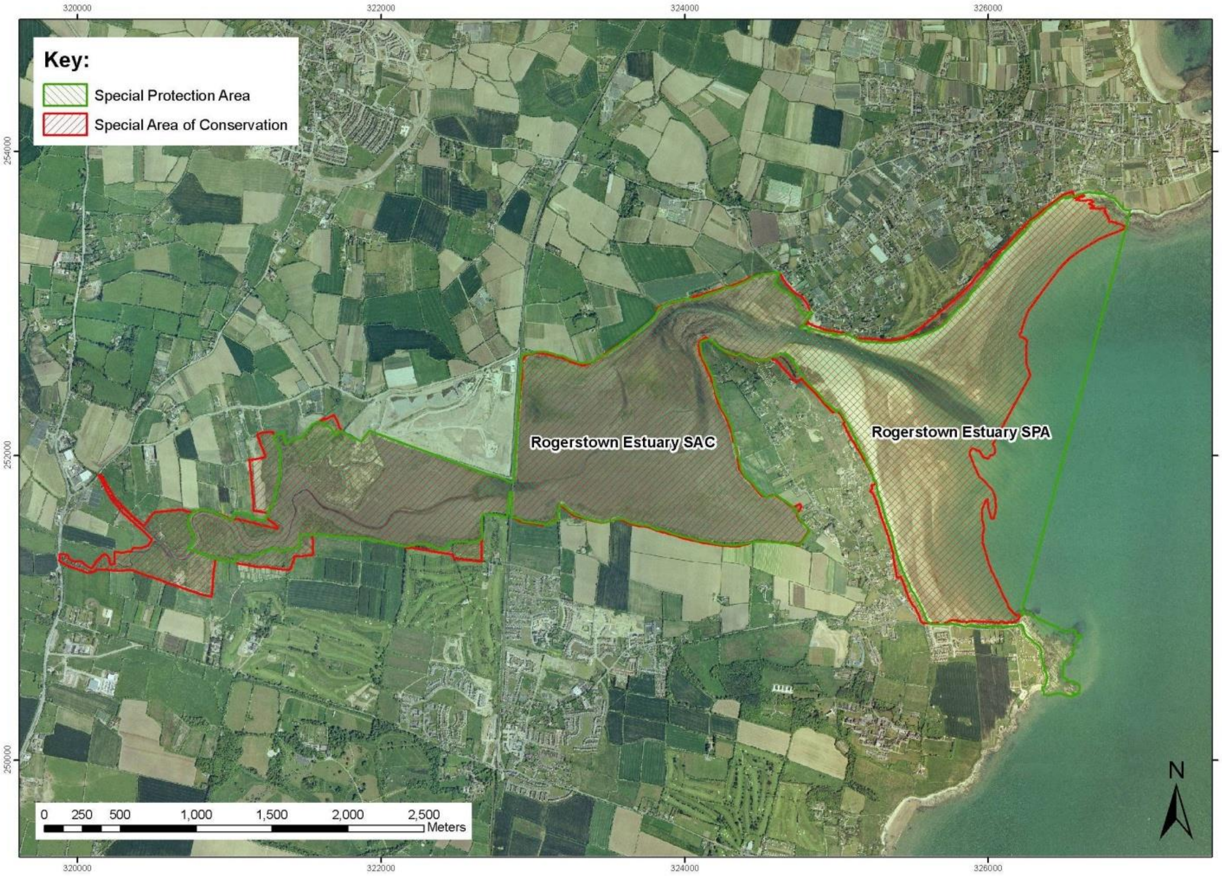

Figure 8.1: Designated SAC and SPA areas in relation to the Burrow, Portrane.

8.1 ROGERSTOWN ESTUARY SAC

Rogerstown Estuary SAC (Site Code IE0000208) (see Figure 8.1) was proposed as eligible for identification as a Site of Conservation Importance (SCI) in December 1999. The conservation objectives for this 586.47ha SAC are described in NPWS (2013a). Appendix IV of the Rogerstown Estuary SAC Conservation Objectives supporting document (NPWS 2013b) contains a site report describing the Portrane dunes in some detail, the key objectives are presented in Table 8.2. This work was originally presented as part of Ryle et al. (2009).

Section 4.4.1 of NPWS (2013b) notes in a discussion of maintaining the physical structure and functioning of the dunes that coastlines naturally undergo a constant cycle of erosion and accretion, and that there are two main causes of this; (a) those resulting from natural causes and (b) those resulting from human interference. Human interference is usually associated with changes in the sediment budget, either directly, through the removal of beach or inshore sediment, or indirectly, by impeding or altering sediment movement.

Whilst the process of coastal erosion is part of a natural tendency towards equilibrium with dunes forming naturally dynamic systems that require continuous supply and circulation of sand, the construction of physical barriers such as sea defences can interrupt longshore drift, leading to beach starvation and increased rates of erosion. The construction of physical barriers can interfere with the sediment circulation by cutting the dunes off from the beach resulting in fossilisation or over-stabilisation of dunes.

This is recognised in the national assessment of white and grey dune systems (NPWS 2013c) which notes that <u>sea defences</u> and <u>coastal protection works</u> (EU threat code J02.12.01) are a <u>high category pressure</u> on white dunes (white dunes) and a <u>medium category pressure</u> on fixed dunes (grey dunes). Fences and fencing (EU threat code G05.09) was ranked as a medium category pressure on white dunes, and not listed for grey dunes.

Table 8.1: Natura 2000 sites Located within the Zone of Influence of the Burrow and the Conservation Interests & Vulnerability/Threats

Natura 2000 Site		Habitat		Wintering Species		Vulnerability / Threats
Code	Name	Code	Name	Code	Name	
208	Rogerstown Estuary SAC	1130	Estuaries			• Landfilling • Pollution from landfill, sewerage and agriculture • Erosion of sand dunes
		1140	Mudflats and sandflats not covered by seawater at low tide			
		1310	*Salicornia* and other annuals colonizing mud and sand			
		1330	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)			
		1410	Mediterranean salt meadows (*Juncetalia maritimi*)			
		2120	Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)			
		2130	Fixed coastal dunes with herbaceous vegetation (grey dunes)			
4015	Rogerstown Estuary SPA	[A999]	Wetlands			• Landfilling • Pollution from landfill, sewerage and agriculture • Erosion of sand dunes • Disturbance to wintering waterfowl from illegal shooting
				[A043]	Greylag Goose (*Anser anser*)	
				[A046]	Light-bellied Brent Goose (*Branta bernicla hrota*)	
				[A048]	Shelduck (*Tadorna tadorna*)	
				[A056] (	Shoveler (*Anas clypeata*)	
				[A130]	Oystercatcher (*Haematopus ostralegus*)	
				[A137]	Ringed Plover (*Charadrius hiaticula*)	
				[A141]	Grey Plover (*Pluvialis squatarola*)	
				[A143]	Knot (*Calidris canutus*)	
				[A149]	Dunlin (*Calidris alpina*)	
				[A156]	Black-tailed Godwit (*Limosa limosa*)	
				[A162]	Redshank (*Tringa totanus*)	

Table 8.2: Qualifying Features and Conservation Objectives for Designation of Rogerstown Estuary SAC.

Qualifying Feature	Representativity	Relative Surface	Conservation Status	Global Assessment	Description
1140 Mudflats and sandflats not covered by seawater at low tide	B	B	C	C	61% of SAC
1130 Estuaries	B	C	C	C	13% of SAC
1320 Spartina swards (*Spartinion maritimae*)	D	-	-	-	10% of SAC
1330 Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	B	C	C	C	4% of SAC
1410 Mediterranean salt meadows (*Juncetalia maritimi*)	B	C	C	C	4% of SAC
2120 Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")	C	C	C	C	1% of SAC
2130 * Fixed coastal dunes with herbaceous vegetation ("grey dunes")	C	C	C	C	1% of SAC
1310 *Salicornia* and other annuals colonizing mud and sand	B	C	C	C	1% of SAC

8.2 ROGERSTOWN ESTUARY SPA

Rogerstown Estuary (Site Code IE0004015) is an important waterfowl site, with a population of Brent Geese of international importance. A further 16 species have populations of national importance. The presence of a significant population of Golden Plover is noteworthy as this species is listed on Annex I of the EU Birds Directive. The estuary is a regular staging post for autumn migrants, especially Green Sandpiper, Ruff, Little Stint, Curlew Sandpiper and Spotted Redshank.

Little Tern has bred at the outer sand spit, but much of the nesting area has now been washed away as a result of erosion. The maximum number of pairs recorded was 17 in 1991. Ringed Plover breed in the same area. The outer part of the estuary has been designated a statutory Nature Reserve and a Special Protection Area under the EU Birds Directive. The inner estuary has been damaged by the refuse tip which covers 40 hectares of mudflat. This site is a good example of an estuarine system, with all typical habitats represented, including several listed on Annex I of the EU Habitats Directive. The qualifying interests of the SPA site are listed in Table 8.3 below.

Table 8.3: Qualifying Features and Conservation Objectives for Designation of Rogerstown Estuary SPA.

Feature Type	Feature	Designation Population	Population	Conservation	Isolation
Species	Greylag Goose *Anser anser*	87	B	A	B
Species	Brent Goose *Branta bernicla hrota*	1194	B	A	C
Species	Shelduck *Tadorna tadorna*	781	B	A	C
Species	Shoveler *Anas clypeata*	72	B	A	C
Species	Oystercatcher *Haematopus ostralegus*	1794	B	A	C
Species	Ringed Plover *Charadrius hiaticula*	187	C	B	C
Species	Grey Plover *Pluvialis squatarola*	343	B	A	C
Species	Knot *Calidris canutus*	2159			
Species	Dunlin *Calidris alpina alpina*	3128	B	A	C
Species	Black-tailed Godwit *Limosa limosa*	212	C	A	C
Species	Redshank *Tringa totanus*	674	B	A	C
Habitat	Wetlands	N/A	N/A	N/A	N/A

8.2.1 Rogerstown Estuary SPA Conservation Objectives

The conservations objectives for the Rogerstown SPA are presented below:

- **Objective 1:** To maintain the favourable conservation condition of the waterbird Special Conservation Interest species listed for Rogerstown Estuary SPA, which is defined by the of attributes and targets outlined in Table 8.4
- **Objective 2:** To maintain the favourable conservation condition of the wetland habitat at Rogerstown Estuary SPA as a resource for the regularly-occurring migratory waterbirds that utilise it. This is defined by the attributes and targets outlined in Table 8.4 below.

Table 8.4: Rogerstown Estuary SPA Conservation Objectives

Feature	Attribute	Measure	Target	Notes
Wintering Species	**Population Trend**	Percentage Change	Long term population trend stable or increasing	Population trends are presented in part four of the conservation objectives supporting document
	Distribution	Number and range of areas used by waterbirds	No significant decrease in the range, timing or intensity of use of areas by ringed plover, other than that occurring from natural patterns of variation	Waterbird distribution from the 2011/2012 waterbird survey programme is discussed in part five of conservation objectives supporting document
Wetland Habitat	**Habitat area**	Hectares	The permanent area occupied by the wetland habitat should be stable and not significantly less than the area of 646 hectares, other than that occurring from natural patterns of variation	The wetland habitat area was estimated as 646ha using OSi data and relevant orthophotographs.

8.3 ENVIRONMENTAL DESIGNATIONS IN CONTEXT OF CFERM OPTIONS

A brief summary of the advantages and disadvantages of each CFERM options in context of the nearby environmentally designated areas and wider issues are presented in Table 8.5 below.

Table 8.5: Advantage and benefits associated with the various CFERM options for the Burrow, Portrane.

CFERM option	Advantage	Disadvantage
Hold the Line Option 1 **Revetment Structure**	▪ Maintains the position of the existing dune line	▪ Likely to accelerate coastal erosion at the terminal of the proposed revetment ▪ Reduced supply of sediment from the dune system to the beach ▪ "Coastal squeeze" will reduce the available beach width ▪ Potential to impact qualifying habitat of SAC ▪ Potential to impact conservation objectives of SPA
Hold the Line Option 2 **Fish tail groynes & renourishment**	▪ Maintains the position of the existing dune line ▪ Maintains the majority of the natural beach dune interaction ▪ Facilitates the transfer of sediment from the dune to the beach area ▪ Prevents further erosion and loss of designated habitat	▪ Less likely to impact the existing coastal processes relative to Hold the Line Option 1 ▪ Groyne structures may reduce the longshore transport of sediment ▪ Potential for increased erosion beyond the Burrow, i.e. at Rush ▪ Less potential to impact qualifying habitat of SAC relative to Option 1. ▪ Less potential to impact conservation objectives of SPA relative to Option 1
Managed Re-alignment	▪ Allows the shoreline to dynamically respond to the prevailing weather conditions and climate change without the intervention of expensive hard engineering options ▪ Possibly create new habitat in the long run which could reduce future coastal erosion	▪ Could reduce extent of Protected habitat if coastal erosion and climate change continues at accelerated rate ▪ Managed realignment is more applicable in addressing flood issues as opposed to erosion issues ▪ As the Burrow is a sand spit, there is a finite space to re-align to ▪ Delaying issue of coastal erosion for future generations
Long term withdrawal from the Burrow	▪ Allows the shoreline to dynamically respond to the prevailing weather conditions and climate change without the intervention of expensive hard engineering options ▪ Avoids expensive capital and on-going maintenance costs associated with Holding the Line ▪ Potential to create a prime nature reserve that could significantly boast green tourism	▪ Could reduce extent of Protected habitat if coastal erosion and climate change continues at accelerated rate ▪ This option would require the relevant authorities to institute an expensive and potentially controversial compensation/relocation/buy-back program

9 CONCLUSION

In response to the unprecedented threat of coastal erosion along the Burrow at Portrane, Fingal County Council engaged RPS to characterise the recent storm events, assess the future threat of coastal erosion and consider a range of protection measures that could be implemented to manage the risk of future climate change.

A previous coastal erosion risk management study undertaken by RPS in 2013 used the Historical Trend Analysis Rule (HTAR) to assess future coastal erosion due to the historical stability of the dune. Using this approach it was estimated that the 2013 vegetation line would retreat by *c.* 24m and 48 m by 2100 under the MRFS and HEFS respectively. This original assessment concluded that up to 11 properties could be at risk by 2100 if no hard engineering measures were implemented to mitigate this risk.

In light of the recent severe storm events RPS re-analysed a more extensive offshore wave dataset to characterise these recent events and assess the change in wave climate at Portrane. In summary this assessment found that:

- Storm Emma was the most extreme easterly storm event ever recorded by the M2 buoy. Wave heights during this event were 35% greater than the next largest event from the east.
- The frequency and magnitude of extreme storm events have increased significantly over the last number of years and is likely to continue to do so due to the impact of climate change..
- What was a 1 in 100 event based the wave data recorded by the ECMWF between 1996 – 2013 is at present closer to a 1 in 10 or 20 year event.

9.1 SUMMARY OF FUTURE COASTAL EROSION

Using numerical modelling techniques, RPS quantified and assessed the morphological response of the 2018 dune system over a 100 year period subject to a combination of extreme storm events. This assessment also accounted for the effect of future climate change by including a Sea Level Rise of +0.75m. In summary this assessment found that:

- The existing dune system could retreat by up to *c.* 8.5m and 12.2m during a 1 in 50 and 1 in 200 year joint probability event respectively.
- The existing vegetation line could retreat landward at a rate of approximately 0.86m per year.
- Based on this rate of retreat, the existing vegetation line could retreat by *c.*86m.
- Under this scenario which accounted for climate change by including a sea level rise of +0.75m, approximately 52 properties could be at risk from coastal erosion
- A further 23 properties could be at risk from coastal flooding if the main dune system was breaching during a 1 in 200 year flooding event.

It is important to acknowledge that this analysis was based on a pseudo-combination of storm events that are statistically likely to occur over a 100 year period; however, the extent and rate of actual erosion by 2118 will be subject to prevailing weather conditions and future climate change and therefore may differ significantly to the findings presented in this report.

9.2 SUMMARY OF AVAILABLE COASTAL PROTECTION OPTIONS

This study found that given the nature and extent of coastal erosion along the Burrow, only the following Coastal Flooding and Erosion Risk Management (CFERM) options could be considered:

Holding the Line Option 1 – Constructing a Revetment Structure

- Under this scenario it is envisaged that a 1250m revetment structure would be constructed at an initial capital cost of *c.* €3 – 4 million subject to detailed design. This revetment structure would provide effective protection against coastal erosion and flooding for *c*. 100 years.
- This option could potentially result in significant environmental impacts to the nearby environmentally designated SPA and SAC habitats by interfering with the existing coastal processes and resulting in a "coastal squeeze".
- Option 1 had a Benefit Cost Ratio of between 1.31 – 2.20 depending on the discount rate used.

Holding the Line Option 2 – Constructing fish tail groynes and regular beach nourishment

- Under this scenario, a series of fish-tail groynes would be constructed at an initial capital cost of €4.5 – 5.5 million subject to detailed design. These structures would reduce the cross-shore and longshore transport of sediment.
- Regular beach renourishment campaigns (i.e. once every *c.* 25 years) would increase existing beach levels and reduce incident wave energy. Each renourishment campaign would likely cost *c.* €1 million subject to the availability of suitable renourishment material etc.
- This option would effectively mitigate the threat of coastal erosion and flooding and could also retain existing designated habitat.
- This option does not sever the natural beach dune interaction so is likely to be considered more environmentally acceptable and sustainable relative to Hold the Line Option 1.
- Option 2 had a Benefit Cost Ratio of between 0.79 – 1.23 depending on the discount rate used.

Managed Re-alignment

- Under this scenario the shoreline would be allowed to dynamically respond to the prevailing weather conditions and future climate change.
- Some hard engineering measures such as buried longstops could be implemented to manage the threat of erosion and flooding in the short term and provide local authorities time to develop a longer term solution
- This option only delays the existing issue for future generations
- Given that the Burrow is a sand spit of finite width, there is no clear point to re-align to.
- Managed re-alignment is generally more applicable to sites affected by coastal flooding.

Long term Withdrawal from the Burrow

- This would involve actively planning to withdraw from the Burrow over the long term
- In order not to exacerbate the existing issues it would be important to prevent further development along the Burrow area.
- Relevant authorities may have to institute controversial buy-back or compensation schemes for local home-owners that are directly affected by this policy.
- It is anticipated that at least 350 properties would be directly affected by this policy.
- This option would reduce long term capital and maintenance spending on hard defences
- There would be an opportunity to create a prime nature reserve in the Burrow area.

9.3 ASSESSMENT OF COASTAL MANAGEMENT OPTIONS

Based on the findings presented in this report it was found that one of the most technically effective solutions that could be implemented along the Burrow, Portrane would be a policy of Hold the Line through the construction of a series of well-designed fish-tail groyne structures. These structures would effectively reduce the cross-shore and longshore elements of the sediment transport regime and provide effective protection against erosion and flooding along approximately 1,250m of beach along the Burrow. Importantly, as this structure would not sever the natural beach dune interaction it is believed that this is a much more environmentally sustainable solution than other solutions that have been proposed previously.

This policy would also include a commitment to renourish the upper beach profile approximately once every 25 years. This would increase the beach levels and reduce the incident wave energy that could attack and erode the dune system along the Burrow. Furthermore, it is believed the combination of fish tail groynes together with a beach renourishment programme would retain and potentially facilitate the creation of new designated habitat which is at present being eroded at a rate of approximately ≥0.90 metres per year.

An economic assessment demonstrated that this policy had a positive Benefit Cost ratio of between 0.79 – 1.23 depending on the discount rate used thus indicating that this option could be an economically viable scheme. It should be noted that the economic assessment undertaken as part of this study was considered conservative as the benefits stemming from recreation, cultural heritage and other sources were omitted. Furthermore, it is believe that the benefit cost ratio of this scheme could be increased further based upon the findings of a detailed Flooding Study of the Rogerstown estuary area that is currently being undertaken by RPS on behalf of the OPW.

One of the main issues associated with this option of Hold the Line is the potential impact of the scheme to interfere with the conservation objectives and qualifying features of the nearby environmentally designated SPA and SAC habitats. It is therefore necessary to engage with all relevant stakeholders, particularly the National Parks and Wildlife Service (NPWS) to ascertain if this option is an environmentally, socially and economically sustainable long term Coastal Management option for the Burrow, Portrane.

With respect to the other Management options, the Long term Withdrawal option is certainly in line with the habitats directive but whether it would be politically acceptable is beyond competence of this report.

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