ROGERSTOWN COASTAL FLOOD EROSION RISK MANAGEMENT STUDY

Stage 1: Coastal Flood and Erosion Risk Assessment

Technical Report

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Rogerstown CFERM Study

Stage 1
Risk Assessment
Technical Report

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1 INTRODUCTION

1.1 Background

In February 2018 RPS were commissioned by Fingal County Council (FCC) to assess the feasibility of a localised, small-scale coastal defence scheme to reduce the flood risk that exists in the Rogerstown Outer Estuary area. The scope of this initial commission was to develop a socially and environmentally sustainable scheme to reduce the risk of coastal flooding throughout the study area. The key locations identified as being at risk were the Burrow peninsula, Rush south and north beaches and Spout Lane in Rush. These locations are illustrated in Figure 1.1.

Following Storm Emma and several other arduous storm events in the winter period of 2017/2018 the position of the shoreline at the Burrow retreated by more than 20m in some areas. Consequently, RPS' commission was extended to include the development of interim emergency coastal protection measures that would provide short term mitigation to the issue of coastal erosion along the Burrow. RPS subsequently developed interim emergency coastal protection measures that involved the construction of a wave attenuation array. This solution comprised precast concrete Seabee units being placed in front of the worst affected section of the Burrow frontage.

In recognition of the ongoing erosion risk across the study area the scope of the original Rogerstown Outer Estuary Coastal Flood Risk Management Works study was revised to include additional elements of work. These additional elements of work included:

- A coastal erosion assessment along the Rush South and North beaches.
- The development of detailed coastal protection options for The Burrow, Rush South and North beaches.
- A preliminary environmental assessment of each option in the context of AA, EIA and NIAR.

The purpose of this document is to report on the findings of the Coastal Flood and Erosion Risk assessment across the study area. The report also includes a review of historical erosion across the study area and a synopsis of planning policies, strategies and other relevant documentation.

The findings from this risk assessment report will be used to inform an Optioneering Report which will identify and assess the technical, environmental and economic viability of potential Coastal Flood and Erosion Management (CFERM) options.

1.2 Study Aims & Objectives

The purpose of this CFERM study is to provide a basis for management policies for areas affected by erosion or flooding and to set the framework for managing these risks in the future. Specifically, the aims of this overall study are to:

- Set out the risks from coastal flooding and erosion to people and the developed, historic and natural environment in a clear and coherent manner.
- Identify opportunities to maintain and improve the environment by managing the risks from floods and coastal erosion.
- Identify the preferred policies for managing the risks from flood and erosion over a defined time period. In most instances, policies are defined up until 2100 as per guidance issued by the Office of Public Works (OPW).
- Identify the consequences of putting the preferred policies into practice.
- Discourage inappropriate development in area where the flood and erosion risks are high.
- Ensure that any proposed scheme meets international and national environmental conservation legislation.

These aims are achieved through a series of study objectives which have been developed by the OPW as specified in Schedule A.1 of the CFERM guidance. These objectives are to:

1. Review and assess existing information.
2. Identify information gaps & arrange for necessary additional field surveys.
3. Address surveys of existing coastal protection structures and other surveys.
4. Undertake an assessment of existing coastal processes and coastline evolution.
5. Prepare detailed current and future coastal change maps.
6. Prepare a detailed risk assessment.
7. Undertake a preliminary environmental assessment.
8. Undertake an options & feasibility assessment.
9. Prepare a Coastal Flood and Erosion Risk Management plan (CFERMp).
10. Produce an economic assessment of benefits and costs.

Objectives 1 to 6 are addressed in this CFERM assessment report whilst Objectives 7 – 10 are addressed in a separate Optioneering Report.

1.3 Site Description

1.3.1 The Burrow

The Burrow is a sandy spit that separates the outer Rogerstown Estuary from the Irish Sea (see Figure 1.1 and Figure 1.2). The area is used extensively for recreation and is of significant environmental importance, holding several National and European designations. The spit is fronted by a wide sandy beach and is bordered by rock headlands at Rush to the north and Portrane to the south.

The nature of the spit and beach is strongly influenced by the tidal action of the estuary and waves approaching the shoreline from the Irish Sea. Lambay Island, which lies around 5km east of the beach, also influences both the wave and tidal conditions. The beach at the Burrow is around 1.8km long, with a bathing area at its southern end that has been awarded Blue Flag status. It is a popular recreational location that offers many amenities to the public and tourists throughout the year.

> The environmental sensitivity of the Burrow is recognised in the Local Development Plan (Fingal County Council, 2017). This plan encourages sustainable development and the gradual removal of temporary mobile homes, huts and wooden chalets that are common across the site. Replacing temporary accommodation with permanent dwellings is also discouraged in the Plan.

Over the last number of years, the Burrow has been adversely affected by episodes of acute coastal erosion which were in turn driven by extreme storm events. In 2018 Storm Emma and a succession of other events resulted in the shoreline retreating by more than 20m along some sections of the Burrow. The coastal retreat during this episode was so severe that a private residential property had to be demolished some months later.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1.1: Location of the key study areas in relation to the Rogerstown Outer Estuary

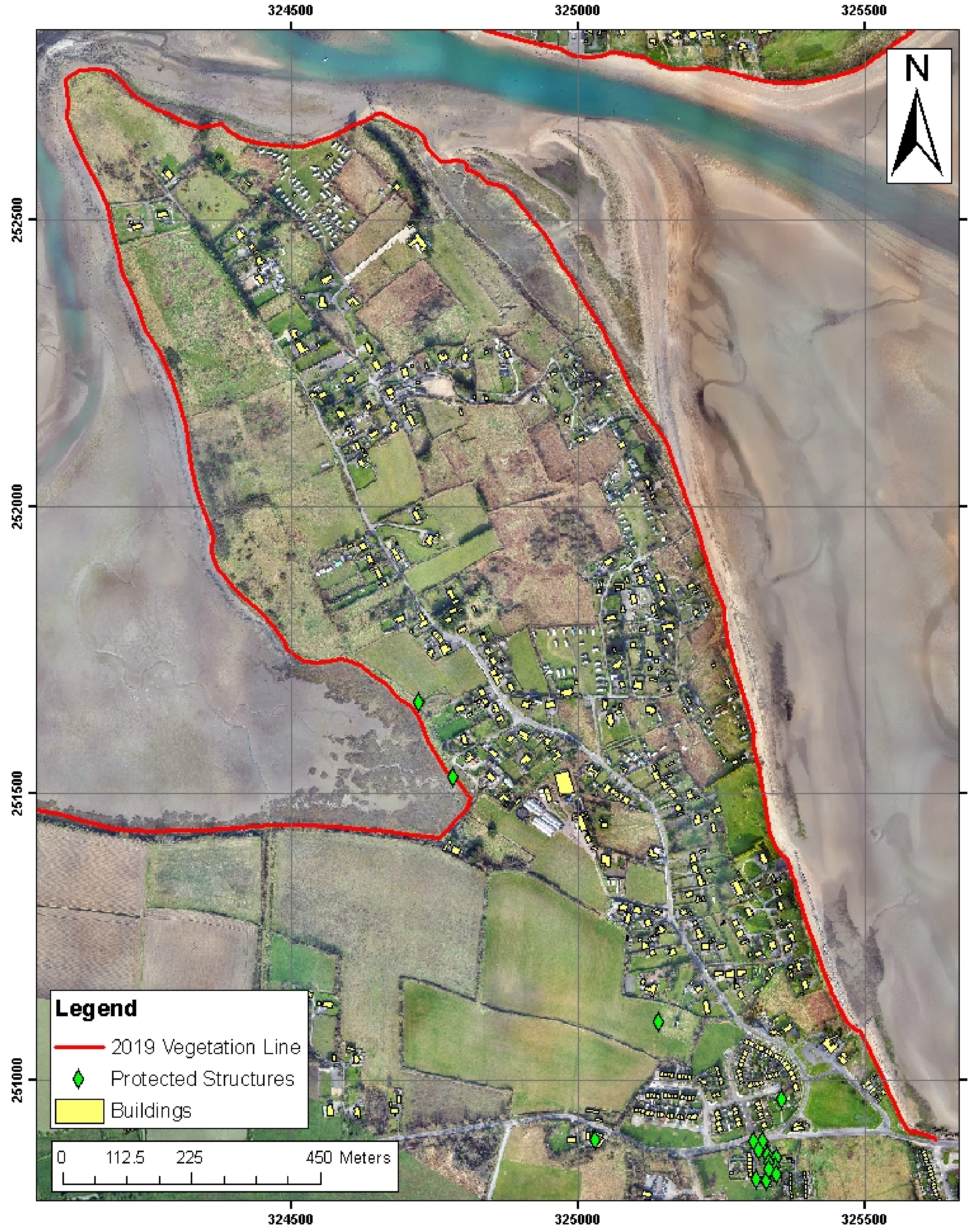


Figure 1.2: Overview of buildings and other assets at the Burrow in relation to the 2019 vegetation line

1.3.1.1 Existing coastal defences along the Burrow

In response to the acute coastal erosion over the last number of years, FCC commissioned RPS to develop an interim coastal protection solution. The purpose of these interim works was to mitigate the damaging effect of coastal erosion where properties were considered at greatest risk until a more long-term management plan could be developed.

To this end RPS designed and developed a wave attenuation array comprised of concrete seabee units to dissipate incident wave energy prior to the waves impacting on the dune line. Having identified this option as the most sustainable and feasible option available, RPS undertook physical model testing at The Queen's University Belfast (QUB) to refine the layout of the wave attenuation array (see Figure 1.3). During a 1 in 50 year storm event, this wave attenuation array was found to reduce the incident wave energy behind the array by *c.*70% (RPS, 2018).

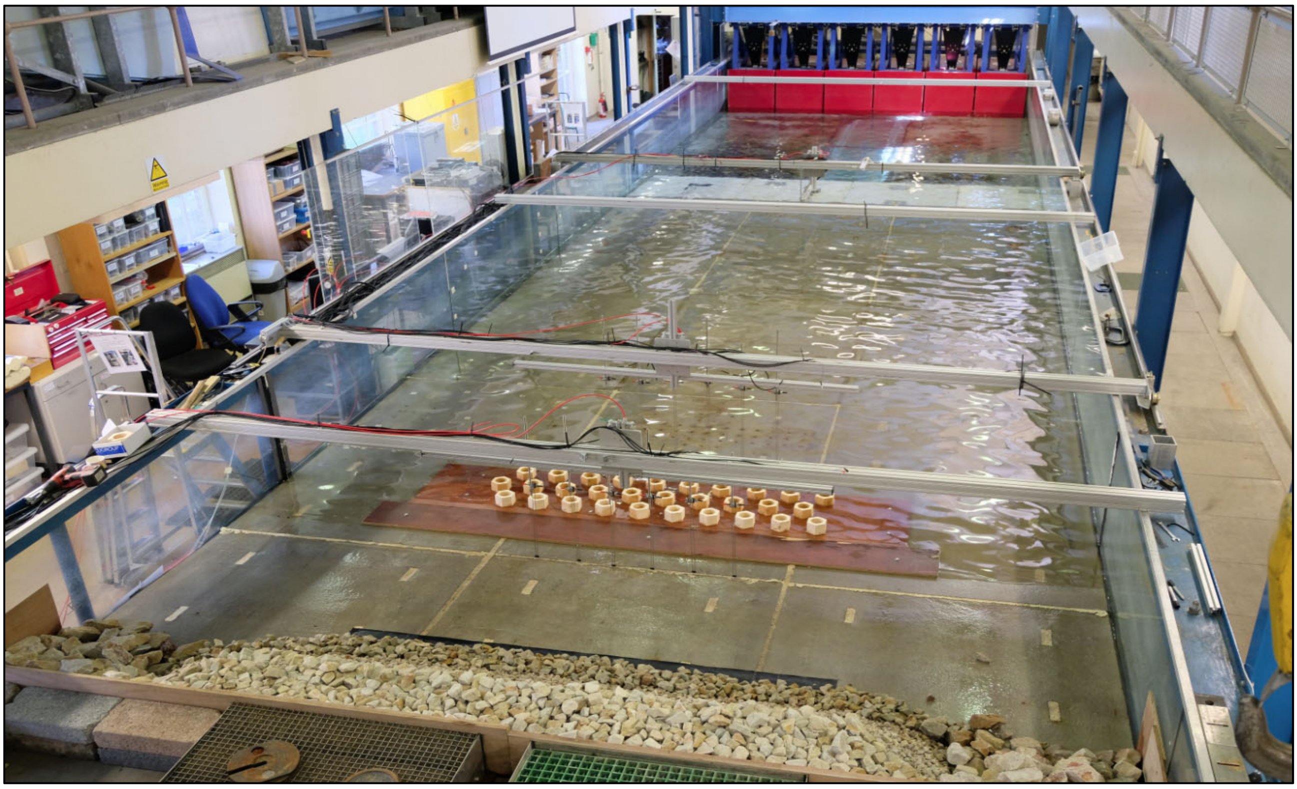


Figure 1.3: The wave tank at the Queen's University Belfast used to test the proposed interim coastal protection solution.

Following the successful hydraulic testing of these interim coastal protection measures, FCC proceeded to implement the proposed solution late in 2018. The wave attenuation array consisted of *c.*355 individual pre-cast seabee units each weighing approximately 4.2T placed along the foreshore region in three individual rows as illustrated in Figure 1.4 overleaf.

In general, these interim coastal protection measures have performed as anticipated having reduced erosion rates in the area immediately behind the units in the period since installation. Furthermore, since being installed the seabee units have also created a perched beach effect whereby sand is trapped on the lee (landward) side of the units which in turn has raised beach levels further reducing potential wave energy breaking onto the dunes.

A survey of the southern section of the Burrow that was undertaken in February 2020 found that erosion rates behind the seabee units were generally *c.*60% less than those observed much further north. It was noted that effectiveness of the seabee units had decreased towards the northern extent of the array. This was because beach levels have continued to drop in this area which in turn decreased the relative crest level and thus the wave attenuation properties of the interim measures.

Figure 1.4: General layout of the temporary interim coastal protection measures along the Burrow – Dec 2018

Figure 1.5: Perched beach held behind the seabee units – Jun 2019

Aside from the interim coastal protection measures at the Burrow, there is also an existing length of sheet piling along the southern section of the beach that effectively prevents the shoreline from retreating beyond its present position. Approximately 100m of the *c.* 180m length of sheet piling is exposed at the southern section of the beach as can be seen in Figure 1.6 below. The original *c.*180m length of sheet piling is illustrated in the aerial photograph presented in Figure 1.8 which is believed to have been taken *c.* 1950.

Unfortunately, there is little information describing this existing defence. Based on anecdotal evidence it is believed that this sheet piling could have been installed in *c*.1950 to provide protection to several small coastal cottages that no longer exist. The sheet piling was found to be *c*.3m deep and capped with concrete. Ground investigations found that the sheet piling was in relatively good condition.

It should be noted that the installation of this defence so far back from the existing coastline indicates that the coastline was once *c*. 10 – 15m behind its current position. This suggests that coastal erosion has been a long-standing issue in this area.

Figure 1.6: Exposed sheet piling along the southern section of the Burrow

Figure 1.7: Buried sheet piling in front of Brook pub – July 2019

Figure 1.8: The southern section of the Burrow *c.*1950 with the sheet piling defences exposed (red line in upper) and *c.*2018 (© Google Earth)

1.3.2 Rush

Rush was formerly a centre for horticulture and agriculture. However, with the emergence of the “Celtic Tiger” and the accessibility of the new M1 motorway in the late 2000s, the area became sought after as a commuter area. This is reflected in the increasing population statistics presented in Table 1.1 which show that the local population has been steadily rising since 1996.

The beach at Rush south is approximately 2.4km in length and is backed by dunes which in the middle section are part of a 9-hole links golf course. As can be seen from Figure 1.10, the immediate hinterland either side of the golf course is moderately populated.

The beach at Rush north is much shorter at *c.*1.0km in length. Numerous residential properties as well as a caravan park and carpark occupy the immediate hinterland in this area. The small carpark at the southern section of this beach is protected by a localised section of rock armour installed to protect the landfall of the east-west electrical interconnector.

Table 1.1: CSO Ireland Census Populations of Rush and Portrane 1996-2016

Year	Rush Population	% Change	Portrane Population	% Change
1996	5,429	-	1,924	-
2002	6,769	24.7	1,726	-10.3
2006	8,280	22.3	1,532	-11.2
2011	9,196	11.1	1,372	-10.4
2016	9,921	7.9	1,236	-9.9

1.3.2.1 Existing coastal defences at Rush

There are several small localised coastal defences along the beaches at Rush north and south. The carpark at either beach is protected by small lengths of rock armour revetment. As can be seen from Figure 1.9 overleaf, the rock armour protecting the car park at Rush south is actually set several metres behind the vegetation line. This indicates that there has most likely been modest levels of accretion in this area since the defences were first installed.

Along Rush south, towards the mouth of the Rogerstown estuary and in the vicinity of Rush boat club, there are several disjointed makeshift defences comprised of waste stone and boulders. However, even in their current condition, these defences are likely to mitigate any risk of erosion in these areas.

Figure 1.9: Existing coastal defences at the car park and boat club at Rush south

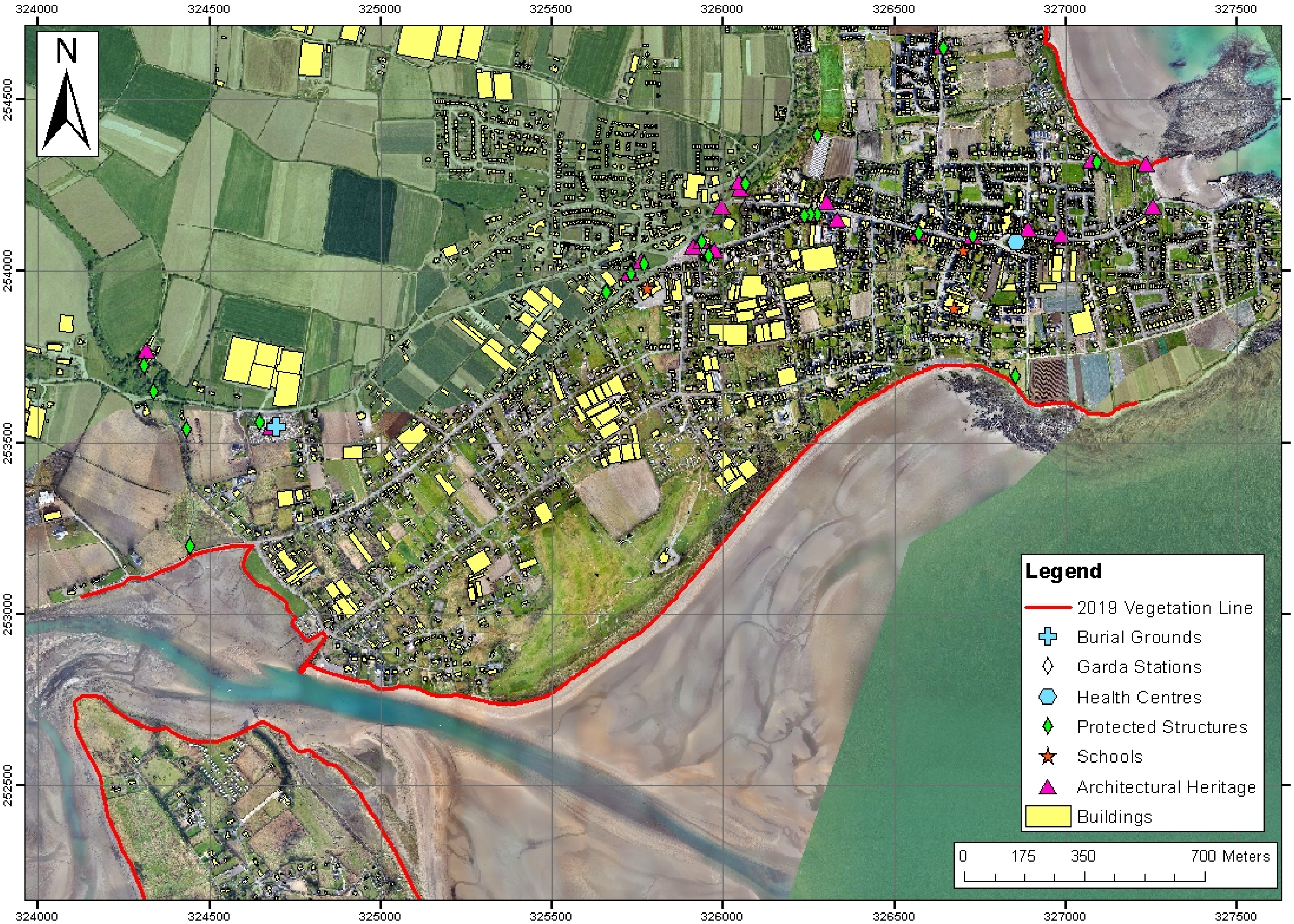


Figure 1.10: Overview of buildings and other assets at Rush south in relation to the 2019 vegetation line

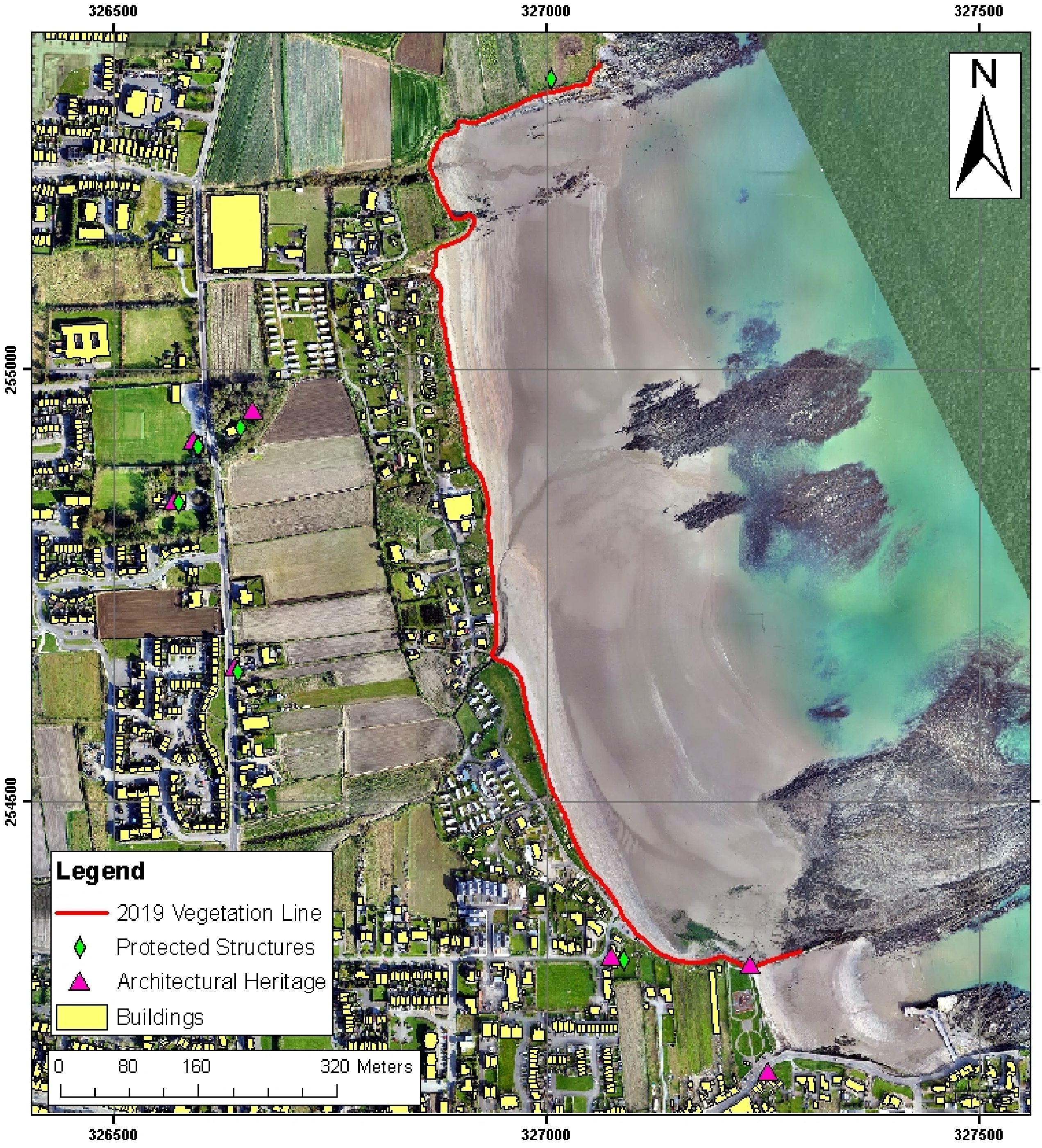


Figure 1.11: Overview of buildings and other assets at Rush north in relation to the 2019 vegetation line

1.3.3 Rogerstown Estuary

The Rogerstown Estuary is situated about 2 km north of Donabate in north County Dublin. It is a relatively small, funnel shaped estuary separated from the sea by a sand and shingle peninsula. The site extends eastwards to include an area of shallow marine water. The estuary receives the waters of the Ballyboghil and Ballough rivers and has a wide salinity range, from near full seawater to near full freshwater. The estuary is divided by a causeway and narrow bridge, built in the 1840s to carry the Dublin Belfast railway line. At low tide extensive intertidal sand and mud flats are exposed and these provide the main food resource for wintering waterfowl that use the site.

The intertidal flats of the estuary are comprised mainly of sands, with soft muds in the northwest sector and along the southern shore. Rogerstown Estuary is of high environmental importance and is designated a Special Protection Area (Rogerstown Estuary SPA; Site Code: 004015) and a Special Area of Conservation (Rogerstown Estuary SAC; Site Code: 00208), a Natural Heritage area, a Ramsar Conservation Wetland and a Statutory Nature Reserve.

1.3.3.1 Existing coastal defences inside Rogerstown estuary

The shoreline inside the estuary is probably the most well defended of the shorelines of the three main study areas. To the west of the Rogerstown estuary approximately 1km of well-conditioned rock armour revetment protects the main Belfast – Dublin rail line.

The lee side of Portrane spit is also partially protected by localised sections of rock armour. However, given that only relatively small wind waves generated across the estuary are likely to affect this coastline, coastal erosion is unlikely to be an important issue in this region.

A seawall protects approximately 250m of minor road along Channel road and Spout lane, part of which is illustrated in Figure 1.12 below. An additional 250m of Channel road is further protected by a rock armour revetment. However, as demonstrated in Figure 1.13 overleaf there are several sections of the concrete seawall that have been badly damaged which would make this area susceptible to flooding from combined tide and surge activity (i.e. mechanism 1 of flooding). As described later in Section 7.3 of this report the crest level of the seawall also gradually reduces towards the west which again contributes to the potential flood risk in this area.

The crest level of the rock armour illustrated in Figure 1.14 is also very low and would be insufficient to prevent coastal flooding either as a result of wave overtopping or the combined action of tide and surge activity.

Figure 1.12: The existing seawall at the junction of Spout lane and Channel road (© Google Earth)

Figure 1.13: Damaged section of the existing seawall along the Channel road (© Google Earth)

Figure 1.14: Low crest level of the existing rock revetment at the western extent of Channel road (© Google Earth)

2 HISTORICAL REVIEW

2.1 Historical Retreat

To better understand the coastal processes across the study areas, a review was undertaken of historical maps and orthophotography acquired from Ordnance Survey Ireland. This data comprised mapping from between 1973 and 2019 and provided insight into the evolution of the beaches over the past *c.*50 years.

Each dataset was accurately geo referenced using ArcGIS and the vegetation line (i.e. the boundary of where visible vegetation growth was observed on the upper beach) was digitised. Figure 2.1 to Figure 2.13 illustrate the historical retreat of the shoreline across the study areas between 1973 and 2019. In these figures the position of past vegetation lines is projected onto orthophotographs that were collected in early 2019 and thus illustrate the recent coastal alignment of each area.

2.1.1 The Burrow

As can be seen from Figure 2.1 and Figure 2.2 the coastal change along the Burrow peninsula since 1973 has been very complex.

Based on the 1973 and 2000 vegetation lines, the southern section of the Burrow has accreted a significant volume of material which resulted in the shoreline advancing seaward by *c.*20m. The position of the shoreline then remained relatively static between 2000 and 2005, exhibiting little net movement. Since 2005 the position of the shoreline remained relatively stable during summer months but retreated significant distances during some winter periods indicating that shoreline movement in this area is a result of ***acute erosion*** (i.e. storm specific, event driven) as opposed to ***chronic erosion*** (gradual, long-term).

Previous studies of the Burrow area had identified a potential long-term pattern in the sediment transport regime whereby sand material was gradually eroded from the beach and dunes along the Burrow and transported to the beach at Rush south. However, as described in Section 4.6, the effect of the strong currents from the Rogerstown estuary are likely to prevent any significant volumes of sediment being transported from along the Burrow to Rush south. These same strong currents are expected to prevent any significant volume of sediment being transported from Rush South or North onto the Burrow which may contribute to a deficit in the sediment supply.

It should be noted that some of the historical photos presented in Section 2.1.1.1 indicate that main erosion pressures were once found along the southern section of the Burrow in c.1950 as opposed to the middle of the Burrow as at present. This does not necessarily demonstrate that the precise location of erosion pressures along the Burrow are governed by a long-term cycle but instead suggests that the prevailing coastal conditions during what could have been a singular event affected the southern section more than the middle section.

Following the winter period of 2018 during which Storm Emma and several other subsequent storms impacted the east coast of Ireland, the shoreline along the southern section of the Burrow retreated by more than 20m in some locations. The erosion and shoreline retreat during this period was so severe that the private residential property illustrated in Figure 2.4 had to be demolished due to its proximity to the edge of the dune.

In respect to the effectiveness of the existing units, an assessment of a topographic survey undertaken in February 2020 found that that erosion rates behind the Seabee units were generally c.60% less than those observed much further north. These erosion rates are summarised in Figure 2.3.

This figure also illustrates the high erosion rates at Beach Lane which is well beyond the zone of influence of the Seabee units which demonstrates that the Seabee units are not the cause of coastal erosion along the northern section of the Burrow.

Figure 2.1: Historical coastal change along the southern region of The Burrow between 1973 and 2019 with recent orthophotography

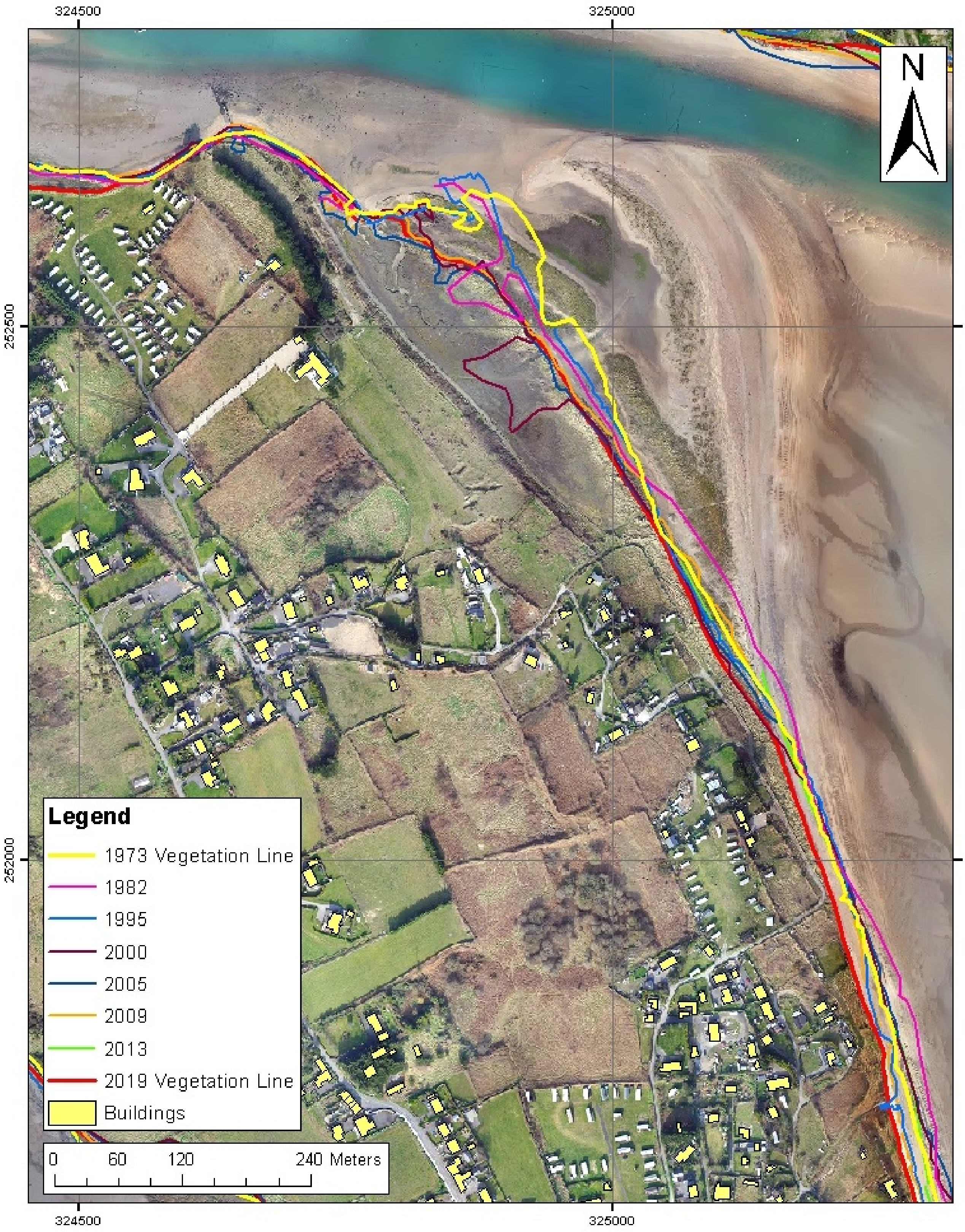


Figure 2.2: Historical coastal change along the northern region of The Burrow between 1973 and 2019 with recent orthophotography

Figure 2.3: Erosion along the Burrow between 2019 and 2020

Figure 2.4: Aerial view of the residential property (inside of red box) that was demolished following the extreme winter period of 2018

2.1.1.1 Historical aerial photography from *c.* 1950

Fingal County Council also provided a series of aerial photographs of the Burrow which dated back to *c.*1950. Although it was not possible to accurately geo-reference these pictures to determine the net shoreline movement between *c.*1950 and present, RPS have presented these historical images alongside contemporary imagery taken from Google Earth in Figure 2.5 to Figure 2.10.

By inspecting these figures it is possible to compare the gradual development of the Burrow and the evolution of the shoreline and beach area between *c.*1950 and present. Unfortunately, no historical aerial photographs were made available for Rush South or North.

It will be seen from Figure 2.5 that *c.*180m length of sheet piling seen along the southern section of the Burrow has since been buried by an accretion of sediment. The small area of land immediately adjacent to the sheet piling is no longer occupied by a cottage and the shoreline is set back relative to *c.*1950.

As demonstrated by Figure 2.6 and Figure 2.7, the middle section of the Burrow was relatively undeveloped compared to the present time. Anecdotal evidence indicates that most of the property on the Burrow during the 1950's comprised of small cottages and holiday caravans etc. Although it will be seen than none of these properties were near the shoreline which is in stark contrast to the current situation along the Burrow. Based on these historical photographs it is estimated that the current position of the shoreline is approximately 15 – 20m landward relative to the *c.*1950 shoreline.

It is difficult to determine if the width of the marshland towards the north of the Burrow has decreased or whether it just appears smaller due to the development of property and access roads etc. Either way, the immediate hinterland in this area is now much more developed than it once was. The width of the marshland further north does appear to have increased in width as shown in Figure 2.9.

As shown in Figure 2.10 the northern extent of the Burrow, at the entrance to Rogerstown estuary, remains relatively undeveloped with both the natural and built environments having underwent the least change. On the contrary, several properties were developed along the frontage of Rush South since *c.*1950.

Figure 2.5: The southern section of the Burrow *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

Figure 2.6: The southern section of the Burrow *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

Figure 2.7: The middle section of the Burrow *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

Figure 2.8: The middle section of the Burrow *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

Figure 2.9: The northern section of the Burrow *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

Figure 2.10: The entrance to Rogerstown estuary in *c.*1950 (upper) and *c.*2018 (lower) (© Google Earth).

2.1.2 Rush South

As is illustrated in Figure 2.11 the inner region of the Rush south beach been gradually retreating whilst the outer region of the beach has been gradually accreting since 1973. In the area fronting the golf course, the vegetation line remained relatively stable from 1995 to 2013, although after this, between 2013 and 2019, the shoreline in this region has retreated by *c.*30m.

At the northern extent of this beach in the region of the carpark and bathing area, the position of the shoreline has advanced by approximately 20m between 1973 and 2019. There are localised sections of the shoreline that is protected by rock armour in this area. The fact that much of this armour is now buried beneath sand indicates this area is a net sediment sink and is gradually advancing landward.

2.1.3 Rush North

The historical analysis of coastal change at Rush north indicated that between 1973 and 2019 there was a modest degree of accretion. This resulted in a general net advancement of the shoreline of up to 20m between 1973 and 2019. There are sections of this shoreline protected by rock armour, particularly around the carpark. This section of armour was constructed to protect the carpark and the gas pipeline that comes ashore at this point.

It will be noted from Figure 2.13 and Figure 2.14 that there are localised sections of Rush north that retreated by several metres between 2012 and 2019. Based on the wave climate, anecdotal evidence it is believed that the coastal retreat between 2012 and 2019 was most likely to have occurred during the time of Storm Emma.

2.1.4 Summary of Coastal Change between 1973 and 2019

Using the geo-referenced digitised shoreline datasets described earlier, RPS assessed the rate of coastal change across the study area between 1973 and 2019. The results from this assessment are presented in Table 2.1. It will be seen from this Table that the rate of erosion has historically been greatest along the Burrow.

Between 2013 and 2018 the shoreline was found to have retreated along the Burrow by up to *c.* 3m per year, this rate was *c.* x1.5 greater than that observed at Rush south during the same period. It should be noted that most of this coastal change is believed to have occurred during the winter period of 2017/2018 when Storm Emma and a succession of additional storm events resulted in acute coastal change along the Burrow. This winter period of 2017/2018 was noted by Met Éireann and the UK Met Office to have been one of the worst winters in recent history.

Table 2.1: Summary of the historical erosion rates at the five study area between 1973 and 2019

Area	Coastal Change (m/yr) (negative = erosion , positive = accretion)								
	1973 - 1982	1982 - 1995	1995 - 2000	2000 - 2005	2005 - 2009	2009 - 2011	2011 - 2013	2013 - 2018	2018 - 2019
The Burrow	0.46	-0.37	-0.96	0.58	-0.70	0.54	-1.12	-3.06	-1.88
Rush South	-0.00		-0.31	1.18	0.59	-0.07	-0.21	-1.91	-0.65
Rush North	0.18			-0.06	0.34			-0.18	

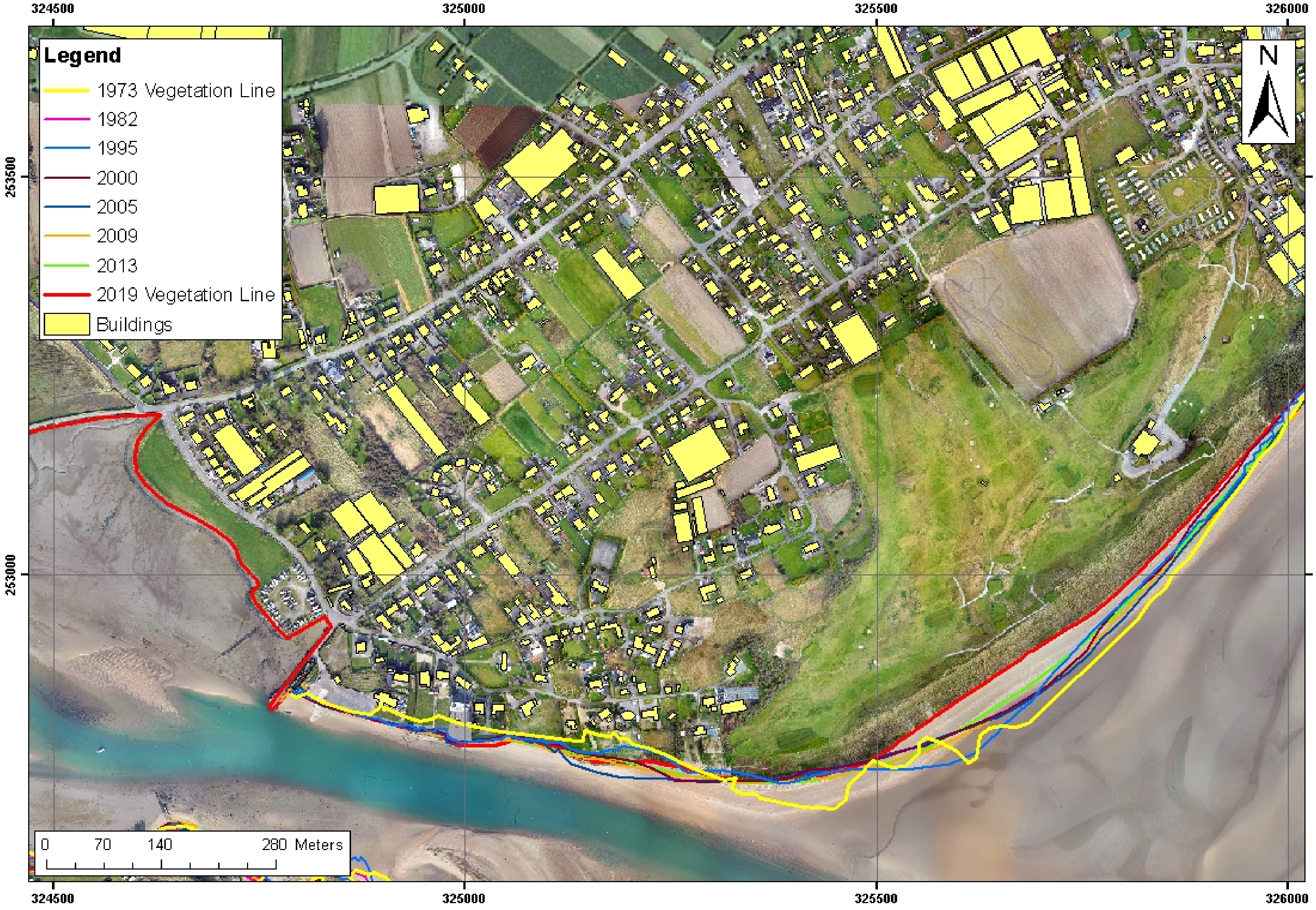


Figure 2.11: Historical coastal change along the inner region Rush South between 1973 and 2019 with recent orthophotography

Figure 2.12: Historical coastal change along the outer region Rush South between 1973 and 2019 with recent orthophotography

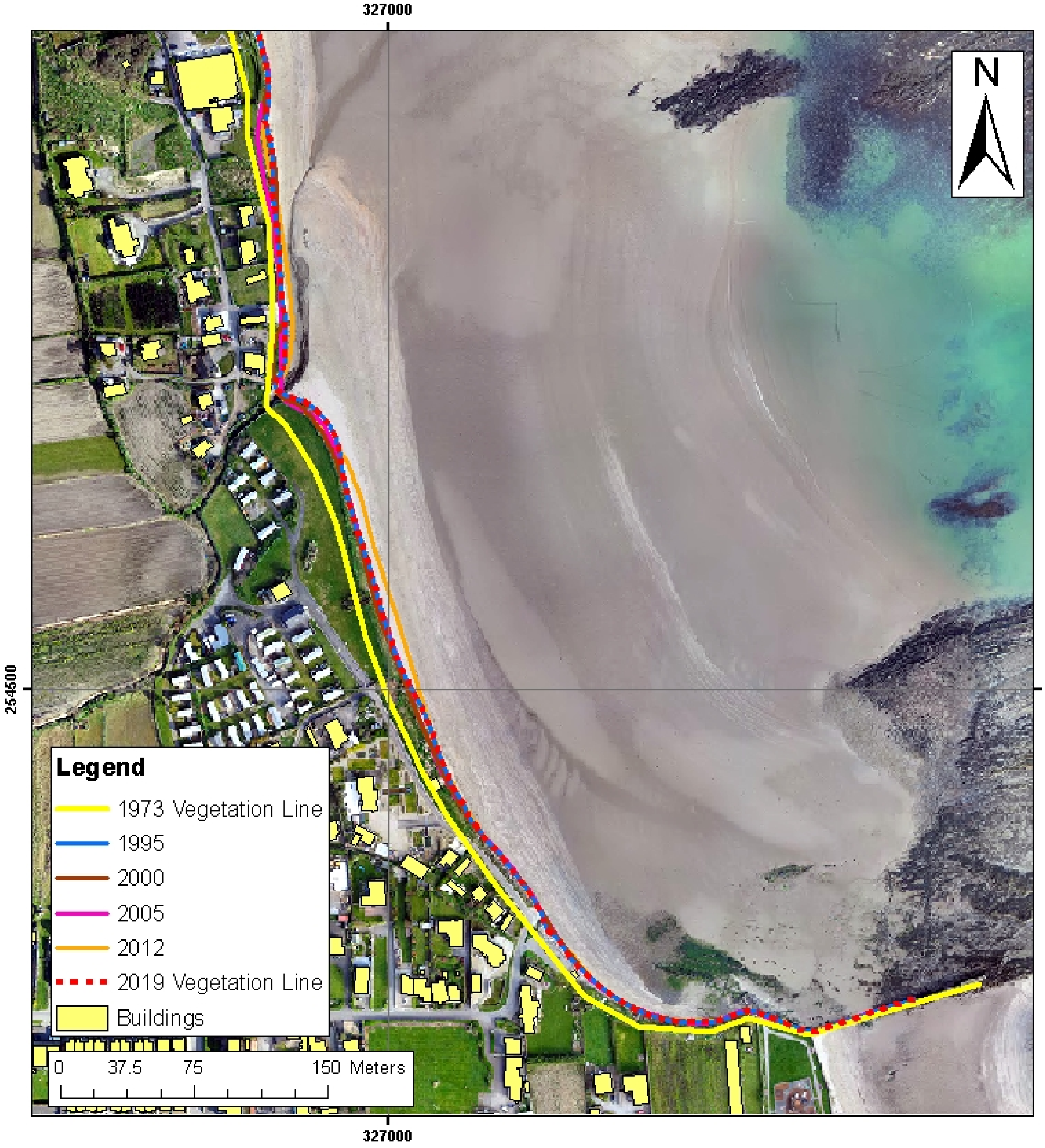


Figure 2.13: Historical coastal change along the lower region of Rush North between 1973 and 2019 with recent orthophotography

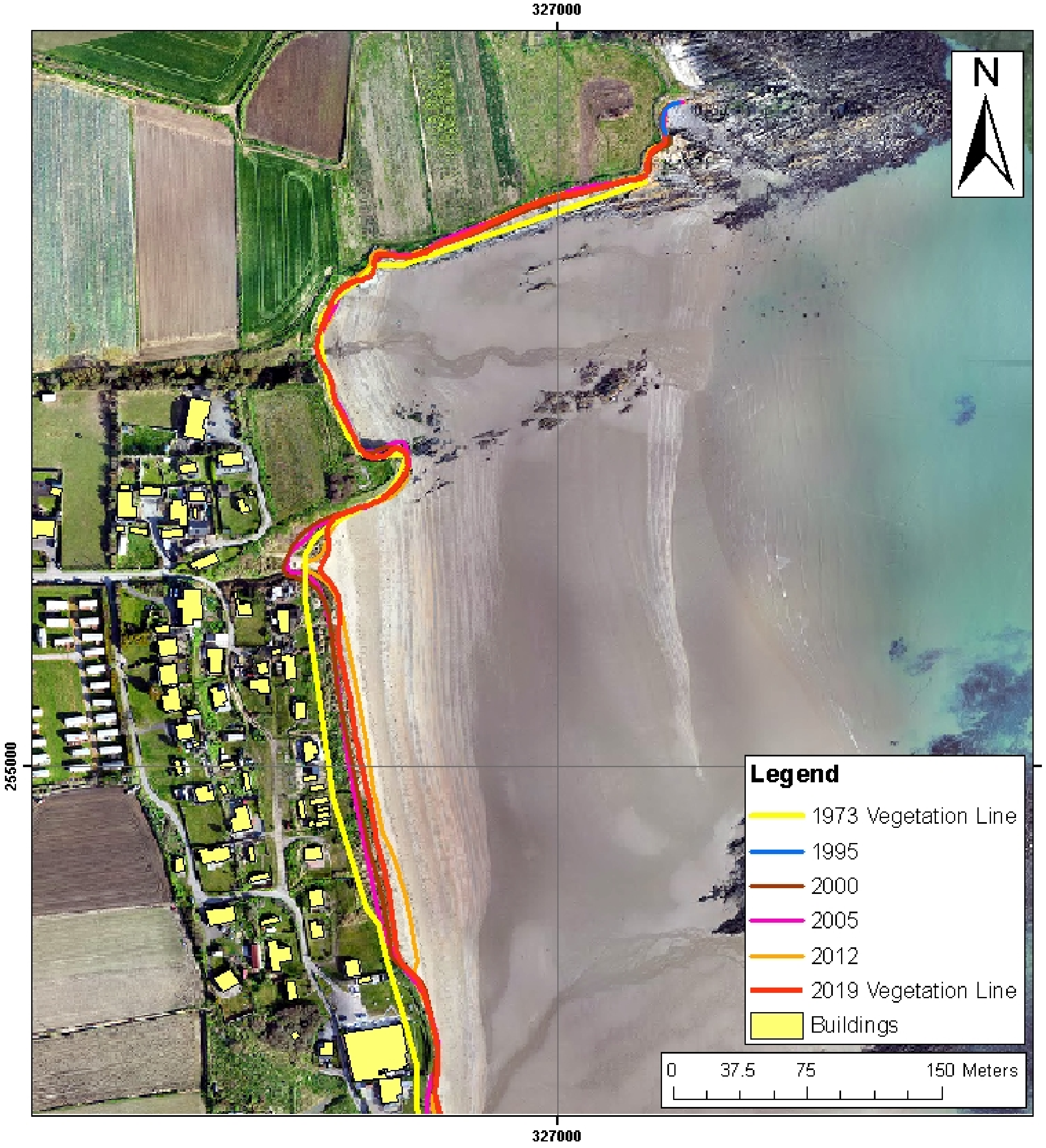


Figure 2.14: Historical coastal change along the upper region of Rush North between 1973 and 2019 with recent orthophotography

3 PLANNING POLICIES

The remit of this CFERM study was reviewed in context of relevant planning and environmental policy. As such, the following documents were consulted during this process:

1. **Fingal Development Plan 2017-2023** (Fingal County Council, 2017)**.**
2. **Regional Planning Guidelines for the Greater Dublin Area 2010-2022** (The Regional Planning Guidelines Office, 2010)**.**
3. **The National Development Plan, 2018 – 2027** (Department of Public Expenditure and Reform, 2018)**;** and
4. **The National Spatial Strategy, 2002–2020** (Department of Environment, Heritage and Local Gov, 2002)

Each of these policy documents are reviewed in the following Sections of this report, with relevant aims and objectives being summarised in each appropriate Section.

3.1 Fingal County Development Plan, 2017 – 2023

The Fingal Development Plan 2017-2023 sets out the Council's proposed policies and objectives for the development of the County over the Plan period. The Development Plan seeks to develop and improve, in a sustainable manner, the social, economic, environmental and cultural assets of the County. The Plan was prepared in accordance with the requirements of the Planning and Development Act, 2000 (as amended).

Some of the main aims of the Fingal Development 2017 – 2023 which were relevant to this CFERM study were to:

1. Plan for and support the sustainable long-term development of Fingal as an integrated network of vibrant socially and economically successful urban settlements and rural communities, strategic greenbelts and open countryside, supporting and contributing to the economic development of the County and of the Dublin City Region.
2. Provide for the future wellbeing of the residents of the County by:
    - Supporting economic activity and increasing employment opportunities.
    - Protecting and improving the quality of the built and natural environments.
    - Ensuring the provision of adequate housing, necessary infrastructure and community facilities.
    - Promoting and improving quality of life and public health.
    - Build on the progress made in the County following the conclusion of the previous development plan.
3. Incorporate sustainable development, climate change mitigation and adaptation, social inclusion, high quality design and resilience as fundamental principles, cross cutting and underpinning the Development Plan.

6. Foster the development of socially and economically balanced sustainable communities.

The Development Plan describes how the Strategic Policy will deliver on these main aims and others by seeking to:

1. Promote sustainable development by providing for the integration of economic, environmental, social and cultural issues into Development Plan policies and objectives, utilising the Strategic Environmental Assessment (SEA) and Appropriate Assessment (AA) processes.
2. Contribute to the creation of a more socially inclusive, equal and culturally diverse society by providing for appropriate community infrastructure, quality public realm and improving access to information and resources. Seek new innovative ways of enhancing social inclusion and ensure the Plan can facilitate initiatives arising from the Social Inclusion and Community Activation Programme (SICAP), where appropriate.

3. Add quality to the places where Fingal's communities live, work and recreate by integrating high quality design into every aspect of the Plan promoting adaptable residential buildings and ensuring developments contribute to a positive sense of place and local distinctiveness of an area.
6. Consolidate development and protect the unique identities of the settlements of Howth, Sutton, Baldoyle, Portmarnock, Malahide, Donabate, Lusk, Rush and Skerries.
11. Protect, maintain and enhance the natural and built heritage of the County, particularly the coastal areas which are of such importance to residents of and visitors to the Dublin region
20. Ensure new developments have regard to the requirements of the Planning System and Flood Risk Management Guidelines.
22. Minimise the County's contribution to climate change, and adapt to the effects of climate change, with particular reference to the areas of land use, energy, transport, water resources, flooding, waste management and biodiversity, and maximising the provision of green infrastructure including the provision of trees and soft landscaping solutions.
23. Promote and maximise the benefits of quality of life, public health and biodiversity arising from implementation of policies promoting climate change adaptation and mitigation.
24. Encourage innovation and facilitate the development of pilot schemes that support climate change mitigation and adaptation.

The Plan is underpinned by the principles of sustainable development, climate change adaptation, social inclusion and high-quality design. Although this study will not go into detail regarding each of these subjects, several key environmental challenges that were identified in the Plan for Fingal are outlined below:

- Protecting the ecological integrity of European (Natura 2000) sites, the Special Amenity Areas and the Dublin Bay Biosphere Reserve, while allowing for ongoing growth and development.
- Management of the coastline including the management of flood risk and dune conservation measures will be increasingly important in response to the impacts of predicted climate change and increased population pressure.
- Maintenance and improvement of the environmental and ecological quality of Fingal's watercourses and coastal waters pursuant to the requirements of the Water Framework Directive.
- Management of flood risk along the County's watercourses taking account of climate change predictions.
- Management of the County's varied landscapes so that change maintains and enhances landscapes of high-quality and improves landscapes.

It should be noted that this Coastal Flooding and Erosion Risk Management Study is in line with Objectives 5 and 6 for Urban Fingal at Portrane. These objectives are to:

Objective PORTANE 5: Ensure the sensitive coastal estuarine area of The Burrow is adequately protected and that any proposed development is subject to environmental assessment including Screening for Appropriate Assessment.

Objective PORTANE 6: Prepare a study to decide on the optimal future development of lands in The Burrow area, having regard to the local issues of coastal erosion, flooding, drainage and the significant landscape and biodiversity sensitivities in the area including a Flora Protection Order, Special Protection Area (SPA), Natural Heritage Area (NHA), Special Area of Conservation (SAC) and designated Ecological Buffer Zone.

This CFERM study is also in line with Objectives 10 and 15 for Urban Fingal at Rush. These objectives are to:

Objective RUSH 10: Prepare and implement the Management Plan for the Outer Rogerstown Estuary Plan and subject the Plan to Screening for Appropriate Assessment prior to its adoption.

Objective RUSH 15: Undertake a study, within one year of the making of this Development Plan, of lands in Rush located at North Beach, and implement its recommendations to ensure that planning policy in

> Rush takes into consideration the dynamic nature of coastal processes and the predicted impacts of climate change in the proper planning and sustainable development of the town and its environs.

In respect to coastal flooding, the Plan sets out several objectives in relation to surface water and flood risk management. Some of these objective relevant to this study are:

> **Objective SW01** Protect and enhance the County's floodplains, wetlands and coastal areas subject to flooding as vital green infrastructure which provides space for storage and conveyance of floodwater, enabling flood risk to be more effectively managed and reducing the need to provide flood defences in the future and ensure that development does not impact on important wetland sites within river / stream catchments.
>
> **Objective SW02** Allow no new development within floodplains other than development which satisfies the justification test, as outlined in the Planning System and Flood Risk Management Guidelines 2009 for Planning Authorities (or any updated guidelines).
>
> **Objective SW03** Identify existing surface water drainage systems vulnerable to flooding and develop proposals to alleviate flooding in the areas served by these systems.
>
> **Objective SW04** Require the use of sustainable drainage systems (SuDS) to minimise and limit the extent of hard surfacing and paving and require the use of sustainable drainage techniques where appropriate, for new development or for extensions to existing developments, in order to reduce the potential impact of existing and predicted flooding risks.
>
> **Objective SW05** Discourage the use of hard non-porous surfacing and pavements within the boundaries of rural housing sites.
>
> **Objective SW06** Encourage the use of Green Roofs particularly on apartment, commercial, leisure and educational buildings.
>
> **Objective SW07** Implement the Planning System and Flood Risk Management-Guidelines for Planning Authorities (DoEHLG/OPW 2009) or any updated version of these guidelines. A site-specific Flood Risk Assessment to an appropriate level of detail, addressing all potential sources of flood risk, is required for lands identified in the SFRA, located in the following areas: Courtlough; Ballymadun; Rowlestown; Ballyboghil; Coolatrath; Milverton, Skerries; Channell Road, Rush;
>
> **Objective SW11** Ensure that where flood protection or alleviation works take place that the natural and cultural heritage of rivers, streams and watercourses are protected and enhanced to the greatest extent possible.
>
> **Objective SW12** Require an environmental assessment of all proposed flood protection or alleviation works

The Plan recognises that coastal erosion is intrinsically linked with coastal flooding as the loss of natural coastal defences such as sand dunes due to erosion can increase the risk of flooding in coastal areas. Specific objectives relating to natural heritage are presented below.

> **Objective NH09:** Support the National Parks and Wildlife Service, Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs, in the maintenance and, as appropriate, the achievement of favourable conservation status for the habitats and species in Fingal to which the Habitats Directive applies.
>
> **Objective NH10:** Ensure that the Council takes full account of the requirements of the Habitats and Birds Directives, as they apply both within and without European Sites in the performance of its functions.
>
> **Objective NH11:** Ensure that the Council, in the performance of its functions, takes full account of the objectives and management practices proposed in any management or related plans for European Sites in and adjacent to Fingal published by the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs.
>
> **Objective NH16:** Protect the ecological integrity of proposed Natural Heritage Areas (pNHAs), Natural Heritage Areas (NHAs), Statutory Nature Reserves, Refuges for Fauna, and Habitat Directive Annex I sites.

Objective NH17: Ensure that development does not have a significant adverse impact on proposed Natural Heritage Areas (pNHAs), Natural Heritage Areas (NHAs), Statutory Nature Reserves, Refuges for Fauna, Habitat Directive Annex I sites and Annex II species contained therein, and on rare and threatened species including those protected by law and their habitats.

Objective NH33: Ensure the preservation of the uniqueness of a landscape character type by having regard to the character, value and sensitivity of a landscape when determining a planning application.

Objective NH36: Ensure that new development does not impinge in any significant way on the character, integrity and distinctiveness of highly sensitive areas and does not detract from the scenic value of the area

As stated in the Plan, the coast is an ever-changing dynamic environment, subject to the continuous natural processed of erosion and deposition. It is recognised that defending long stretches of soft shoreline from erosion and coastal flooding may become technically and economically unsustainable in the future as a result of climate change conditions. Expanding on this, the Plan presented several specific Natural Heritage objectives that relate to coastal protection. These objectives are presented below:

Objective NH53: Ensure the County's natural coastal defences, such as beaches, sand dunes, salt marshes and estuary lands, are protected and are not compromised by inappropriate works or development.

Objective NH54: Where coastal erosion is considered a threat to existing properties, explore the technical and economic feasibility of coastal adaptation and coastal retreat management options.

Objective NH55: Employ soft engineering techniques as an alternative to hard coastal defence works, wherever possible.

Objective NH56: Identify, prioritise and implement necessary coastal protection works subject to the availability of resources, whilst ensuring a high level of protection for natural habitats and features, and ensure due regard is paid to visual and other environmental considerations in the design of any such coastal protection works.

Objective NH57: Undertake erosion risk management studies for high risk areas so that the long-term erosion risks to property can be clearly identified long before the risk may be expected to occur.

Objective NH58: Develop a coastal erosion policy for Fingal based on best international practice to outline how the Council will deal with existing properties at risk of erosion and how future coastal erosion problems will be managed having regard to national climate change legislation, mitigation and adaptation policies, and the need to protect the environment.

3.2 Regional Planning Guidelines for the Greater Dublin Area 2010-2022

A regional approach to integrated coastal zone management (ICZM) is supported by the NSS and recommended by the EU. The ICZM model offers a means to sustainably manage the development of the coastal zone through a collaborative and community focussed approach to planning and management of coastal resources. It is also concerned with the promotion of sustainable marine focused tourism and leisure activities, and protection of marine and coastal environments.

A balance must be struck between the wide range of activities possible. This balance includes the requirements of provisions for recreation, public slipways and marina activity against international and national obligations to protect and responsibly manage designated cultural and natural heritage coastal areas. Globally, marine environments are experiencing growing pressure from increasing populations along the coast; infrastructural and recreational development within coastal areas; the necessary building of flood defences causing a coastal squeeze on marine habitats; the effects of climate change (flooding, increases in invasive species, and reduction in ocean salinity); and pollution from land side agricultural and industrial activities.

Coastal erosion and flooding has the potential to affect properties, businesses and infrastructure and can lead to loss of coastal archaeology and sites of architectural or tourism importance. ICZM needs to address this issue looking at:

- Precautionary approaches should be taken including the creation of buffer zones to restrict development within areas of high-risk erosion, predicted sea level increase or high coastal flooding risk and
- Suitable sustainable options for protecting key assets- natural, built and infrastructure; and a full exploration of all the issues including habitat impact, through the preparation of Coastal Zone Management Plans with local authorities, state bodies and communities working together. The completion of the Catchment Flood Risk Assessment and Management Studies (CFRAMS) and the Irish Coastal Protection Strategy will also provide valuable information to local authorities on flood risk in coastal areas, which can input into future Coastal Zone Management Plan.

Regional planning guidelines in respect to Integrated Coastal Zone Management (ICWM)) are presented in *Section 7.5* whilst the main strategic policy is presented below.

> **Strategic Policy GIP4:** Promote the development of cross boundary Integrated Coastal Zone Management with all coastal local authorities in the GDA area so that future Development Plans can be guided in relation to the management of coastal areas drawing from a mutually supported plan for marine and coastal areas that has engaged with key stakeholders.

To achieve this strategic policy, a series of strategic recommendations were presented in the guidelines. A selection of these recommendations is presented below.

> **GIR22:** The completion of an ICZM for Dublin Bay, building on research and the completion and implementation of the recommendations of the Dublin Bay Taskforce and working collaboratively to achieve an agreed framework plan or strategy incorporating land and marine planning and policies in an integrated manner and with regard to Article 6 of the Habitats Directive.
>
> **GIR23:** The expansion of collaborative ICZM, and consideration of the complementary process and framework of marine spatial planning, for similar cohesive coastal landscape blocks to Dublin Bay along the eastern seaboard. This process shall take account of the:
>
> - Water Framework Directive,
> - Birds Directive,
> - Marine Strategy Framework Directive,
> - Flood Risk Assessment studies,
> - Article 6 of the Habitats Directive,
> - Best available information on the regional impacts of climate change and
> - All current and future alignments between these directives, assessments, and plans.
>
> **GIR24** That the concept of coastal parks is considered in future planning as a means of enhancing coastal habitats marine protection and sustainable marine based tourism and of integrating coastal (blue) infrastructure with green infrastructure.

Any proposed scheme within the Rogerstown estuary area should be consistent with the objectives of the plans outlined above. Development should make a positive contribution to fulfilling the strategic objectives of the policy documents in a manner consistent with present planning and environmental policies.

3.3 National Development Plan 2018 – 2027

The National Development Plan highlights that an investment of €350 million since 1995 has already delivered 42 major flood relief schemes around the country. These schemes are currently providing protection to 9,500 properties and an economic benefit to the State in damage and losses avoided estimated at 1.9 billion.

The plan states that €430 million has been allocated for flood mitigation initiatives over the period 2016 to 2021 to protect threatened communities from river and coastal flood risk. This funding is supporting the development and implementation of a significant existing flood relief investment programme which includes eight major flood relief schemes under construction and 26 schemes under design and at planning to protect 11,200 properties. The plan lists several major projects however none of these are in the Rogerstown estuary area.

The Plan continues "*The Government is committed to the policy objective of delivering further capital works/flood relief schemes to minimise the impacts of river and coastal flooding on society through the roll-out of the 29 Flood Risk Management Plans. Delivery of this capital works programme will be underpinned by a total investment of up to €940 million over the lifetime of the National Development Plan.*

The 29 plans include proposed flood relief schemes which will need to be prioritised. The prioritisation process, which relates primarily to the proposed physical flood-protection measures, will be based on an evaluation process including Multi-Criteria Analysis and benefit to cost-ratio (which represents the overall benefits, on balance across each of the objectives, per Euro cost of a proposed measure), and the risk arising from the nature of the local flood waters within a community. The prioritisation will be applied on a regional basis."

The latest National Development Plan does not discuss coastal erosion.

3.4 The National Spatial Strategy 2002 - 2020

The National Spatial Strategy (NSS) is a coherent national planning framework for Ireland for up to 2020 years. The NSS aims to achieve a better balance of social, economic and physical development across Ireland, through more effective planning policy. The National Development Plan has been formulated in accordance with the NSS, specifically through a chapter on balanced regional development. Within the NSS, this relates to coastal development through the following:

- The sustainable development of the marine and natural resources sectors has a key role to play in supporting and advancing the economic well-being of rural and coastal areas. It is of importance for peripheral coastal communities. The following spatial issues arise:
    - Coastal infrastructure commensurate with the needs of the seafood and marine leisure sectors, at strategic ports and other key locations of particular importance for local economies must be developed.
    - An appropriate balance must be struck between the wide range of economic, leisure and amenity activities and uses in coastal and island areas.
    - Access infrastructure appropriate

3.5 Summary of Planning Policies

In summary, the key strategic aims and objectives of the local, regional and national planning documents that were reviewed as part of this CFERM study can be summarised by the points below.

- To preserve and improve amenities.
- To foster balanced Regional Development.
- To enhance and promote a high-quality environment.
- Invest in long-term environmental sustainability to achieve our national goal of preserving the integrity of our natural environment for future generations as well as meeting our international responsibilities and Climate Change obligations; this also involves a more balanced, efficient and sustainable use of our land resources.
- To meet the future development needs of the community.
- To promote a high-quality design in new development.
- To ensure that nature conservation policies contribute to conservation of the abundance and diversity of the Irish wildlife and its habitats.
- To minimise the adverse effects on wildlife, where conflict of interest is unavoidable.
- To meet international responsibilities and obligations for nature conservation.

3.6 Other Relevant Documents

In addition to the national and regional planning policy documents discussed in the previous Section of this report there are two further documents of relevance to this CFERM report. These two documents are presented below and discussed in the following Section of this report.

1. **National Adaptation Framework Planning for a Climate Resilient Ireland** (Depart. of Communications, Climate Action and Env., 2018); and
2. **Flood Risk Management, Climate Change Sectoral Adaptation Plan** (Office of Public Works, 2019)

3.6.1 National Adaptation Framework, Planning for a Climate Resilient Ireland

Arising from the 2012 National Climate Change Adaptation Framework (NCCAF), the National Adaptation Framework (NAF) was developed and approved in accordance with Section 5 of the Climate Action and Low Carbon Development Act 2015. In accordance with the 2015 Act, this NAF specifies the national strategy for the application of adaptation measures in different sectors and by local authorities in their administrative areas in order to reduce the vulnerability of the State to the negative effects of climate change and to avail of any positive effects that may occur.

The NAF therefore sets out the context to ensure local authorities, regions and key sectors can assess he key risks and vulnerabilities of climate change, implement climate change resilience actions and ensure climate adaption considerations are mainstreamed into all local, regional and national policy making.

The structure of the NAF is split into four separate chapters which address the following topics:

Chapter 1 provides a summary of observed and projected climate change globally as well as the international and European policy drivers for adaptation to climate change. The chapter also presumed several observed and projected climate change impacts in Ireland and a summary of the impacts that may arise in Ireland as a result.

Chapter 2 sets out the progress on climate change adaptation planning in Ireland to date, including work undertaken at sectoral and local government level and initiatives engaging civil society and research.

Chapter 3 provides guiding principles for adaptation at national level and steps to create an enabling environment for adaptation planning. It sets out the sectors for which adaptation plans under the NAF are proposed, along with proposals for local authority or regional level adaptation strategies.

Chapter 4 outlines how the Framework will be implemented with revised Governance and reporting arrangements and actions and supporting objectives to be progressed.

The NAF document is very comprehensive and contains a significant volume of information that is of relevance to this study. However, in the interest of brevity, RPS have summarised each of the following Chapters below.

Chapter 1

The key findings presented below are based on the information presented in Chapter 1 of the Planning for a Climate Resilient Ireland Document.

- Warming of the global climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901 to 2010, global mean sea level rose by 0.19m (0.17 to 0.21m).
- Looking forward, Regional Climate Modelling (RCM) simulations have projected:
    - A sea level rise of *c.*55-60cm to 2100 (based on medium scale climate warming scenarios) (Dunne et al., 2008; Lowe et al., 2009).

- Changes in mean sea level predicted will be the primary driver in magnifying the impacts of changing storm surge and wave patterns in coastal areas.
- Heavy rainfall events will increase in winter and autumn (Nolan, 2015).
- Wind and extreme events: the energy content of the wind is projected to decrease during spring, summer and autumn. The projected decreases are largest for summer, with values ranging from 3% to 15% (Nolan, 2015).
- Storms affecting Ireland will decrease in frequency, but increase in intensity, with increased risk of damage (Nolan, 2015).

These changes are projected to continue and increase over the coming decades (Gleeson et al, 2013; Nolan, 2015). Projected changes include temperature rise, changes in the frequency and intensity of extreme weather events; increased flows to river catchments; ongoing sea level rise; and changes in precipitation patterns and regimes. Observed and projected climate changes and impacts are also outlined in Table 3.1 overleaf.

The NAF document emphasises how these changes, in turn, will impact on several key socio, economic and environmental sectors in different ways which will require appropriate and relevant sectoral responses within the context of this Framework. Just two negative sectoral impacts arising from climate change have been summarised below:

> **Coastal areas:** Coastal erosion and flooding currently pose a serious risk to Ireland's coastal areas and this is particularly the case as Ireland's major cities and key pieces of infrastructure are located on the coast. **Key impacts include inundation of coastal areas, increase in the intensity of cyclones which will result in more extreme storm activity and an increase in coastal erosion.**
>
> **Human health and wellbeing:** Increase in extreme events will have significant impacts on health and wellbeing including risk of physical injuries/death, mental health effects from loss and displacement, such as from flooding and waterborne infectious diseases

Chapter 2

Chapter 2 presents progress to date in Ireland in planning for climate change and developing climate resilience. It discusses the link between climate adaptation and current emergency planning responses to extreme weather events as well as several other issues.

It is stated that of the projected six-fold projected increase in damages from flooding for the EU by 2050, about one-third is accounted for by increased flood risk due to climate change and two-thirds by the effects of anticipated socio-economic change (Jongman et al., 2014). A similar rate of increase in Ireland would see direct damages from flooding of roughly €1.15 billion per year by 2050 should appropriate adaptation measures not be introduced.

The chapter proceeds to discuss much of the statutory framework in place for dealing with flood adaptions and how national and local planning approaches can be implemented at various temporal and spatial scales.

Chapter 3

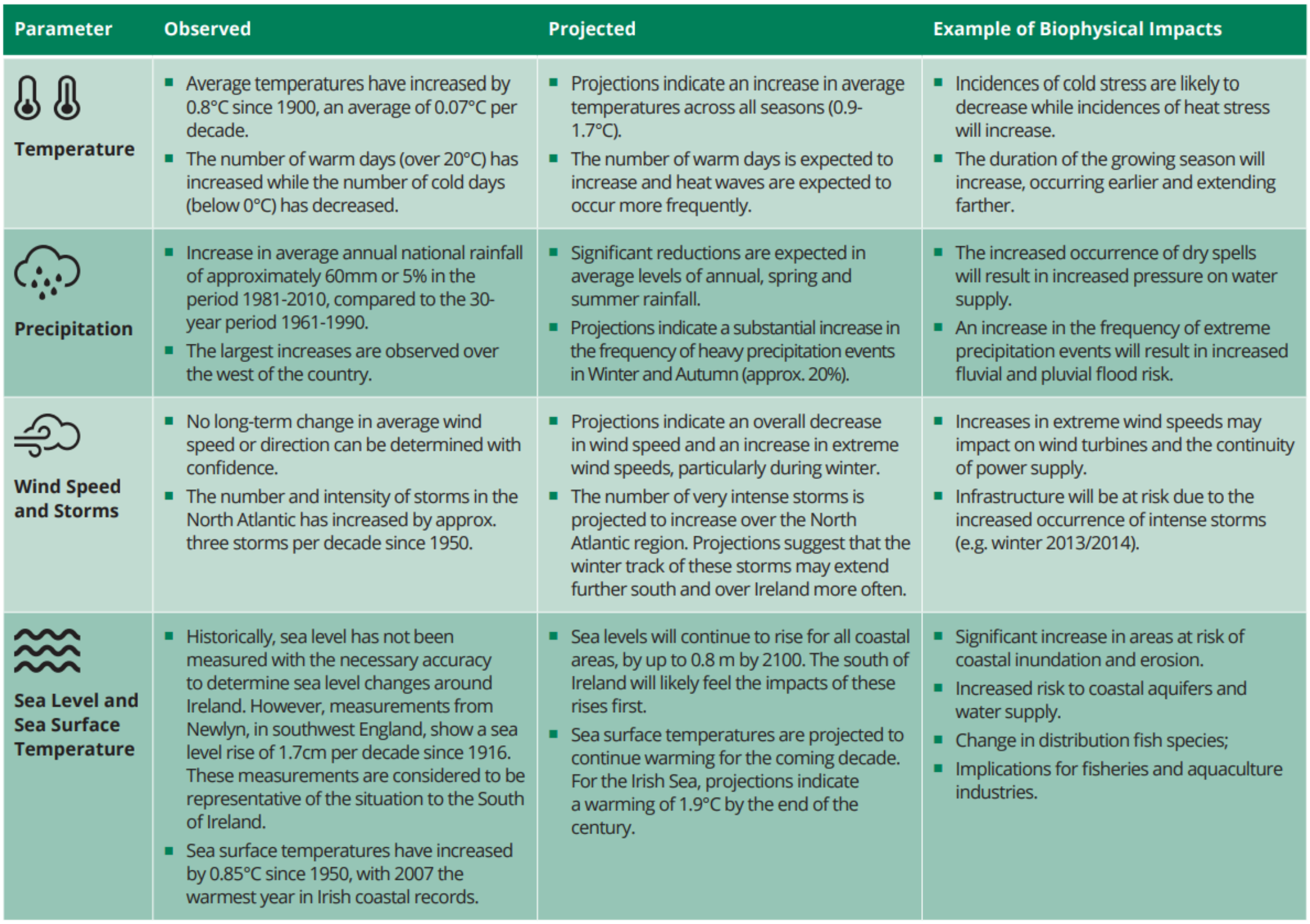
The key elements of the new National Adaptation Framework for delivering climate resilience is described in several sub-sections throughout this chapter. These sub-sections include but are not limited to the legislative and policy context for the Framework, a guiding set of principles for adaption, future research priorities and the reporting an implementation arrangements to ensure delivery.

There is a strong emphasis on promoting climate resilience in this chapter. Climate resilience can be defined as the capacity of a system, whether physical, social or ecological, to absorb and respond to climate change and by implementing effective adaptation planning and sustainable development (including governance and institutional design) to reduce the negative climate impacts while also taking advantage of any positive outcomes. This will allow the system to either return to its previous state or to adapt to a new state as quickly as possible.

It is recognised through the ongoing development of Ireland's *Capital Investment Plan (2018 -2017)* that climate resilience will require significant capital investment and evaluation of public expenditure. A key objective of the Plan is to illuminate the role of public capital investment in helping to achieve national climate action goals. These actions include those aimed at increasing flood resilience and adapting to climate change. The plan specifically identifies flood defences and adapting to new climate conditions.

In order to evaluate public expenditure, the document states that is essential that choices are informed by an assessment of the economic and financial impacts as early as possible at the appraisal stage. In respect to this CFERM study, preliminary and subsequent options that are short listed will be subject to a range of appraisal methodologies including a high-level cost assessment, Cost Benefit Analysis (CBA) and Multi Criteria Analysis (MCA)

Table 3.1: Summary of observed and projected climate changes and impacts for Ireland (NAF *Planning for a Climate Resilient Ireland*, 2018)



Parameter	Observed	Projected	Example of Biophysical Impacts
Temperature	▪ Average temperatures have increased by 0.8°C since 1900, an average of 0.07°C per decade. ▪ The number of warm days (over 20°C) has increased while the number of cold days (below 0°C) has decreased.	▪ Projections indicate an increase in average temperatures across all seasons (0.9-1.7°C). ▪ The number of warm days is expected to increase and heat waves are expected to occur more frequently.	▪ Incidences of cold stress are likely to decrease while incidences of heat stress will increase. ▪ The duration of the growing season will increase, occurring earlier and extending farther.
Precipitation	▪ Increase in average annual national rainfall of approximately 60mm or 5% in the period 1981-2010, compared to the 30-year period 1961-1990. ▪ The largest increases are observed over the west of the country.	▪ Significant reductions are expected in average levels of annual, spring and summer rainfall. ▪ Projections indicate a substantial increase in the frequency of heavy precipitation events in Winter and Autumn (approx. 20%).	▪ The increased occurrence of dry spells will result in increased pressure on water supply. ▪ An increase in the frequency of extreme precipitation events will result in increased fluvial and pluvial flood risk.
Wind Speed and Storms	▪ No long-term change in average wind speed or direction can be determined with confidence. ▪ The number and intensity of storms in the North Atlantic has increased by approx. three storms per decade since 1950.	▪ Projections indicate an overall decrease in wind speed and an increase in extreme wind speeds, particularly during winter. ▪ The number of very intense storms is projected to increase over the North Atlantic region. Projections suggest that the winter track of these storms may extend further south and over Ireland more often.	▪ Increases in extreme wind speeds may impact on wind turbines and the continuity of power supply. ▪ Infrastructure will be at risk due to the increased occurrence of intense storms (e.g. winter 2013/2014).
Sea Level and Sea Surface Temperature	▪ Historically, sea level has not been measured with the necessary accuracy to determine sea level changes around Ireland. However, measurements from Newlyn, in southwest England, show a sea level rise of 1.7cm per decade since 1916. These measurements are considered to be representative of the situation to the South of Ireland. ▪ Sea surface temperatures have increased by 0.85°C since 1950, with 2007 the warmest year in Irish coastal records.	▪ Sea levels will continue to rise for all coastal areas, by up to 0.8 m by 2100. The south of Ireland will likely feel the impacts of these rises first. ▪ Sea surface temperatures are projected to continue warming for the coming decade. For the Irish Sea, projections indicate a warming of 1.9°C by the end of the century.	▪ Significant increase in areas at risk of coastal inundation and erosion. ▪ Increased risk to coastal aquifers and water supply. ▪ Change in distribution fish species; ▪ Implications for fisheries and aquaculture industries.

Chapter 4

Finally, Chapter 4 outlines how the NAF will be implemented and governed at both national and local level. Naturally, much of this chapter deals with legislative and statutory issues at a high level. No information from chapter 4 has therefore been included in this report.

For further information on these issues, readers are referred to Chapter 4 of the *NAF Planning for a Climate Resilient Ireland* document.

3.6.2 Flood Risk Management, Climate Change Sectoral Adaptation Plan

This Plan has been prepared under the National Adaptation Framework (Depart. of Communications, Climate Action and Env., 2018), and updates its predecessor by considering new information available on climate change and its potential impacts. The purpose of the Plan in respect to flood risk management is to:

- outline the potential impacts of climate change on flooding and flood risk management in Ireland.
- identify the objectives for an effective and sustainable approach to adaptation as part of flood risk management for the future.
- promote a coordinated approach to adaptation:
    - within the flood risk management sector and sustainable flood risk management measures in other sectors, and,
    - across the policies and actions of other Sectors including Local Authorities, and,
- recommend any further actions required to meet the objectives for adaptation.

The long-term goal adopted by the OPW on climate adaptation for flooding and flood risk management is:

Promoting sustainable communities and supporting our environment through the effective management of the potential impacts of climate change on flooding and flood risk.

To deliver this goal, the OPW has identified the following adaptation objective:

Objective 1: Enhancing our knowledge and understanding of the potential impacts of climate change for flooding and flood risk management through research and assessment

Objective 2: Adapting flood risk management practice to effectively manage the potential impact of climate change on future flood risk

Objective 3: Aligning adaptation to the impact of climate change on flood risk and flood risk management across sectors and wider Government policy

The Climate Change Sectoral Adaption Plan is a very detailed and comprehensive document which addresses a plethora of topics and issues including the background to flood risk management in Ireland, current management practice, climate impact screening and the prioritisation of impacts amongst others.

For the purposes of brevity, RPS have not reproduced this information in this report. However, it should be noted that RPS have thoroughly reviewed this document and have remained cognisant of the salient points and guidance throughout the entirety of this CFERM study.

4 DATA AND ANALYSIS

4.1 Topographic Survey

At the inception of this project RPS commissioned Six West to undertake an aerial survey of the study area. This survey was undertaken during a spring low tide and captured high resolution topographic data as well as the corresponding ortho-photography. This data was then supplemented by an additional survey of the same area that was undertaken in early 2019. This survey proceeded the construction of the temporary coastal protection measures which were installed at the Burrow to mitigate the acute coastal erosion.

The second survey undertaken in early 2019 enabled RPS to compare to similar datasets and quantify volume changes across the study areas. The extent of the survey area is illustrated in Figure 4.1 below.

Information from these survey campaigns was used to develop a range of numerical models as described in the following Sections of this report.

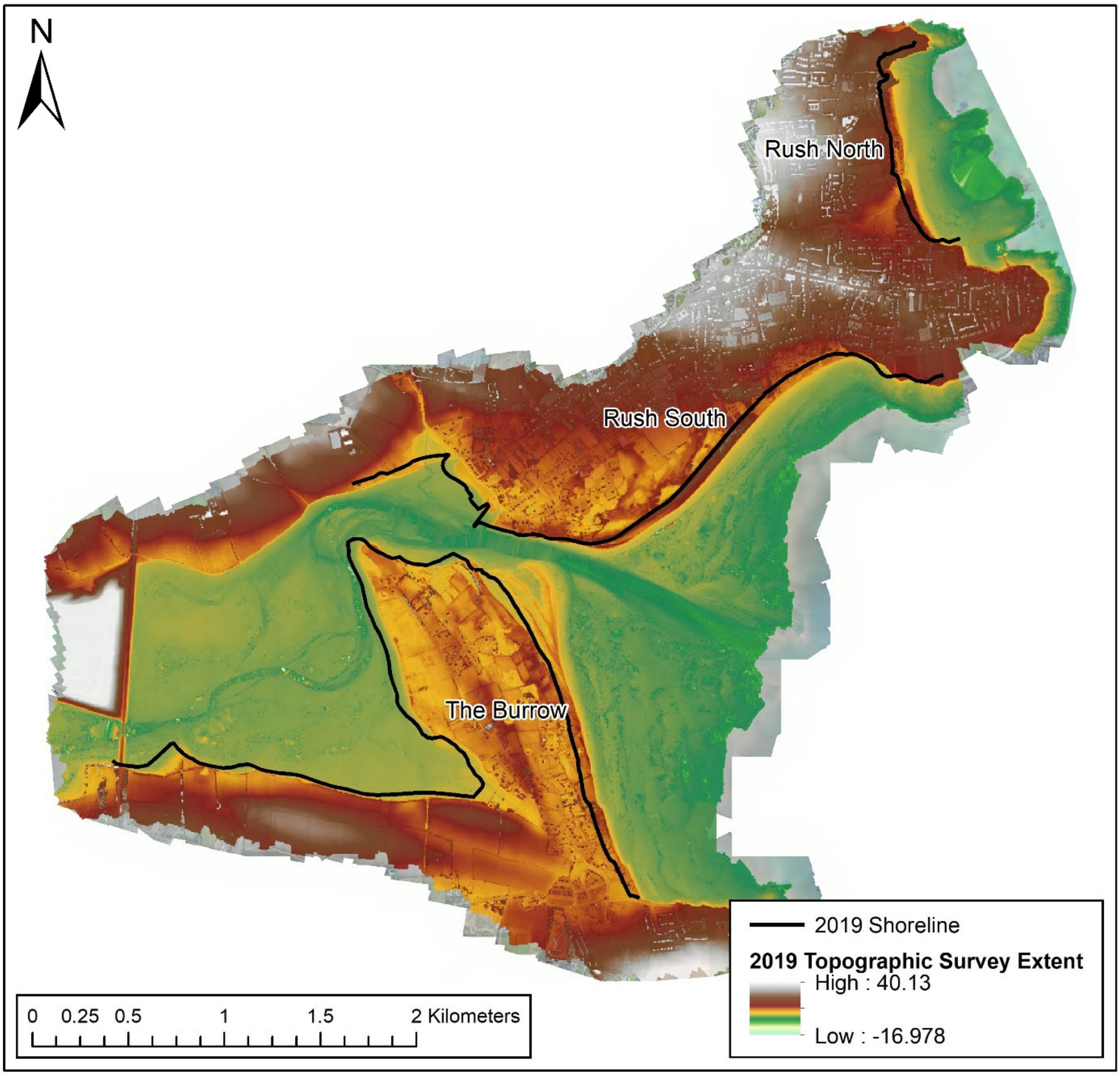


Figure 4.1: Extent of topographic survey procured in 2018 and again in 2019

4.2 Analysis of previous surveys

Using survey data that was collected as part of earlier studies of Portrane and the surrounding area, RPS assessed and quantified the change in bed levels and beach volumes across ea. As summarised in Table 4.1, sufficiently detailed data was only available for this analysis between 2008 and 2019 and that the data collected in 2013 did not cover the inner estuary or Rush north.

Table 4.1: Summary of available LIDAR/topographic information

Year	The Burrow	Rush South	Rush North	Rogerstown Estuary (north)	Rogerstown Estuary (south)
2008	✓	✓	✓	✓	✓
2013	✓	✓	X	X	X
2018	✓	✓	✓	✓	✓
2019	✓	✓	✓	✓	✓

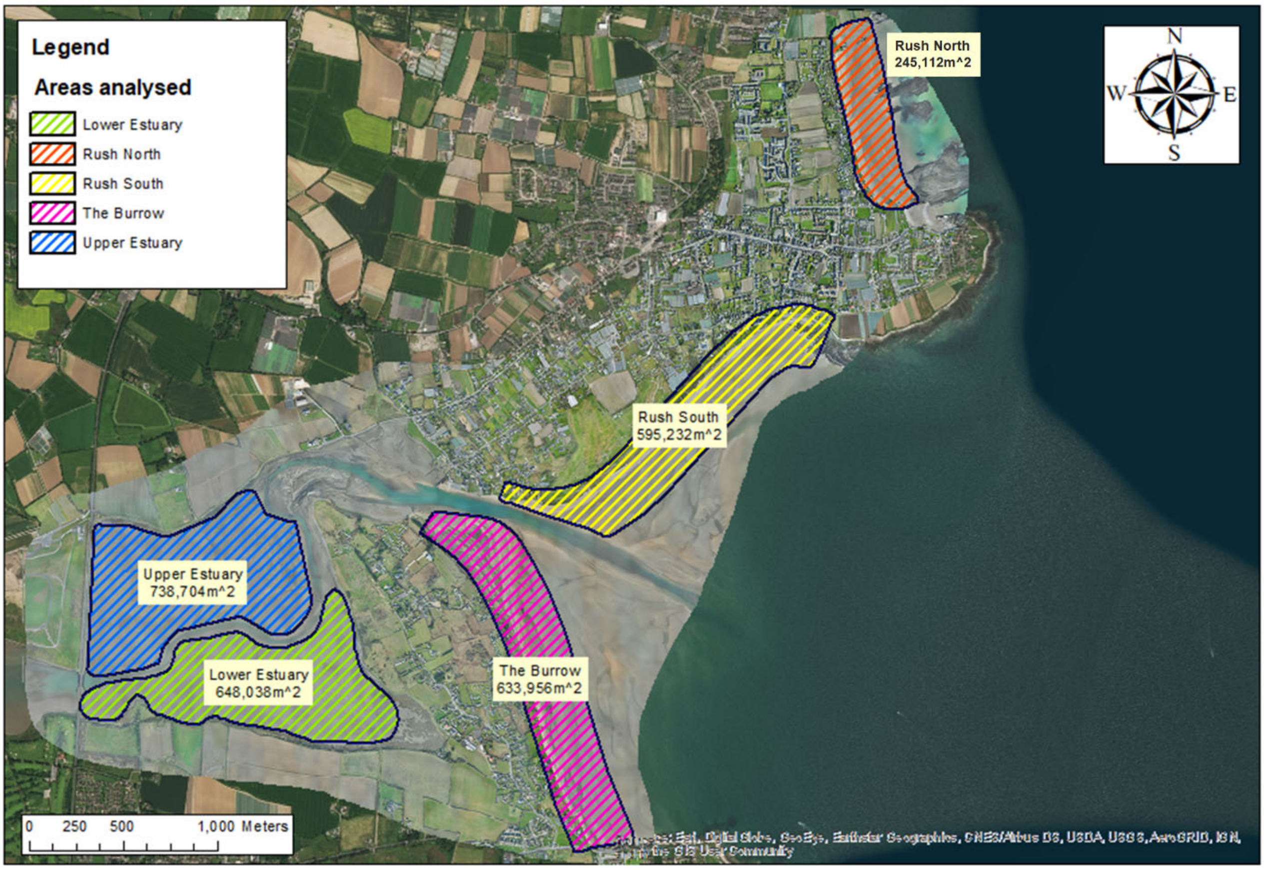


Figure 4.2: Extent of various intertidal regions across the study area

Using AutoCAD Civil 3D, RPS created a Triangulated Irregular Network (TIM) surface using datasets for each intertidal region and year. These volumes were statistically analysed to calculate a mean surface elevation for each surface. Based on this assessment it was found that the elevation of the beaches along the Burrow and Rush south have decreased on average by *c.*1.60m since 2008.

The bed level change at Rush north is significantly lower having only changed by -0.65m since 2008. The results of this assessment are presented in Table 4.2.

Table 4.2: Summary of bed led level change across the various intertidal regions of the study area

Year	The Burrow	Rush South	Rush North	Rogerstown Estuary (north)	Rogerstown Estuary (south)
2008	1.64	1.43	1.14	0.10	0.98
2013	0.74	0.27	n/a	n/a	n/a
2018	0.25	0.06	0.70	0.020	0.19
2019	0.00	-0.20	0.52	0.01	0.10
2019 - 2008	**-1.64**	**-1.62**	**-0.65**	**-0.09**	**-0.88**

Using AutoCAD Civil 3D, RPS calculated the total volume changes at each study area for various periods between 2008 and 2019; the results from this analysis are presented in Table 4.3 below. It will be seen from this Table that over 0.50 million m^3 of sediment material has been removed the intertidal region along the Burrow since 2008. Importantly, it will be seen from this Table that the intertidal beach area at Rush south also lost *c.*0.50 million m^3 of material during the same period. This indicates that sand is not moving between beaches but is instead being transported offshore and out of the local sediment cell.

These findings are contrary to the conclusions of previous studies which found that the local sediment systems at the Burrow and Rush south were once closely interlinked with sediment being exchanged between the two beaches during both calm and storm conditions. The change in sediment dynamics between the two beaches is attributed to a significant change in bed levels across the two beaches which has in turn altered the prevailing wave climate and sediment transport processes within the Rogerstown estuary area. As reported in Section 4.5, climate change and an increase in the incident wave energy are also believed to contribute to this change in sediment dynamics. This is discussed further in Section 5.4.4.

It should also be noted that contrary to anecdotal accounts, the sediment removed from the Burrow and Rush south does not appear to have been transported to within the estuary. This assessment found that there has been a notable decrease in bed levels and sediment volumes within the estuary as summarised in Table 4.2 and Table 4.3.

Table 4.3: Summary of total volume change across the various intertidal regions of the study area

Year	Total Volume Change [m^3]				
	The Burrow	Rush South	Rush North	Rogerstown Estuary (north)	Rogerstown Estuary (south)
2008 - 2013	-370,643	-239,359	n/a	n/a	n/a
2013 - 2018	-206,807	-84,764	n/a	n/a	n/a
2018 - 2019	-119,154	-139,514	-43,173	-11,110	-55,124
Total volume change	**-696,604**	**-463,637**	**-43,173**	**-11,110**	**-55,124**

4.3 Computational Models

4.3.1 Modelling Overview

RPS used the MIKE 21 and LitPack numerical modelling software package developed by DHI, to assess coastal processes across the study area. This was achieved by developing a range of one and two dimensional numerical models for Portrane, Rush South and Rush North.

These models were used in conjunction with hydrographic and topographic survey data to evaluate the following:

- The existing tidal flow regime.
- The average annual and extreme inshore wave climate.
- The shoreline sediment dynamics.
- The current and future scenario coastal erosion risk.
- The current and future scenario coastal flooding flood risk.

4.3.2 Coastal Process Modelling Software

A suite of coastal process models, based on the MIKE software developed by DHI, was used to assess the coastal processes within the Rogerstown study area. The MIKE system is a state of the art, industry standard, modelling system, based on a flexible mesh approach. This software was developed for applications within oceanographic, coastal and estuarine environments.

A brief synopsis of the MIKE system and modules used for this assessment is outlined below:

1. **MIKE 21 FM system** - Using this flexible mesh modelling system, it is possible to simulate the mutual interaction between currents, waves and sediment transport by dynamically coupling the relevant modules in two dimensions.
2. **The Hydrodynamic (HD) module** - This module is capable of simulating water level variations and flows in response to a variety of forcing functions in lakes, estuaries and coastal regions. The HD Module is the basic computational component of the MIKE 21 Model system providing the hydrodynamic basis for the Sediment Transport and Spectral Wave modules. The Hydrodynamic module solves the two-dimensional incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. Thus, the module consists of continuity, momentum, temperature, salinity and density equations. In the horizontal domain both Cartesian and spherical coordinates can be used.
3. **The Spectral Wave (SW) module** – This module simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas and accounts for key physical phenomena including wave generation, dissipation, refraction, shoaling and wave-current interaction.
4. **The Sediment Transport module** - The Sediment Transport Module simulates the erosion, transport, settling and deposition of non-cohesive sediment in marine and estuarine environments and includes key physical processes such as forcing by waves, flocculation and sliding. The module can be used to assess the impact of marine developments on erosion and sedimentation patterns by including common structures such as jetties, piles or dikes. Point sources can also be introduced to represent localised increases in current flows as a result of various coastal structures such as revetments, groynes or outfalls.
5. **Littoral Processes (LitDrift) module** - This module in an integrated modelling system that simulates non-cohesive transport along quasi-stationary coastlines using an n-line approach. It can be used as a powerful tool for sediment budget analysis which is paramount to all coastal morphology studies.

   It should be noted that this module simulates potential sediment transport, i.e. the magnitude of sediment transport that could be expected if there was an abundance of freely mobile sediment available. In many instances where there is a shortage of sediment available the actual rates may be lower than the potential sediment transport rates.

4.3.3 Tide, Waves and Sediment Transport Model

The models used to assess the coastal processes within the study area were developed from RPS' existing model of the area originally developed for a previous study (RPS, 2014).

The updated model was developed using a range of bathymetric/topographic data sources. The principle dataset used was the high-resolution data procured by Six West Ltd in an airborne survey in early 2019. The survey extent is shown in Section 3, Figure 4.1. This data was used to define most of the topography for the 2D model.

All bathymetry datasets were set with the depths relative to Mean Sea Level (MSL) before being input to the model.

The model was created using flexible mesh technology to provide detailed information on the coastal processes around the Rogerstown study area. The model uses mesh sizes varying from approximately 0.9km at the boundaries to 20m at the shoreline. The overall extent and bathymetry of the outer and inner Portrane models are shown in Figure 4.3 and Figure 4.4 respectively, whilst Figure 4.5 shows the bathymetry and mesh structure of this model.

This model was used to assess the tidal regime, wave climate and sediment regime for the study area.

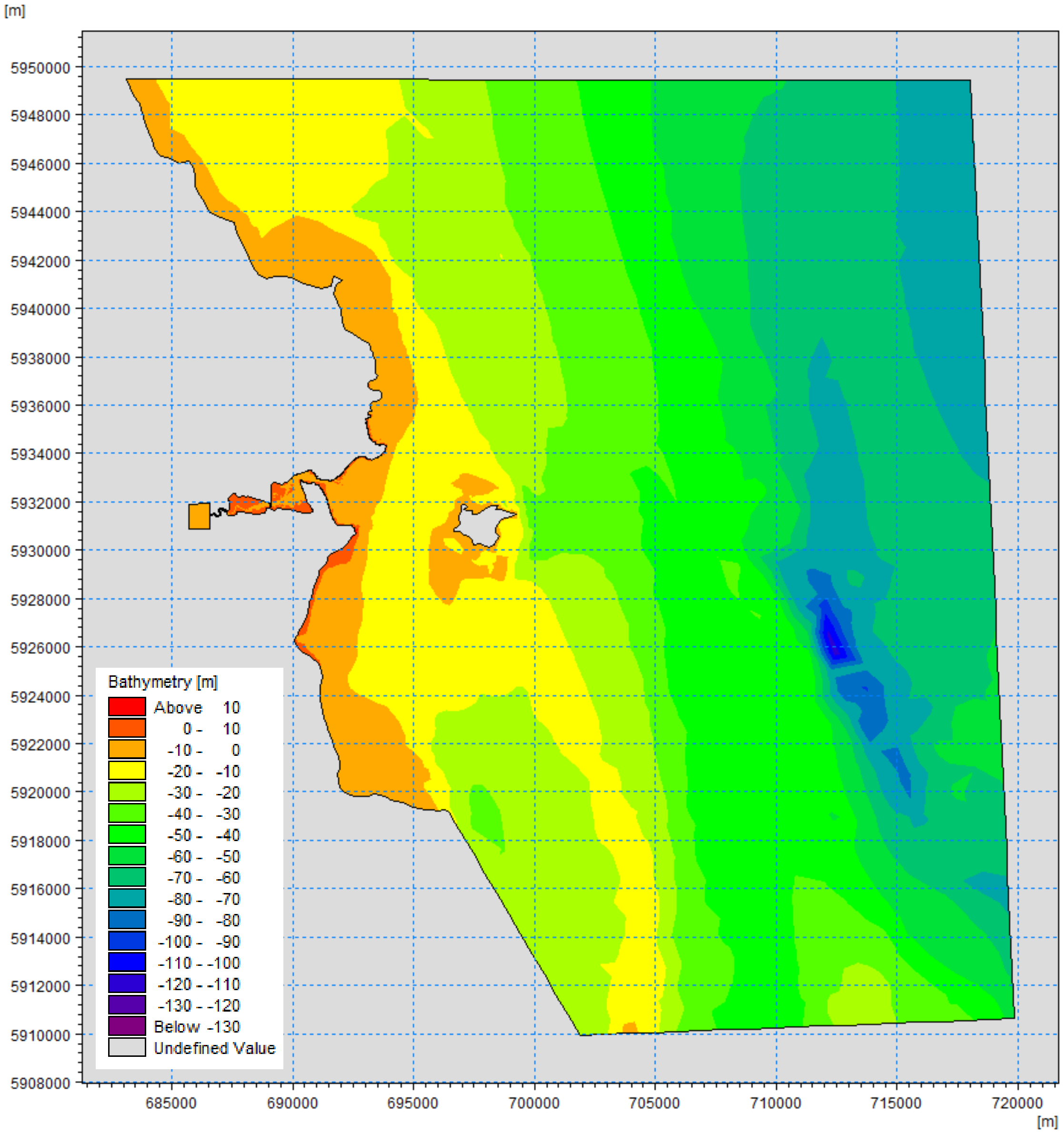


Figure 4.3: Extent and bathymetry of the Rogerstown Tide, Wave and Sediment model

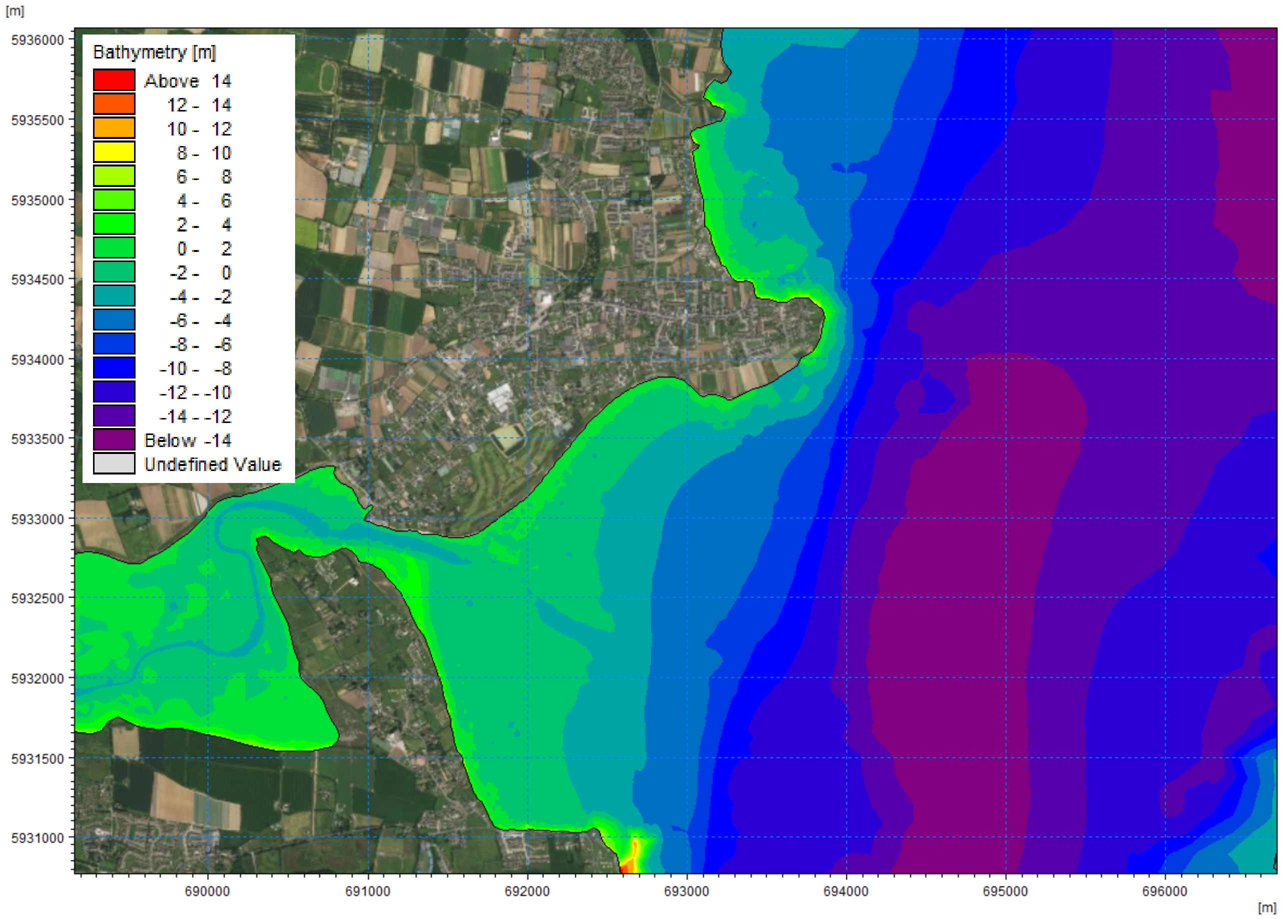


Figure 4.4: Detailed bathymetry of Rogerstown model across the study area

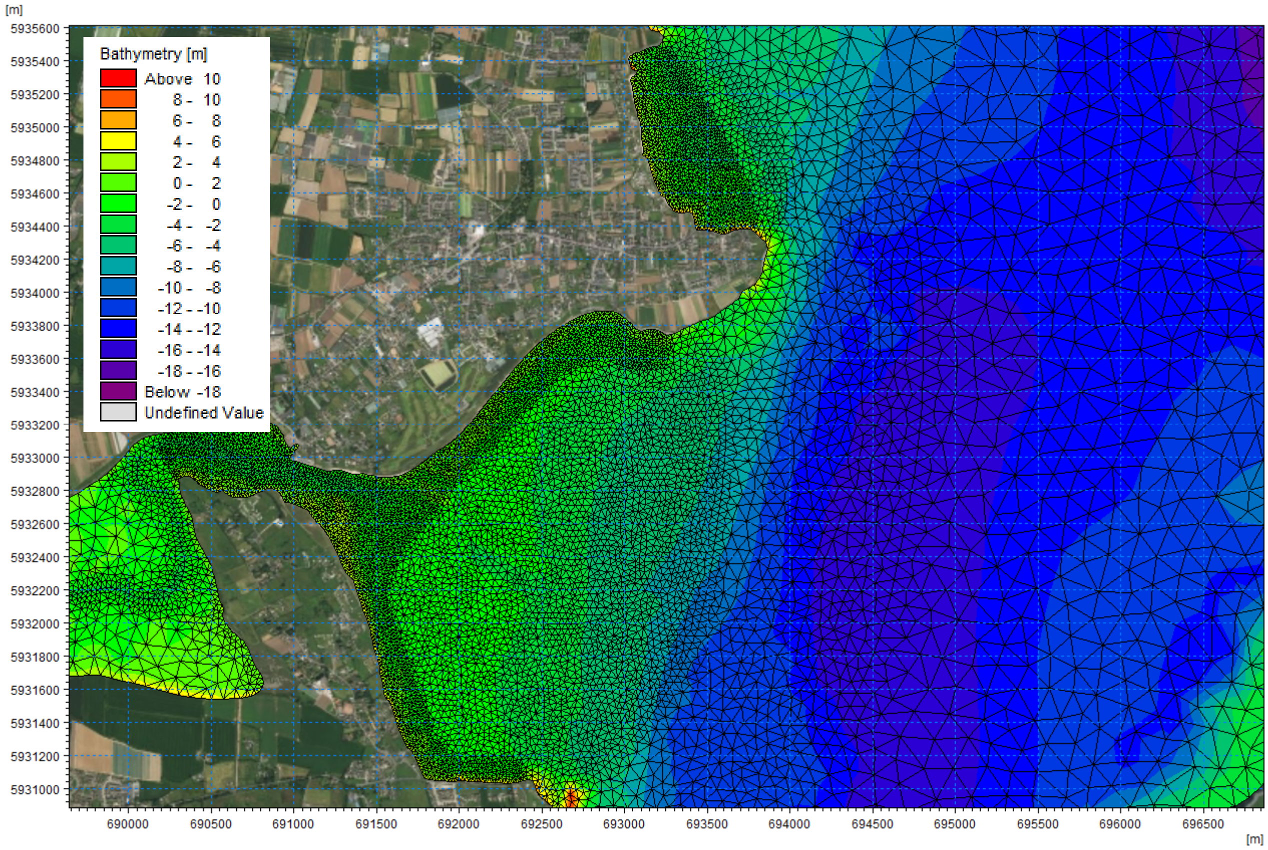


Figure 4.5: Detailed mesh structure of the Rogerstown model across the study area

4.3.4 Flood Model

The 2D Rogerstown model was modified so that it could be used to assess the threat of flooding across the study area. This was achieved by increasing the landward extent of the model in the individual study areas to include relevant areas of the hinterland.

Relevant areas of the hinterland were determined based on the topography of the study areas, i.e. any areas where the elevation was significantly greater than the 0.5% HEFS AEP water level were not included in the model. The general extent of the flood model is presented in Figure 4.6.

The model mesh was refined in regions of most importance to achieve satisfactory model performance. The flexible mesh technology allowed the size of the computational cells to vary across the domain of the model, allowing smaller cells of *c.* 5m^2 to be positioned in areas of rapidly changing bathymetry, such as offshore banks and channels, along with detailed areas of topography. Larger cells in the order of 100m^2 to 200m^2 were used in areas of more consistent bathymetry/topography.

An example of the detail of the mesh used in The Burrow area of the model is illustrated in Figure 4.7.

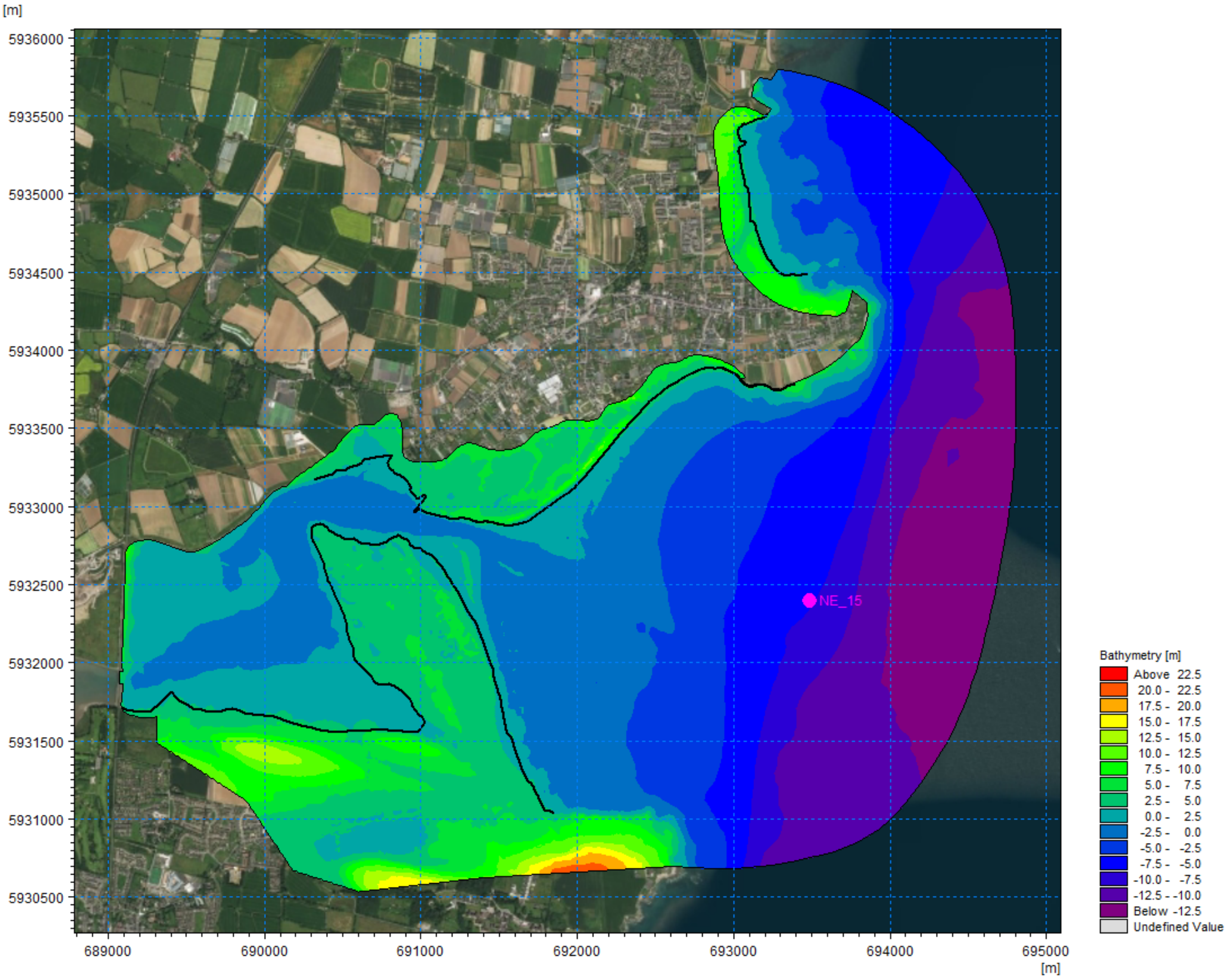


Figure 4.6: Extent and bathymetry of Rogerstown study flood model

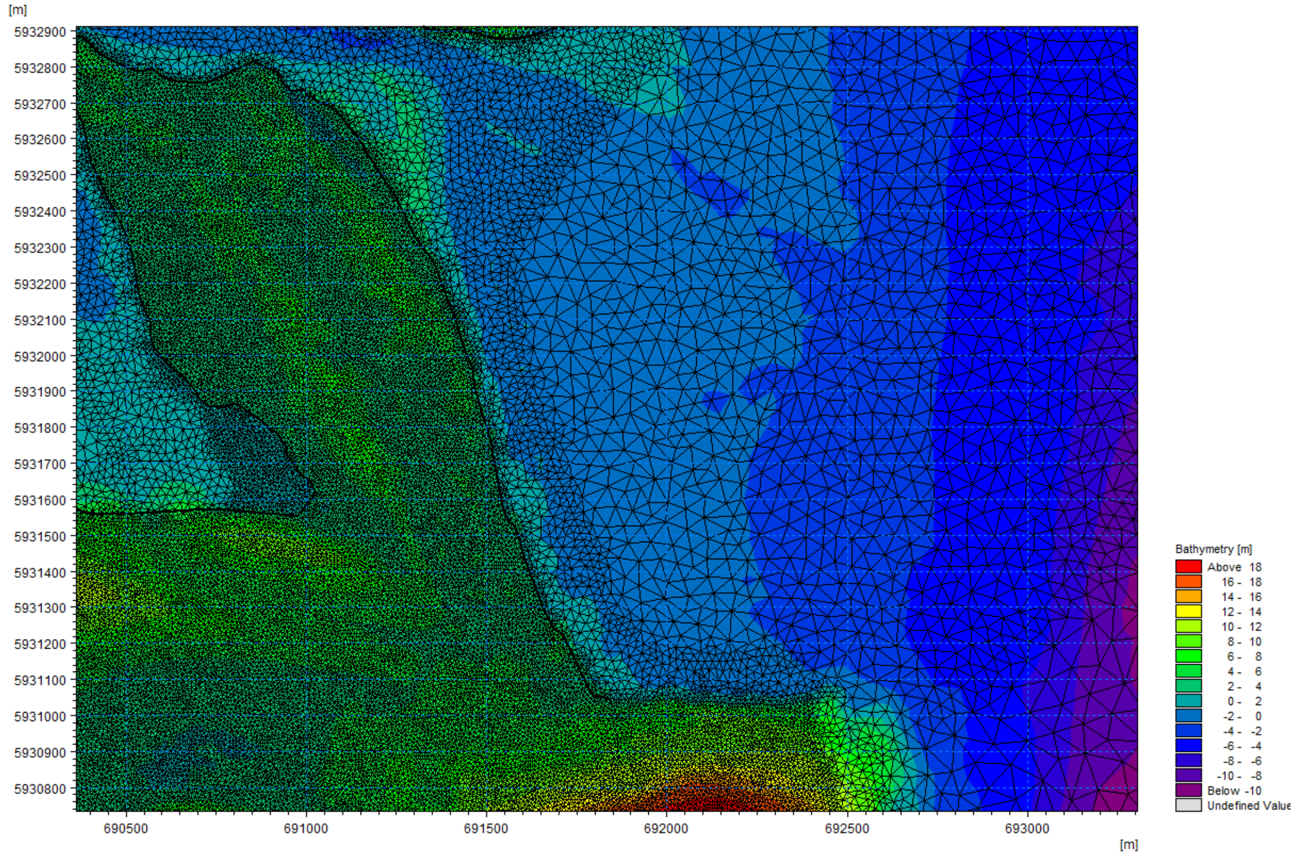


Figure 4.7: Mesh detail in the region of the burrow where the cell sizes were reduced to as small as *c.* 5m^2 to account for rapid changes in the bathymetry/topography

4.3.5 Tidal Boundary Conditions

The MIKE 21 model described in Section 4.3.3 was used to simulate the hydrodynamic regime within the study area. The tidal boundaries for the hydrodynamic model were derived from RPS' Tide and Storm Surge Forecast (TSSF) model (RPS, 2018), the extent and bathymetry of which is illustrated in Figure 4.8.

The ICPSS model was developed using flexible mesh technology with the mesh size (model resolution) varying from circa 24km along the offshore Atlantic boundary to circa 200m around the Irish coastline.

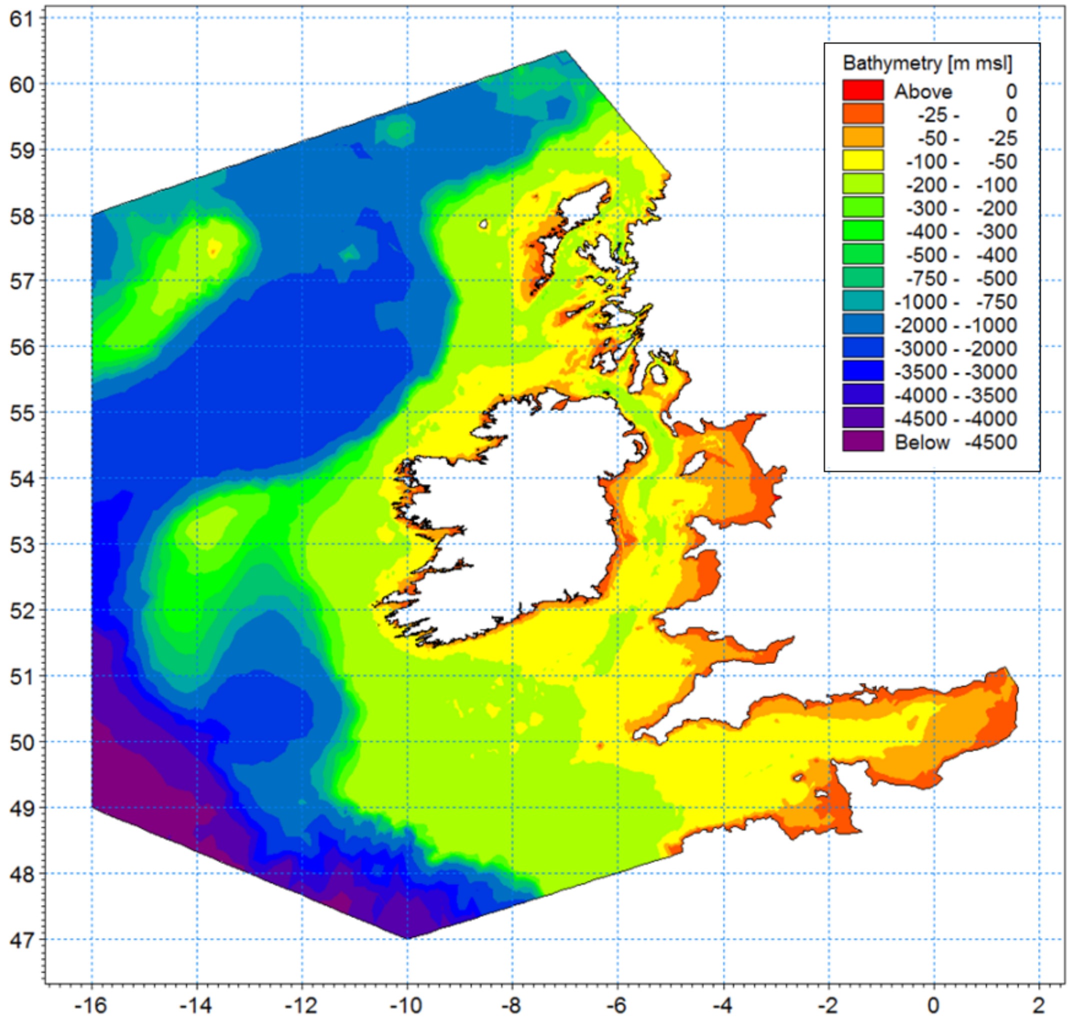


Figure 4.8: Extent and bathymetry of Irish Seas Tidal and Storm Surge model

4.4 Tidal Information

4.4.1 Standard Tidal Information

The normal astronomical tidal levels for the study area were derived using the data presented for Malahide in the Admiralty Tidal Tables for 2019. The resulting standard water levels for Malahide are presented in Table 4.4.

The hydrodynamic model used to simulate the tidal conditions at the study area was found to accurately represent these standard tidal conditions.

Table 4.4: Tidal elevations at Malahide to Chart Datum (CD) and Mean Sea Level (MSL)

Year	Chart Datum (CD)[m]	Mean Sea Level (MSL)[m]
Mean High Water Spring	4.2	1.90
Mean High Water Neap	3.2	0.90
Mean Low Water Neap	1.1	-1.20
Mean Low Water Spring	0.5	-1.80

4.4.2 Extreme Tidal Levels

As the wave heights that can approach the shoreline are strongly influenced by water depth, reference was made to an extreme tidal analysis undertaken as part of the Irish Coastal Protection Strategy Study (ICPSS) (RPS, 2010). This study established extreme high-water levels within the study area for a range of Annual Exceedance Probability (AEP) events. The location selected was near Rogerstown and the extreme water levels are presented in Table 4.5.

Table 4.5: Extreme water level information at ICPSS Point NE15 near the Burrow

AEP event [%]	Chart Datum [m]	Ordnance Datum Malin [m]	Mean Sea Level [m]
50	4.89	2.55	2.59
20	5.01	2.67	2.71
10	5.11	2.77	2.81
5	5.21	2.87	2.91
2	5.34	3.00	3.04
1	5.44	3.10	3.14
0.5	5.53	3.19	3.23

4.5 Offshore Wave and Wind Information

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 4.9 the M2 wave buoy is approximately 45km to the east of Portrane at the offshore point 53.48°N, 5.42°W. This instrument records various wave parameters including significant wave height, direction and wave period for 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 have resulted in erosion at the Burrow in the 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 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.

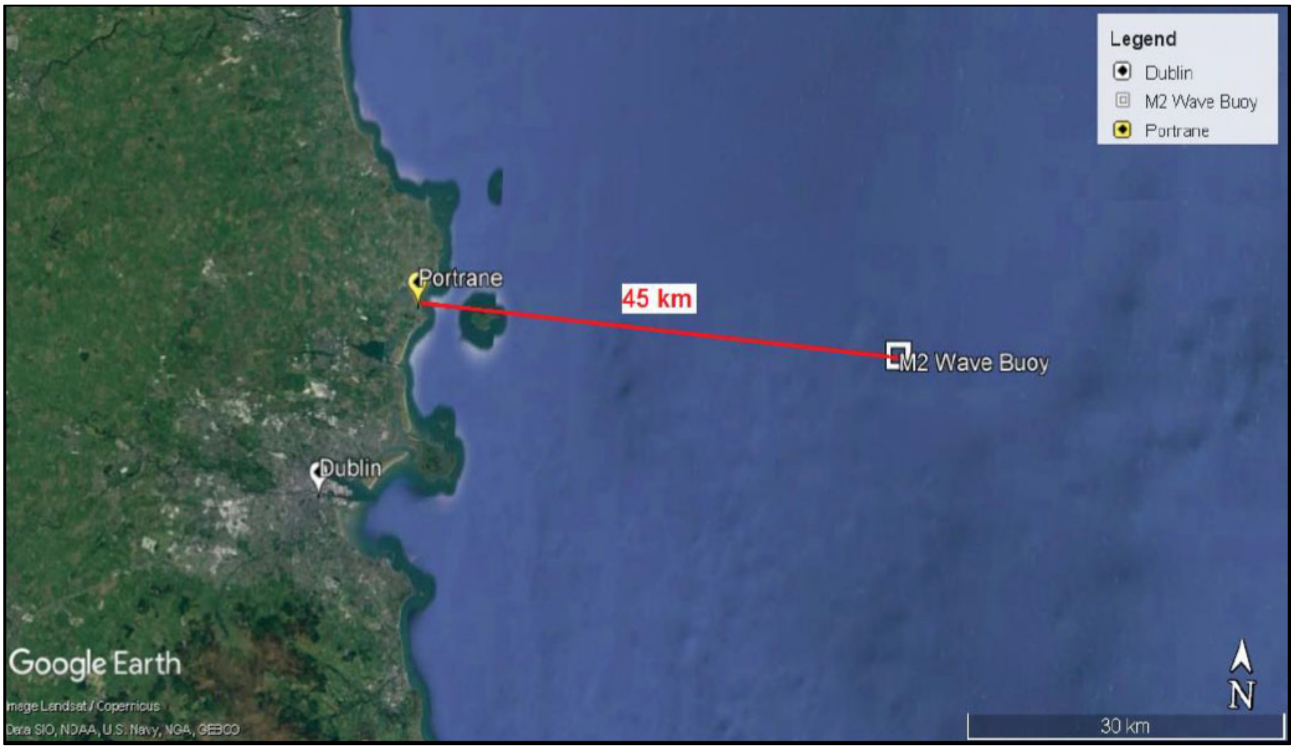


Figure 4.9: Location of the M2 wave buoy in relation to Portrane

An assessment of the M2 buoy data found that despite greater gust speeds being recorded during previous storm events, it was during Storm Emma in 2018 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 events 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 4.6 lists the five 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 event recorded on the 02/03/2018 was also c.35% greater than the next largest event which was previously recorded on 30/12/2009.

Table 4.6: 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 [ºN]
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 4 winter seasons between 2014 and 2018 is illustrated in Figure 4.11. It should be noted that the gaps in this data are 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, one in mid-October and the second 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 180ºN 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 4.10 below illustrates all 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.

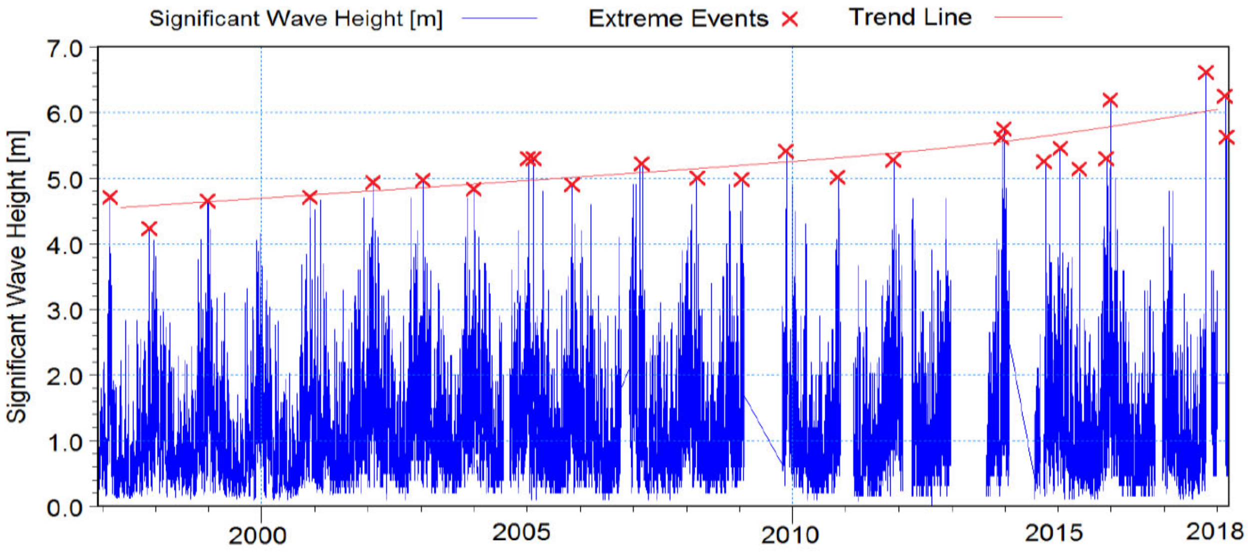


Figure 4.10: Significant wave heights from all wave directions at the M2 buoy between 1996 and 2018

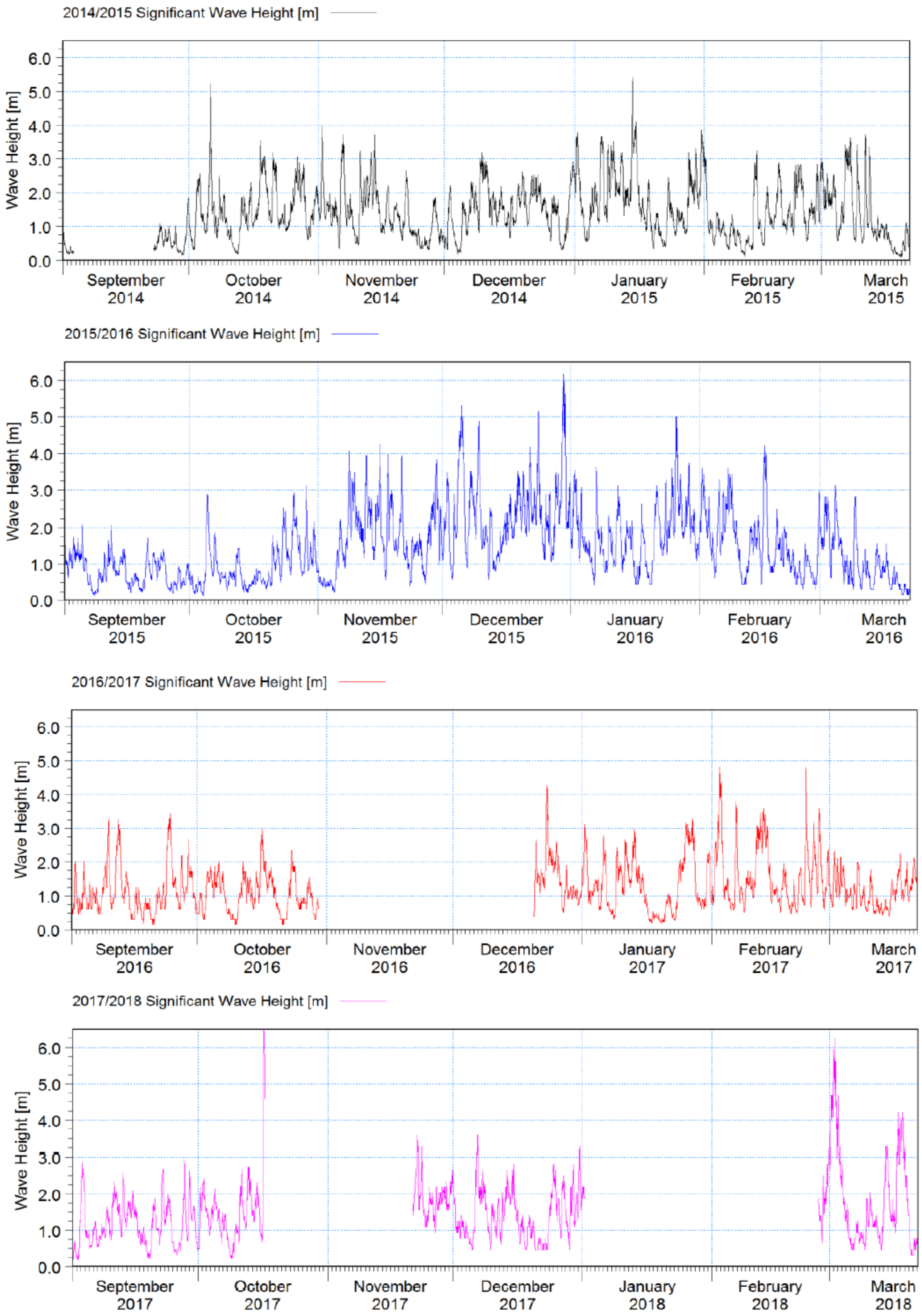


Figure 4.11: Winter wave climate at the M2 buoy from 2014/2015 to 2017/2018

4.5.1 Extreme Value Analysis

To assess the wave climate at the study area RPS undertook an Extreme Value Analysis (EVA) of the offshore wave dataset. Given the location of the study site the offshore wave and wind climate was divided into seven 30° sectors from the north through east to the south. The analysis was undertaken for each of these seven 30° sectors and for all wave directions (omnidirectional) for the period between 1996 – 2013 and 1996 – 2018. This dataset was five years longer than the data used for the previous study (RPS, 2014) and contained significantly more extreme wave and storm events.

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 each relevant directional sector.

The analysis found that the waves with the largest significant wave height affecting the Burrow originated from the Easterly sector. Table 4.7 provides a summary of the results from the 1996-2013 and the 1996-2018 period. The data presented in this Table demonstrates that 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. This analysis also indicates that Storm Emma could have equated to a c. 1 in 125-year event.

Table 4.8 provides a summary of the results from the omnidirectional analysis. Figure 4.12 and Figure 4.13 show the extreme value plots output from the omnidirectional analysis for the periods between 1996 – 2013 and 1996 – 2018 respectively.

Table 4.9 and Table 4.10 present the significant wave heights and wind speeds for the seven directional sectors at point 53.5°W 5.5°N.

Table 4.7: Extreme Easterly sig. wave heights for 1996-2013 and 1996-2018 at the M2 buoy

AEP event [%]	Sig. Wave Height 1996 - 2013 [m]	Sig. Wave Height 1996 - 2018 [m]
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 4.8: Extreme omnidirectional sig. wave heights for 1996-2013 and 1996-2018 at the M2 buoy

AEP event [%]	Sig. Wave Height 1996 - 2013 [m]	Sig. Wave Height 1996 - 2018 [m]
2	4.66	5.14
5	5.22	5.82
10	5.40	6.27
20	5.59	6.71
50	5.94	7.26
100	6.4	7.68
200	7.08	8.10

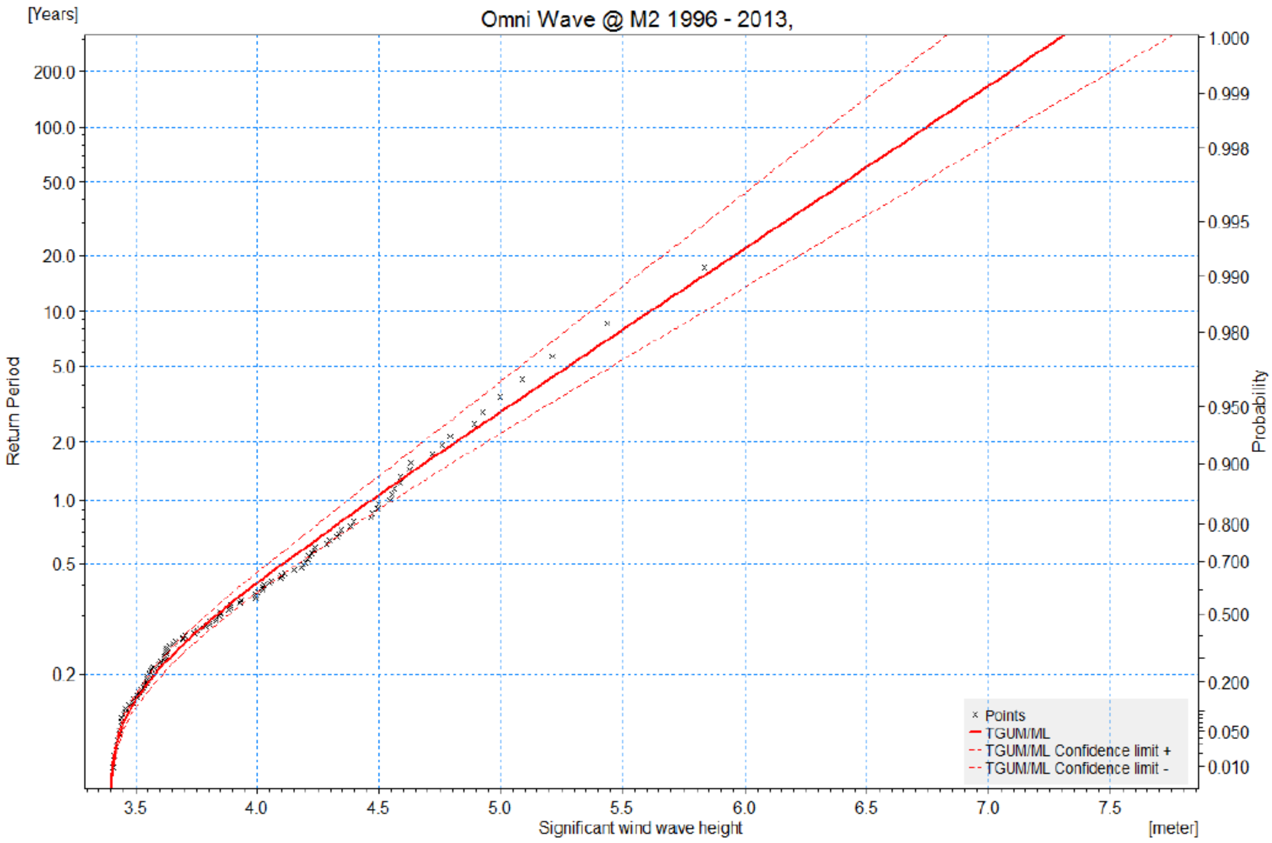


Figure 4.12: Extreme event analysis of offshore waves from all directions between 1996 and 2013

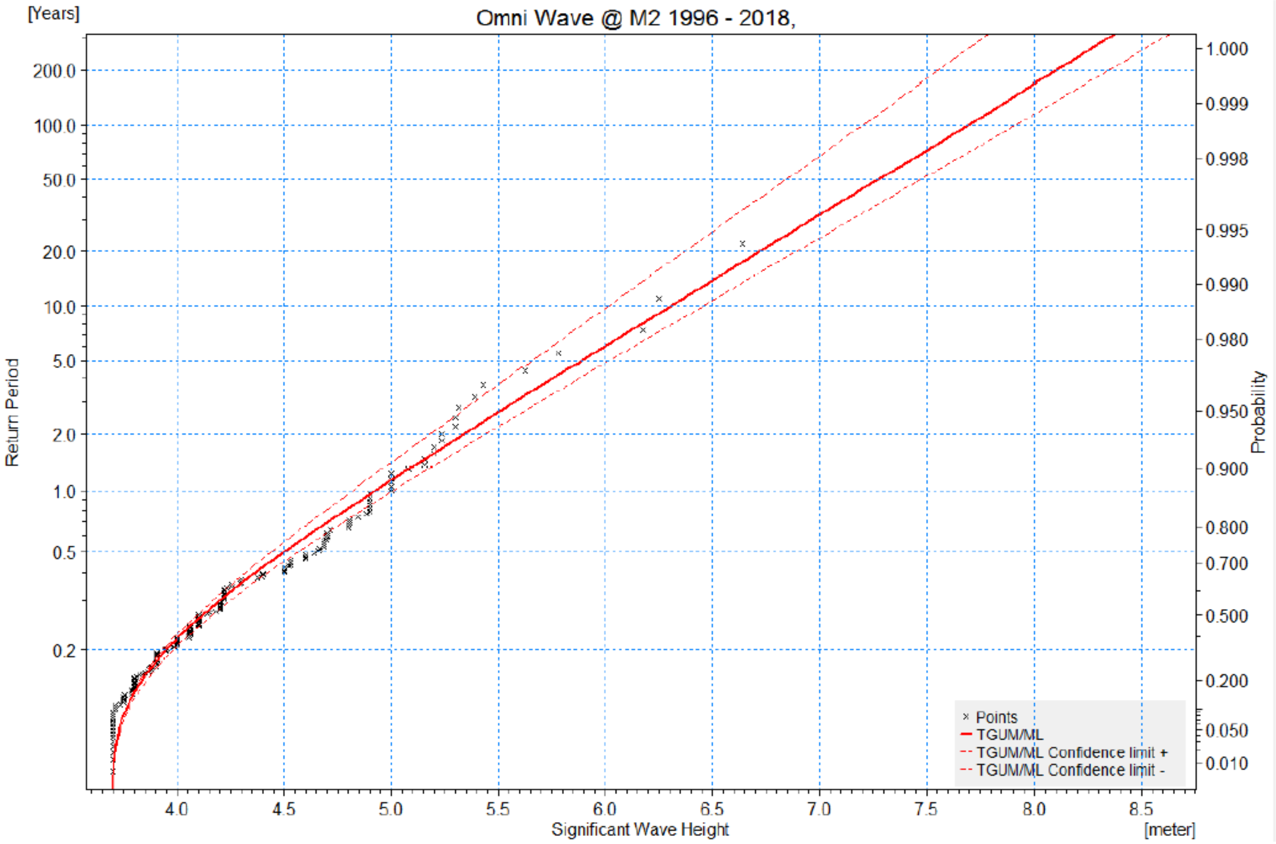


Figure 4.13: Extreme event analysis of offshore waves from all directions between 1996 and 2018

Table 4.9: Results of extreme offshore wave and wind analysis 53.5°W 5.5°N (Table 1 of 2)

Direction 345°- 15°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	3.98	16.60
20	4.71	18.01
10	5.26	18.99
5	5.82	19.93
2	6.57	21.11
1	7.13	21.98
0.5	7.70	22.82

Direction 15°- 45°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	3.55	16.16
20	4.18	17.58
10	4.64	18.58
5	5.05	19.54
2	5.61	20.75
1	6.02	21.64
0.5	6.42	22.50

Direction 45°- 75°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	3.32	15.58
20	3.98	17.13
10	4.47	18.29
5	4.96	19.44
2	5.60	20.97
1	6.08	22.13
0.5	6.55	23.28

Direction 75°- 105°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	3.47	16.16
20	4.12	17.76
10	4.60	18.95
5	5.08	20.14
2	5.71	21.71
1	6.19	22.90
0.5	6.55	23.28

Table 4.10: Results of extreme offshore wave and wind analysis 53.5°W 5.5°N (Table 2 of 2)

Direction 105°- 135°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	3.29	15.79
20	3.92	17.03
10	4.40	17.92
5	4.87	18.78
2	5.49	19.87
1	5.96	20.68

Direction 135°- 165°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	4.12	18.45
20	4.70	19.44
10	5.13	20.12
5	5.54	20.76
2	6.08	21.57
1	6.48	22.15

Direction 135°- 165°

Annual Exceedance Probability [%]	Significant Wave Height [m]	Wind Speed [m/s]
50	5.45	20.30
20	5.83	21.34
10	6.10	22.08
5	6.35	22.81
2	6.68	23.73
1	6.91	24.41

4.5.2 Joint Probability Analysis

The level of exposure of any shoreline to wave action is governed primarily by the local tidal regime as the maximum height of any incident wave is a function of water depth. As incident waves are limited by water depth larger waves tend to break further offshore. However, beaches often experience large irregular increases in water levels called surges. These surge events increase the local water depth allowing larger waves to reach the shore and expose more landward sections of the shore to wave attack. It is the combination of high waves with high water levels that is particularly important in causing the erosion of the dune system at the Burrow.

A joint probability analysis of wave heights with water levels and wind speeds with water levels was undertaken using techniques and methods derived during the JOIN-SEA project (Defra /Environment Agency, 2005). This method involves selecting a correlation coefficient between each pair of variables and using the associated tools to derive matched combinations of known Annual Exceedance Probability (AEP) events. Due to the limited availability of long-term tide gauge data in the study area RPS made use of previous studies and experience in determining the most suitable correlation coefficients for each case.

Once an appropriate correlation coefficient was selected, the relevant set of AEP water levels and wind speeds or wave heights derived during the EVA stage of this study, as described in Section 4.5.1, were input into the JOIN-SEA spreadsheet for analysis. Combinations of wave heights and water levels for joint AEPs of 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% were derived for each relevant directional sector at appropriate offshore locations. For every joint AEP storm event, a series of six water levels with corresponding wave heights and/or wind velocities were output from the joint probability analysis to illustrate the complete joint probability spectrum.

The correlation coefficients derived for each direction at the coastline of the study site are presented in Table 4.11.

Table 4.11: Derived correlation coefficients between offshore waves and water levels

Direction [°]	**345-15**	**15-45**	**45-75**	**75-105**	**105-135**	**135-165**	**165-195**
Correlation Coefficient	0.1	0.1	0.175	0.25	0.425	0.6	0.6

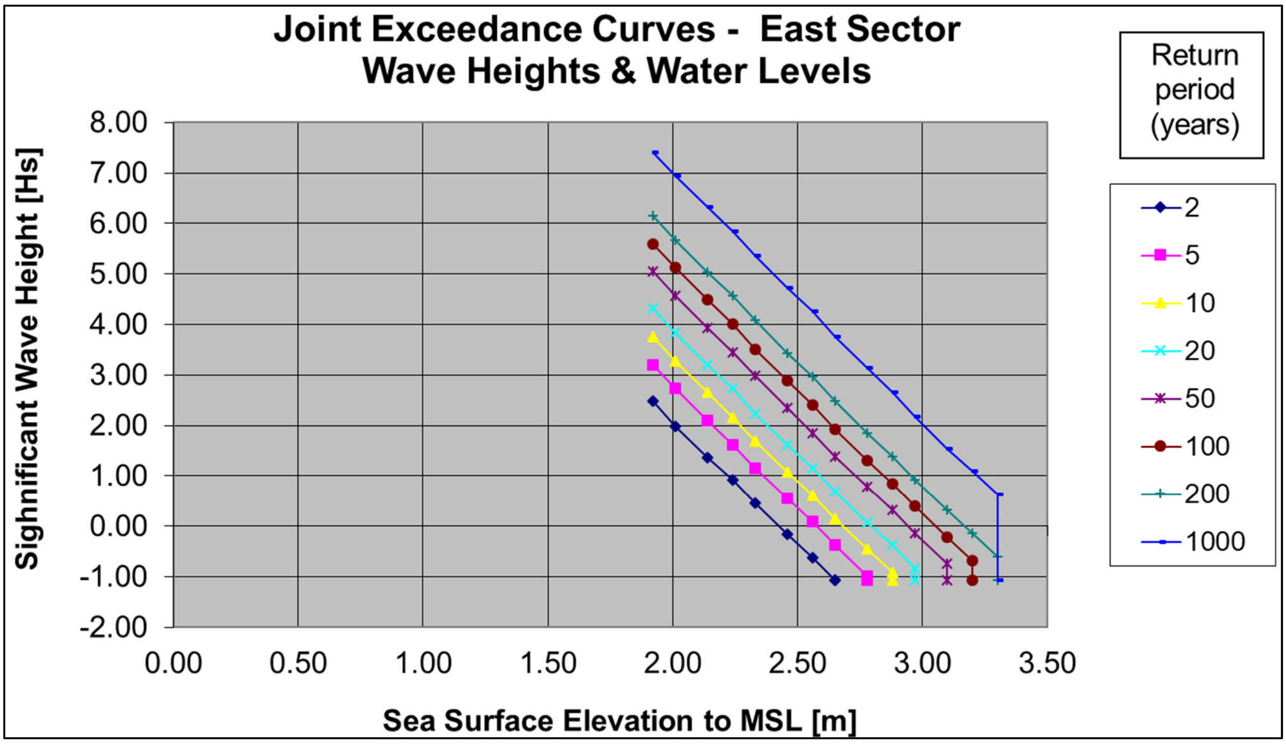


Figure 4.14: Joint exceedance curves – East sector wave heights and water levels 53.5°W 5.5°N

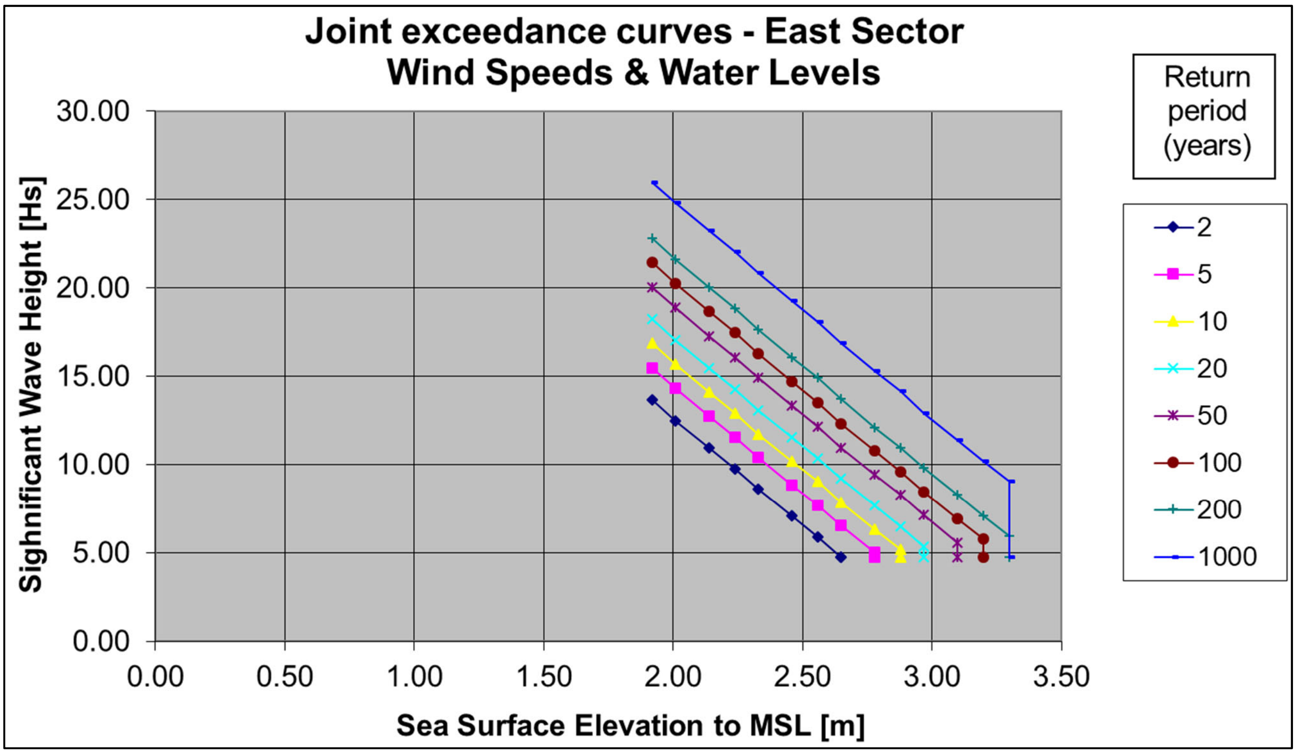


Figure 4.15: Joint exceedance curves - East sector wind speeds and water levels 53.5°W 5.5°N

Table 4.12: Joint exceedance return period (inverse of AEP) values for wave heights and water levels - East sector 53.5°W 5.5°N

Value of first variable:	**Joint exceedance return period (years)**							
	2	**5**	**10**	**20**	**50**	**100**	**200**	**1000**
Present-day sea level at SW53 (MSL)	**Value of second variable:**			**Significant Wave Height (m)**				
1.92	2.48	3.21	3.76	4.32	5.05	5.60	6.15	7.41
2.01	1.99	2.73	3.28	3.83	4.57	5.12	5.67	6.94
2.14	1.37	2.09	2.65	3.20	3.93	4.49	5.04	6.32
2.24	0.91	1.62	2.17	2.73	3.44	4.01	4.56	5.84
2.33	0.45	1.16	1.69	2.24	2.98	3.51	4.08	5.37
2.46	-0.15	0.55	1.08	1.61	2.34	2.90	3.43	4.73
2.56	-0.61	0.09	0.62	1.15	1.85	2.42	2.97	4.25
2.65	-1.07	-0.37	0.16	0.69	1.39	1.92	2.49	3.77
2.78	#N/A	-0.98	-0.45	0.08	0.78	1.31	1.84	3.14
2.88	#N/A	#N/A	-0.91	-0.38	0.32	0.85	1.38	2.66
2.97	#N/A	#N/A	#N/A	-0.84	-0.14	0.39	0.92	2.18
3.10	#N/A	#N/A	#N/A	#N/A	-0.75	-0.21	0.32	1.55
3.20	#N/A	#N/A	#N/A	#N/A	#N/A	-0.67	-0.14	1.09
3.30	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	-0.60	0.63
3.52	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.00

Table 4.13: Joint exceedance return period (inverse of AEP) values for wind speeds and water levels - East sector 53.5°W 5.5°N

Value of first variable:	**Joint exceedance return period (years)**							
	2	**5**	**10**	**20**	**50**	**100**	**200**	**1000**
Present-day sea level at SW53 (MSL)	**Value of second variable:**				**Wind Speed (m/s)**			
1.92	13.69	15.49	16.86	18.25	20.06	21.44	22.81	26.00
2.01	12.48	14.32	15.67	17.05	18.87	20.25	21.62	24.81
2.14	10.94	12.73	14.12	15.48	17.29	18.67	20.05	23.23
2.24	9.78	11.54	12.91	14.30	16.09	17.48	18.86	22.04
2.33	8.62	10.38	11.72	13.10	14.92	16.27	17.67	20.85
2.46	7.08	8.85	10.19	11.53	13.34	14.72	16.07	19.28
2.56	5.92	7.69	9.03	10.37	12.14	13.53	14.91	18.09
2.65	4.76	6.53	7.87	9.21	10.98	12.32	13.72	16.89
2.78	#N/A	5.00	6.34	7.67	9.44	10.78	12.12	15.32
2.88	#N/A	#N/A	5.18	6.51	8.28	9.62	10.96	14.14
2.97	#N/A	#N/A	#N/A	5.35	7.12	8.46	9.80	12.94
3.10	#N/A	#N/A	#N/A	#N/A	5.59	6.93	8.27	11.37
3.20	#N/A	#N/A	#N/A	#N/A	#N/A	5.77	7.11	10.21
3.30	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	5.95	9.05
3.52	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.00

4.6 Existing & Future Climate Change

Since previous studies of erosion at Portrane (RPS, 2014) both Ireland and the UK have experienced a succession of extreme weather events that when considered together as a group indicate a definite change in the current climate. Some of these events included:

- Ex-hurricane Ophelia that hit Ireland in late 2017 was only downgraded from a hurricane to an extra-tropical cyclone 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 saw 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 4.10),
- An analysis of the extreme offshore conditions (see Section 4.5.1) indicates that extreme offshore wave heights increased by c.14% between 2013 and 2018.

Although it is beyond the scope of this study to determine whether these events were a direct result of climate change, it is reasonable to assume that climate change most likely contributed to the magnitude, duration and frequency of these events.

4.6.1 Potential Impacts of Climate Change

The notable change in the frequency and intensity of extreme events affecting the study area are in line with conclusions presented in the fifth climate change assessment report which was issued by the Intergovernmental Panel on Climate Change (IPCC 2014). This report concluded that:

- It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur through the 21st century at the global scale. It is likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas.
- It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy rainfalls will increase in the 21st century over many areas of the globe.
- It is highly likely that mean sea level rise will contribute to upward trends in extreme coastal high-water levels in the future.
- There is high confidence that changes in heat waves, glacial retreat, and/or permafrost degradation will affect high-mountain phenomena such as slope instabilities, mass movements, and glacial lake outburst floods. There is also high confidence that changes in heavy precipitation will affect landslides in some regions.

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 Rogerstown estuary.

- 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. (Baatsen, 2015).
- 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. (Baatsen, 2015).
- 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).

As reported in the National Adaptation Framework document "Planning for a Climate Resilient Ireland" (Depart. of Communications, Climate Action and Env., 2018), observational information and data for over 40 Global Climate Observation System (GCOS) Essential Climate Variables confirms that Ireland's climate is changing. These changes are projected to continue and increase over the coming decades (Gleeson, 2013); (EPA, 2015)

> The overwhelming consensus of the recent scientific literature is that climate change is occurring much more rapidly than initially anticipated in the early IPCC reports. Furthermore, the majority of this literature indicates that 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.

5 COASTAL PROCESSES

5.1 Existing Tidal Regime

The tidal currents around the study area are complex due to the interaction of the Rogerstown Estuary and Irish Sea tides. The characteristics of the existing tidal regime across the study area were established using the MIKE 21 FM Hydrodynamic module using the tidal model domain and tidal boundary conditions described in Section 4.3. This model was run for a typical 1-month summer period which included a range of spring and neap conditions. Average flow conditions were also applied to the watercourses discharging to the Rogerstown estuary.

Output from these simulations are presented in Figure 5.1 to Figure 5.4 which illustrate current flow information during typical low water, mid-flood, high water and mid-ebb phases of a spring tidal regime.

The length and direction of the vectors displayed on each of the outputs are proportional to the magnitude of the current velocity at each nodal point in the grid. It will be seen from these figures that the current flows along each of the three beaches do not generally exceed 0.25m/s during any phases of the spring tidal regime.

Perhaps the most dominant feature of all four figures is the prominent jet of water from Rogerstown estuary. At low water, this current is met with little resistance from the main body of water outside of the estuary which facilitates an acceleration of flow at the mouth of the estuary. When the tide begins to turn during mid-flood, current flows from the estuary are impeded which is reflected in a reduction in current velocities. It will be seen from Figure 5.2 and Figure 5.4 that even during mid-flood and mid-ebb conditions, the tide almost reaches the toe of the dunes along the Burrow.

The wider and higher beach levels at Rush south and Rush north mean that the tide does not generally reach the shoreline until high water. The low beach levels and thus increased water depths across the Burrow is an important factor that governs the height of incident waves that can approach the shoreline during arduous storm conditions.

At high water, it will be seen that current velocities along the southern and northern section of the beach at the Burrow and Rush south respectively are almost slack. It will be noted that despite simulated surface elevations indicating that the tide has reached high water, significant tidal currents can still be seen entering the Rogerstown estuary. This indicates there is a slight phase difference between the tides inside and outside of the Rogerstown estuary.

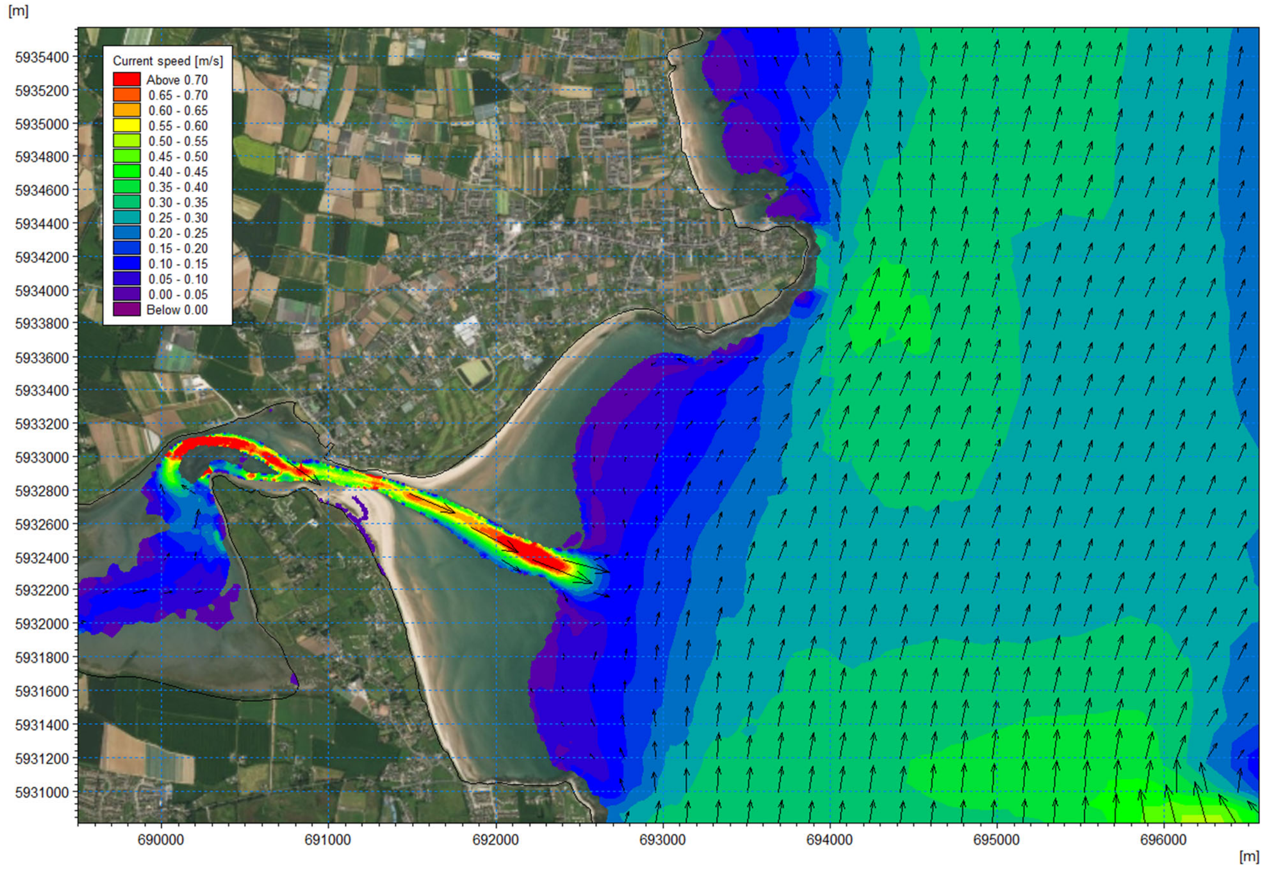


Figure 5.1: Typical spring low water tidal flows at Rogerstown

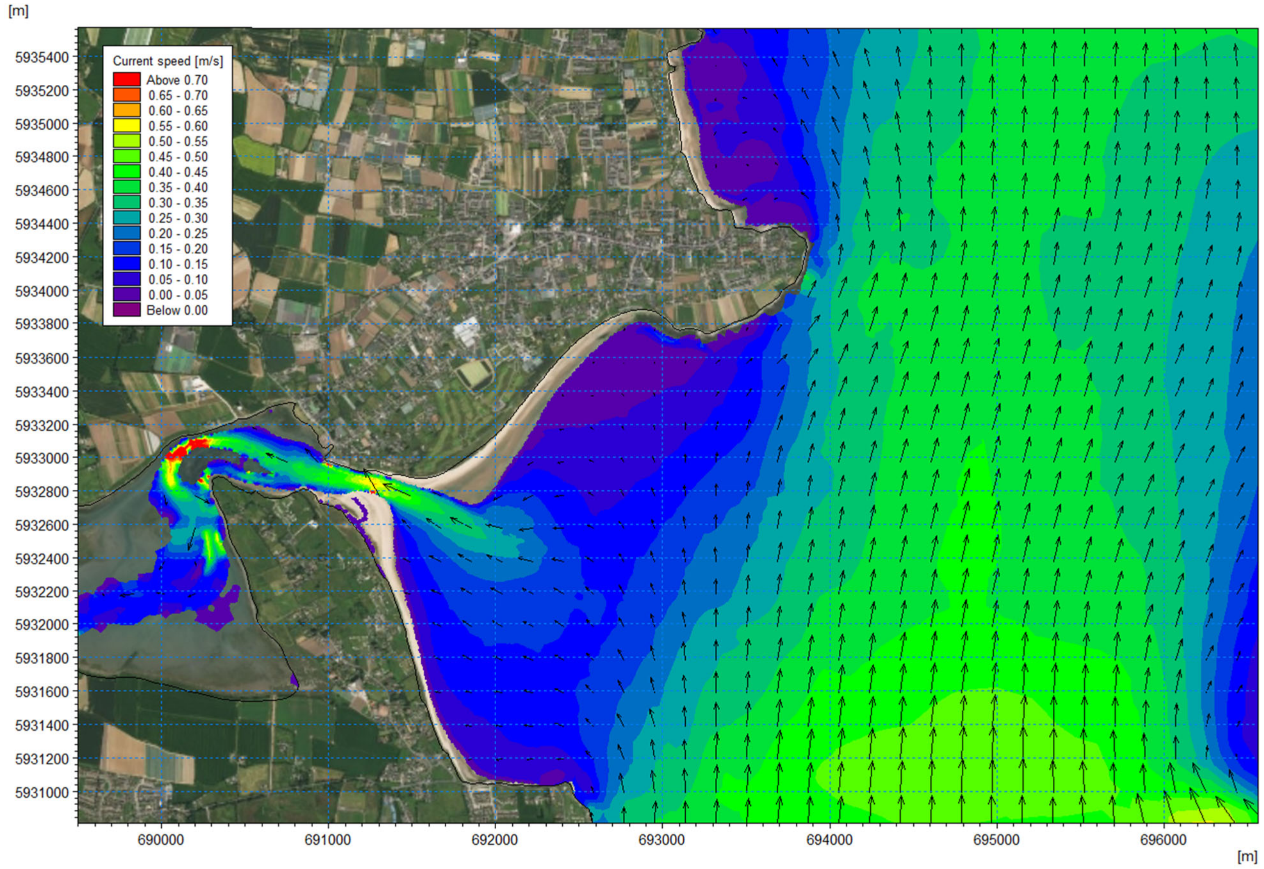


Figure 5.2: Typical spring mid flood tidal flows at Rogerstown

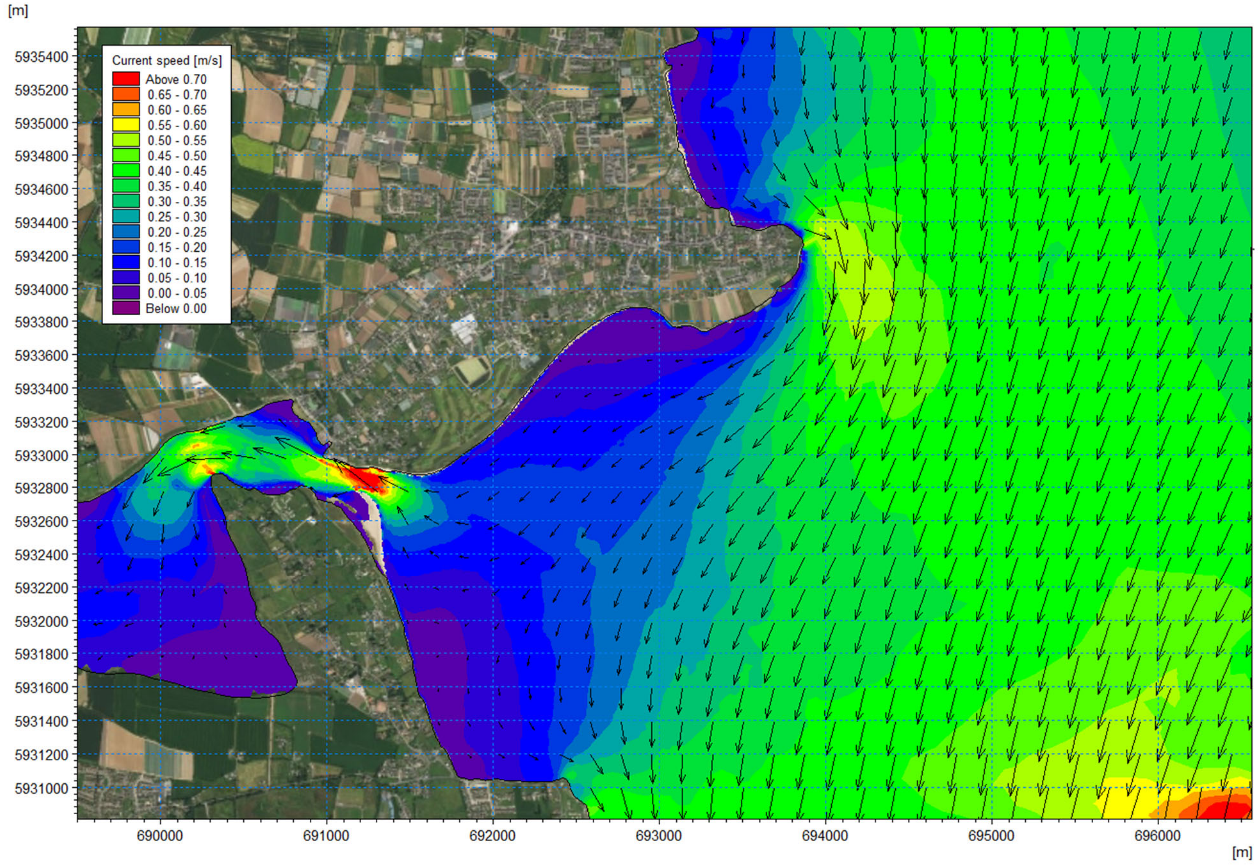


Figure 5.3: Typical spring high water tidal flows at Rogerstown

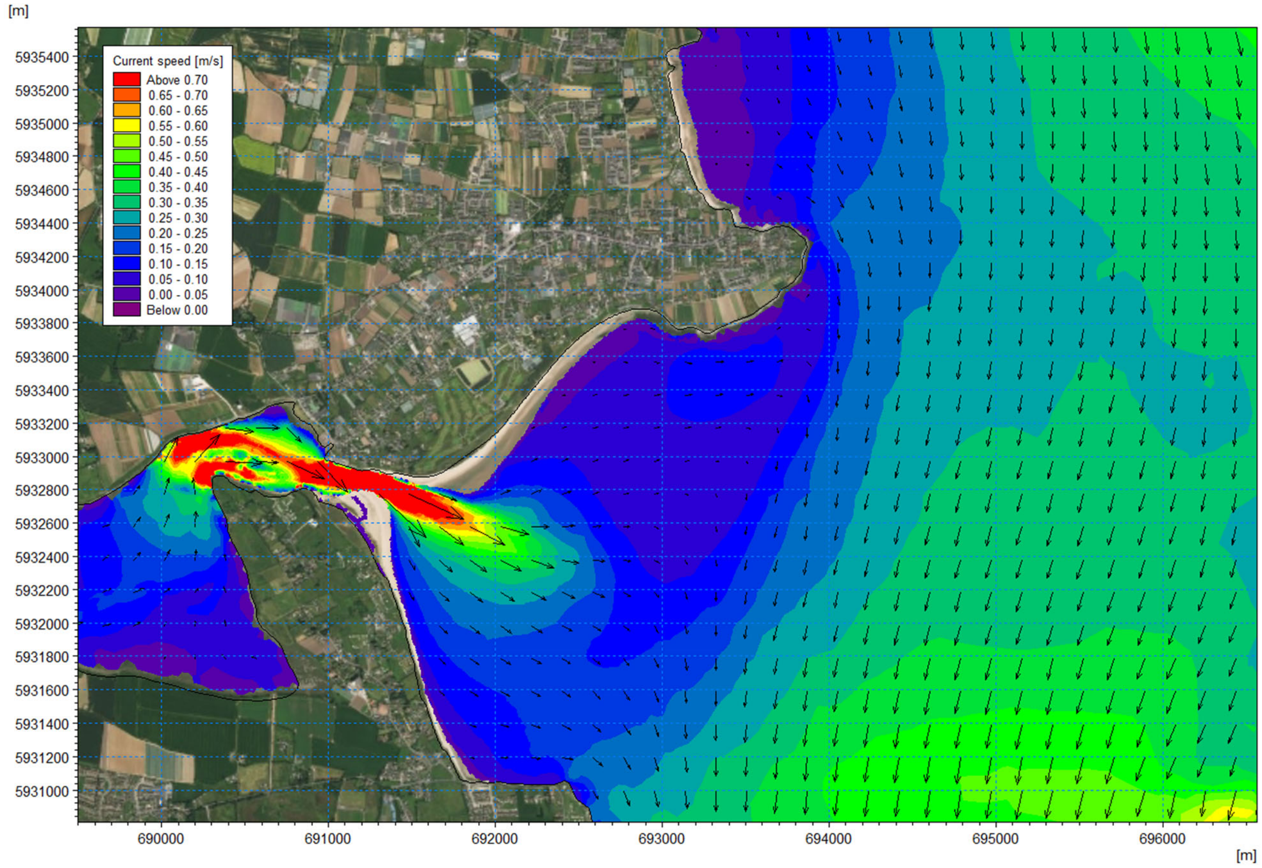


Figure 5.4: Typical spring mid ebb tidal flows at Rogerstown

5.2 Inshore Wave Climate

The inshore wave climate along the shoreline was established by transforming offshore waves taken from the European Centre for Medium Range Forecasts (ECMWF) wave model for the period from 1979 – 2018 by using the MIKE 21 SW model previously described in Section 4.3.3. This is a spectral wave model that describes the propagation, growth and decay of waves in nearshore areas. The model takes account of the effects of refraction, shoaling and energy dissipation due to bottom friction and wave breaking.

It will be seen from Figure 5.5 below that the dominant waves that affect the Burrow and Rush generally approach from the north east and south easterly sectors. The nature of the sediment transport during typical storm events from these sectors is assessed in more detail in Section 5.4.3.

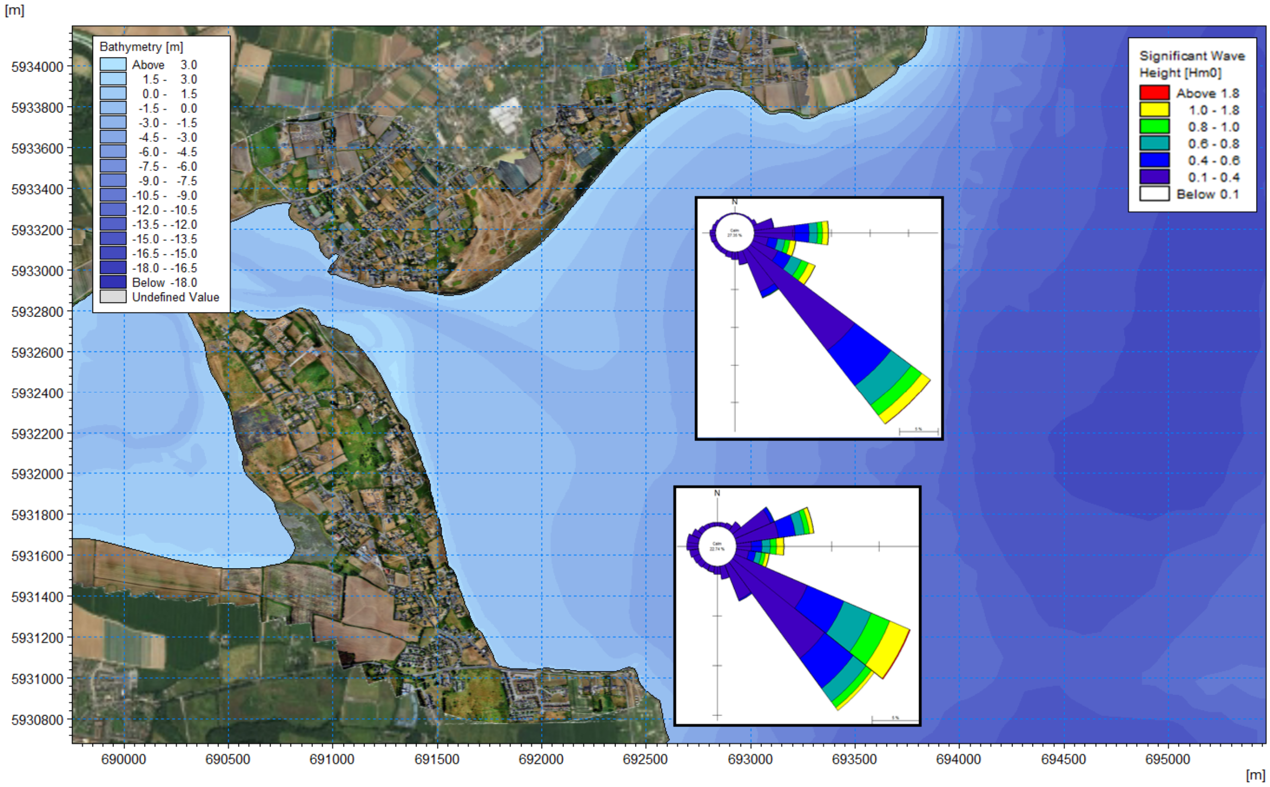


Figure 5.5: The inshore wave climate at the Burrow and Rush south between 1979 and 2018.

5.3 Extreme inshore wave conditions

To identify the most onerous conditions for each study site, the offshore waves that were transformed into the nearshore were split into seven directional sectors from North to South. The Burrow was split into North and South sections for the analysis with the results shown in Table 5.1. It was found that overall East, South-Southeast and South sectors generated the most onerous conditions at the study sites.

Based on the output of this initial analysis, offshore waves were then transformed into the nearshore for a range of joint probability return period storm conditions from the easterly sector. The joint probability conditions were taken from the analyses presented in Section 4.5.2 and included the relevant wave and wind conditions for each return period.

Figure 5.6 to Figure 5.8 illustrate the most onerous wave condition for a 1 in 2 year, 1 in 50 year and 1 in 200 year event from the east respectively. It should be noted that the results from the Spectral Wave simulations demonstrated that despite the offshore wave heights being significantly different, there was only a small difference observed in the inshore wave heights at each study site for each of the directional sectors simulated. This was an important finding as it indicates that the coastline could be exposed to a similar level of wave attack across a range of storm events.

Table 5.1: Inshore Wave climate for 2% AEP event at study sites for various directional sectors

	Portrane South		Portrane North	
Sector	**Significant Wave Height [m]**	**Wave Period [s]**	**Significant Wave Height [m]**	**Wave Period [s]**
N	0.86	4.37	0.70	4.03
NNE	0.95	3.71	0.82	3.37
ENE	1.01	3.76	0.91	3.32
E	1.04	3.85	0.99	3.34
ESE	0.99	3.93	1.04	3.42
SSE	0.98	4.23	1.13	3.74
S	0.85	4.46	1.10	4.19

	Rush South		Rush North	
Sector	**Significant Wave Height [m]**	**Wave Period [s]**	**Significant Wave Height [m]**	**Wave Period [s]**
N	0.64	4.99	1.18	4.79
NNE	0.88	4.79	1.26	4.53
ENE	1.06	4.42	1.32	4.86
E	1.19	4.38	1.36	5.05
ESE	1.32	4.32	1.35	5.18
SSE	1.51	4.53	1.31	5.72
S	1.54	4.90	1.13	5.92

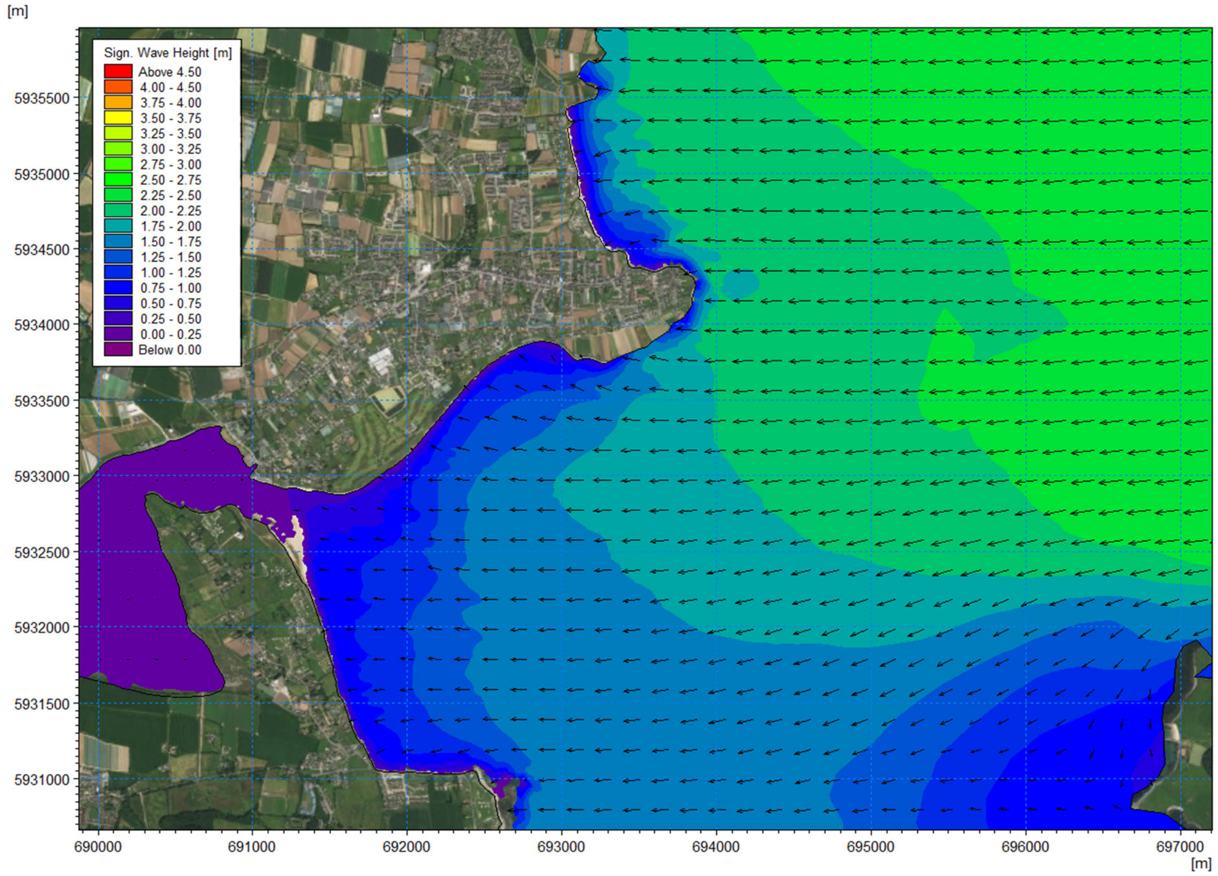


Figure 5.6: Significant wave height and mean wave direction - 1 in 2 year return period storm from 90°

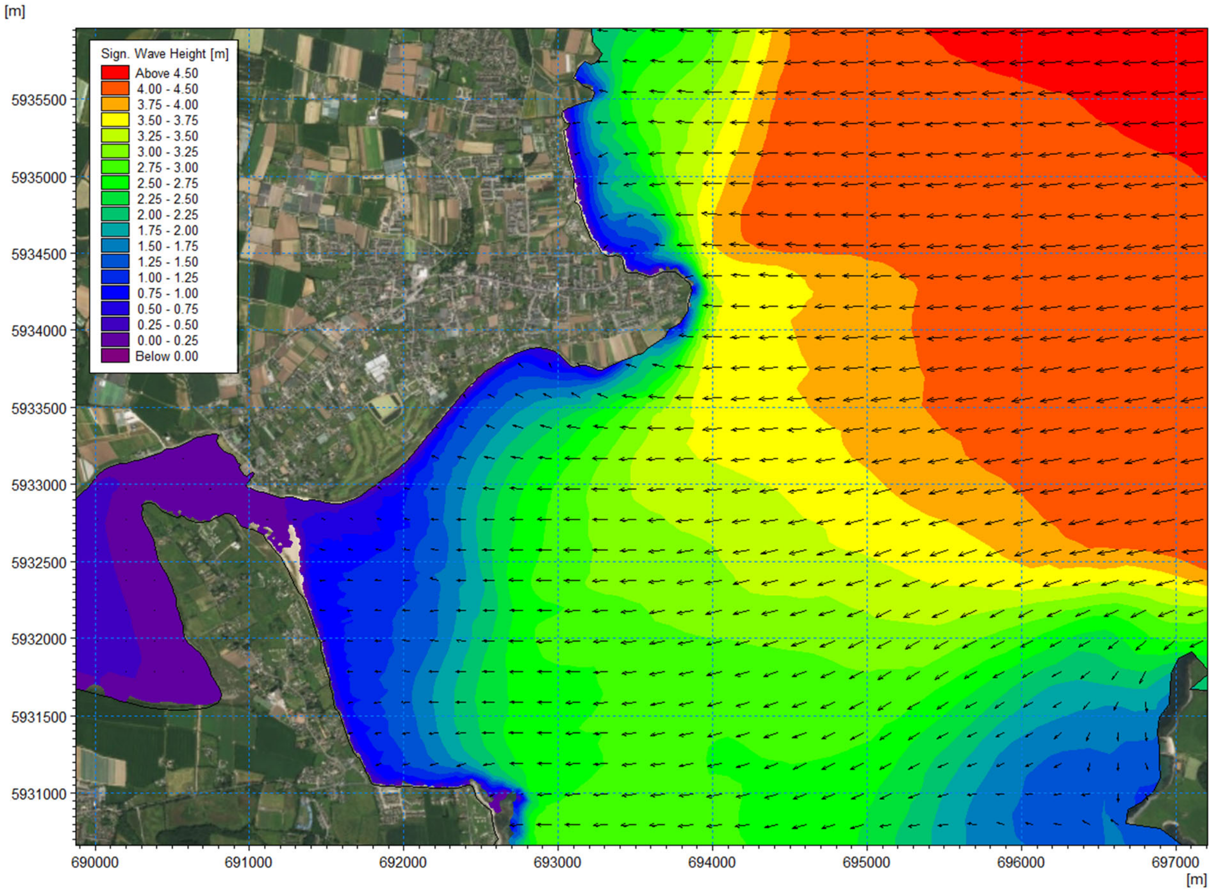


Figure 5.7: Significant wave height and mean wave direction - 1 in 50 year return period storm from 90°

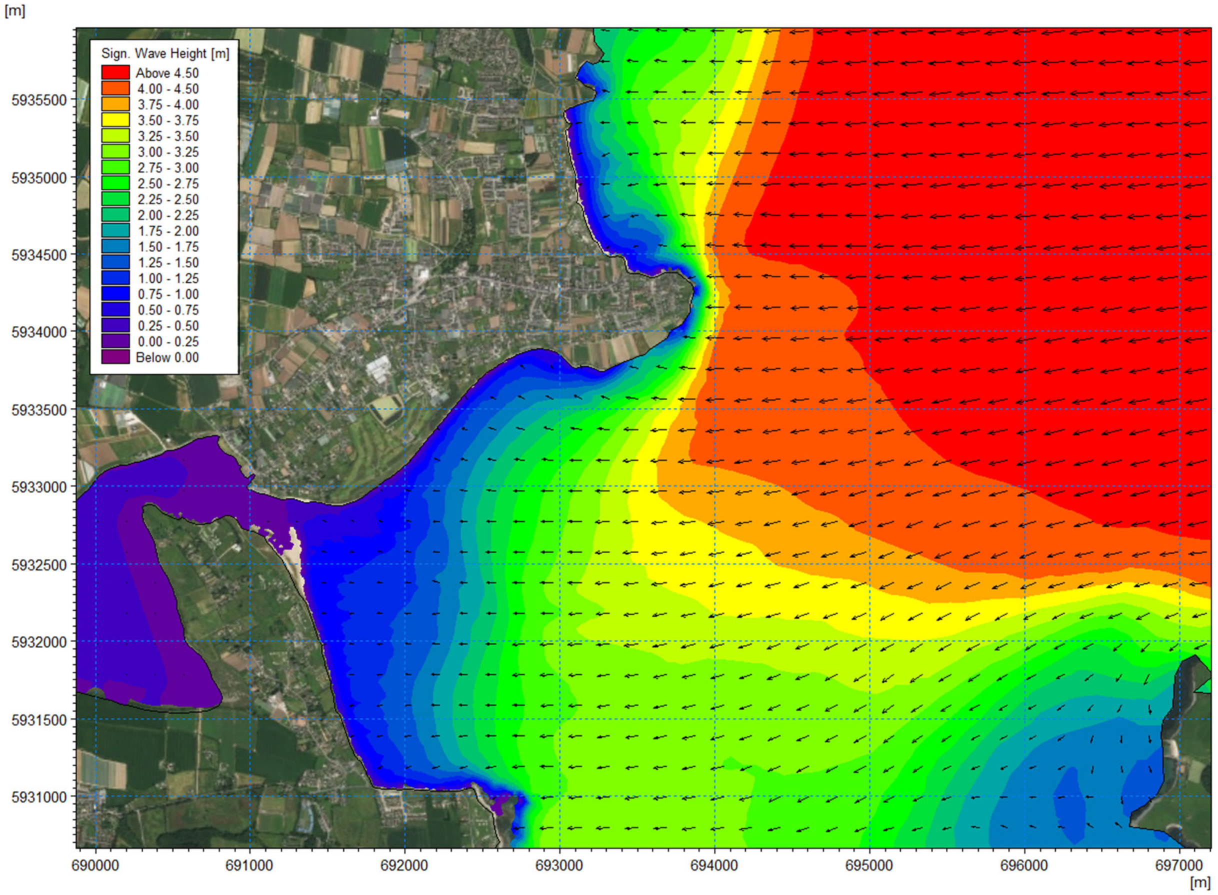


Figure 5.8: Significant wave height and mean wave direction - 1 in 200 year return period storm from 90°

5.4 Sediment Transport Regime

5.4.1 1D Sediment Transport

RPS utilised the results from the inshore wave modelling described in Section 5.2 in conjunction with the LitDrift modelling system to quantify and assess the littoral transport across the study site. Littoral transport is the term used for the transport of non-cohesive sediments, i.e. mainly sand, in the littoral zone along a shoreline mainly due to the action of breaking waves and to a lesser extent the longshore tidal currents.

LitDrift is a modelling system that can be used to assess basic shoreline evolution, quantify littoral budgets and to determine the *equilibrium orientation* of a coastline whereby the transport of sediment is on average close to zero. Figure 5.9 shows the location of the cross-shore profiles used to assess the sediment transport regime within the Rogerstown study area.

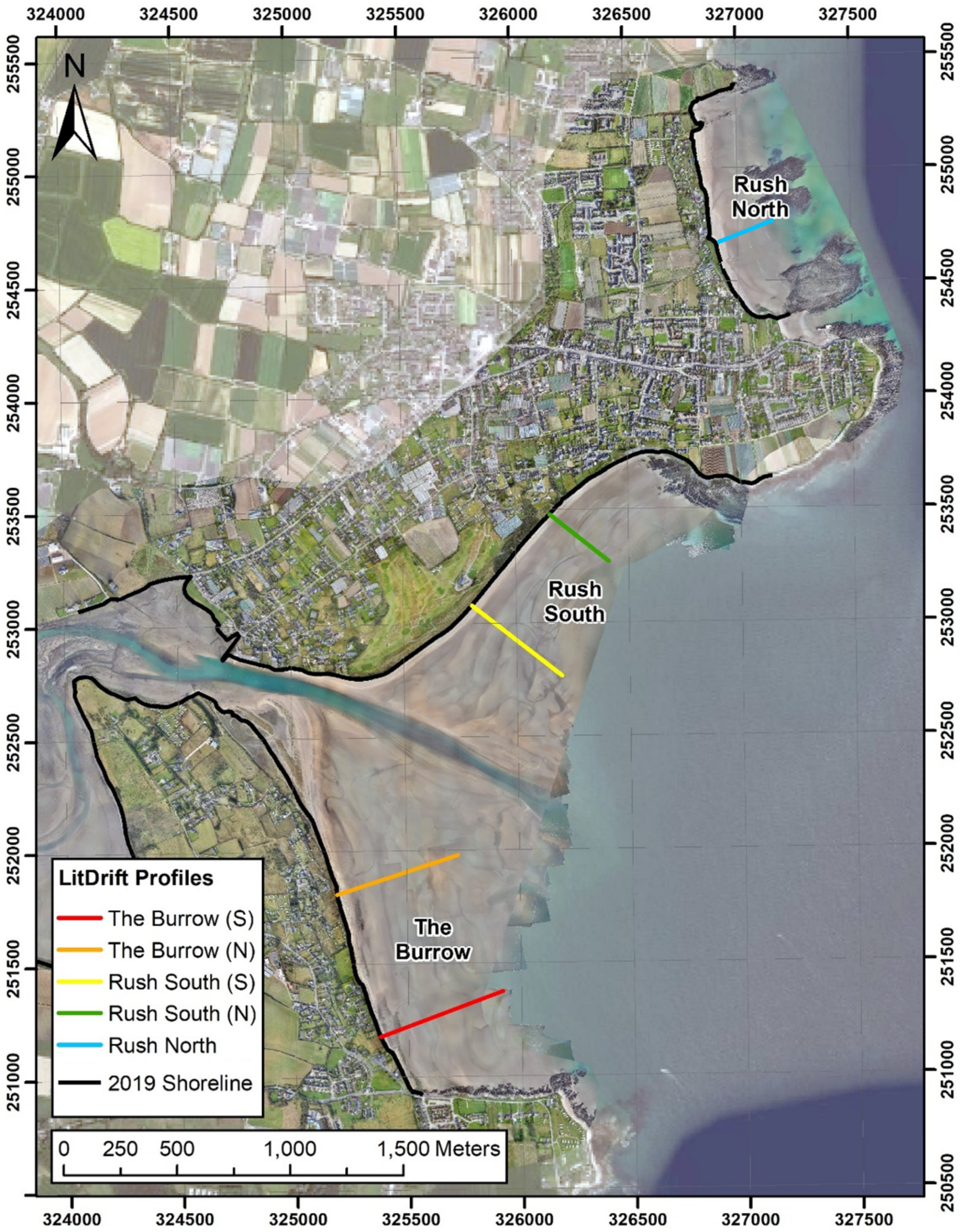


Figure 5.9: Cross-shore profiles used to assess sediment transport regime within the Rogerstown study area

A negative sediment drift indicates sediment moving to the left of the shore normal, i.e. northwards, whilst a positive sediment drift indicates sediment is moving to the right of the shore normal, i.e. southwards. A sediment grain size of 0.2mm was used to represent the sand material in this analysis.

5.4.1.1 1D Sediment transport along the Burrow

Figure 5.10 and Figure 5.11 illustrate the net sediment drift per year at the southern and northern profiles of the Burrow respectively. The figures show that the net drift of sediment material at the Burrow is always in the northward direction (towards the Rogerstown estuary). The net drift ranged from c. 8,000m^3 in 1992 to as much as c. 21,000m^3 in 1996 and 2002. This variability is governed primarily by the frequency and magnitude of storm events which are most common during the winter months. Sediment transport during winter (December to February) can be as much as four times greater than that observed during any other season.

The difference in the net annual drifts observed between the northern and southern profile can be attributed to the marginal differences in prevailing wave climates. As waves approach from the south, they refract and shoal around the headland to the south of the Burrow, causing them to deflect and approach the shore almost normal. This effect is less acute towards the south, thus approaching waves on the southern frontage are more oblique (i.e. approach the shoreline at an angle), resulting in higher transport rates relative to those observed further north.

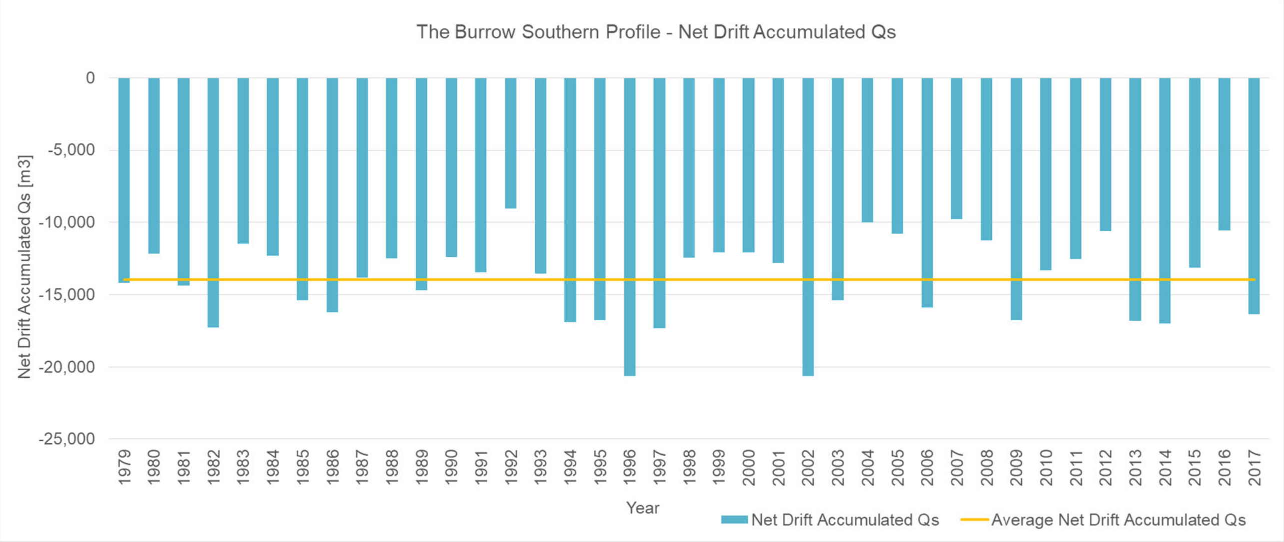


Figure 5.10: The Burrow (southern profile) net sediment drift per year from 1979 to 2017

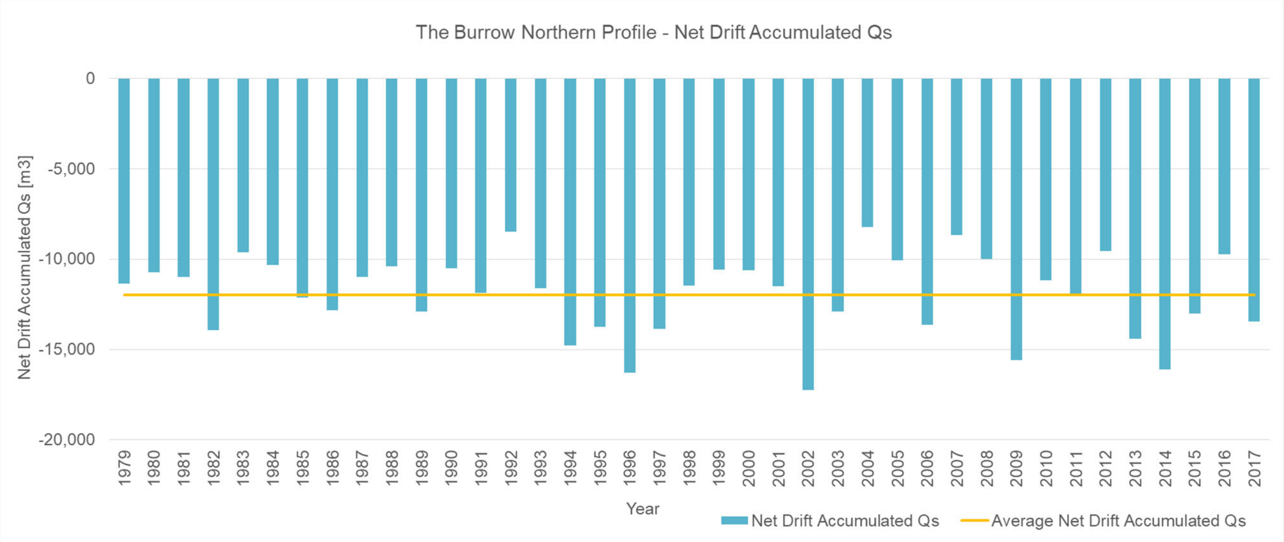


Figure 5.11: The Burrow (northern profile) net sediment drift per year from 1979 to 2017

5.4.1.2 1D Sediment transport along Rush South

The net sediment drift per year at the southern and northern profiles of Rush South is illustrated in Figure 5.12 and Figure 5.13 respectively.

At the southern profile it was found that the sediment drift is always in the southward direction (i.e. towards the Rogerstown estuary). The net sediment drift per year ranges from *c.* 10,000m^3 in 2011 and 2015 to *c.* 33,000m^3 in 1996. The average net sediment drift at the southern profile was found to be *c.* 17,000m^3.

It will be seen from Figure 5.13 that the net littoral drift along the northern section of Rush south is significantly lower than those observed at the southern profile. Although it should be noted that a low net littoral drift does not necessarily indicate low rates of sediment transport but instead indicates that there is an almost equal amount of north and south sediment transport.

These findings are in line with the historical review presented in Section 2, anecdotal evidence and the output from the coastal change assessment presented in Section 6 all of which indicate that there is a pivot point along Rush south whereby the shoreline tends to accrete and erode to the north and south respectively.

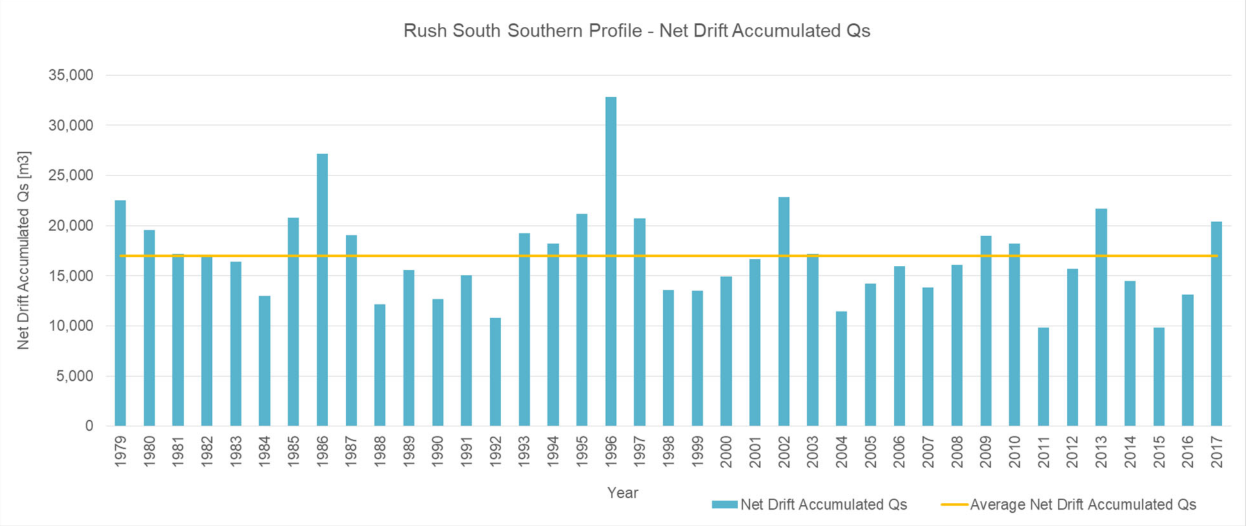


Figure 5.12: Rush South (southern profile) net sediment drift per year from 1979 to 2017

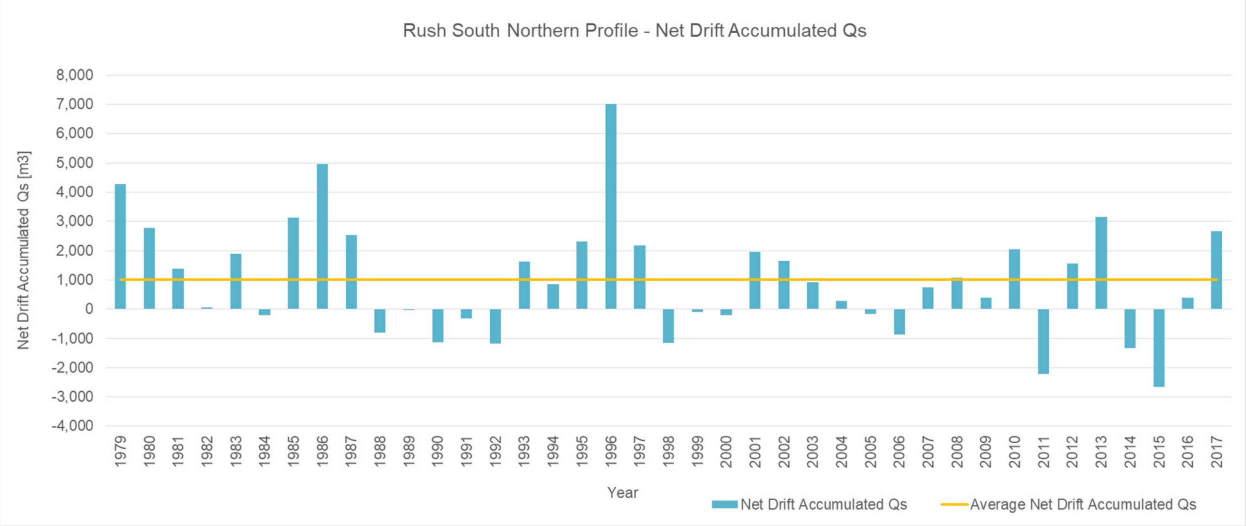


Figure 5.13: Rush South (northern profile) net sediment drift per year from 1979 to 2017

5.4.1.3 1D Sediment transport along Rush North

Similar to the upper profile at Rush south, Figure 5.14 shows the net annual drift at Rush North is very low relative to that observed along the Burrow. This can be attributed to the fact that this small beach is afforded significant wave protection by the two headlands that flank either side of the beach and the rocky outcrops that characterise the nearshore area.

The output from these long-term simulations support findings from other sections of this report which found that the beach in this area is dynamically stable and may even be accreting small volumes of sediment on an annual basis.

As illustrated in Figure 5.14, the average net drift per year was found to be *c.* 600m^3 in the southward direction.

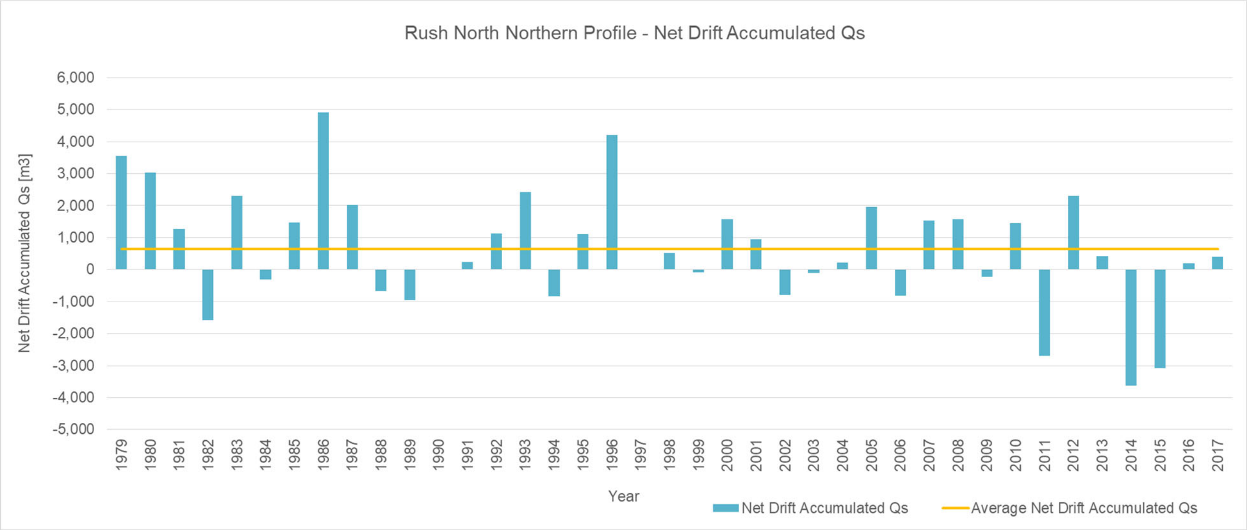


Figure 5.14: Rush North net sediment drift per year from 1979 to 2017

5.4.2 Summary of 1D Sediment Transport regime

An assessment of the long-term sediment transport at the Rogerstown estuary between 1979 and 2017 found that the nature of the net annual littoral drift budgets was significantly different at all three of the study areas. This difference was attributed to the orientation of the coastlines and the natural wave protection offered by the surrounding areas.

The net annual average littoral drift along the Burrow was found to be in the region of *c.*13,000m^3 per year in a northerly direction towards the Rogerstown estuary. At Rush South, the net annual average littoral drift varied between 17,000m^3 and 1,000m^3 towards the southern and northern extent of the beach respectively. These findings indicate that the northern section of Rush south is, on average, much more stable than the southern section of the beach and more stable than the Burrow. The dominant direction of sediment transport at Rush south was towards the south in the direction of the Rogerstown estuary.

The sediment transport regime at Rush north was found to be much more stable, with a net average annual sediment drift of less than 1,000m^3. This low net rate of littoral drift was attributed to the significant natural wave protection that this beach is afforded by the two headlands that flank either end of the beach. The findings from this assessment indicated that the beach at Rush north was dynamically stable and demonstrated minimal erosional pressure.

5.4.3 2D Sediment Transport

5.4.3.1 Background

Given that the sediment transport regime within the Rogerstown study area is highly two dimensional, particularly in the region of the Rogerstown estuary, RPS undertook a range of 2D combined tide, wave and sediment transport simulations. These simulations were used to assess and characterise the sediment transport regime during calm conditions and during typical storm events from the dominant wave directions, i.e. the north east and south east sectors.

For the purposes of this assessment, RPS used the same tidal boundary conditions described in Section 4.3.5. The waves used for each simulation were representative of those that would be observed at the study site during a typical Beaufort force 10 storm. Under these conditions, wind speeds range between 24.5–28.4 m/s, producing heavy seas and arduous inshore conditions. The beach material in the sediment transport module was represented by a fine to medium sand which was found to be reflective of the three sites.

It should be noted that the sediment transport model does not account for dune erosion or avalanching and in that sense cannot be considered as a full morphological model. However, it is a proven tool for assessing and quantifying bed load and suspended sediment transport which are both crucial in governing the overall sediment budget. Furthermore, output in the form of sediment distribution patterns from these simulations can be used to inform assessments undertaken by experienced coastal engineers to determine where erosion or accretion is likely to occur.

The output from these simulations are presented in two different plots for each of the three scenarios that were assessed. The first figure illustrates the actual average daily sediment transport potential with the direction and magnitude of transport shown by vector arrows. Given that these figures can be difficult to interpret RPS have summarised the direction and rate of sediment transport in a second figure whereby a traffic light colour system indicates high (red) to low (green) rates of sediment transport.

5.4.3.2 2D Sediment transport during calm conditions

The sediment transport regime across the study area during calm conditions is illustrated in Figure 5.15 overleaf. It will be seen from this figure that the dominant feature is the seaward flow coming from the Rogerstown estuary which clearly separates the Burrow from Rush south. This strong current of water would also transport any suspended material beyond the nearshore region. There is virtually no sediment transport across any of the three study area beaches.

5.4.3.3 2D Sediment transport during a north easterly gale

As demonstrated in Figure 5.16 the sediment transport potential across the entire domain is significantly higher during north easterly storm events. At Rush north, the incident waves result in complex eddying across most of the beach, but this does not transport sediment in any one direction. Sediment transport is increased around the headland at the Martello Tower. However, given that this area is dominated by rocky outcrops, the actual rate of sediment transport past this point is expected to be relatively low.

At Rush south, the littoral currents are highest along the toe of the dune resulting in a corresponding increase in southerly sediment transport towards the Rogerstown estuary. There is only a modest amount of southerly sediment transport across the foreshore at Rush south.

> Sediment displaced from Rush north or Rush south during a north easterly storm event is unlikely to end up on the beach at the Burrow. This is due to the dominating effect of the Rogerstown estuary flow which would transport sediment from Rush offshore.

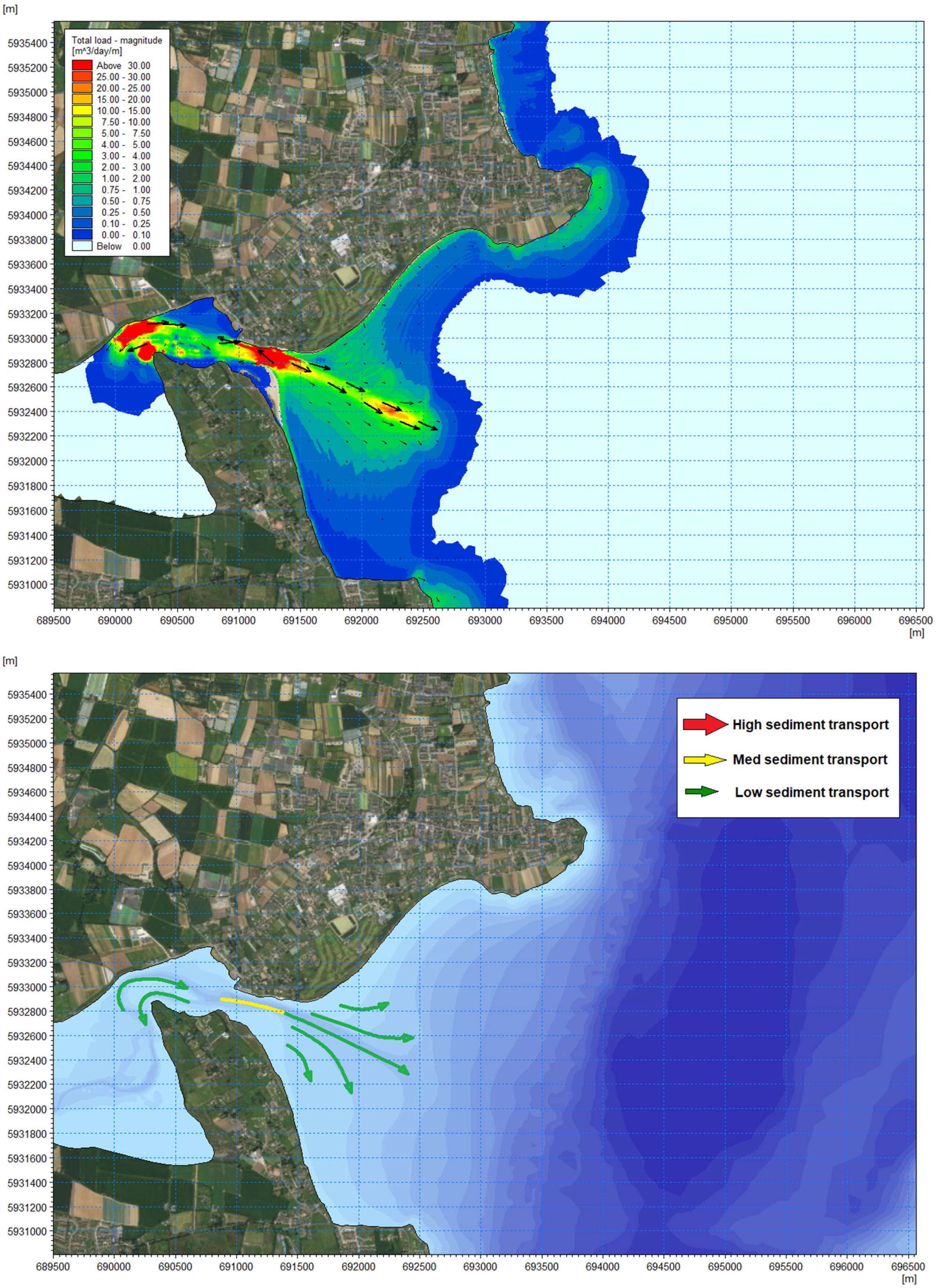


Figure 5.15: Actual (upper) and summarised (below) average sediment transport at Rogerstown during typical calm conditions

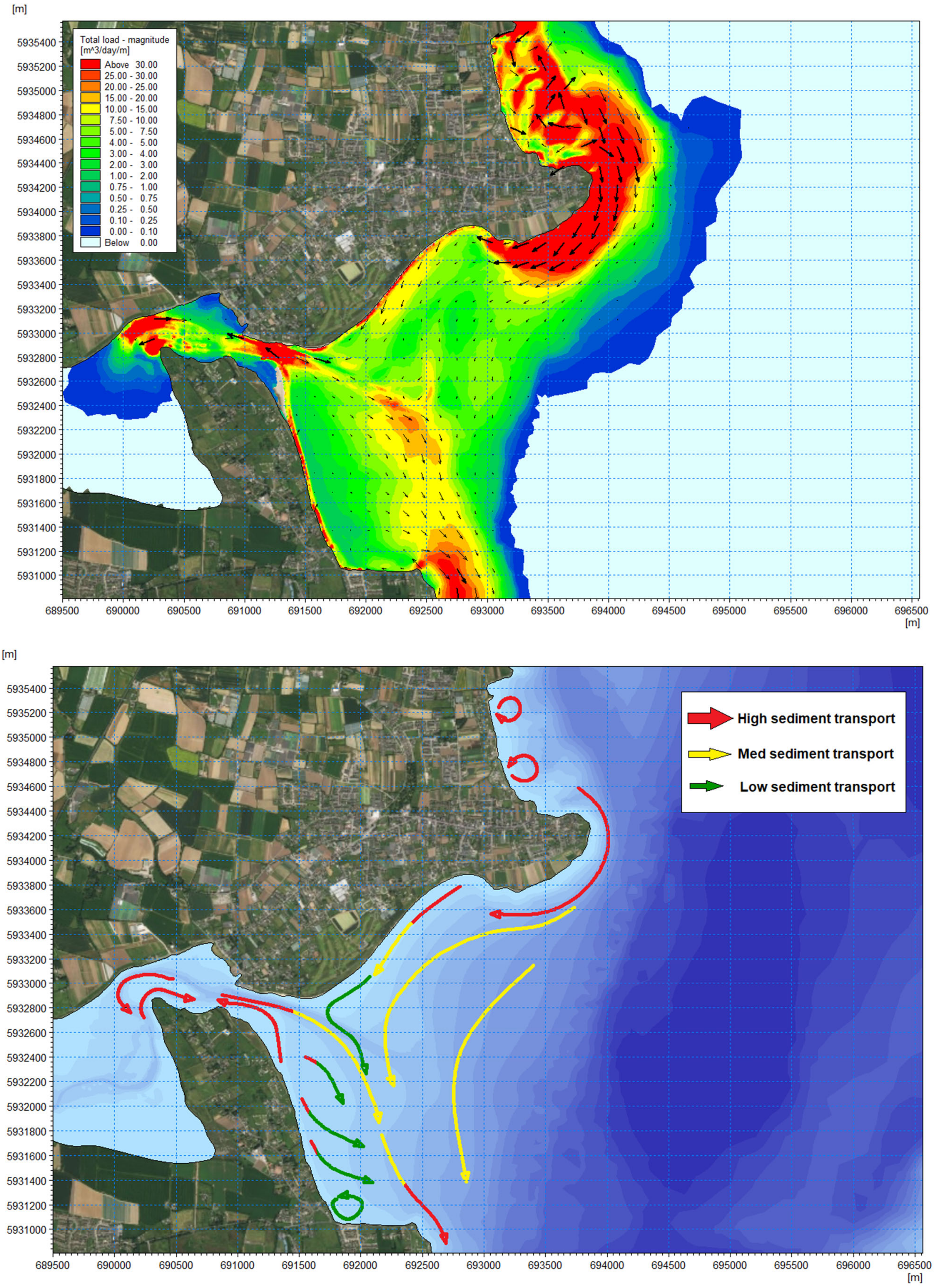


Figure 5.16: Actual (upper) and summarised (below) average sediment transport at Rogerstown during a typical north easterly storm event

5.4.3.4 2D Sediment transport during a south easterly gale

In many aspects the sediment dynamics across the study area during a south easterly and north easterly gale are very similar with the beach at Rush north experiencing similar eddying effects and a general south west movement of sediment from Rush south towards the Rogerstown estuary.

As illustrated in Figure 5.17, both regimes are characterised by strong littoral currents coming from the estuary. It may seem paradoxical that the direction of sediment transport along Rush south is towards the south during a south easterly storm event. But this can be attributed to the refraction and shoaling which realigns the direction of incident waves so that they approach almost perpendicular to the shoreline. This combined with the orientation of the shoreline means that sediment is transported in a southerly direction.

During a south easterly event, sediment is transported along the beach of Burrow towards the north. The strong tidal jet from the Rogerstown estuary will prevent the bulk of this material reaching Rush south. This material will instead be transported offshore and potentially lost from this local sediment cell. Given the distance of the beaches at the Burrow and Rush from the offshore region, it is unlikely that this material would be transported back onshore.

5.4.4 Summary of the 2D Sediment Transport regime

The findings from the combined 2D tide, wave and sediment transport simulations verified the conclusions of the 1D sediment transport assessment. It was demonstrated that although there can be high rates of sediment transport along Rush north, the eddying effects are such that the actual net movement of sediment is low. In almost all the assessed storm scenarios, the dominant direction of sediment transport along Rush south and the Burrow was found to be towards the Rogerstown estuary.

The littoral currents associated with the tidal exchange with the Rogerstown Estuary and high rates of offshore sediment transport were found to strongly influence the overall sediment transport regime within the area. The currents from the Rogerstown estuary effectively intercepts the transport of sediment between the Burrow and Rush and transports it offshore. Over the long term, this could lead to a deficit in the supply of sediment to the Burrow and therefore contribute to erosional pressures.

In summary, the beach at Rush north appears to be dynamically stable under almost all conditions. At Rush south, waves from the north east and south east maintain the sediment budget, with a small volume of material coming from along the Burrow. Conversely, the Burrow depends almost exclusively on sediment supply from the south east as the strong littoral currents coming from the Rogerstown estuary prevent the effective transfer of sediment between the two beaches.

The findings from this assessment indicate that the sediment transport regime along the Burrow is no longer in a state of dynamic equilibrium due to a deficit in the supply of sediment. This deficit enhances existing erosion pressures along the Burrow coastline.

This shift can be attributed to an increase in the frequency and magnitude of arduous storm events which have in turn lowered beach levels and increased wave energy at the toe of the dunes along the Burrow. The supply of sediment to the beach is no longer believed to be in proportion to the volume of sand leaving the beach owing to this increased wave energy.

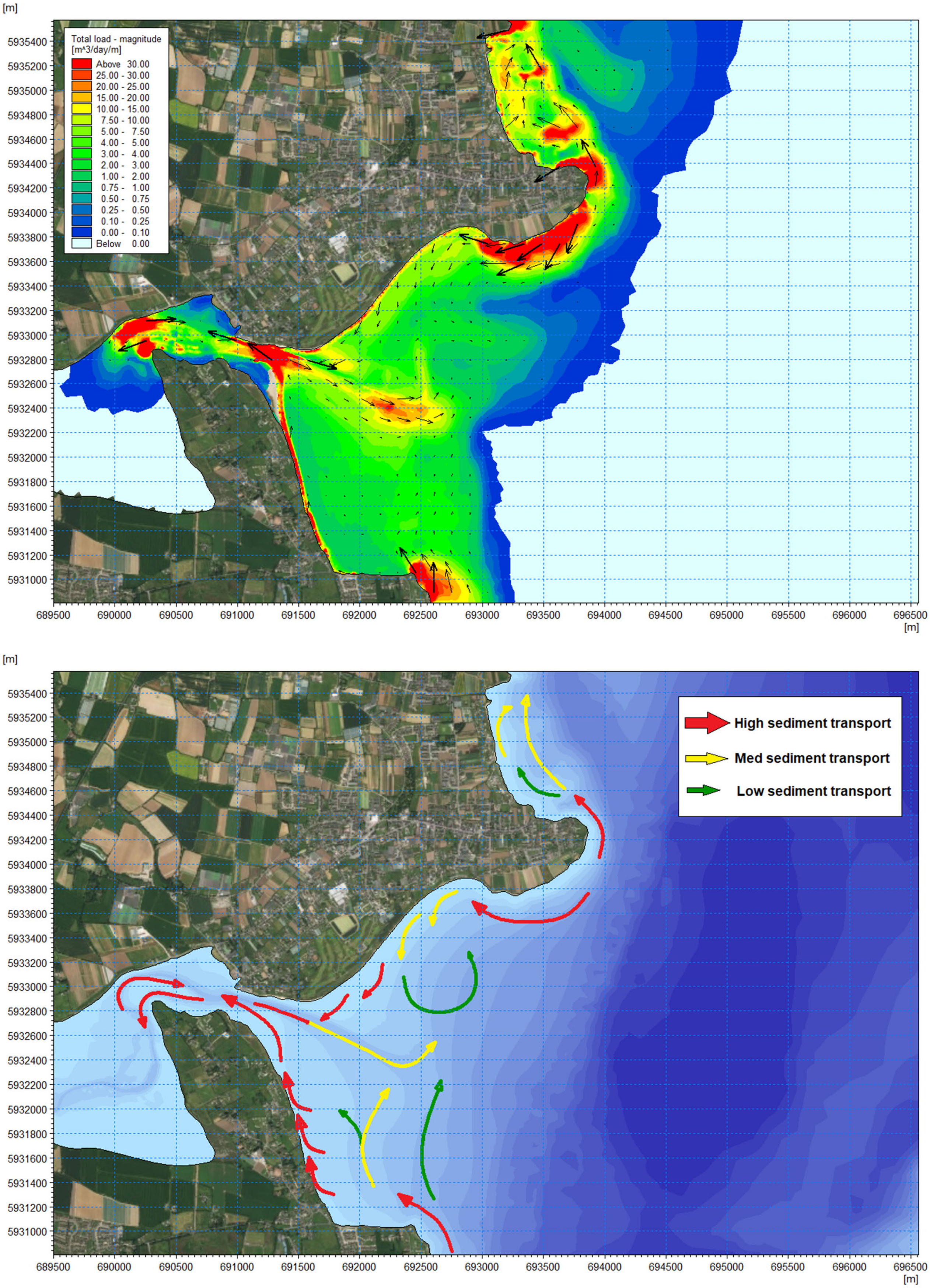


Figure 5.17: Actual (upper) and summarised (below) average sediment transport at Rogerstown during a typical south easterly storm event

6 COASTAL EROSION RISK ASSESSMENT

6.1 Background

Coastal erosion is an important natural phenomenon that has been occurring uninterrupted for millions of years (until recent human intervention). Erosion plays a fundamental role in redistributing sediment throughout a coastal system and contributes to the formation of a variety of coastal landscapes, many of which have now been designated as special habitats owing to their unique environmental characteristics.

Excessive erosion, however, can result in significant negative impacts in areas where there is not enough hinterland to accommodate the ongoing exchange of sediment and the potential retreat of the shoreline. This is particularly problematic in urbanised areas where important infrastructure, sites of cultural heritage and/or public amenities can be threatened by erosion.

Assessing the potential consequences of coastal erosion therefore forms a key element in the development of any coastal erosion management strategy. The following section of this report describes how RPS used the Historical Retreat Analysis method to calculate the current erosion risk and how these risks were projected forward to enable RPS to quantify the risk associated with future coastal erosion in later sections of this report.

6.2 Historical Trend Analysis

6.2.1 Background

Historical Trend Analysis is one of the key approaches used in the analysis of coastal change over historical timescales. By quantifying and assessing past coastal change, it is possible to project and estimate future trends based on events that have already occurred.

The historical trend analysis at the Burrow and Rush was completed using the Digital Shoreline Analysis System (DSAS) which is a tool that has been produced by the US Geological Society (USGS, 2018). One of the main benefits of using DSAS in coastal change analysis is its ability to compute the rate of change statistics for a time series of shoreline positions. The statistics allow the nature of shoreline dynamics and trends in change to be evaluated.

6.2.2 Schematisation of the Shoreline & Workflow

For the analysis at all three locations, shoreline data was available from 1973 to 2019, spanning 46 years. However, it will be seen from Table 6.1 which summarises the available shoreline information for each beach that only a piecemeal dataset was available for Rush North.

Table 6.1: Summary of available shoreline data

Year	The Burrow	Rush South	Rush North
1973	✓	✓	✓
1982	✓	X	X
1995	✓	✓	X
2000	✓	✓	✓
2005	✓	✓	✓
2009	✓	✓	X
2011	✓	✓	X
2013	✓	✓	✓
2018	✓	✓	X
2019	✓	✓	✓

Using the DSAS tool, RPS divided the shoreline of each study area into 10m transects and grouped these 10m transects into 100 - 200m sections. The DSAS tool was then used to calculate a range of coastal change statistics for each 10m transect. In summary, these statistics included:

- **Net Shoreline Movement (NSM):** reports the distance between the oldest and the youngest shorelines.
- **Linear Regression Rate (LRR):** determines a rate-of-change statistic by fitting a least square regression to all shorelines at a specific transect. Further statistics associated with LRR include Standard Error of Linear Regression (LSE), Confidence Interval of Linear Regression (LCI) and R-Squared of Linear Regression).

Figure 6.1 shows an example of how the 10m transects were cast from a baseline to intersect shoreline data along the Burrow whilst Figure 6.2 illustrates how the beach was split into the different 100 – 200m sections. Figure 6.3 illustrates how Rush north and Rush south beaches were split into sections for the analysis.

For each transect, a linear regression analyses was performed on all shoreline data using a least-squared residual approach. The best fit lines were then projected forward to estimate the magnitude of future coastal change for each transect and thus shoreline section.

RPS are acutely aware that recent events indicate a potential "turning point" in the coastal processes along the Burrow and that the erosion rates calculated as part of the Historical Trend Analyses may not reflect recent observations. However, without sufficient long-term high-resolution data it is not possible to determine if these events are unique outliers or the beginning of a new long-term trend.

In line with best practice and guidance from relevant statutory authorities, RPS have estimated erosion rates using all available shoreline data in the Historical Trend Analyses. Despite this, a Sensitivity Analyses of this method found that average erosion rates could be up to x3 greater if historical data prior to 2013 was excluded. More information of this Sensitivity Analyses is presented in Appendix B.

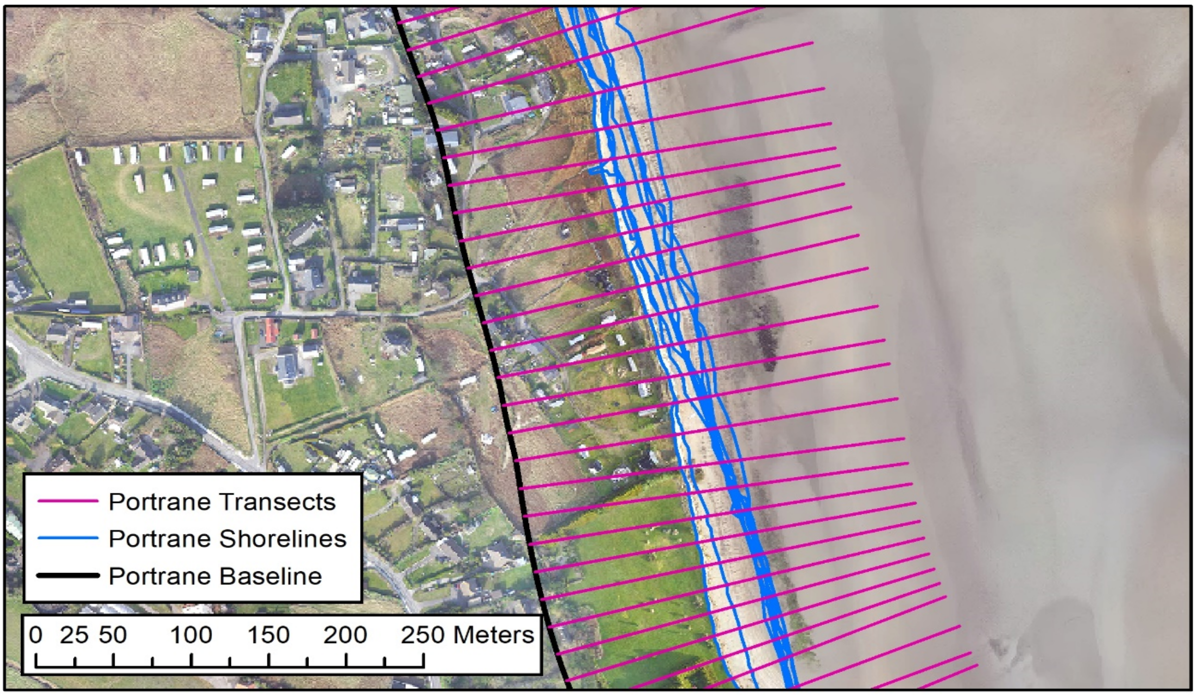


Figure 6.1: Example of transects intersecting shoreline data at Portrane

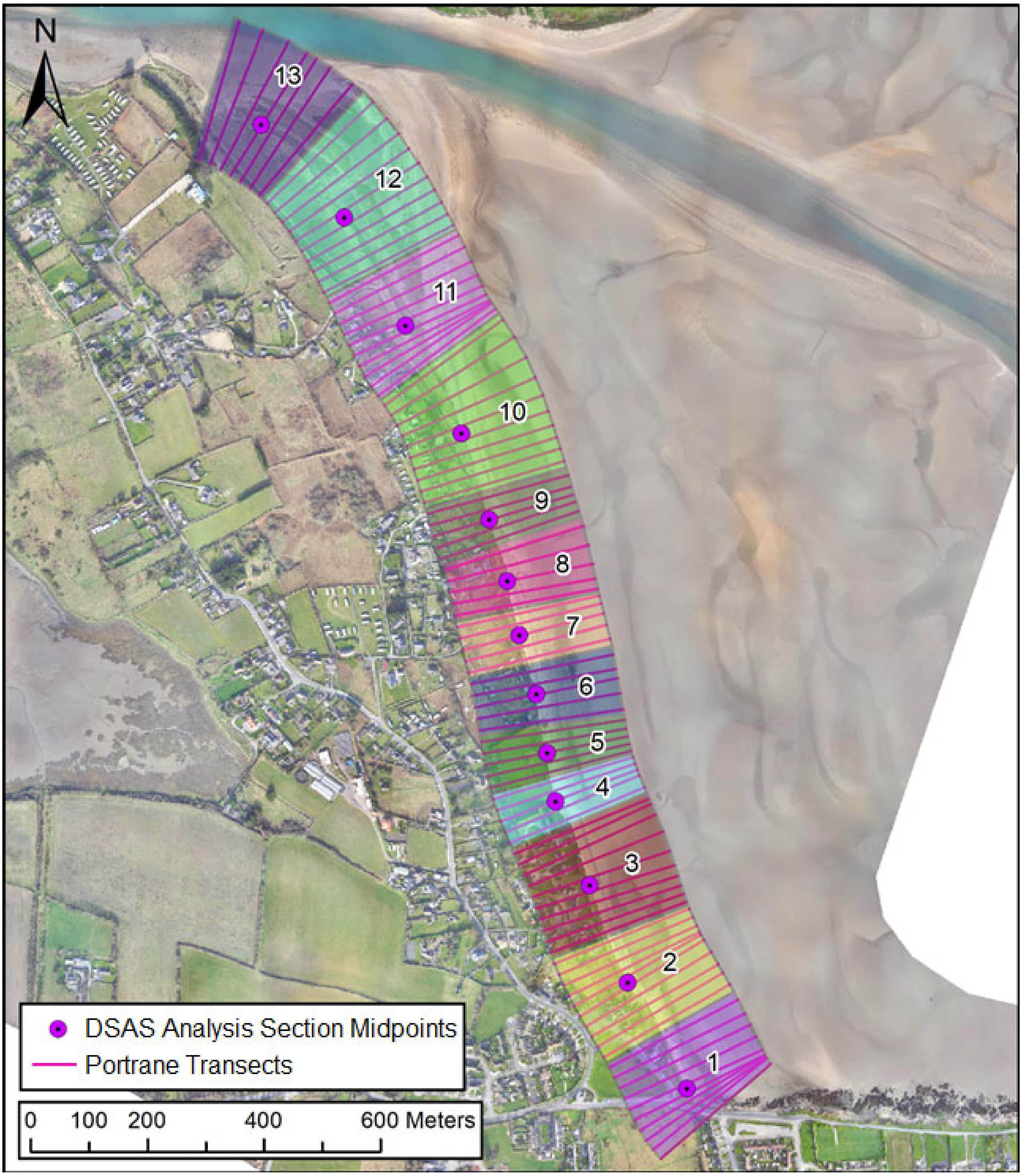


Figure 6.2: The Burrow beach split into sections for DSAS analysis

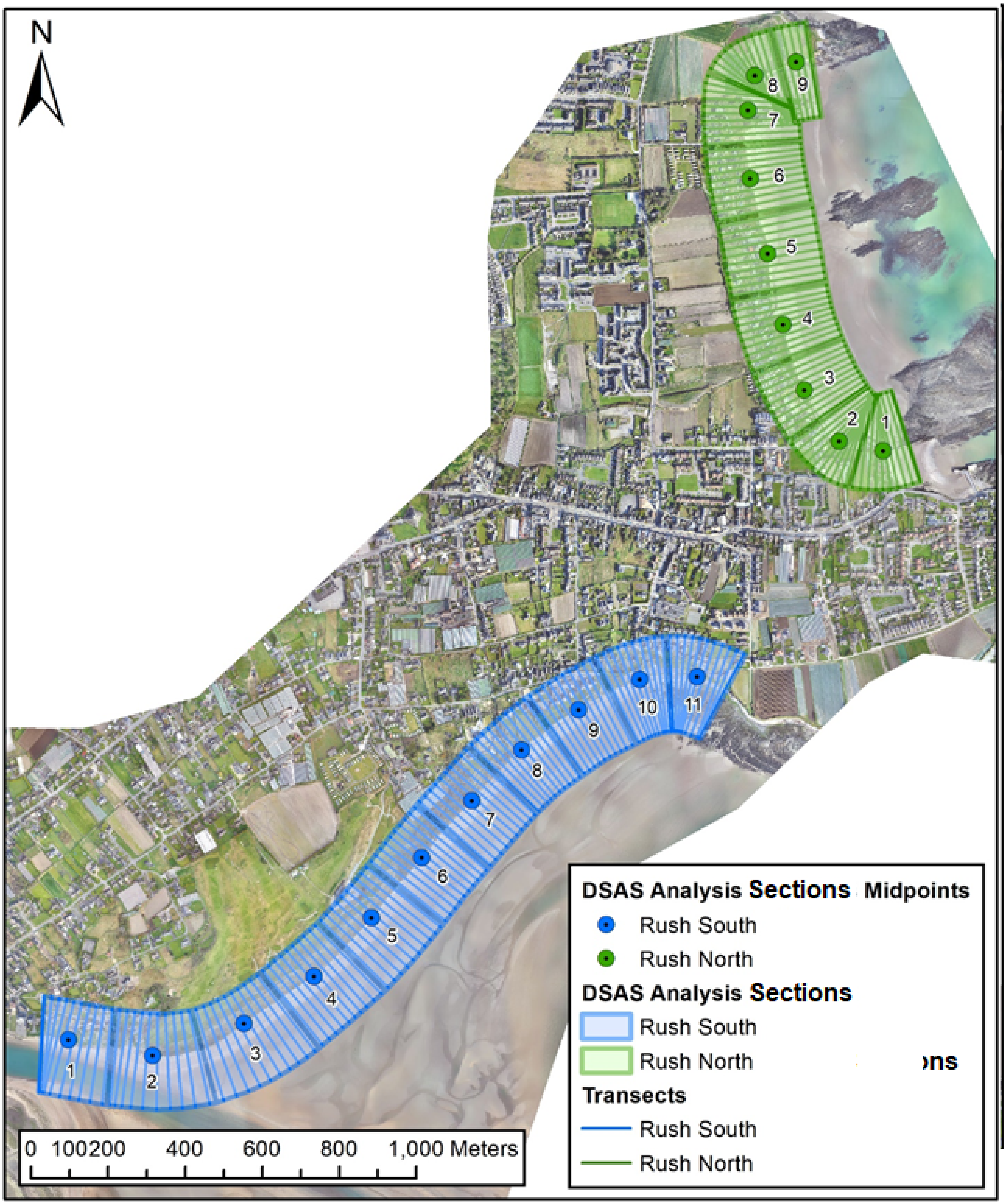


Figure 6.3: Rush North and Rush South split into sections for DSAS analysis

6.2.3 Coastal Change Assessment – The Burrow

Using the data and workflow outlined in the previous section, RPS created a linear regression plot for each of the twelve sections along the Burrow. Examples of these regression plots for Sections 3, 7 and 10 are presented in Figure 6.4 to Figure 6.6 whilst similar plots for all sections can be found in Appendix A.

By comparing the rate of change between 1973 and 2019 it was possible to estimate future coastal change. Using this approach, the shoreline was predicted to retreat by 103, 36 and 32 metres by 2100 at Sections 3, 7 and 10 respectively. The projected coastal change across each of the twelve sections along the Burrow is summarised in Table 6.2.

The rate of coastal change was found to be greatest towards the southern section of the Burrow, with a maximum rate of coastal retreat of 1.29m/yr at section 4. At the northern extent of the Burrow, the rate of coastal change was less severe and more uniform at an almost constant rate of *c.*0.45m/yr ±<0.01m.The average rate of coastal retreat along the entire Burrow was found to be *c.* 0.60m/yr ±0.92m. Existing sheet piling in section one is expected to arrest coastal erosion along the southern most part of the Burrow.

It will be noted from the plots below that despite the regression line fitting the existing data points relatively well between 1973 – 2019, the confidence intervals for each regression plot steadily increase by up to ±40m by 2100. This potential error margin is naturally one of the greatest limitations with using a historical dataset to project future coastal erosion. However, given the inherent limitations of undertaking long-term morphological modelling this approach was the most appropriate and suitable for this assessment.

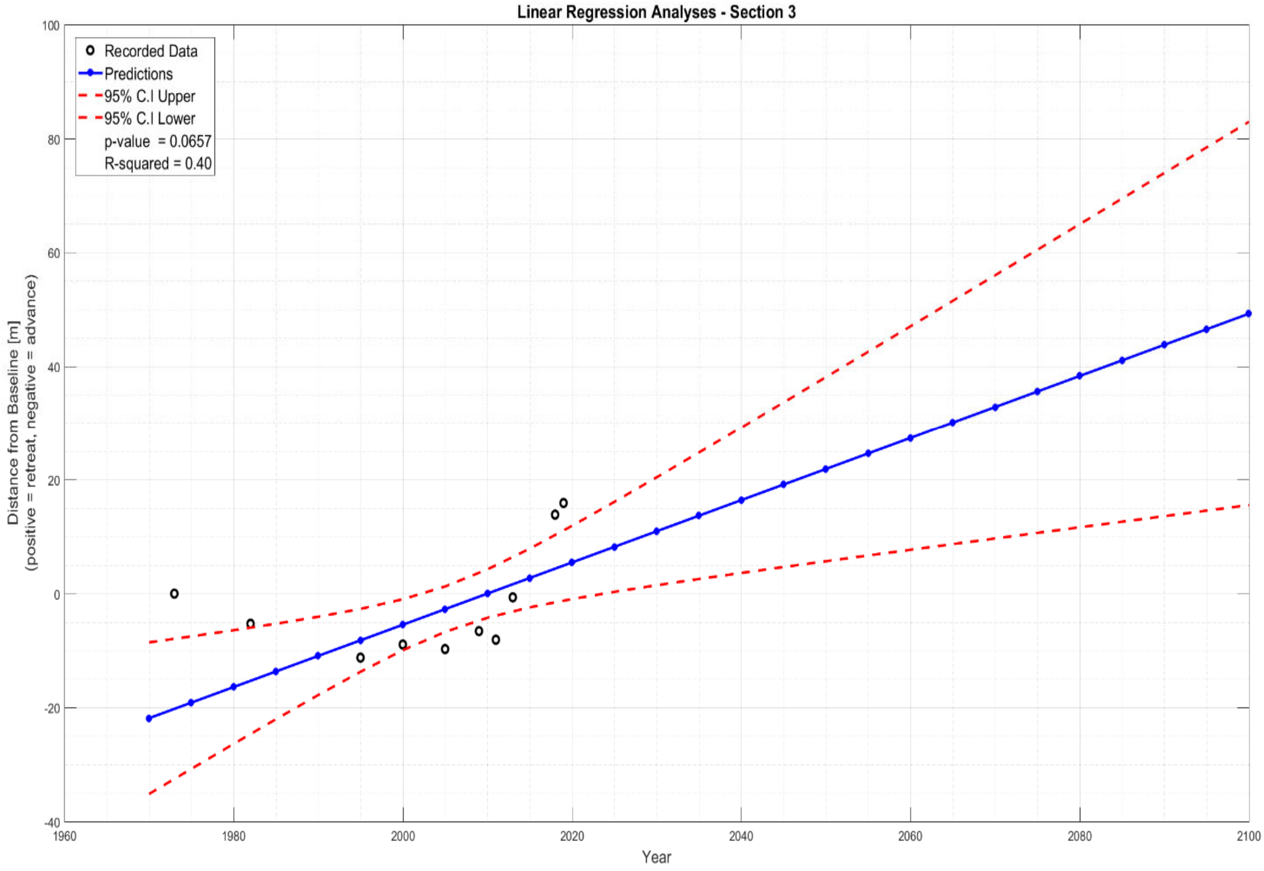


Figure 6.4: Example of the linear regression analyses undertaken along the Burrow at Section 5

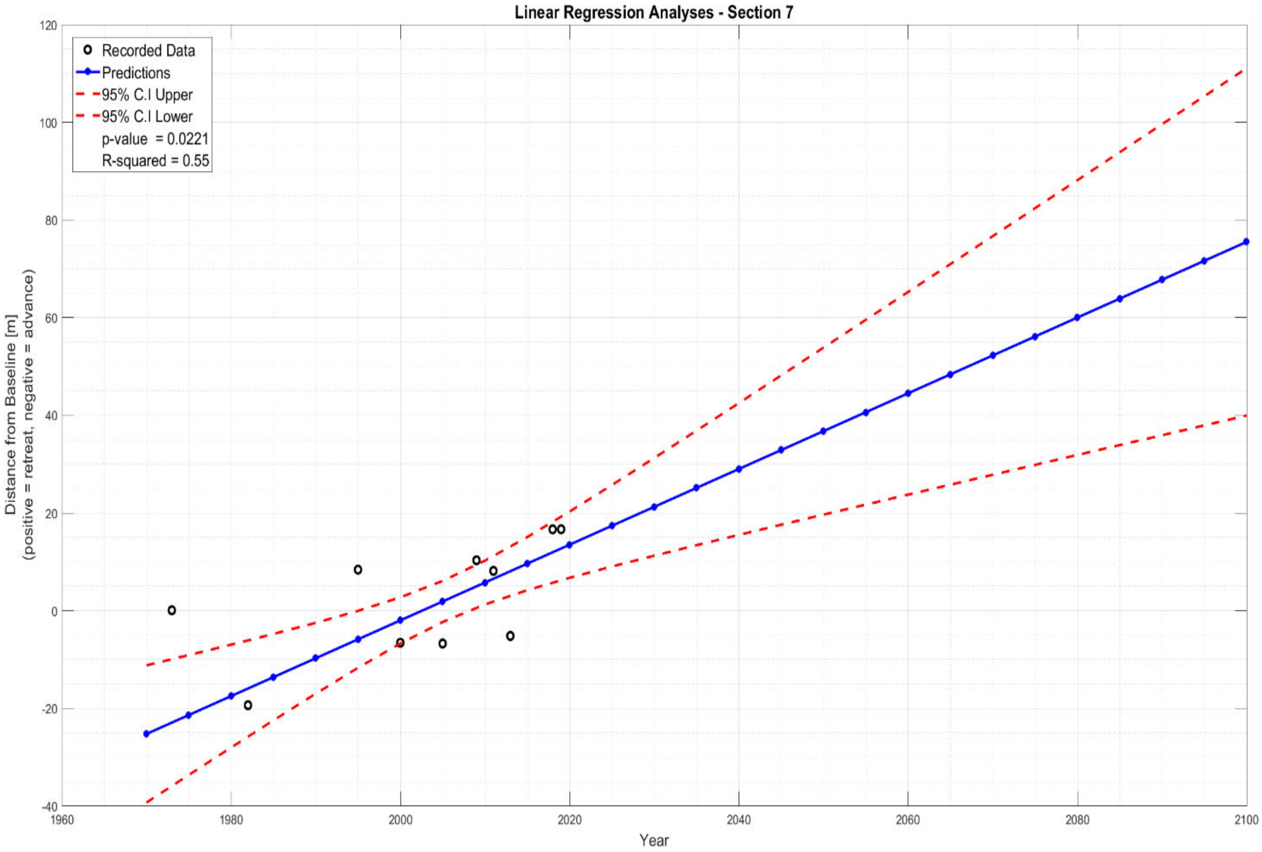


Figure 6.5: Example of the linear regression analyses undertaken along the Burrow at Section 7

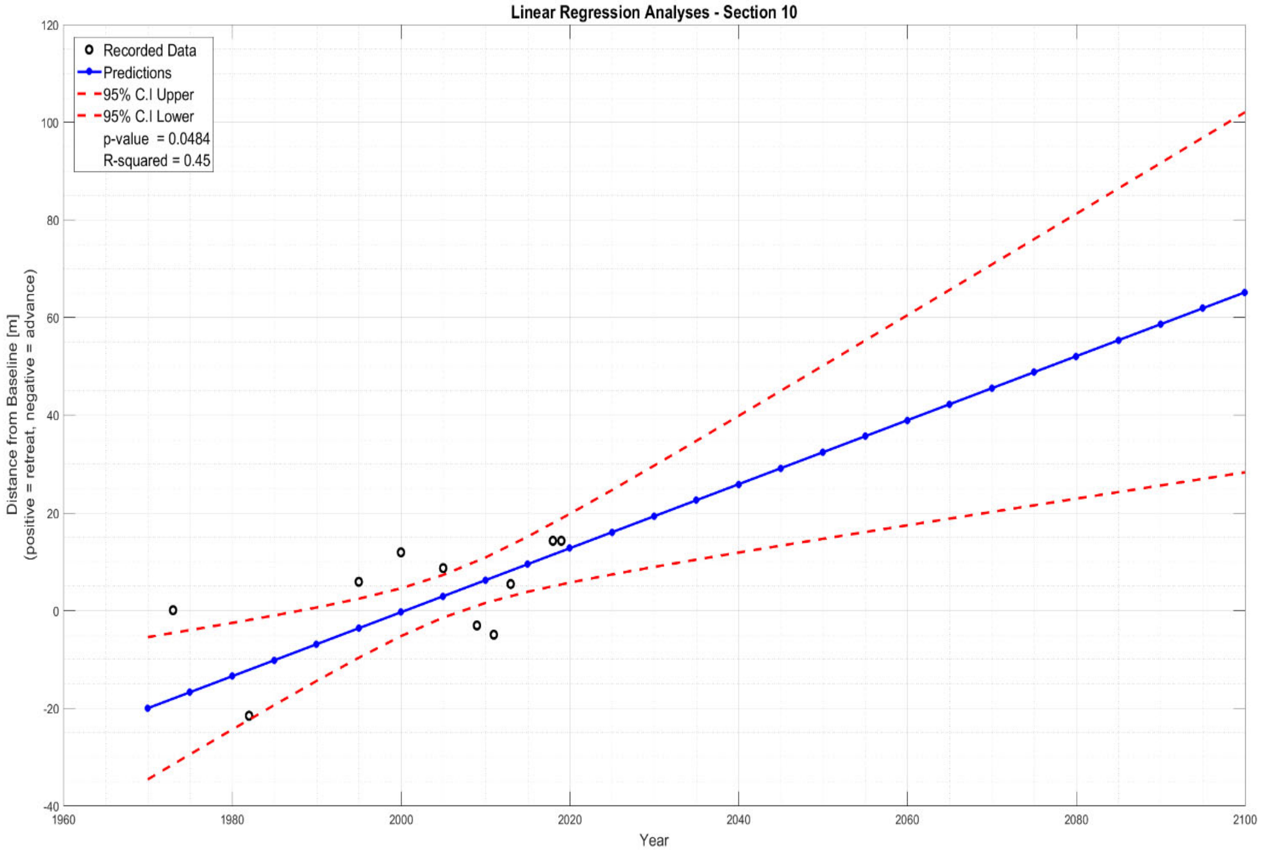


Figure 6.6: Example of the linear regression analyses undertaken along the Burrow at Section 10

Table 6.2: Summary of projected coastal change along the Burrow based on a linear regression analysis of shoreline data from 1973 - 2100

Year	Distance of shoreline relative to 1973 baseline (-'ive = accretion, +'ive = retreat)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	8.35	12.92	10.90	4.67	4.88	3.32	4.52	4.86	4.75	4.01	4.37	4.54
1990	16.70	25.84	21.80	9.35	9.76	6.64	9.03	9.71	9.49	8.01	8.75	9.08
2000	25.05	38.76	32.70	14.02	14.64	9.96	13.55	14.57	14.24	12.02	13.12	13.62
2010	33.40	51.68	43.60	18.69	19.52	13.28	18.06	19.42	18.98	16.02	17.50	18.16
2020	41.75	64.59	54.51	23.37	24.40	16.60	22.58	24.28	23.73	20.03	21.87	22.70
2030	50.10	77.51	65.41	28.04	29.28	19.92	27.09	29.13	28.47	24.03	26.24	27.24
2040	58.45	90.43	76.31	32.71	34.16	23.24	31.61	33.99	33.22	28.04	30.62	31.78
2050	66.80	103.35	87.21	37.39	39.05	26.56	36.13	38.84	37.96	32.05	34.99	36.32
2060	75.15	116.27	98.11	42.06	43.93	29.88	40.64	43.70	42.71	36.05	39.36	40.86
2070	83.50	129.19	109.01	46.73	48.81	33.20	45.16	48.55	47.46	40.06	43.74	45.40
2080	91.85	142.11	119.91	51.40	53.69	36.52	49.67	53.41	52.20	44.06	48.11	49.94
2090	100.20	155.03	130.81	56.08	58.57	39.84	54.19	58.26	56.95	48.07	52.49	54.48
2100	108.55	167.94	141.72	60.75	63.45	43.16	58.71	63.12	61.69	52.07	56.86	59.02
Δ 2020 & 2100	66.80**	103.35	87.21	37.39	39.05	26.56	36.13	38.84	37.96	32.05	34.99	36.32

🟩	Accretion
🟥	Erosion

** Coastal retreat arrested by sheet piling along Section 1

6.2.4 Coastal Change Assessment – Rush South

RPS undertook a similar assessment to that described in the previous Section for the coastal change along Rush south. This assessment found the coastal change in this region to be much more variable than that observed along the Burrow (see Figure 6.7 to Figure 6.9). Some localised sections of Rush south demonstrated a historical trend of coastal retreat, particularly in the area near Rush Golf Club, however the analysis of the shoreline in this region was particularly challenging due to the poor resolution of some the historical imagery which did not always clearly illustrate the edge of the dune vegetation line . As such, coastal change assessment in this area can be considered conservative.

Towards the middle of the beach at Rush south, the shoreline was found to be much more stable having demonstrated little change over the last *c.* 50 years. This point, around section 6, was found to represent a pivot point along the beach whereby the coastline to the south west and north east tended to demonstrate evidence of erosion and accretion respectively between 1973 and 2019. Further north towards the carpark, the shoreline had advanced by approximately 10metres since 1973 thus indicating that this area tends to accrete notable volumes of sediment.

The average rate of coastal retreat along the inner sections of Rush south between 2020 and 2100 was calculated to be *c.*0.44m/yr ±0.32m. The projected rate of retreat for the same period across sections 5 to 7 was negligible at 0.03m/yr ±0.10m. Further north, the coastal change assessment indicated that the shoreline could advance between 2020 and 2100 at a rate of *c.* 0.29m/yr ±0.05m.

A summary of the coastal change assessment statistics and future projections for Rush South are presented in Table 6.4.

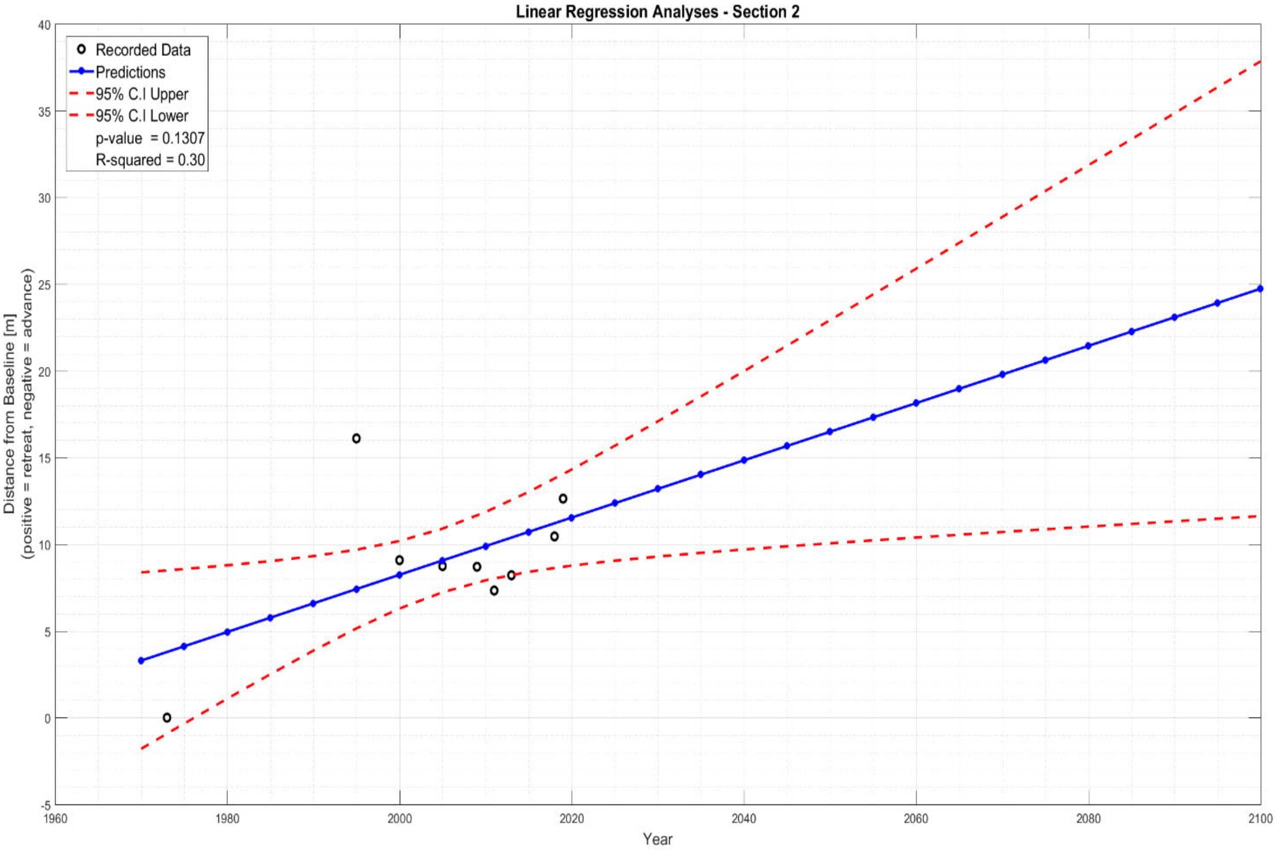


Figure 6.7: Example of the linear regression analyses undertaken along Rush south at Section 2

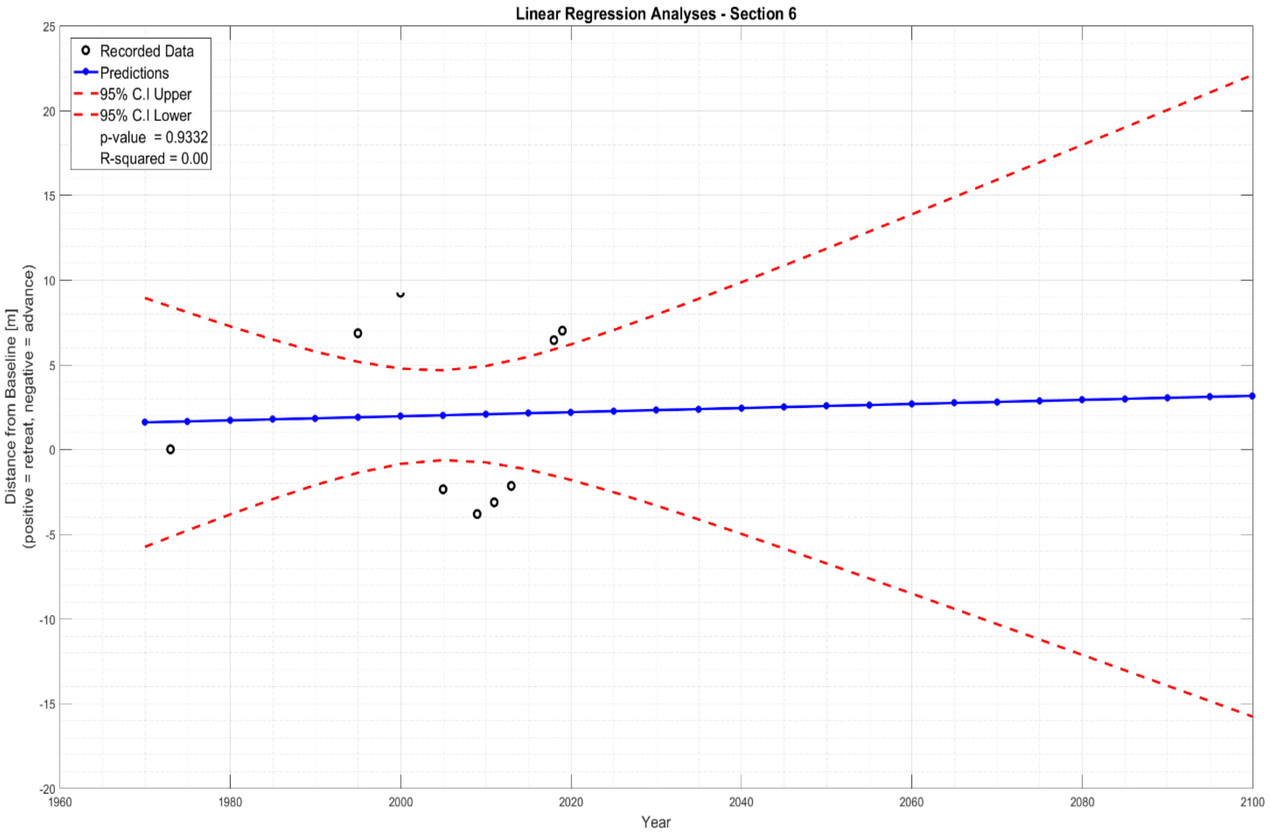


Figure 6.8: Example of the linear regression analyses undertaken along Rush south at Section 6

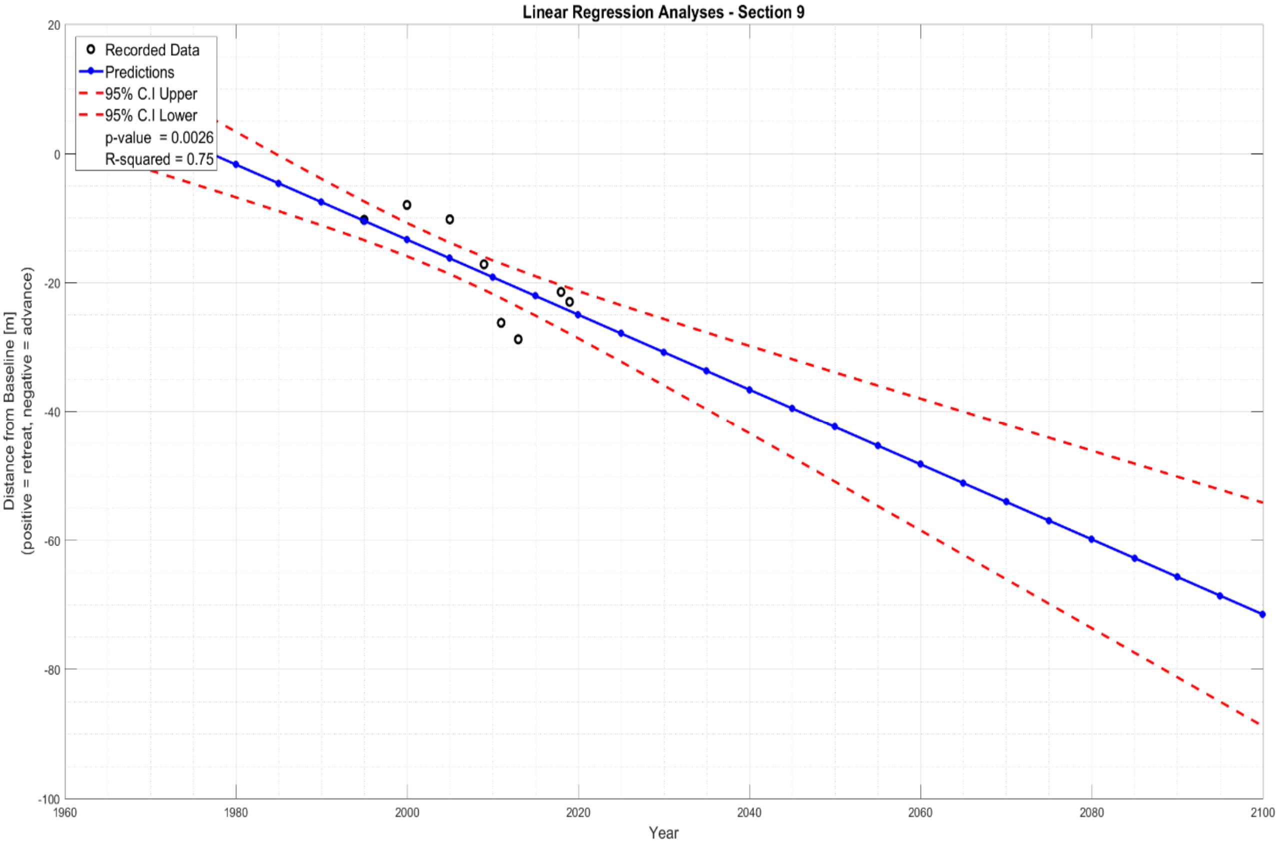


Figure 6.9: Example of the linear regression analyses undertaken along Rush south at Section 9

Table 6.3: Summary of projected coastal change along Rush South based on a linear regression analysis of shoreline data from 1973 - 2100

Year	Distance of shoreline relative to 1973 baseline (-'ive = accretion, +'ive = retreat)										
	1	2	3	4	5	6	7	8	9	10	11
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.24	-1.09	8.49	10.24	3.70	0.12	-2.66	-2.23	-5.81	-2.34	-1.41
1990	0.47	-2.19	16.99	20.48	7.40	0.24	-5.32	-4.46	-11.63	-4.68	-2.83
2000	0.71	-3.28	25.48	30.72	11.09	0.36	-7.98	-6.69	-17.44	-7.01	-4.24
2010	0.95	-4.37	33.98	40.96	14.79	0.48	-10.64	-8.92	-23.26	-9.35	-5.65
2020	1.18	-5.46	42.47	51.19	18.49	0.60	-13.29	-11.15	-29.07	-11.69	-7.06
2030	1.42	-6.56	50.96	61.43	22.19	0.73	-15.95	-13.39	-34.88	-14.03	-8.48
2040	1.66	-7.65	59.46	71.67	25.89	0.85	-18.61	-15.62	-40.70	-16.36	-9.89
2050	1.89	-8.74	67.95	81.91	29.58	0.97	-21.27	-17.85	-46.51	-18.70	-11.30
2060	2.13	-9.83	76.45	92.15	33.28	1.09	-23.93	-20.08	-52.33	-21.04	-12.72
2070	2.37	-10.93	84.94	102.39	36.98	1.21	-26.59	-22.31	-58.14	-23.38	-14.13
2080	2.60	-12.02	93.44	112.63	40.68	1.33	-29.25	-24.54	-63.95	-25.71	-15.54
2090	2.84	-13.11	101.93	122.87	44.38	1.45	-31.91	-26.77	-69.77	-28.05	-16.95
2100	3.08	-14.20	110.42	133.11	48.07	1.57	-34.56	-29.00	-75.58	-30.39	-18.37
Δ 2020 & 2100	1.89	-8.74	67.95	81.91	29.58	0.97	-21.27	-17.85	-46.51	-18.70	-11.30

🟩	Accretion
🟧	Erosion

6.2.5 Coastal Change Assessment – Rush North

At Rush North, the coastal change over the previous 50 years has been much more uniform in comparison to the other two study areas. The beach along in this study area has continuously accreting modest amounts of sediment for many years which has in turn resulted in the shoreline advancing by up to 10metres since 1973.

Examples of the linear regression analysis that was undertaken as part of the coastal change assessment at Rush north are presented in Figure 6.10 to Figure 6.12 for Sections 2, 4 and 6. It will be seen from these plots that the shoreline is gradually advancing seaward. Using these linear regression plots, RPS calculated that the shoreline between sections 3 and 7 would advance between 2020 and 2100 at a rate of *c.* 0.17m/yr ±0.2m

A localised section of this beach is protected to the south by rock armour which fronts the public carpark and a small number of adjacent private properties. This area is afforded more general protection by the natural rocky outcrops that characterise this region of the coast as well as the headlands that flank either end of the beach.

A summary of the coastal change assessment statistics and future projections for Rush North are presented in Table 6.4.

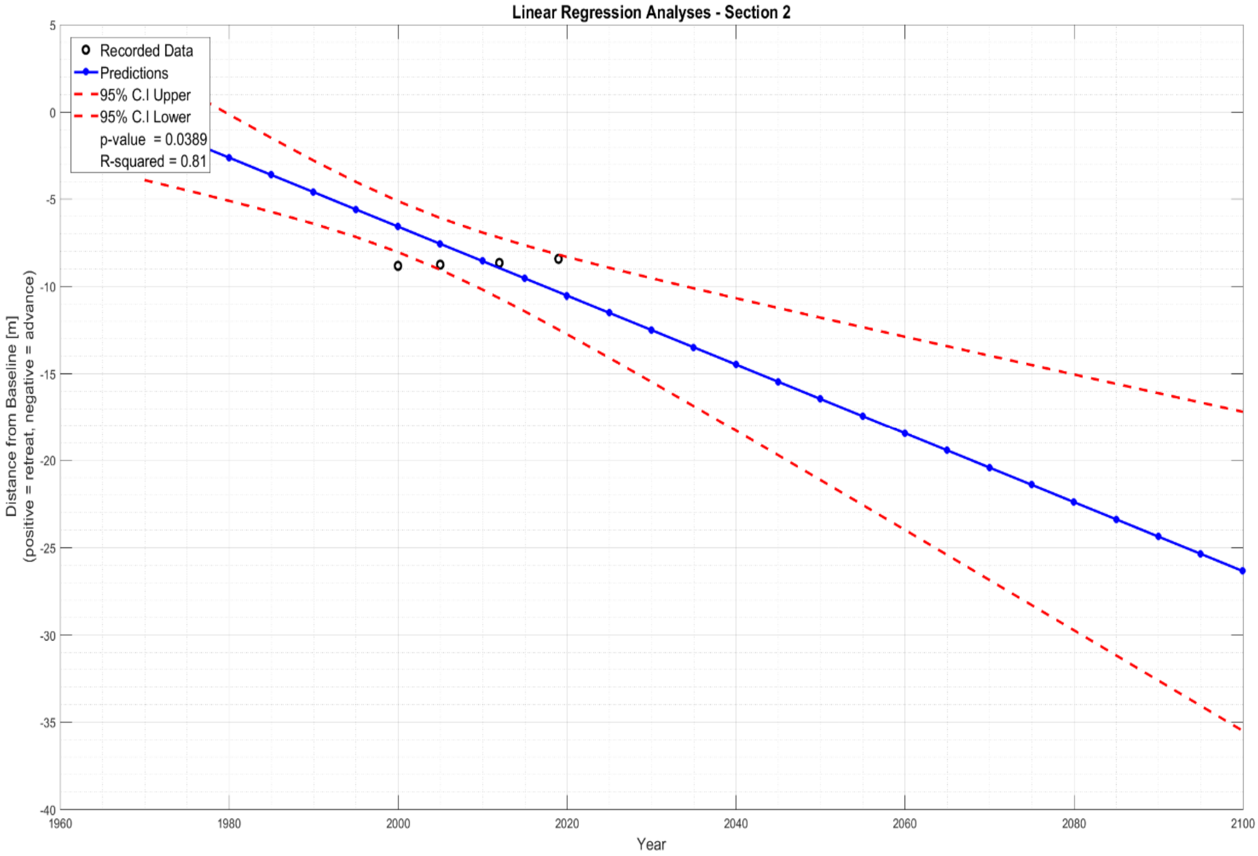


Figure 6.10: Example of the linear regression analyses undertaken along Rush north at Section 2

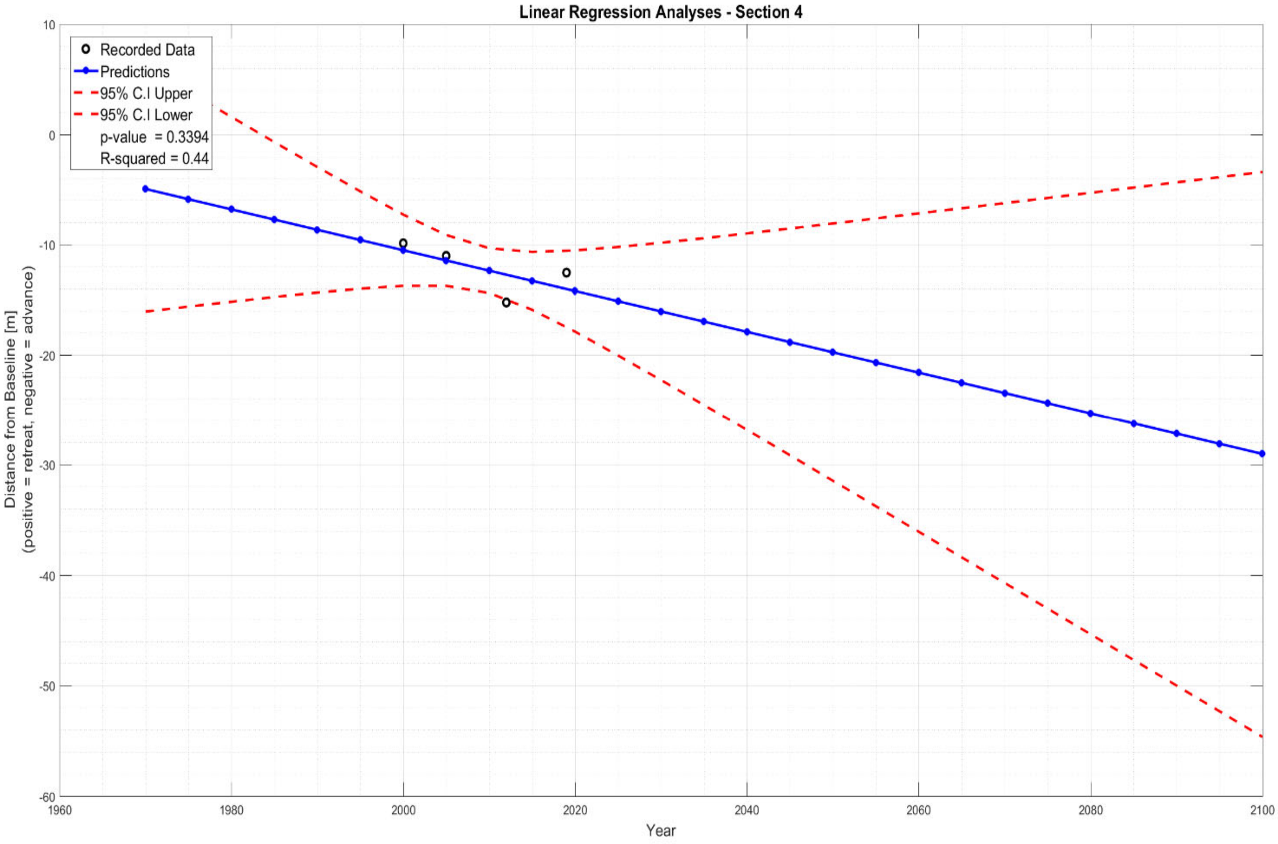


Figure 6.11: Example of the linear regression analyses undertaken along Rush north at Section 4

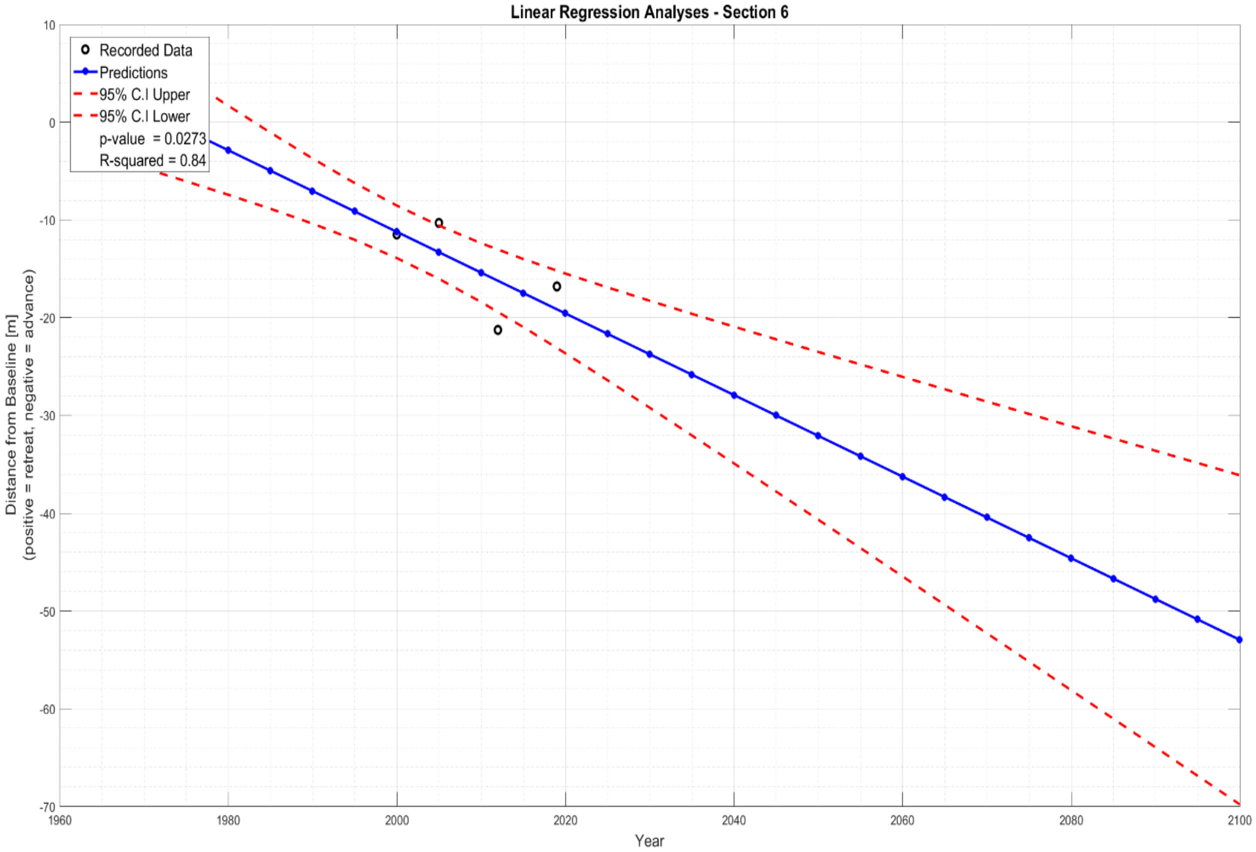


Figure 6.12: Example of the linear regression analyses undertaken along Rush north at Section 6

Table 6.4: Summary of projected coastal change along Rush North based on a linear regression analysis of shoreline data from 1973 - 2100

Year	**Distance of shoreline relative to 1973 baseline (-'ive = accretion, +'ive = retreat)**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	-0.06	0.21	-1.23	-1.85	-1.02	-4.23	-0.47	0.07	0.54
1990	-0.13	0.41	-2.46	-3.70	-2.05	-8.47	-0.93	0.14	1.08
2000	-0.19	0.62	-3.69	-5.56	-3.07	-12.70	-1.40	0.22	1.63
2010	-0.26	0.82	-4.92	-7.41	-4.09	-16.94	-1.86	0.29	2.17
2020	-0.32	1.03	-6.15	-9.26	-5.12	-21.17	-2.33	0.36	2.71
2030	-0.38	1.23	-7.38	-11.11	-6.14	-25.41	-2.79	0.43	3.25
2040	-0.45	1.44	-8.61	-12.96	-7.16	-29.64	-3.26	0.51	3.80
2050	-0.51	1.64	-9.84	-14.82	-8.19	-33.88	-3.72	0.58	4.34
2060	-0.58	1.85	-11.08	-16.67	-9.21	-38.11	-4.19	0.65	4.88
2070	-0.64	2.05	-12.31	-18.52	-10.23	-42.34	-4.65	0.72	5.42
2080	-0.70	2.26	-13.54	-20.37	-11.26	-46.58	-5.12	0.80	5.96
2090	-0.77	2.46	-14.77	-22.22	-12.28	-50.81	-5.59	0.87	6.51
2100	-0.83	2.67	-16.00	-24.08	-13.30	-55.05	-6.05	0.94	7.05
Δ 2020 & 2100	-0.51	1.64	-9.84	-14.82	-8.19	-33.88	-3.72	0.58	4.34

🟩	Accretion
🟥	Erosion

6.3 Coastal Change Assessment - Future Projection Maps

Using the findings presented in the previous Sections of this report RPS produced a series of future coastal change maps that illustrated the projected position of the shoreline by 2050 & 2100 for the following scenarios:

1. Existing climate conditions and erosion rates.
2. Medium Range Future Scenario (MRFS) climate conditions whereby sea levels are expected to rise by +0.50m by 2100.
3. High End Future Scenario (HEFS) climate conditions whereby sea levels are expected to rise by +1.00m by 2100.

The position of the shoreline under each climate scenario was calculated by projecting the best fit line from the series of linear regression analyses at each site as described in the previous Sections of this report. The future projection maps for various climate conditions and epochs are presented in Sections 6.3.3 and 6.3.4.

A description of how RPS accounted for the impact of future climate change in context of the coastal change assessment is described in the following section.

6.3.1 Considering the impact of Climate Change

There are several quantitative models that relate sea level rise (i.e. climate change) to coastal change with the most well-known being the Bruun rule (Bruun, 1962). This rule proposes that, in the absence of sediment sources and sinks, a beach profile gradually re-adjusts after a rise in relative mean sea level, as sediment is eroded from the upper beach profile and deposited onto the adjacent seafloor. This rule is represented by:

$$\Delta y = -S * \frac{L}{h+B} = -\frac{S}{\tan\beta}$$

Whereby shoreline change (Δy) is related to sea level rise (S), the horizontal length of the active profile (L), the depth of the active profile base (h), the berm crest elevation above sea level (B) and the average slope of the active profile ($\tan\beta$).

Several studies have noted the limited applicability of the Bruun rule to most coastal environments due to the theory’s limiting assumptions of physical setting and constraints within the sediment transport regime (Thieler et al. 2000; Cooper and Pilkey 2004). To overcome this, alterative models have been developed that combine the Bruun rule with different assumptions to represent the net sediment budget.

One alternative which was used for this study, is the R-DA model (Davidson-Arnott, 2005). In this model it is assumed that as sea level rises, the beach and foredune are eroded and sediment is transported landward, causing a landward and upward migration of the beach–foredune intersection. Similarly, there is a net onshore migration of sediment in the nearshore, causing an upward and landward migration of the shoreline and the seaward limit of the active profile.

The expression for coastal change in the R-DA model is identical to that of the Bruun rule described in the equation above. However, in the R-DA model, the term $\tan\beta$ is the nearshore slope averaged over only the submerged portion of the active beach profile, not the entire profile, so it does not depend on the berm crest elevation (B).By explicitly including beach–dune sediment exchange and landward aeolian (windblown) sediment transport, the R-DA model allows for preservation of the foredune system under rising sea levels.

The differences in the Bruun Rule and the R-DA model are illustrated in Figure 6.13 overleaf.

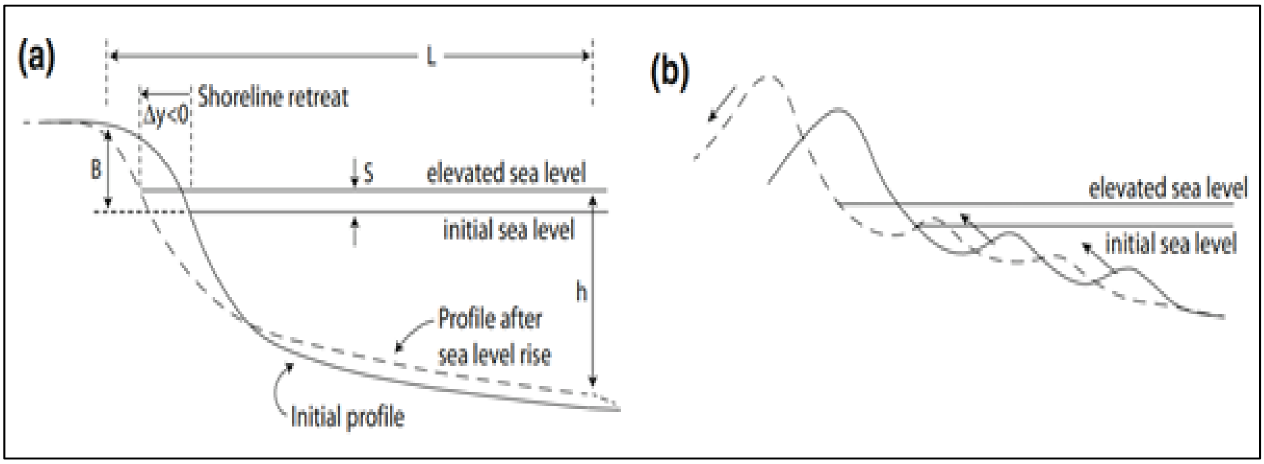


Figure 6.13: Shoreline change according to the Bruun Rule (a) and the R-DA model (B)

Using the slope of the upper foreshore along the Burrow, Rush South and Rush North in conjunction with the R-DA model, RPS estimated the additional coastal retreat that could be reasonably expected under the MRFS and HEFS climate change scenarios due to sea level rise. Based on this assessment it was found that the shorelines across the various study areas could retreat by as much as an *additional* 40m HEFS climate conditions.

The future coastal change maps for the Burrow, Rush South and Rush North based on the MRFS and HEFS climate conditions are presented in Sections 6.3.3 and 6.3.4 for various epochs.

6.3.2 Assumptions and Caveats

Whilst the coastal change assessment presented in this report has been undertaken by a team of experienced coastal engineers using the best available data and industry accepted methods, the assessment has been based on several important assumptions and caveats, primarily:

- There will be no significant changes to the coastal processes, particularly the incident wave climate by 2100.
- The linear regression analysis of historic shoreline change across the study areas will be representative of future shoreline change.
- There will be no significant changes in sediment sources or sinks by 2100.
- There will be no significant changes in anthropogenic features or pressure by 2100.
- The underlying geology across the study area is comprised of soft, erodible sediment.
- The beach profile across the study area can dynamically adjust to prevailing conditions to maintain the existing hydraulic conditions.

The actual rate of coastal change across the study areas will be determined by the rate of future climate change and potential changes to the factors described above which were assumed to have remained constant for the purposes of this study. However, the overwhelming consensus of the recent scientific literature is that climate change is occurring much more rapidly than initially expected.

Most 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 (Baatesen et al,. 2015). Potential evidence and impacts of future climate change at the study area is discussed in future detail in Sections 4.6 and 4.6.1.

6.3.3 Future Projection Maps - 2050 with various climate scenarios

The projected extent of future coastal change across the study area by 2050 under various climate scenarios is summarised in Table 6.5. The corresponding coastal evolution maps are presented in Figure 6.14 to Figure 6.16 for the Burrow, Rush south and Rush north respectively. The typical confidence values presented in Table 6.5 have been based on the output from the historical trend analysis presented in Section 6.2 and does not include any uncertainty factor for future climate change.

As reported in Table 6.5, based on the historical trend analysis, by 2050 the coastline at the Burrow could retreat by between 19 – 39m (±14m). At Rush south and Rush north the coastline could retreat by up to 28m and 4m respectively.

Table 6.5: Projected coastal change across the study area by 2050 with various climate scenarios

Study Area	Average Coastal Change by 2050 [m]			
	Climate Scenario			Typical Confidence in Trend Analysis
	Existing Climate	Medium Range Future Scenario (MRFS)	High End Future Scenario (HEFS)	
The Burrow	Retreat of *c.*19m	Retreat of *c.*29m	Retreat of *c.*39m	±14m
Rush South	Retreat of *c.*14m	Retreat of *c.*21m	Retreat of *c.*28m	±10m
Rush North	Advance of *c.* 5m	Retreat of *c.*2m	Retreat of *c.*4m	±6m

Based on these projections, up to 15 properties along the Burrow are expected to be lost to coastal erosion by 2050 with many of these being lost within the next few decades. These buildings are comprised primarily of residential properties and a small number of private out-buildings and/or mobile homes. Several commercial and public buildings are also included in this total.

At Rush north, one property is expected to be at risk from erosion by 2050 under the HEFS climate scenario. No properties are expected to be at risk in Rush south under any of the climate scenarios assessed as part of this study.

The number of properties expected to be at risk based on these projections is summarised in Table 6.6.

Table 6.6: Total number of buildings at risk from coastal erosion area by 2050 with various climate scenarios

Study Area	Buildings lost to coastal erosion by 2050		
	Climate Scenario		
	Existing Climate	Medium Range Future Scenario (MRFS)	High End Future Scenario (HEFS)
The Burrow	6	10	15
Rush South	0	0	0
Rush North	0	1	3

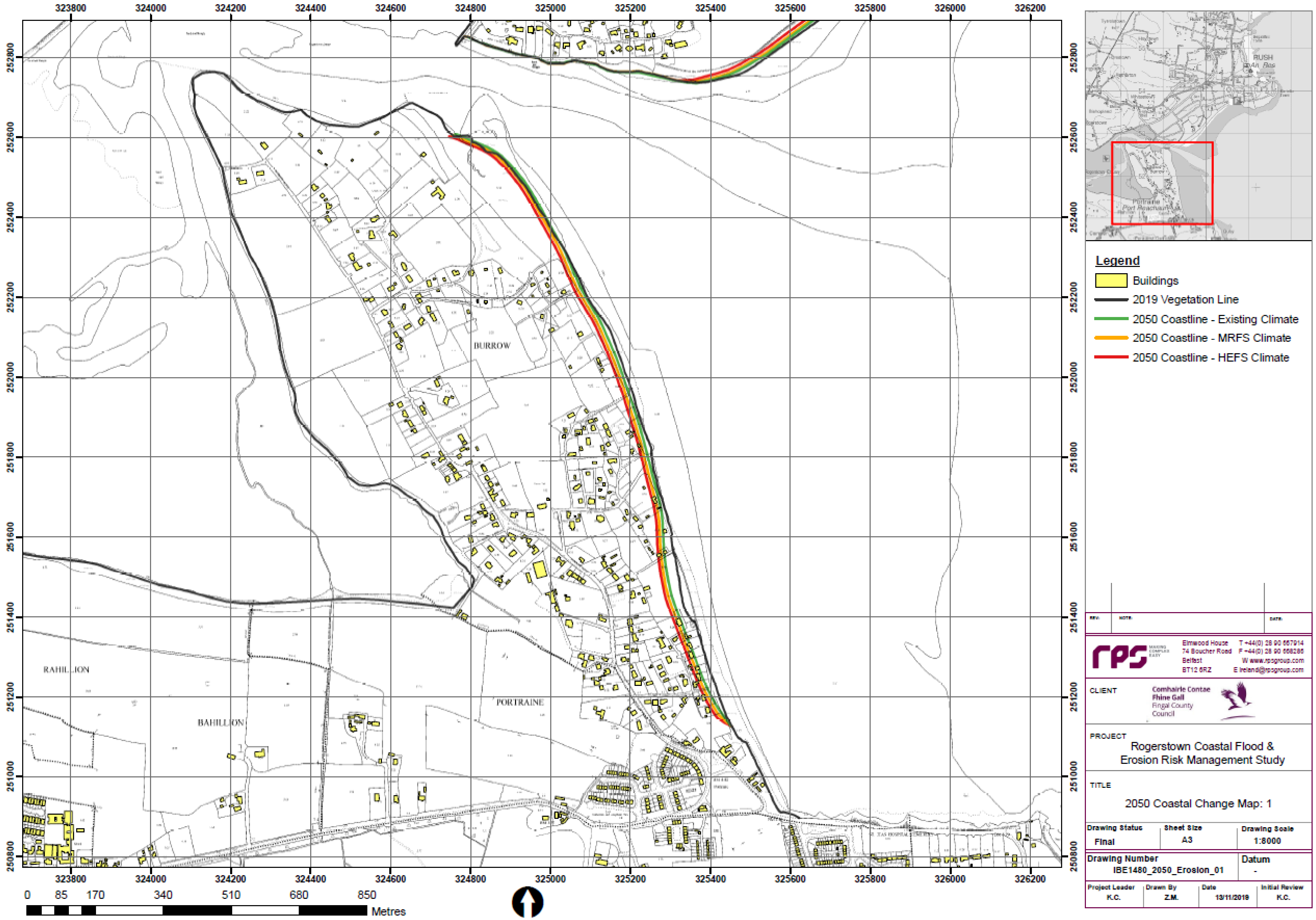


Figure 6.14: Projected coastal change at the Burrow by 2050 based on various climate scenarios

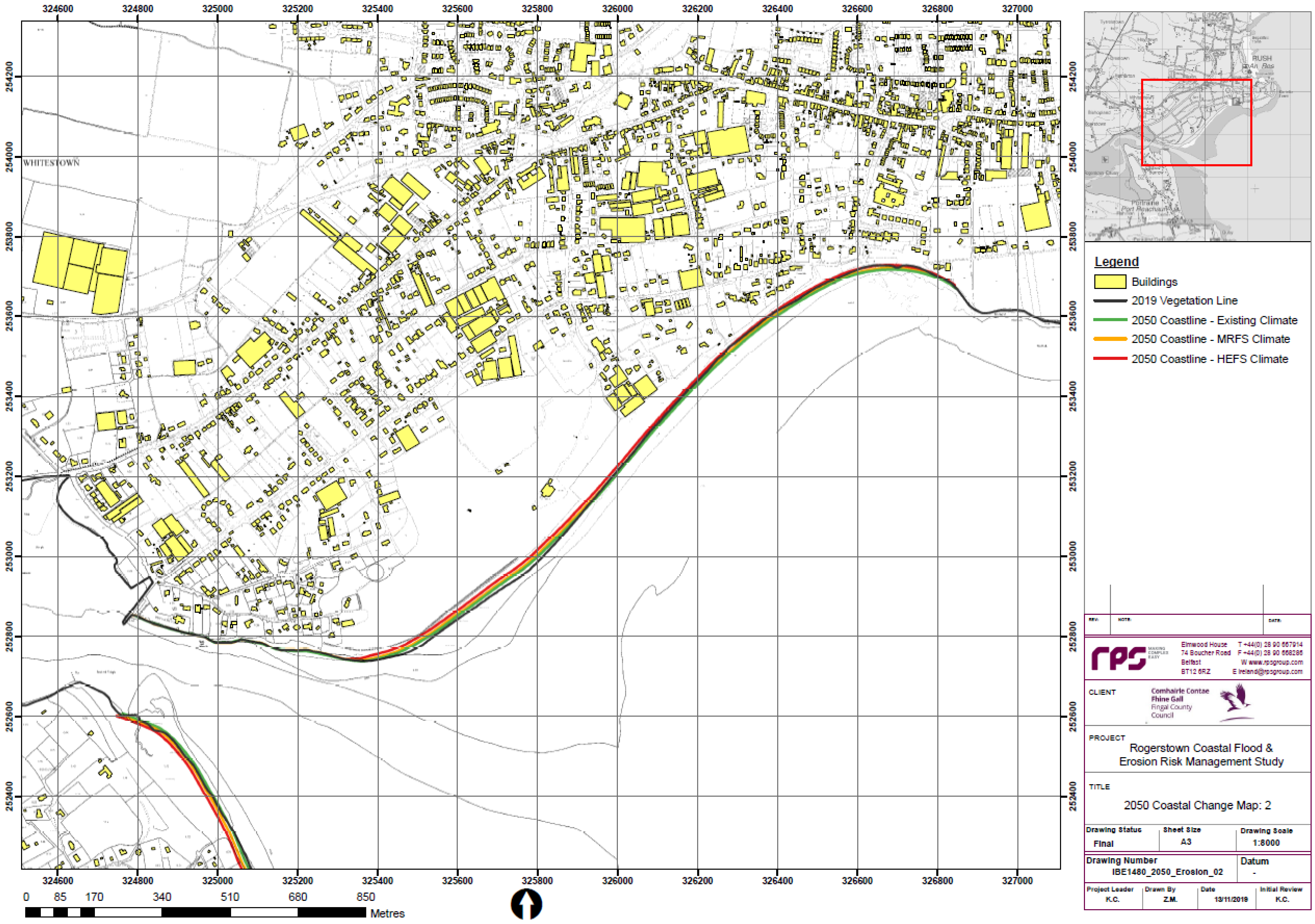


Figure 6.15: Projected coastal change at Rush South by 2050 based on various climate scenarios

Figure 6.16: Projected coastal change at Rush north by 2050 based on various climate scenarios

6.3.4 Future Projection Maps - 2100 with various climate scenarios

The projected extent of future coastal change across the study area by 2100 under various climate conditions is summarised in Table 6.7. The corresponding coastal evolution maps are presented in Figure 6.17 to Figure 6.19 for the Burrow, Rush South and Rush North respectively.

Table 6.7: Projected coastal change across the study area by 2100 with various climate scenarios

Study Area	Average Coastal Change by 2100 [m]			
	Climate Scenario			Typical Confidence in Trend Analysis
	Existing Climate	Medium Range Future Scenario (MRFS)	High End Future Scenario (HEFS)	
The Burrow	Retreat *c*.48m	Retreat of *c*.68m	Retreat of *c*.88m	±30m
Rush South	Retreat of *c*.36m	Retreat of *c*.50m	Retreat of *c*.64m	±30m
Rush North	Advance of *c*.14m	Retreat of *c*.4m	Retreat of *c*.9m	±10m

The number of buildings that could potentially be lost to erosion by 2100 based on the HEFS coastal change projections is summarised Table 6.8 below. It will be seen from this table that a total of 46 buildings across the Burrow could be affected by erosion by 2100 under the HEFS climate conditions.

No buildings were found to be at risk from coastal erosion at Rush south, however coastal erosion is expected to adversely impact Rush Golf Club under the MRFS & HEFS climate conditions. As shown in the coastal change maps, the public carpark towards the north may also be impacted by erosion by 2100.

The assessment also indicated that up to six buildings could be affected at Rush north by 2100 under the HEFS. These buildings are comprised of unoccupied small private residential dwellings and several static caravans. It should be noted that there is a significant number of buildings, many of which are private residential buildings, which are in close proximity (±5m) to the 2100 HEFS coastal change line. Given the level of inherent uncertainty associated with climate change and coastal change assessments, it is reasonable to conclude that these buildings could also be at potential risk of future coastal erosion.

In addition to the buildings considered to be at risk from erosion, several minor roads used primarily for access are expected to at risk from erosion along the Burrow and at Rush north.

Table 6.8: Total number of buildings at risk from coastal erosion area by 2100 with various climate scenarios

Study Area	Buildings lost to coastal erosion by 2100		
	Climate Scenario		
	Existing Climate	Medium Range Future Scenario (MRFS)	High End Future Scenario (HEFS)
The Burrow	19	36	46
Rush South	0	0	0
Rush North	0	3	6

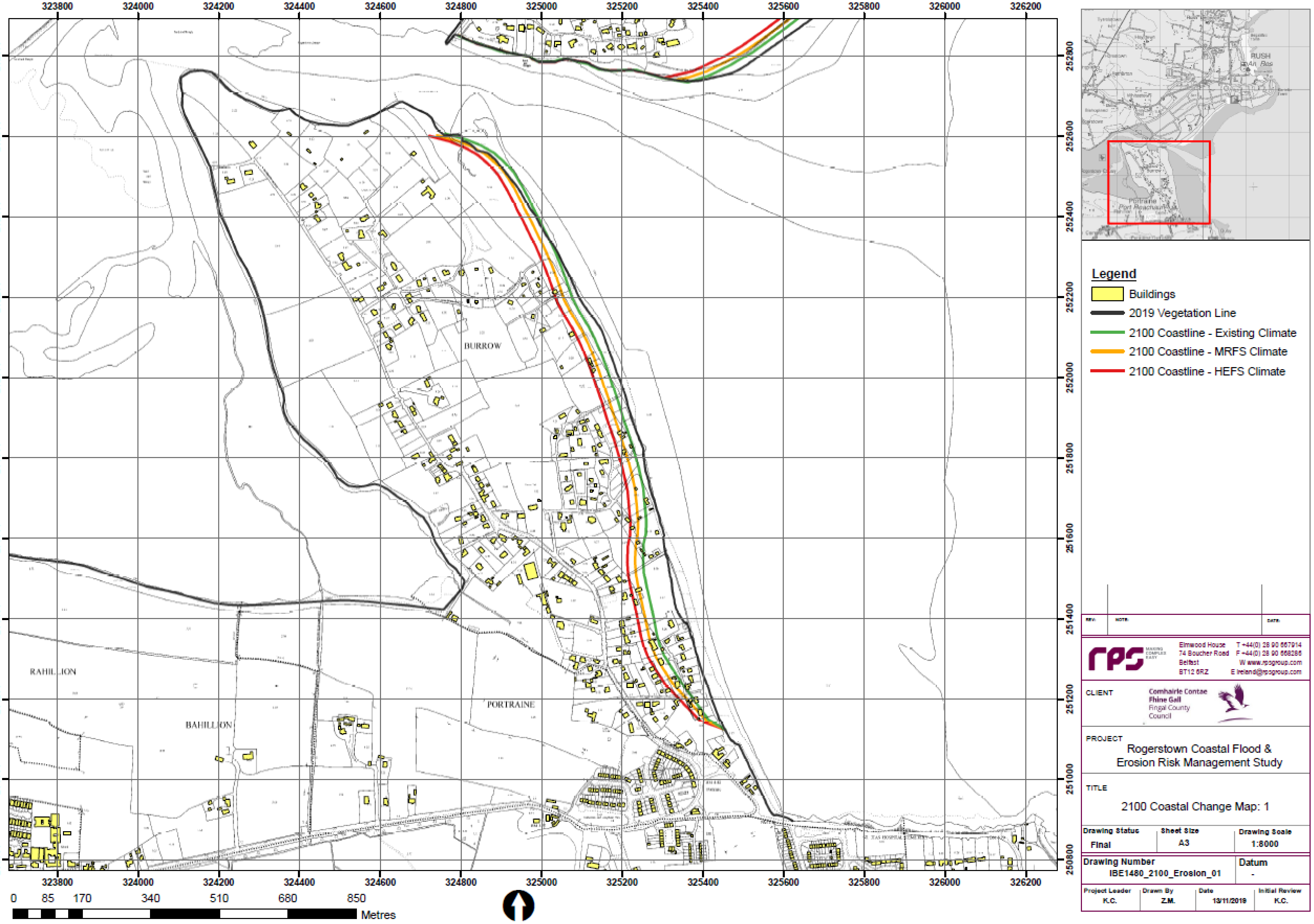


Figure 6.17: Projected coastal change at the Burrow by 2100 based on various climate scenarios

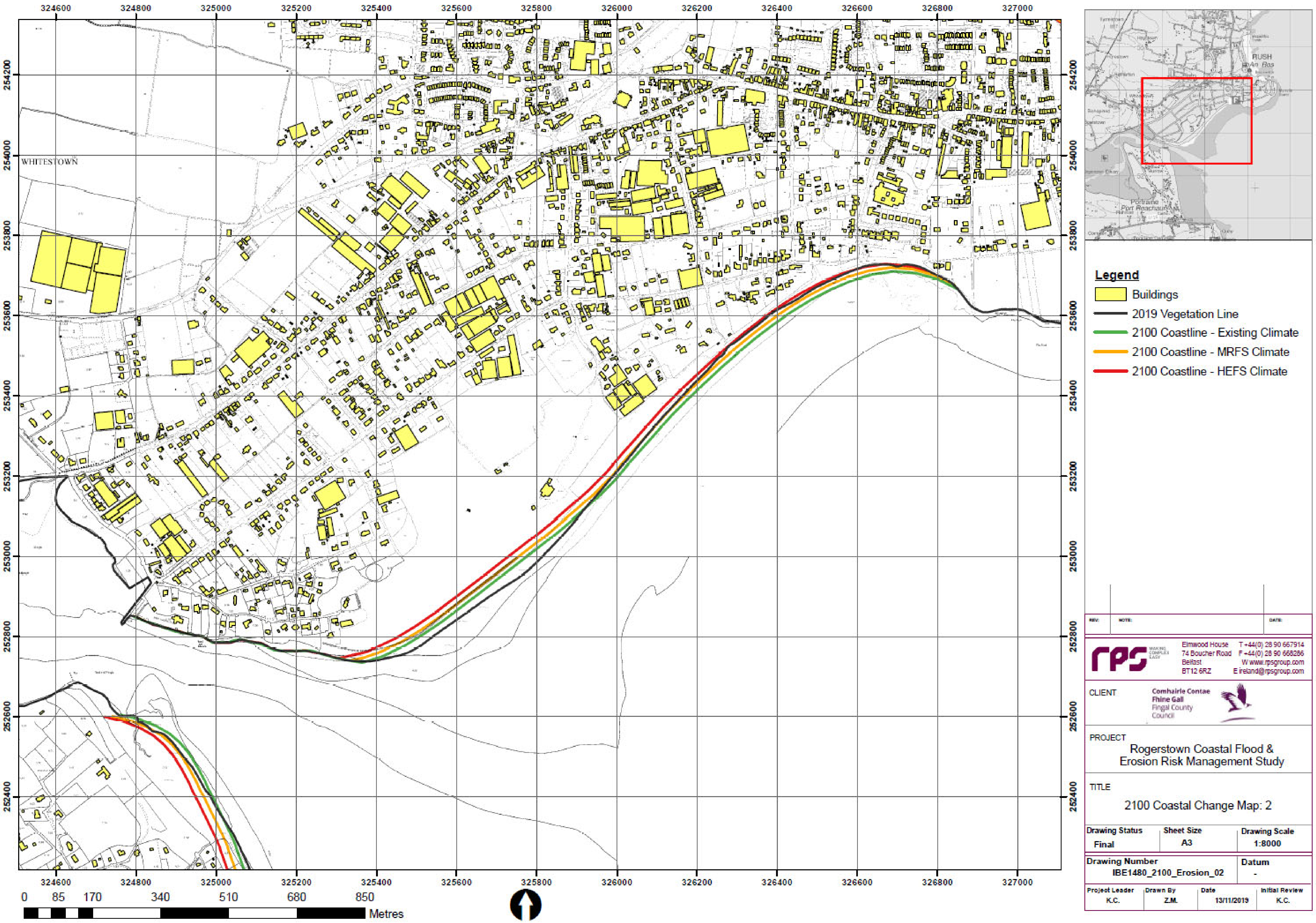


Figure 6.18: Projected coastal change at Rush South by 2100 based on various climate scenarios

Figure 6.19: Projected coastal change at Rush North by 2100 based on various climate scenarios

6.4 Summary of Future Coastal Change

Using the Digital Shoreline Analysis System (DSAS) tool RPS assessed the historical coastal change across the study area between 1973 and 2019. The coastal change statistics produced from this assessment were subsequently used to estimate the magnitude of coastal change for each epoch and climate scenario relative to the position of the current shoreline. In summary, this assessment found that:

At the Burrow

- Based on shoreline data from 1973 to 2019, the greatest rate of coastal retreat along the Burrow was found to be 1.29m/yr along section 4.
- The average rate of coastal retreat along the entire Burrow was found to be c. 0.60m/yr ±0.92m.
- By 2100 undefended regions of this shoreline could retreat by up to *c.* 88m ±30m depending on future climate change.
- The number of buildings at risk from coastal erosion by 2100 ranged between 36 and 49 depending on the future climate change scenario.

At Rush South

- Based on shoreline data from 1973 to 2019, the average rate of coastal retreat along the inner sections of Rush south was found to be *c.*0.44m/yr ±0.32m. The middle section of this beach was relatively stable whilst the northern section was found to be advancing at an average rate of *c.* 0.29m/yr ±0.05m.
- By 2100 localised regions of Rush south could retreat by up to *c.*64m ±30m depending on future climate change.
- No buildings were found to be at risk from coastal erosion under any of the climate change scenarios that were assessed as part of this study. However, a region of Rush Golf Club could potentially be affected by future coastal erosion depending on the rate of future climate change.

At Rush North

- Based on existing climate conditions, the shoreline along this beach has been advancing at a rate of c. 0.17m/yr ±0.2m since 1973. By 2100 the position of the shoreline at Rush north could therefore advance by c.15m ±10m.
- The impact of future climate change could however prevent this shoreline from advancing. This shoreline could retreat by as much as 9m under the HEFS climate scenario.
- This could put up to 9 buildings could be at risk from coastal erosion by 2100 depending on the future climate change scenario.

RPS are acutely aware that recent events indicate a potential "turning point" in the coastal processes along the Burrow and that the erosion rates calculated as part of the Historical Trend Analyses may not reflect recent observations. However, without sufficient long-term high-resolution data it is not possible to determine if these events are unique outliers or the beginning of a new long-term trend.

In line with best practice and guidance from relevant statutory authorities, RPS have estimated erosion rates using all available shoreline data in the Historical Trend Analyses. Despite this, a Sensitivity Analyses of this method found that average erosion rates could be up to x3 greater if historical data prior to 2013 was excluded. More information of this Sensitivity Analyses is presented in Appendix B.

7 FLOOD RISK ASSESSMENT

7.1 Background

Coastal flooding can cause damage to homes and businesses, along with damage to and loss of service from infrastructure, such as water supply or roads. Flooding may also impact on the environment by damaging or polluting habitats and damaging cultural heritage assets.

An assessment of coastal flooding is a key element in the development of any coastal protection strategy, particularly in regions like the Burrow where a soft dune system can act as a natural flood defence barrier. The following section of this report quantifies the flood potential from both combined tide and surge (i.e. mechanism 1 of coastal flooding) and wave overtopping (mechanism 2 of coastal flooding) and assesses the risk associated with both mechanisms.

Assessing flood risk from rivers (i.e. fluvial flooding) was beyond the scope of this study. However, as a fluvial flood risk had already been identified at Rush south in the Fingal-East Meath Flood Risk Assessment and Management Study (FEMFRAMS, 2012), RPS included this risk in the Flood Maps presented in Section 7.4.

7.2 Mechanism 1 – Combined Tide and Surge

Owing to the relatively low-lying nature of the study area, the effect of combined tide and surge activity is expected to be the main source of flood risk. The method used to assess this flood mechanism is described in the following Sections of this report.

7.2.1 Assessing Combined Tide and Surge Flooding

7.2.1.1 Flood Model Boundary Conditions

As illustrated in Figure 4.6 the flood model was constructed with only one seaward boundary. This meant that it was possible to simulate specific tidal levels across the study area by applying a single sinusoidal surface elevation curve to this boundary.

Temporally varying water levels were used to represent the coastal influence at the study sites. The inclusion of a temporal element within any detailed assessment of tidal flood risk is an important consideration due to the relatively rapid variation in even extreme tidal levels associated with the normal tidal cycle. In general, this limits the duration of exposure and consequently is an important consideration in establishing the volume of water that can enter vulnerable areas.

RPS' experience with detailed modelling of coastal flooding has indicated that it is seldom sufficient to simply model a single tidal cycle, as extreme tidal surges often persist over multiple tidal cycles. Consequently, the most onerous tidal flooding is normally a result of the accumulation of flood waters entering the area over multiple tidal cycles.

Tidal boundary conditions were taken from the Irish Seas Tidal and Storm Surge Model, as shown earlier in Figure 4.8, and scaled using the ICPSS extreme water level values in Table 7.1 below.

Table 7.1: Extreme water level information at ICPSS Point NE15 near the Burrow

AEP event [%]	Chart Datum [m]	Ordnance Datum Malin [m]	Mean Sea Level [m]
50	4.89	2.55	2.59
20	5.01	2.67	2.71
10	5.11	2.77	2.81
5	5.21	2.87	2.91
2	5.34	3.00	3.04
1	5.44	3.10	3.14
0.5	5.53	3.19	3.23

7.2.1.2 Model Roughness

Roughness in the 2D domain was applied based on land type areas defined in the Environmental Protection Agency (EPA) CORINE Land Cover Map with representative roughness values associated with each of the land cover classes in the dataset.

7.2.1.3 Model Representation of Erosion Scenarios

Using the baseline hydrodynamic model described in Section 4.3.3, RPS developed additional hydrodynamic models to represent the modified position of the coastline due to erosion at each study area by 2050 & 2100 for both the MRFS and HEFS future climate change scenarios.

A summary of the model run combinations that were undertaken as part of this flood assessment is presented in Table 7.2. In total, 35 individual simulations were undertaken in support of this assessment.

Table 7.2: Summary of water level, epoch and erosion extent combinations assessed as part of the flood risk assessment

Flood Scenario (AEP event %)	**Epoch & Climate Scenario**				
	2019	**2050**		**2100**	
	Present Day Conditions	**MRFS (+0.20m SLR)**	**HEFS (+0.33m SLR)**	**MRFS (+0.50m SLR)**	**HEFS (+1.00m SLR)**
50	✓	✓	✓	✓	✓
20	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓
1	✓	✓	✓	✓	✓
0.5	✓	✓	✓	✓	✓

7.2.1.4 Assumptions, limitations and Uncertainty

The flood risk analysis undertaken as part of this study has been based primarily on available bathymetric and topographic data together with the various Annual Exceedance Probability (AEP) water levels presented in Table 7.1

The modelling does not take into account other hydrological factors that affect flood risk such as the hydrological response of a catchment area which is determined by a range of factors including but not limited to urbanisations, vegetation, soils and geology. Other factors such as rainfall and ground saturation levels are also excluded from the flood analysis. As the scope of this study was to assess coastal flooding, i.e. flooding from combined tide and surge activity (flood mechanism 1) and wave overtopping (flood mechanism 2), the potential impact of fluvial flooding has not been considered in this assessment.

7.3 Mechanism 2 – Wave Overtopping

An additional source of flood risk across the study area is from wave overtopping. As described in earlier Sections of this report, the potential for wave overtopping at either the Burrow or Rush north or south is generally limited as there are few coastal defence structures that could be overtopped by incident waves.

There are however two areas whereby flooding due overtopping could have a notable impact, these locations are along Channel road at Rush South. At Channel road, *c.*530m of concrete wall protects a minor road that provides access to a number of private residential properties (see Figure 7.1). As will be seen from Figure 7.2 overleaf, the crest level of this wall ranged between *c.*2.70m and 3.29m to the west and east of the small bridge on Channel Road respectively (i.e. chainage 330m in Figure 7.2).

It will be noted that this crest level is very low in relation to the extreme tidal levels presented in Section 4.4.2 of this report. Indeed, there are several points along this wall that would be susceptible to combined tide and surge flooding (i.e. mechanism 1 flooding) during 1 in 5 year return period events. Furthermore, the culvert under the small bridge illustrated in Figure 7.1 would allow extreme tides to propagate into the hinterland behind the seawall, thus contributing to the known flood problem in this area.

At the Burrow, approximately180m of the coastline is protected by vertical sheet piling (see Figure 7.38). As illustrated in Figure 7.4 the height of this defence ranges between 2.9m and 3.4m.

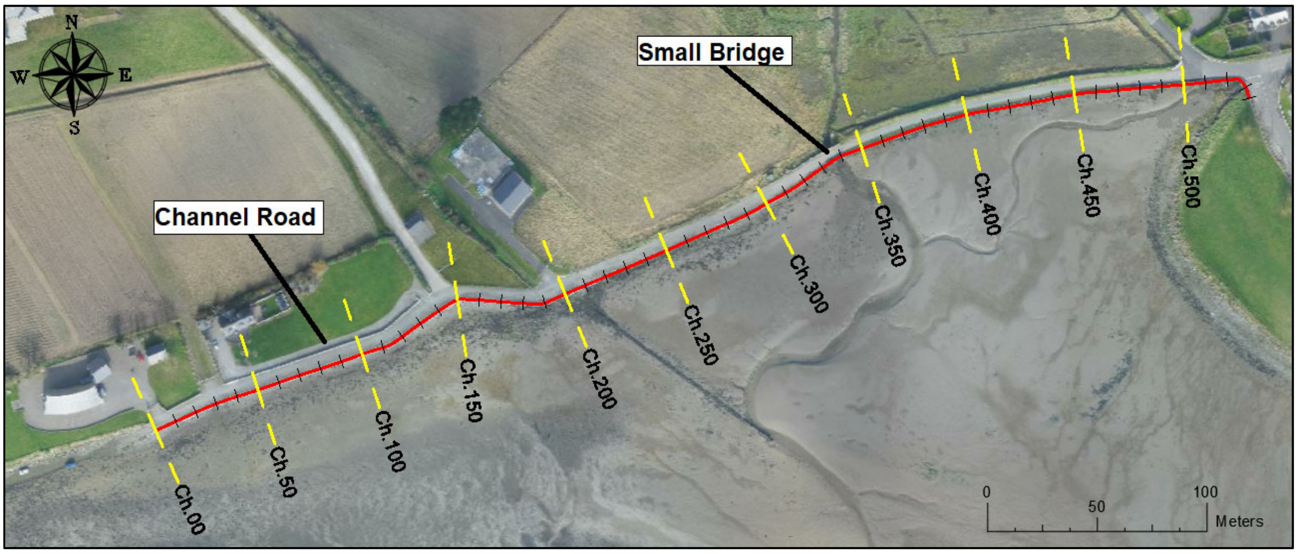
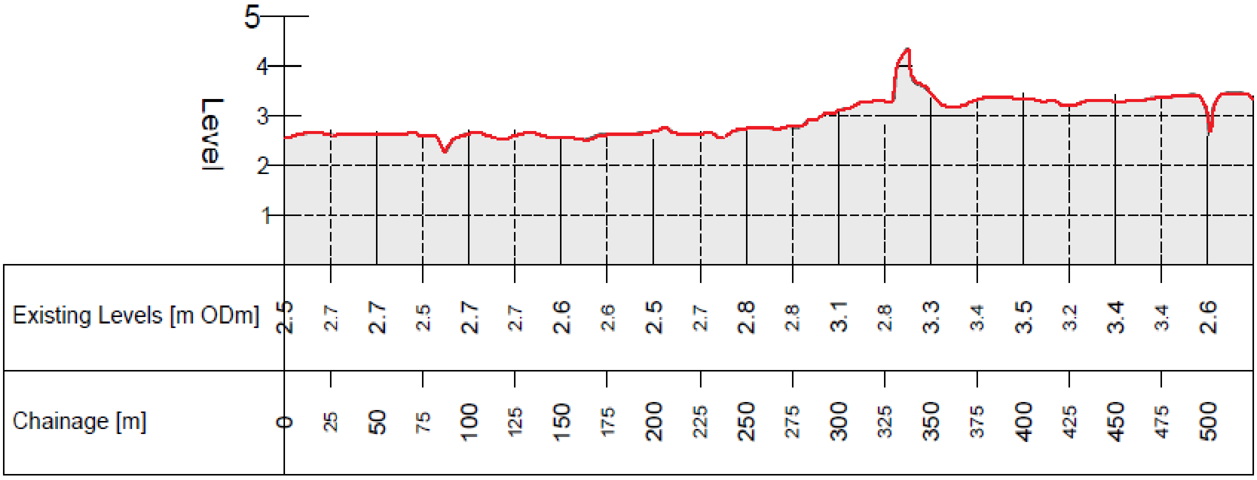


Figure 7.1: Location and alignment of the seawall along Channel road and the small bridge at ch.330m



Existing Levels [m ODm]	2.5	2.7	2.7	2.5	2.7	2.7	2.6	2.6	2.5	2.7	2.8	2.8	3.1	2.8	3.3	3.4	3.5	3.2	3.4	3.4	2.6
Chainage [m]	0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500

Figure 7.2: Long-section of the seawall alignment at Channel Road and Spout Lane (levels to ODm)

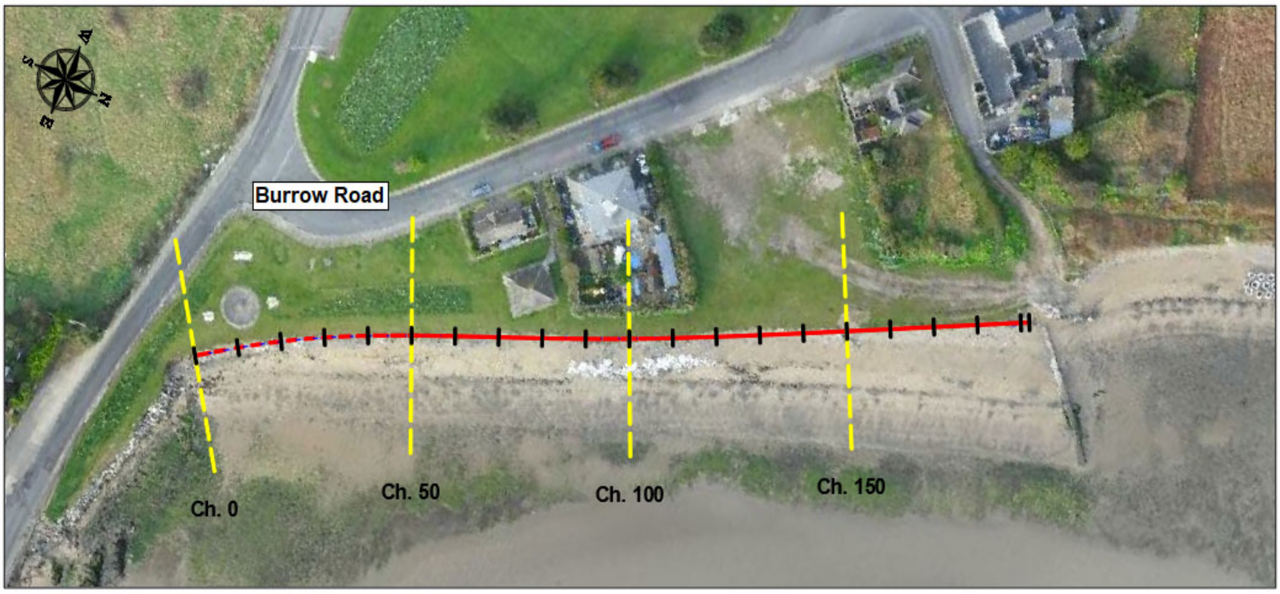


Figure 7.3: Location and alignment of the sheet piling at Burrow road

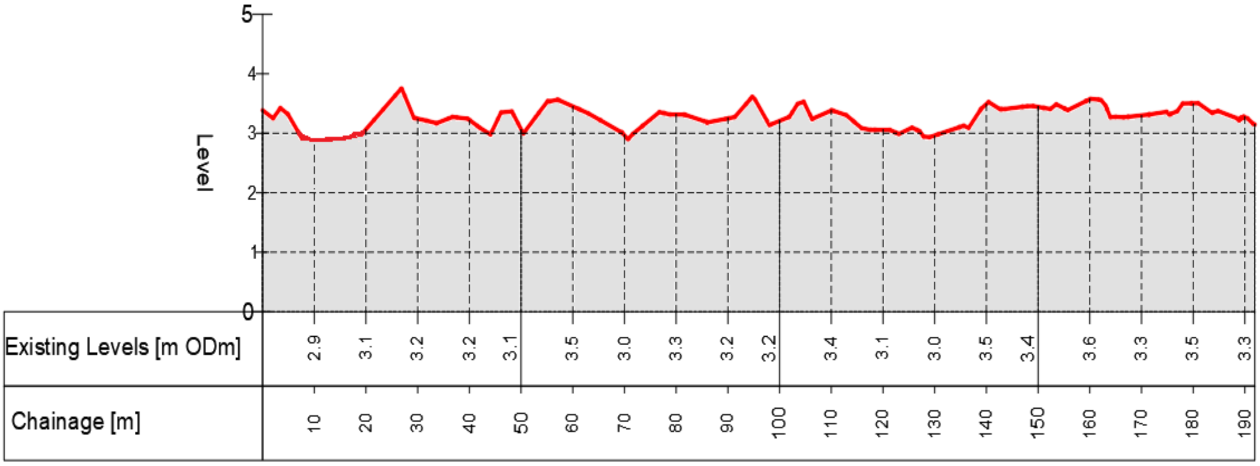


Figure 7.4: Long-section of the sheet piling at Burrow road (levels to ODm)

7.3.1 Assessing Wave Overtopping

The second edition of the EurOtop “Manual on wave overtopping of sea defences and related structures” (EurOtop, 2018) describes methods to predict wave. The manual recommends a series of empirical methods to represent the physics of the overtopping process in a series of equations that relate the main overtopping response parameter to key wave and structure parameters.

The EurOtop manual also provides guidance for using an Artificial Neural Network (ANN) tool to predict mean overtopping discharges for all structure geometries, given by several hydraulic and geometrical parameters as input. The ANN tool is based on a large extended database that contains more than 13,000 physical model tests. For the purposes of this study, RPS utilised the online ANN tool to predict the mean and 95%’ile discharge rates.

7.3.2 Wave Overtopping at Channel road

To assess the overtopping risk at Channel road, RPS examined the 1 in 200 year wave climate that was described in Section 5.2. It will be seen from Figure 7.5 below which illustrates the extreme 1 in 200 year inshore wave climate that waves inside the Rogerstown estuary, near Channel road do not exceed 0.36m. This significant reduction in wave heights relative to those observed outside of the estuary can be attributed to the complex bathymetry and topography at the entrance to the estuary which acts to diffract and refract incident waves. Furthermore, the wave-current interaction between the outgoing flow and incident waves would also reduce the prevailing wave heights in this area.

Despite the predicted incident wave measuring only 0.36m during this storm event, RPS took a conservative approach and assumed an incident wave height of 0.70m to assess wave overtopping of this seawall. This wave height was reflective of a worst-case scenario whereby local flow conditions did not limit wave heights and sea levels were increased by +0.5m due to climate change, i.e. this represented the Medium Range Future Scenario conditions.

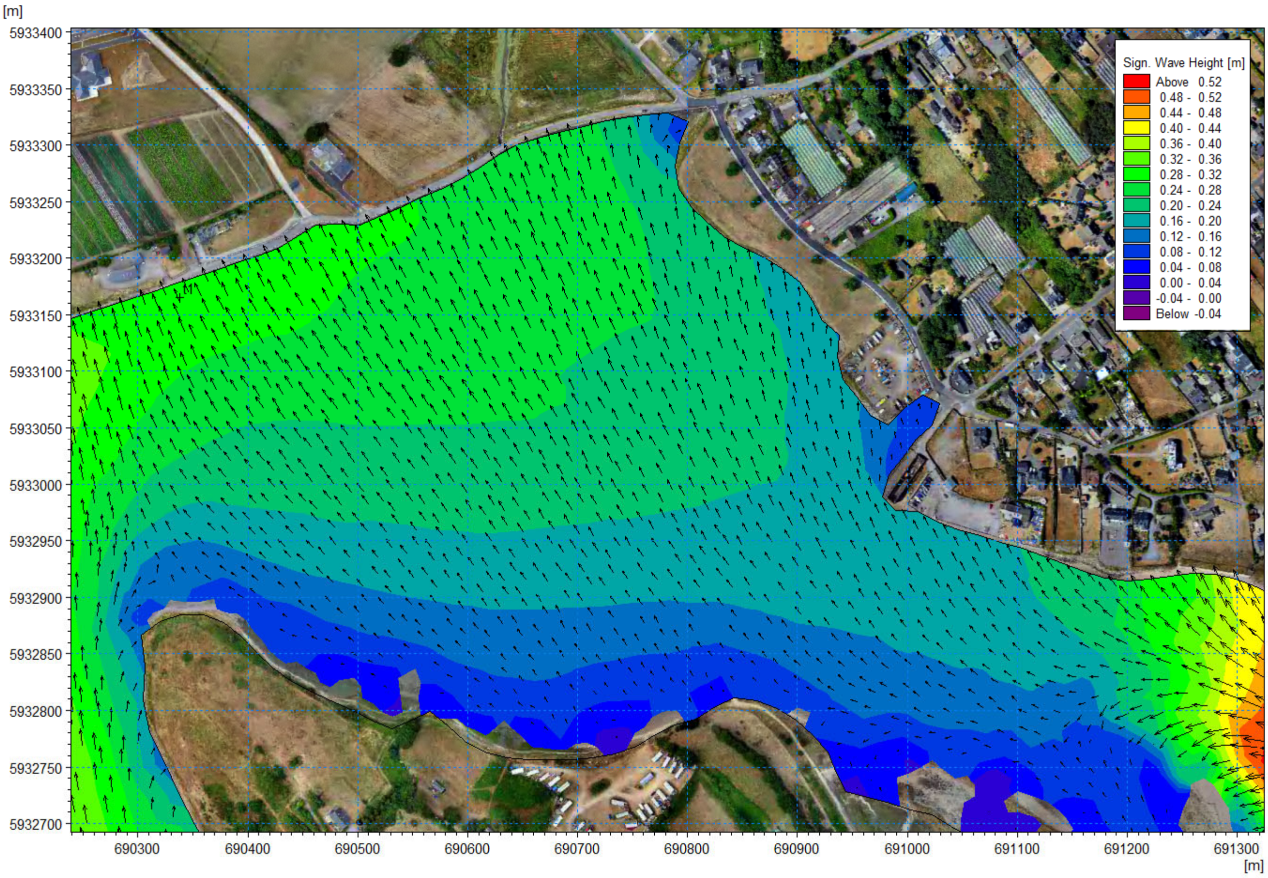


Figure 7.5: The inshore wave climate at the Channel road during a 1 in 200 year south easterly storm event

The input parameters that were used in the ANN tool for Channel Lane are presented in Table 7.3 below. RPS calculated the wave overtopping discharges along Channel road and Spout lane for a range of crest levels to account for the heterogeneous nature of the sea wall in this area.

Table 7.3: Input parameters for the Artificial Neural Network wave overtopping assessment. Based on a MRFS 1 in 200 year wave climate at Channel road

Test Scenario	Crest height [ODm]	Significant wave height [m]	SWL [ODm]	Spectral wave period [s]	Toe of wall [ODm]	Toe submergence [m]	Roughness factor	Crest height relative to SWL
1	2.7	0.70	2.1	4	1.24	0.86	1	0.6
2	2.8	0.70	2.1	3	1.24	0.86	1	0.7
3	2.9	0.70	2.1	3	1.24	0.86	1	0.8
4	3.0	0.70	2.1	3	1.24	0.86	1	0.9
5	3.1	0.70	2.1	3	1.24	0.86	1	1
6	3.2	0.70	2.1	3	1.24	0.86	1	1.1
7	3.3	0.70	2.1	3	1.24	0.86	1	1.2
8	3.4	0.70	2.1	3	1.24	0.86	1	1.3

The average discharge rates at Channel road and Spout lane for a MRFS 1 in 200 year wave event are presented in Table 7.4 overleaf. The Euclidean (E) distance validity parameter is also given for each test scenario. In general, it can be considered that optimal values of E should be lower than 0.5, while values of E close to 1 would give un-reliable predictions (i.e. very wide confidence intervals).

This assessment found that even under the most arduous wave conditions the average discharge rate along Channel Road and Spout Lane did not exceed 0.02 L/s/m. When the crest level of the sea wall was increased from 2.7 to 3.4m, the mean discharge rate decreased by c.50% to 0.01 L/s/m. Output from the ANN tool for all scenarios is presented in Table 7.4 overleaf. It should be noted that all assessments were found to produce predictions with low confidence intervals and were therefore considered reliable (i.e. E < 0.5).

It is clear from this analyses that wave overtopping is not the primary mechanism of flooding at Channel Road and Spout Lane as even the discharge rates for an onerous 1 in 200 year event are considered tolerable according to the EurOtop II manual.

The flood risk assessment presented in the following sections of this report has therefore been based on flooding from joint tide and surge activity only (i.e. Mechanism 1).

It should be noted that despite these results, wave overtopping may still occur at this site. This is because there are inherent limitations associated with the ANN wave overtopping tool. Based RPS' experience of physical modelling testing, overtopping rates from the ANN tool can in some instances be under-rated particularly in instances like that at Channel road whereby waves propagate across complex bathymetries and approach at oblique angles. Nevertheless, it remains that main flood risk at this site stems from joint tide and surge activity only (i.e. Mechanism 1).

Table 7.4: Output parameters from the Artificial Neural Network wave overtopping assessment

Test Scenario	Average Discharge Rate [L/s/m]	Euclidean distance validity parameter [E]
1	0.02	0.02
2	0.01	0.02
3	0.01	0.02
4	0.01	0.02
5	0.01	0.02
6	0.01	0.03
7	0.01	0.04
8	0.01	0.05

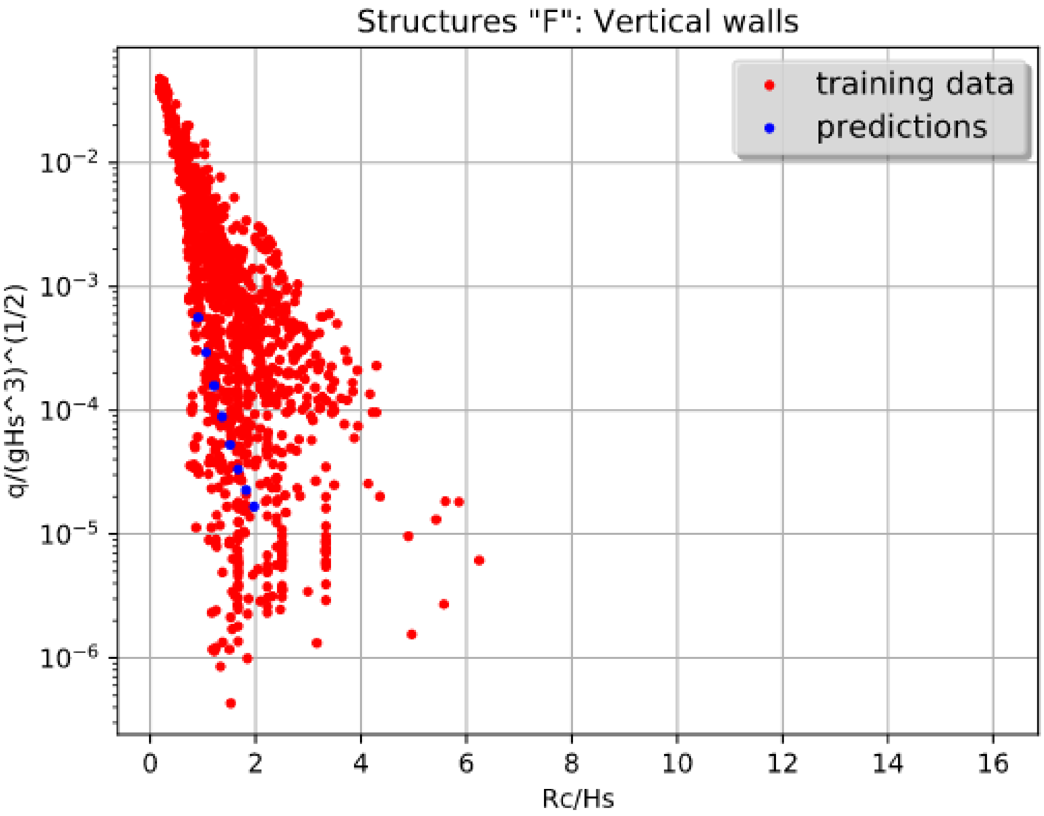


Figure 7.6: Output of the wave overtopping discharge illustrated as a function of the relative crest freeboard. The predictions (blue) are printed together with the NN training data (red) that are “similar” to the user scenario/s

7.3.3 Wave Overtopping at the Burrow

Unlike the waves at Channel road, the waves that can potentially overtop the sheet piling along the southern section of the Burrow can approach from a range of directional sectors and water levels. In this instance, it was necessary to assess overtopping for a range of north easterly, easterly and south easterly wave events. RPS therefore utilised the extreme inshore wave climate information presented in Section 5.2 to undertake the wave overtopping assessment.

To determine which directional sector yielded the largest overtopping rates along the sheet piling RPS first used the ANN tool to assess overtopping from waves from the from the north east through to the south east for up to 1 in 1000 year events under existing conditions. The input parameters for these calculations were based on the joint probability wave events described in Section 4.5.2 above. Given that this involved more than 250 simulations RPS have not presented a table detailing the input parameters as was done in the previous section. However, as can be seen in Figure 7.7 and Figure 7.8 the majority of the overtopping assessments fell within the training data which meant that the results could generally be considered as reliable.

RPS’ assessment found that overtopping rates along this defence generally ranged between 0.02 L/s/m to 0.95 L/s/m for 1 in 2 year to 1 in 1000 year return period events respectively. Wave events from the easterly sector were also found to produce the most arduous wave overtopping conditions. RPS therefore re-analysed all these events using the ANN tool but by adding an additional +0.50m and +1.00m onto the prevailing water levels to account for the MRFS and HEFS climate change conditions.

The average overtopping rates for all the existing, MRFS and HEFS easterly events are summarised in Table 7.5. It will be seen from this table that the magnitude of overtopping along the Burrow increases significantly under future climate change conditions.

It should be noted that as the water levels were increased for the MRFS & HEFS climate change scenarios, the wave overtopping assessments began to shift towards the upper range of training data. This can be seen by comparing Figure 7.7 and Figure 7.8. Despite this, there were a suitable number of overtopping assessments that were considered reliable based on the Euclidean distance parameter.

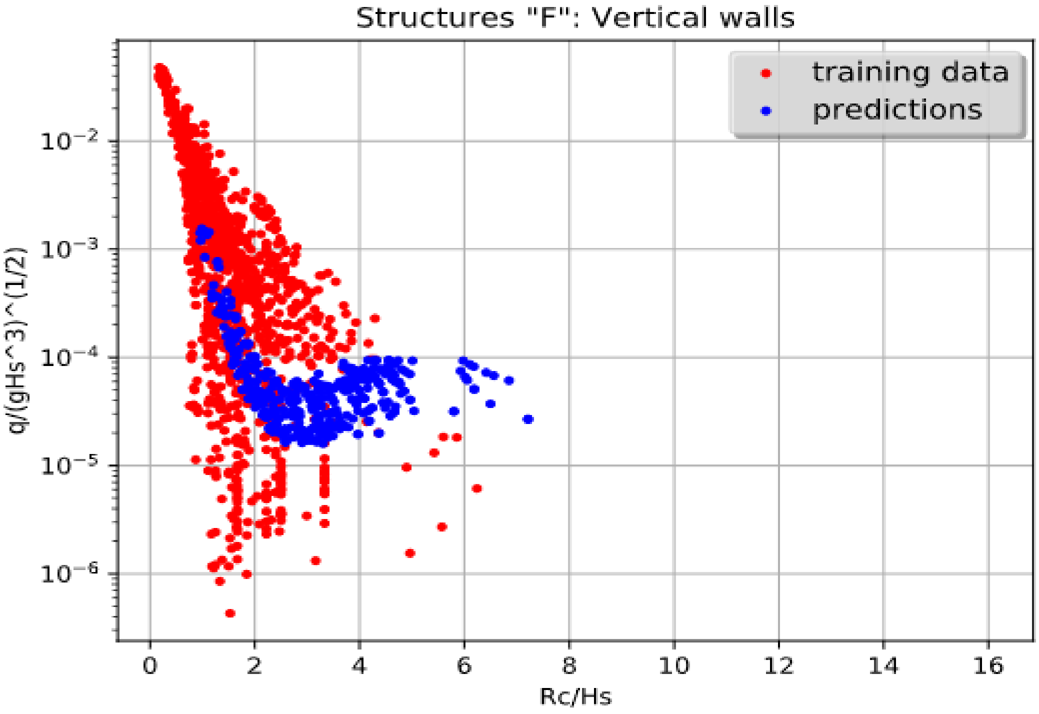
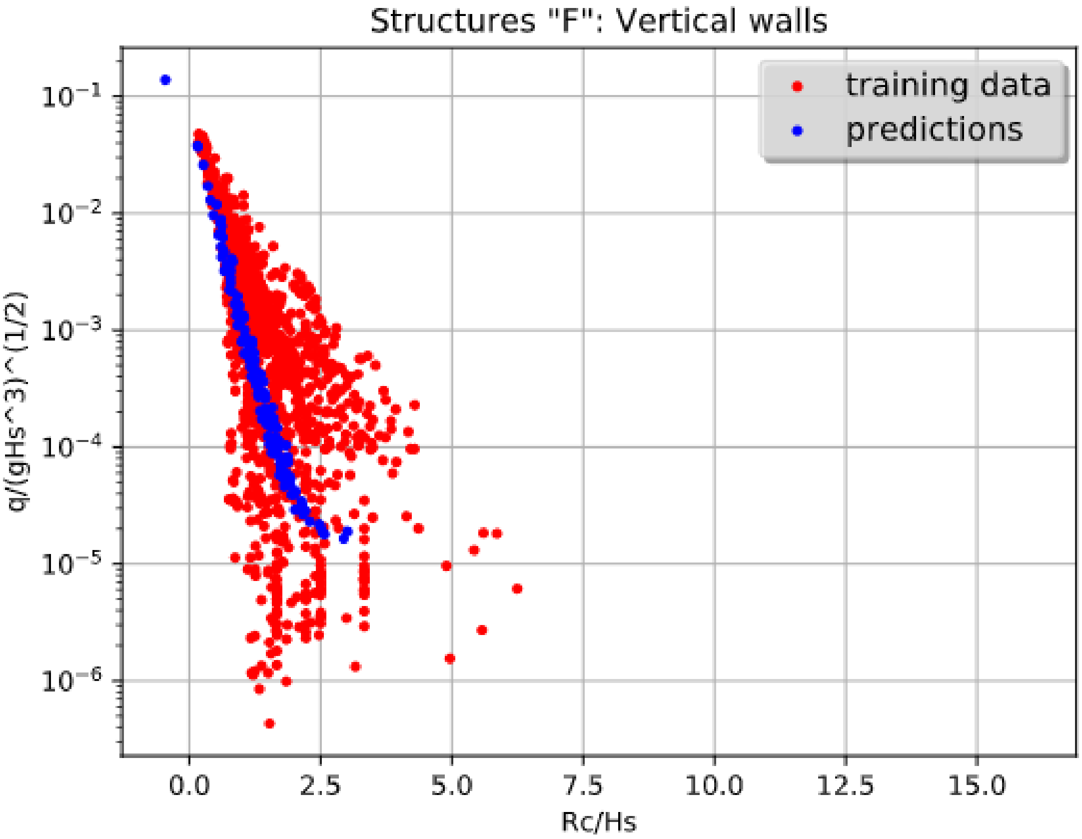


Figure 7.7: Output of the wave overtopping discharge illustrated as a function of the relative crest freeboard. The predictions (blue) are printed together with the NN training data (red) that are “similar” to the user scenario/s



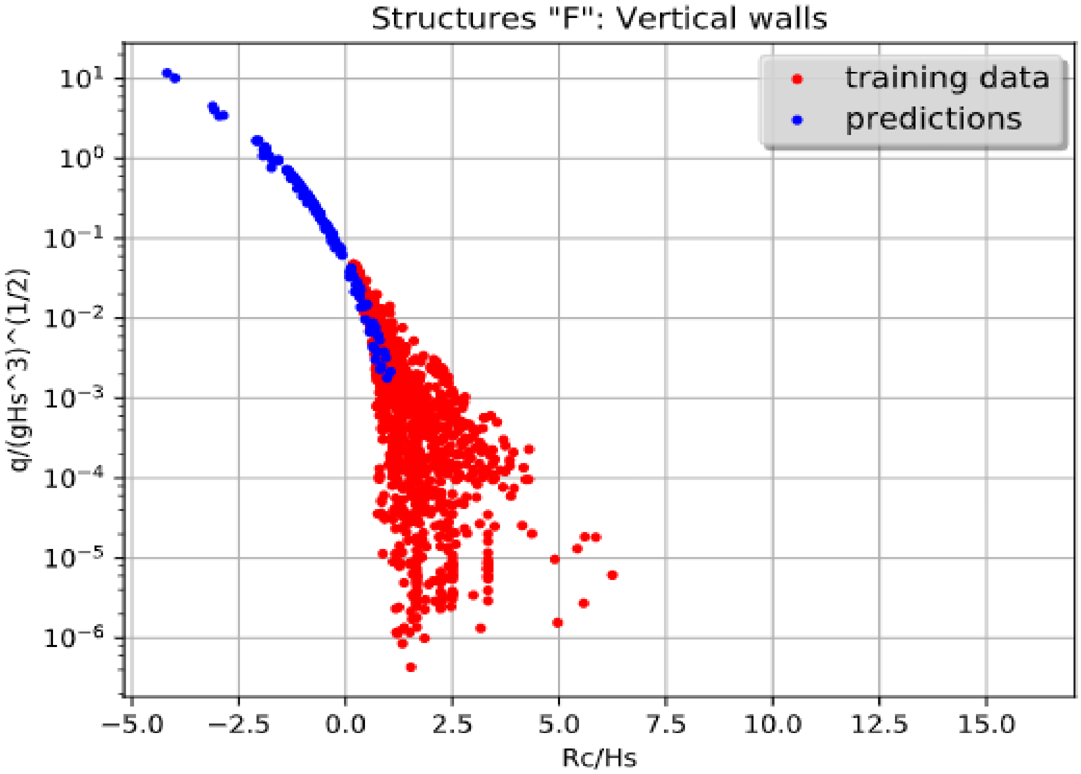


Figure 7.8: Output of the wave overtopping discharge illustrated as a function of the relative crest freeboard for the MRFS (upper) and HEFS (lower) climate scenario. The predictions (blue) are printed together with the NN training data (red) that are “similar” to the user scenario/s

Table 7.5: Summary output of the wave overtopping assessment – average overtopping discharge rates for a range of easterly return period events under different climate conditions.

Return Period	Existing Climate Average Discharge Rate [L/s/m]	MRFS Climate Average Discharge Rate [L/s/m]	HEFS Climate Average Discharge Rate [L/s/m]
2	0.02	0.06	3.41
5	0.02	0.14	5.53
10	0.03	0.27	7.23
20	0.04	0.66	9.68
50	0.07	1.66	14.34
100	0.10	2.65	19.00
200	0.19	5.01	26.11
1000	0.95	14.30	54.72

To include for the effect of wave overtopping in the flood risk assessments, RPS created a series of overtopping discharge curves for all return period events for all climate change scenarios. These curves are illustrated in Figure 7.10, Figure 7.11 and Figure 7.12 respectively. The corresponding discharge curve for each flood scenario was applied as a source term along the boundary illustrated in Figure 7.9

Figure 7.9: The corresponding discharge curve for each flood scenario was applied as a source term along the boundary illustrated in Figure 7.9.

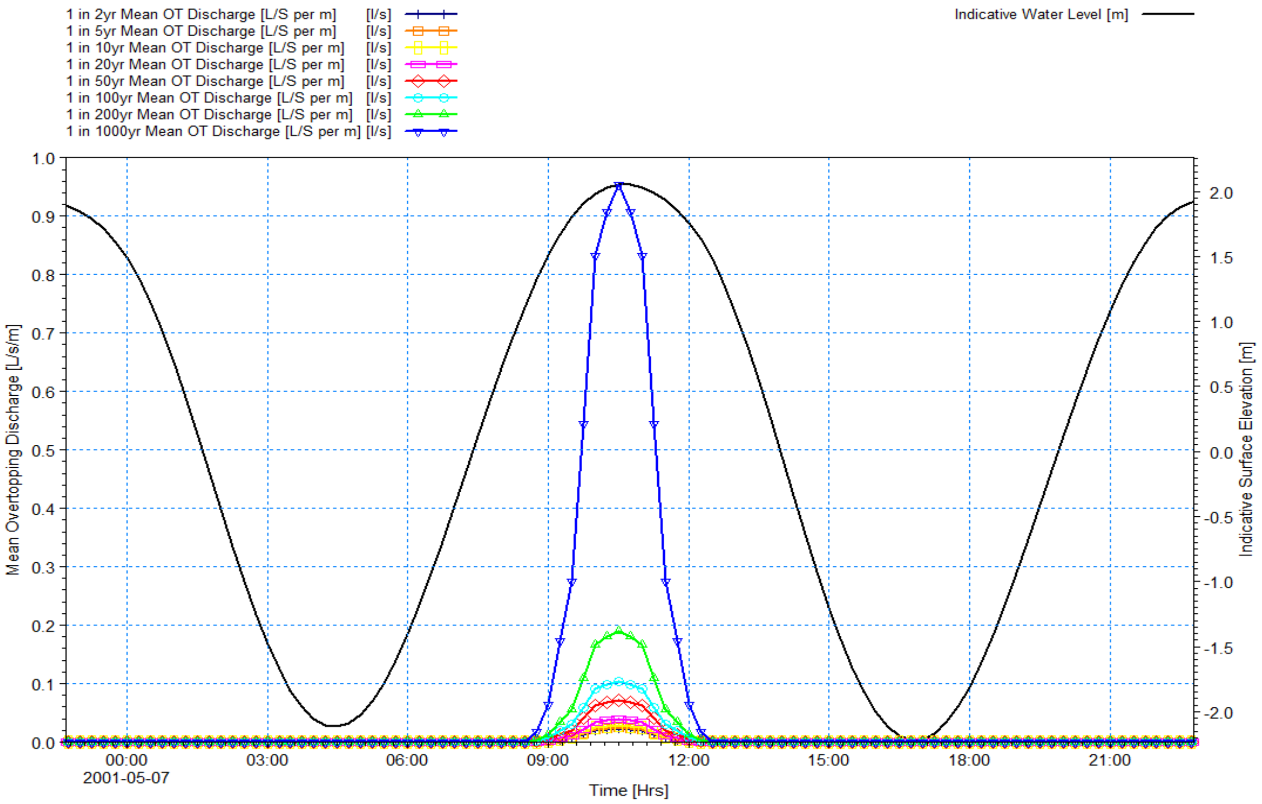


Figure 7.10: Mean overtopping discharge rates at the Burrow under existing climate conditions

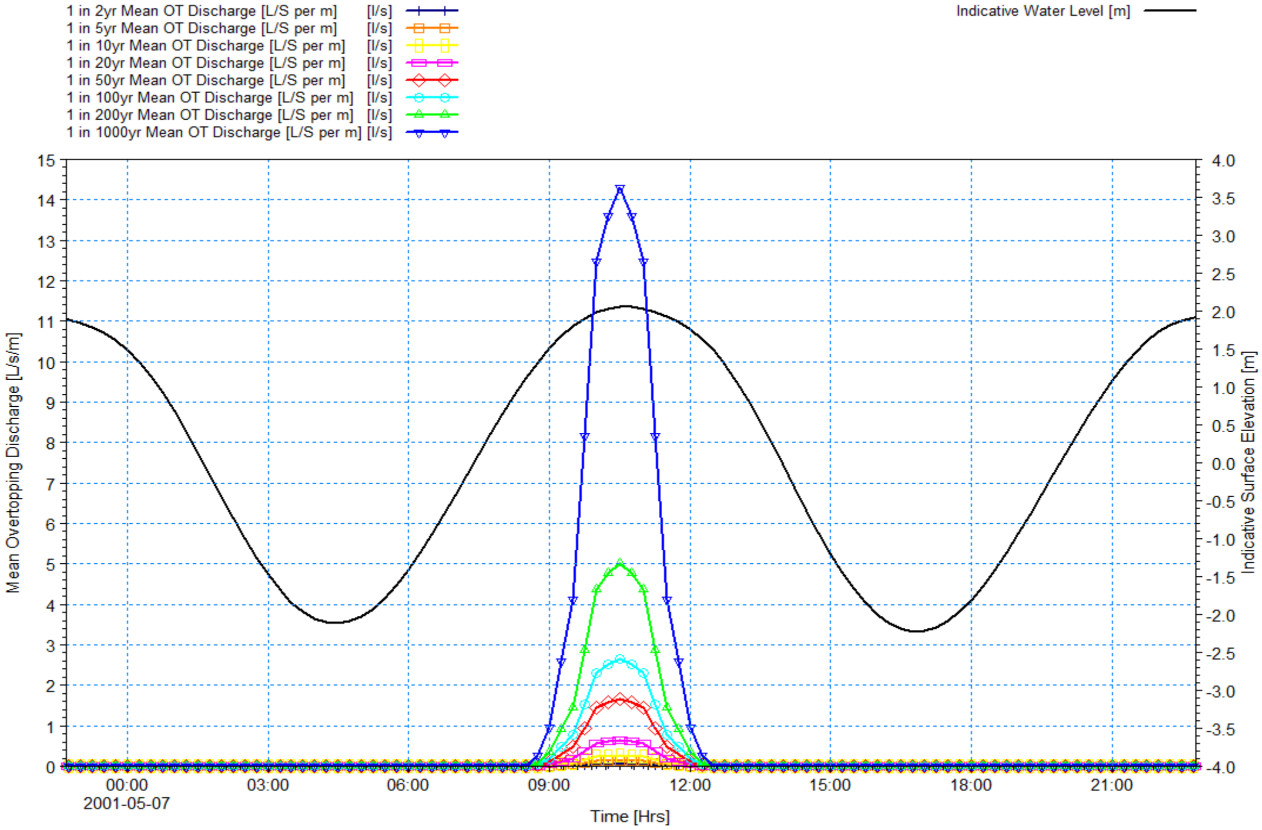


Figure 7.11: Mean overtopping discharge rates at the Burrow under MRFS climate conditions

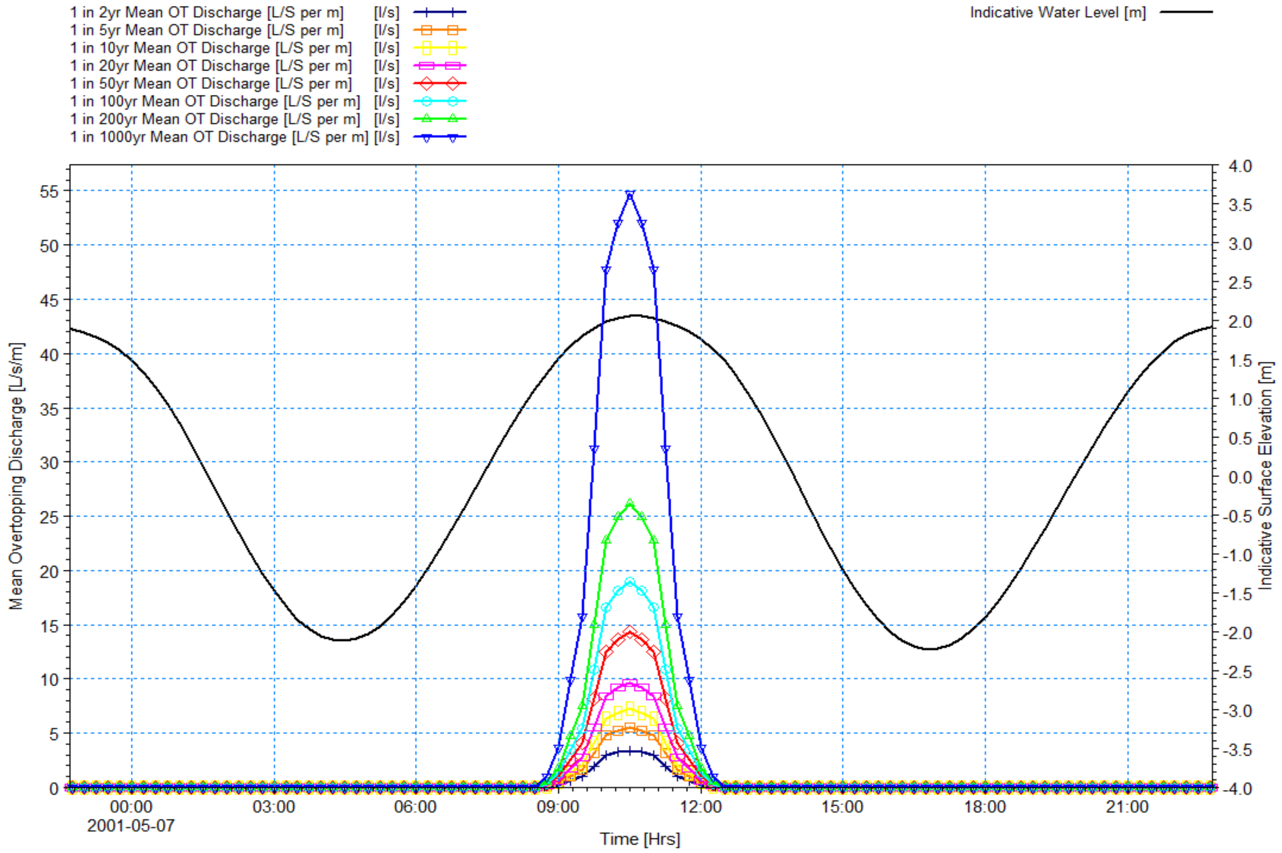


Figure 7.12: Mean overtopping discharge rates at the Burrow under HEFS climate conditions

7.4 Flood Risk Assessment – Flood Maps

7.4.1 Presentation of Model Results

Following the simulation of each AEP event, epoch and erosion scenario combination, ArcGIS was used to present the results of the flood simulations on suitable background mapping. Before commencing with the mapping procedure, the raw outputs of the numerical models were checked and cleaned to remove outliers and islands that were not connected to the coastal flooding mechanisms.

The extreme water levels applied to the coastal boundary of the flood model presented in Figure 4.6 were taken from the Irish Coastal Protection Strategy Study (ICPSS) (RPS, 2010). This study modelled the combination of meteorological conditions that govern the generation of storm waves and extreme water levels around the coast of Ireland.

It should be noted that the fluvial flood risk extents remain unchanged for all the climate scenarios presented in Sections 7.4.2 to 7.4.4. This is because RPS were provided only with the present-day scenario fluvial flood extents from the FEMFRAM study (Halcrow Barry, 2014).

7.4.2 Flood Risk Assessment – Existing Conditions

Within this section of the report the flood hazard has been determined for a range of flood events using the existing topography (as surveyed in 2019) with the soft dune systems along the study sites in their current position (i.e. present day conditions).

In line with the project scope and as summarised in Table 7.6, simulations were undertaken for seven return period flood events ranging from a 0.5% AEP event to a 50% AEP event. This table also summarises the average wave overtopping discharge rates that were applied to the sheet piling along the southern extent of the Burrow for each corresponding AEP event.

Table 7.6: Summary of flood risk assessment inputs for existing climate scenario model runs

AEP event [%]	Water Level ODm [m]	Overtopping at the Burrow [L/s/m]
50	2.55	0.02
20	2.67	0.02
10	2.77	0.03
5	2.87	0.04
2	3.00	0.07
1	3.10	0.10
0.5	3.19	0.19

Given that there are several sites across the study area, individual maps have been produced for each site.

Figure 7.13 to Figure 7.16 illustrate the current scenario flood extents for the Rogerstown study area. The figures illustrate the flood extents for the 1 in 10 year (10% AEP), 1 in 200 year (0.5% AEP) and 1 in 1000 year (0.1% AEP) return period storm events.

The number of properties which are expected to be at risk from flooding during the various return period events under existing climate conditions is summarised in Section 7.5 of this report.

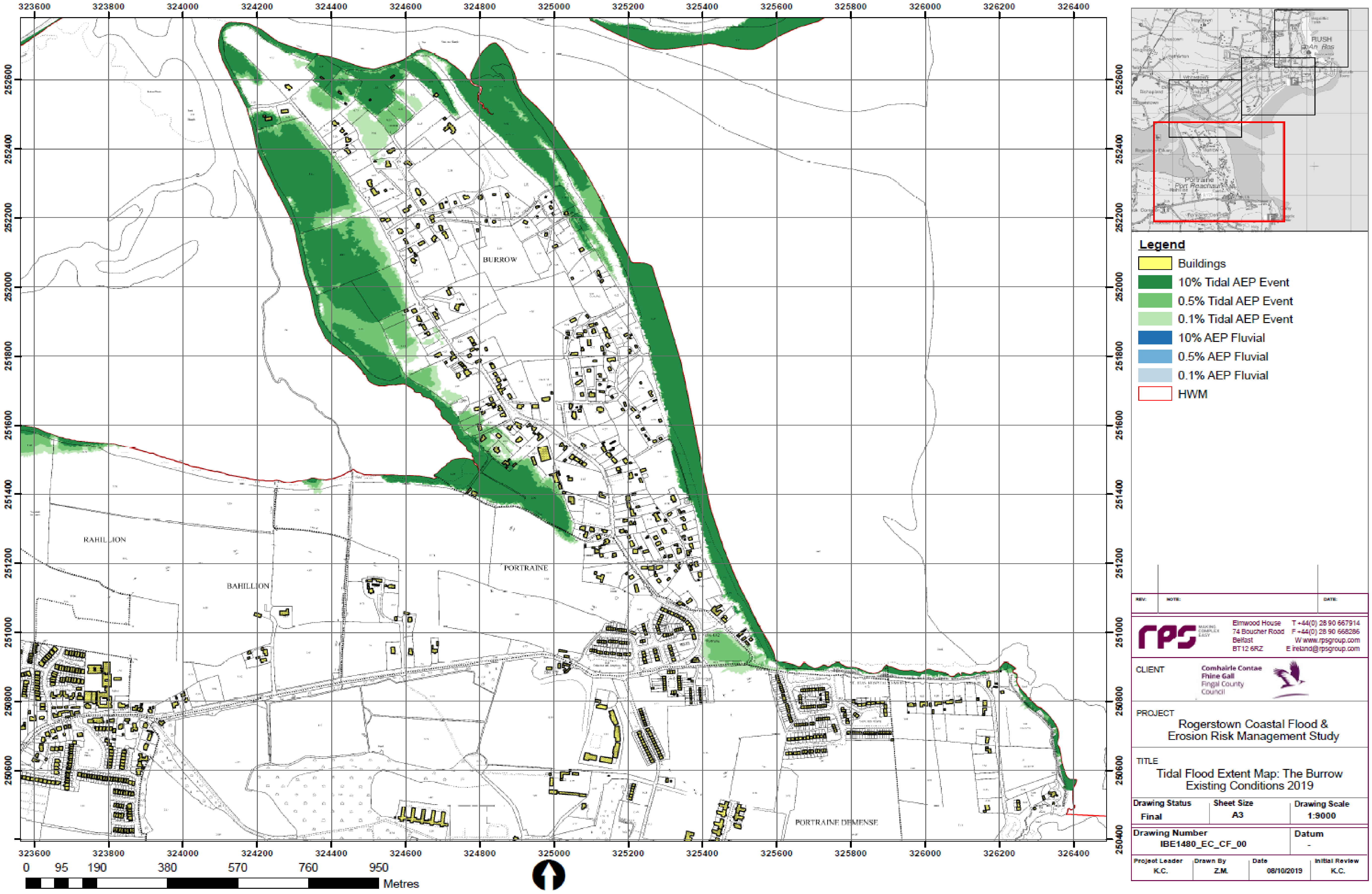


Figure 7.13: Tidal Flood Extent Map: The Burrow – Present Day Conditions (i.e. no sea level rise or coastal change)

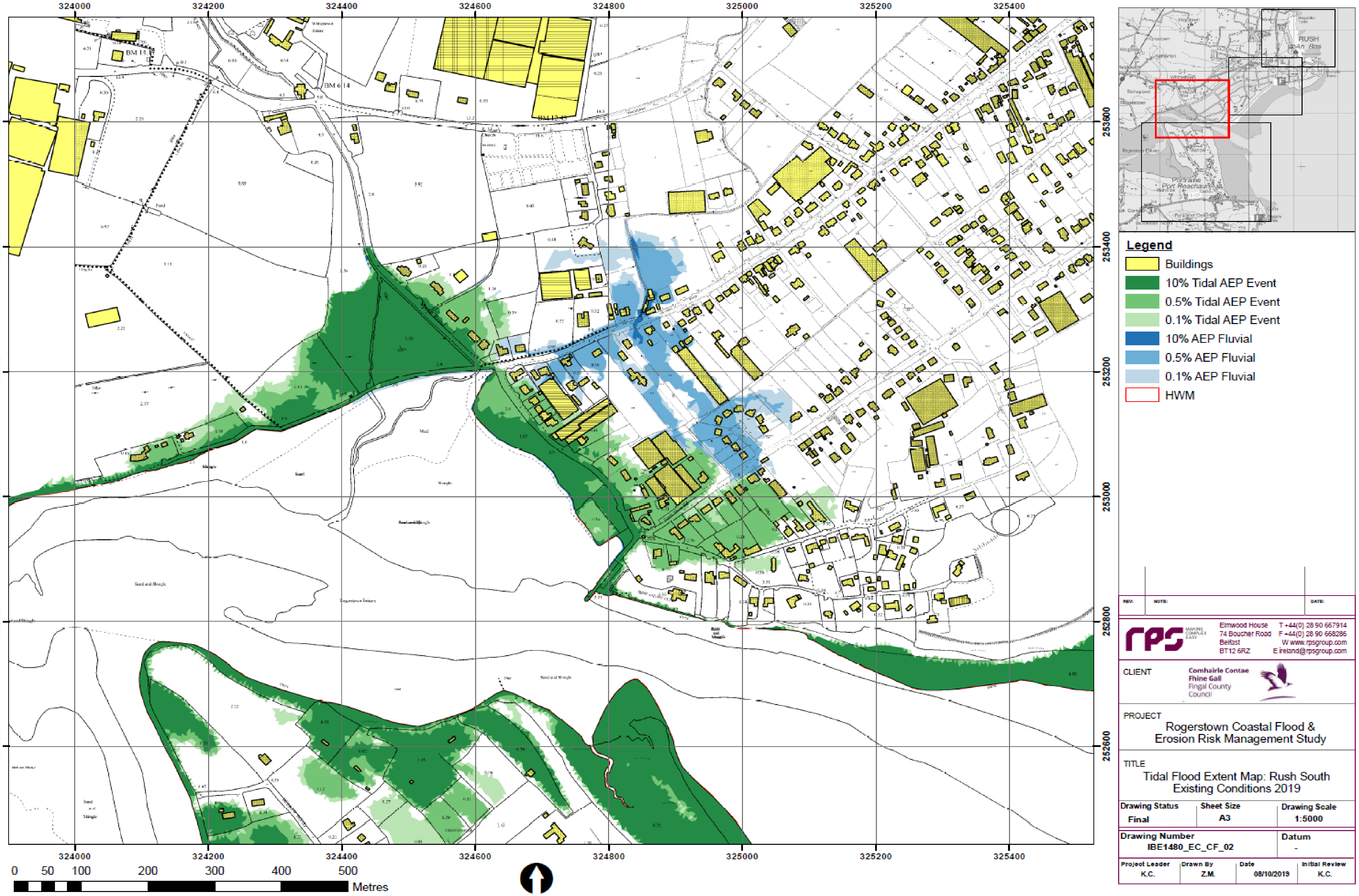


Figure 7.14: Tidal Flood Extent Map: Rush South (1) – Present Day Conditions (i.e. no sea level rise or coastal change)

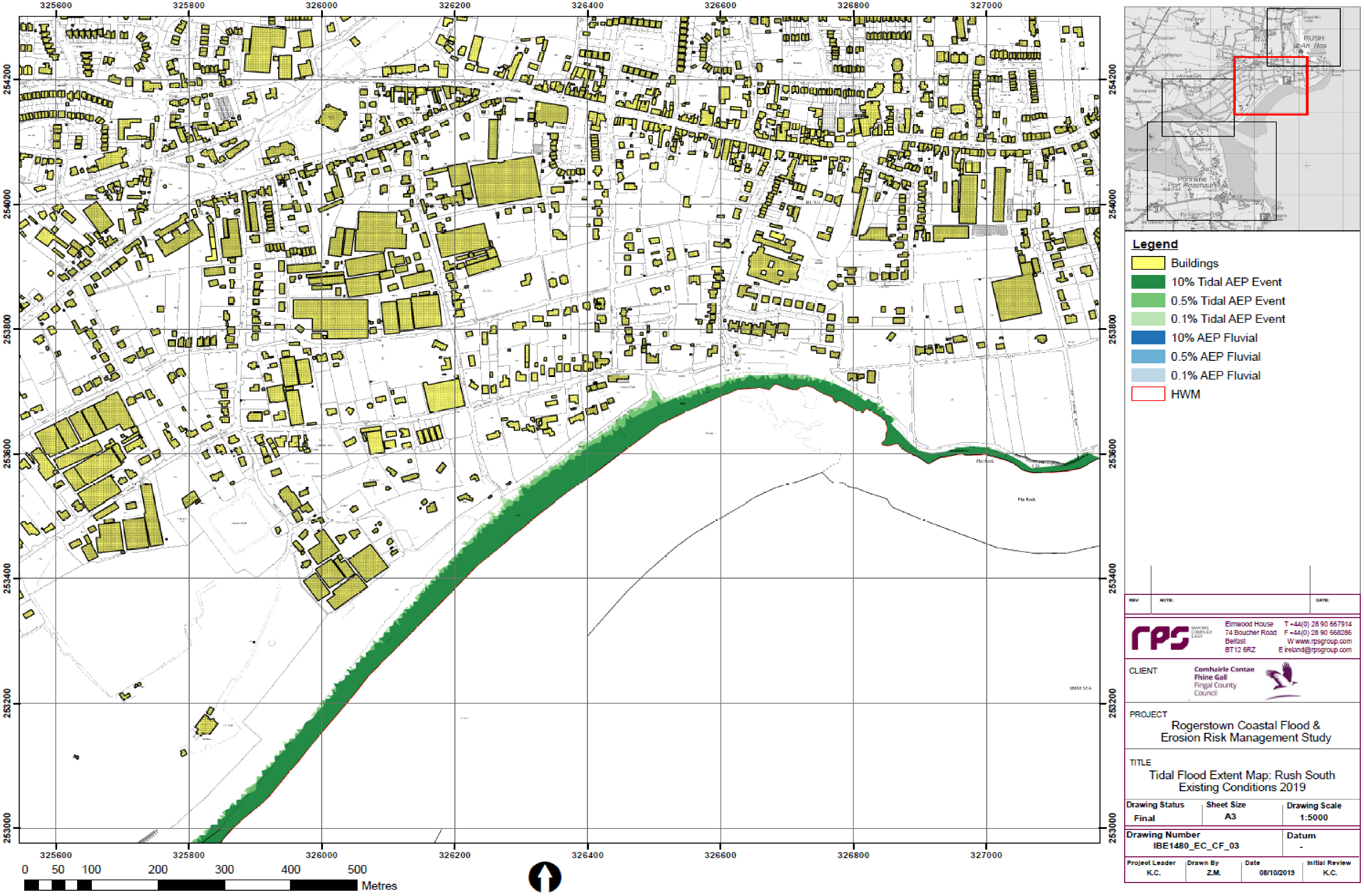


Figure 7.15: Tidal Flood Extent Map: Rush South (2) – Present Day Conditions (i.e. no sea level rise or coastal change)

Figure 7.16: Tidal Flood Extent Map: Rush North – Present Day Conditions (i.e. no sea level rise or coastal change)

7.4.2.1 Flood Risk Assessment Model Verification

Flooding was reported in the Channel Road/Spout Road area of Rogerstown, Rush in January 2014. Figure 7.18 and Figure 7.19 show the extent of flooding in these areas. The flood extents from this event were used to verify the tidal inundation model built for this area.

In order to characterise this flood event, RPS compared the surface elevations recorded by the Marine Institute's tide gauges at Dublin Port and Howth harbour during the time of the event. These levels were then compared with the extreme water levels presented in the Irish Coastal Protection Strategy Study (RPS, 2010) for Howth Harbour (pt. NE 18). As will be seen from Figure 7.17 the maximum surface elevations at Dublin Port and Howth were 2.91m and 2.82m respectively at *c.* 12:15 on 03/01/2014. At Dublin Port this equated to a *c.* 1 in 75 year event whilst at Howth the event had a return period of *c.* 1 in 20 – 1 in 50 years. Based on this data, it was estimated that this event had a return period of *c.* 1 in 50 years.

By comparing photographs that were taken during this flood event with the output from the flood model simulations, it can be seen that the general flood extents are well represented by the numerical model simulations. Photographs illustrating the extent of flooding at Spout land and Channel road are illustrated in Figure 7.18 and Figure 7.19 overleaf.

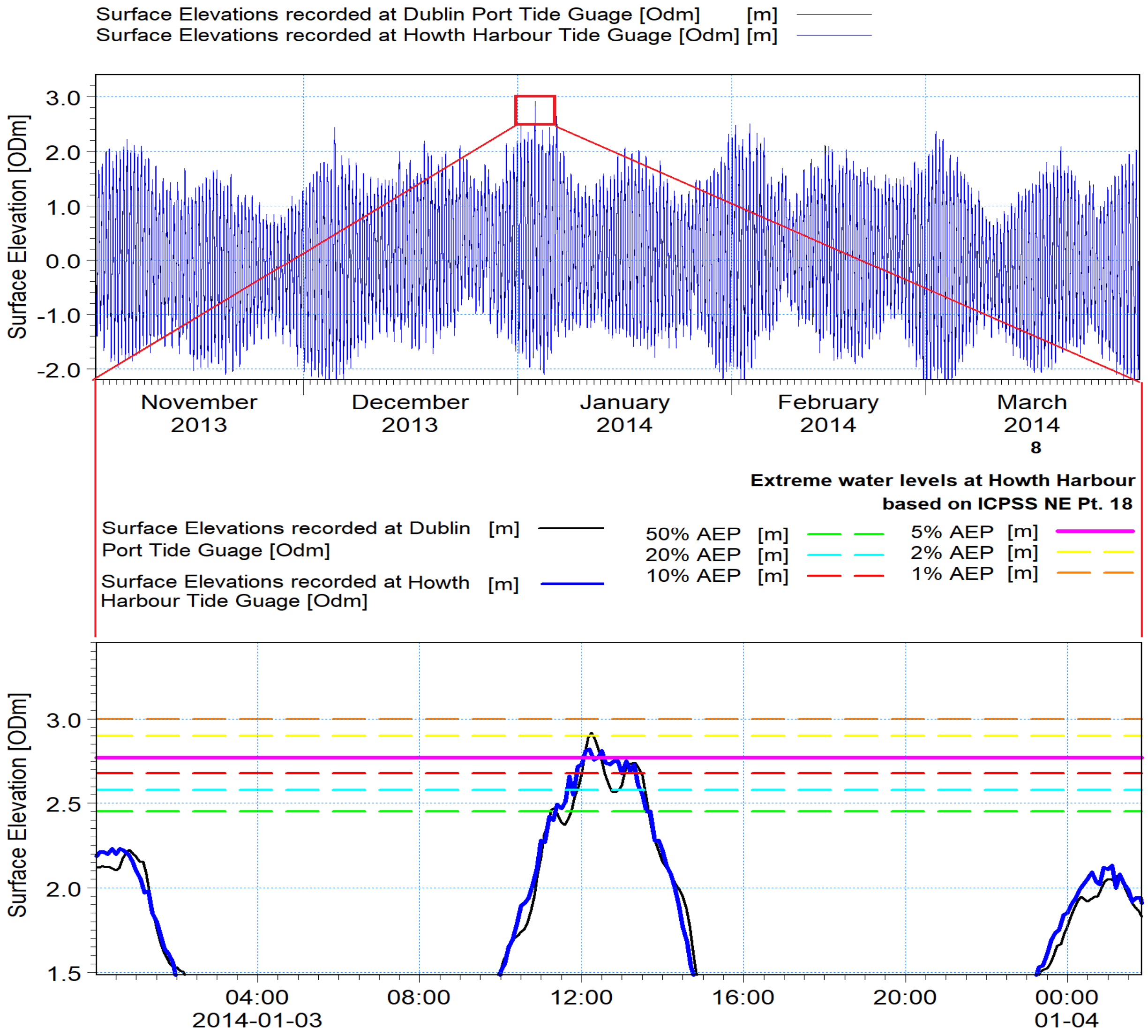


Figure 7.17: Comparison of tide gauge data from Dublin Port and Howth harbour during the Jan 2014 flood event with extreme water levels from the ICPSS study

Figure 7.18: Flooding on Spout Road looking southwest towards Channel Road, Rush (Early 2014)

Figure 7.19: Flooding on South Shore Road, Rush, looking southeast towards the junction with Linkside/Crescent Road (Early 2014)

7.4.3 Flood Risk Assessment – 2050 with various climate scenarios

The flood risk assessment described in Section 7.4.2 was repeated to include for the effect of future coastal erosion and sea level rise by 2050. To this end, the flood model of the study area was updated to adjust the position of the shoreline at the Burrow, Rush south and Rush north based on the coastal change maps presented in Section 6.3.1 for both the MRFS and HEFS climate scenarios.

These models were then used to assess the flood risk across the study areas for a range of return period events. As before, the model simulations included the corresponding average discharge rates at the sheet piling along the southern extent of the Burrow. For reference, the extreme water levels and average overtopping rates used for this assessment are summarised in Table 7.7 below.

Table 7.7: Summary of flood risk assessment inputs for the 2050 water levels & coastal change

AEP event [%]	MRFS		HEFS	
	Water Level ODm[m]	**Overtopping at the Burrow** [L/s/m]	**Water Level** ODm [m]	**Overtopping at the Burrow** [L/s/m]
50	2.75	0.04	2.88	0.06
20	2.87	0.08	3.00	0.14
10	2.97	0.15	3.1	0.27
5	3.07	0.35	3.2	0.66
2	3.20	0.67	3.33	1.66
1	3.30	1.38	3.43	2.65
0.5	3.39	2.60	3.52	5.01

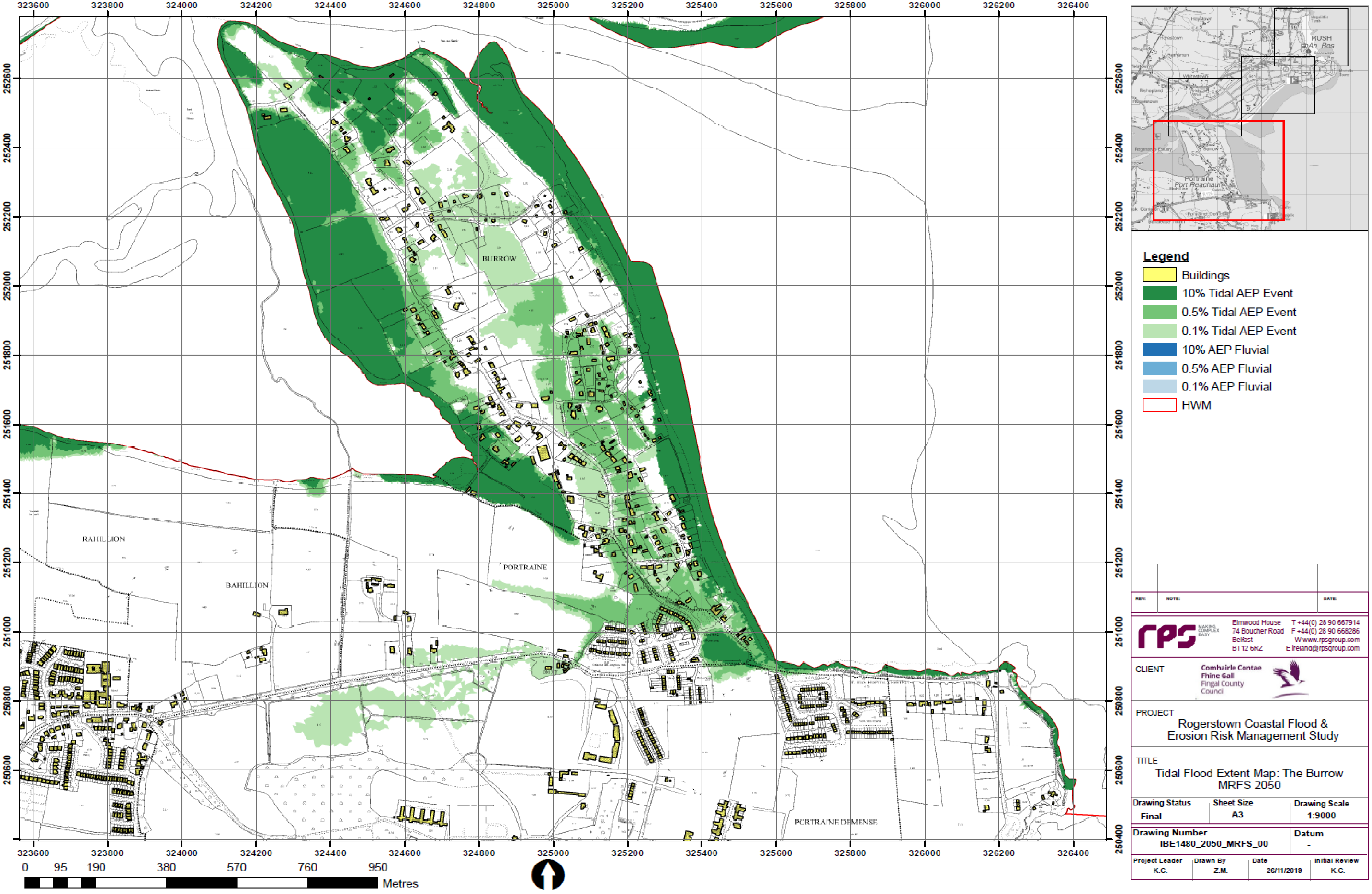
Figure 7.20 to Figure 7.23 illustrate the flood extents for the Rogerstown study area based on the 2050 MRFS climate scenario with corresponding erosion lines and extreme water levels with sea level rise. The figures illustrate the flood extents for the 1 in 10 year (10% AEP), 1 in 200 year (0.5% AEP) and 1 in 1000 year (0.1% AEP) return period storm events.

Similar plots have been presented in Figure 7.24 to Figure 7.27 for the 2050 HEFS climate scenario again with the erosion lines and extreme water levels with sea level rise that correspond to the 2050 HEFS epoch and climate scenario.

The flood risk illustrated in these figures demonstrate that there are only minor changes to the flood risk at Rush South and Rush North during the MRFS and HEFS climate scenarios. In both scenarios, there is notable flooding of Rush South which stems primarily from tidal and storm surge activity.

At the Burrow, the flood risk during the MRFS scenario is analogous to that predicted for the HEFS, however it will be seen by comparing Figure 7.20 and Figure 7.24 that the flood risk during the 0.5% AEP event propagates further into the hinterland. The result of this is that several additional properties are at risk under the HEFS climate scenario. The overall flood extent is also notably greater at the southern extent of the Burrow, however there is not a proportional increase in the number of properties affected.

The number of properties which are expected to be at risk from flooding during the various return period events during the 2050 epoch under the MRFS and HEFS climate scenarios is summarised in Section 7.5 of this report.



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PROJECT
Rogerstown Coastal Flood & Erosion Risk Management Study

TITLE
Tidal Flood Extent Map: The Burrow
MRFS 2050

Drawing Status	Sheet Size	Drawing Scale
Final	A3	1:9000

Drawing Number	Datum
IBE1480_2050_MRFS_00	-

Project Leader	Drawn By	Date	Initial Review
K.C.	Z.M.	26/11/2019	K.C.

Figure 7.20: Tidal Flood Extent Map: The Burrow - 2050 Medium Range Future Scenario (i.e. +0.20m sea level rise and *c.*29m of coastal retreat)

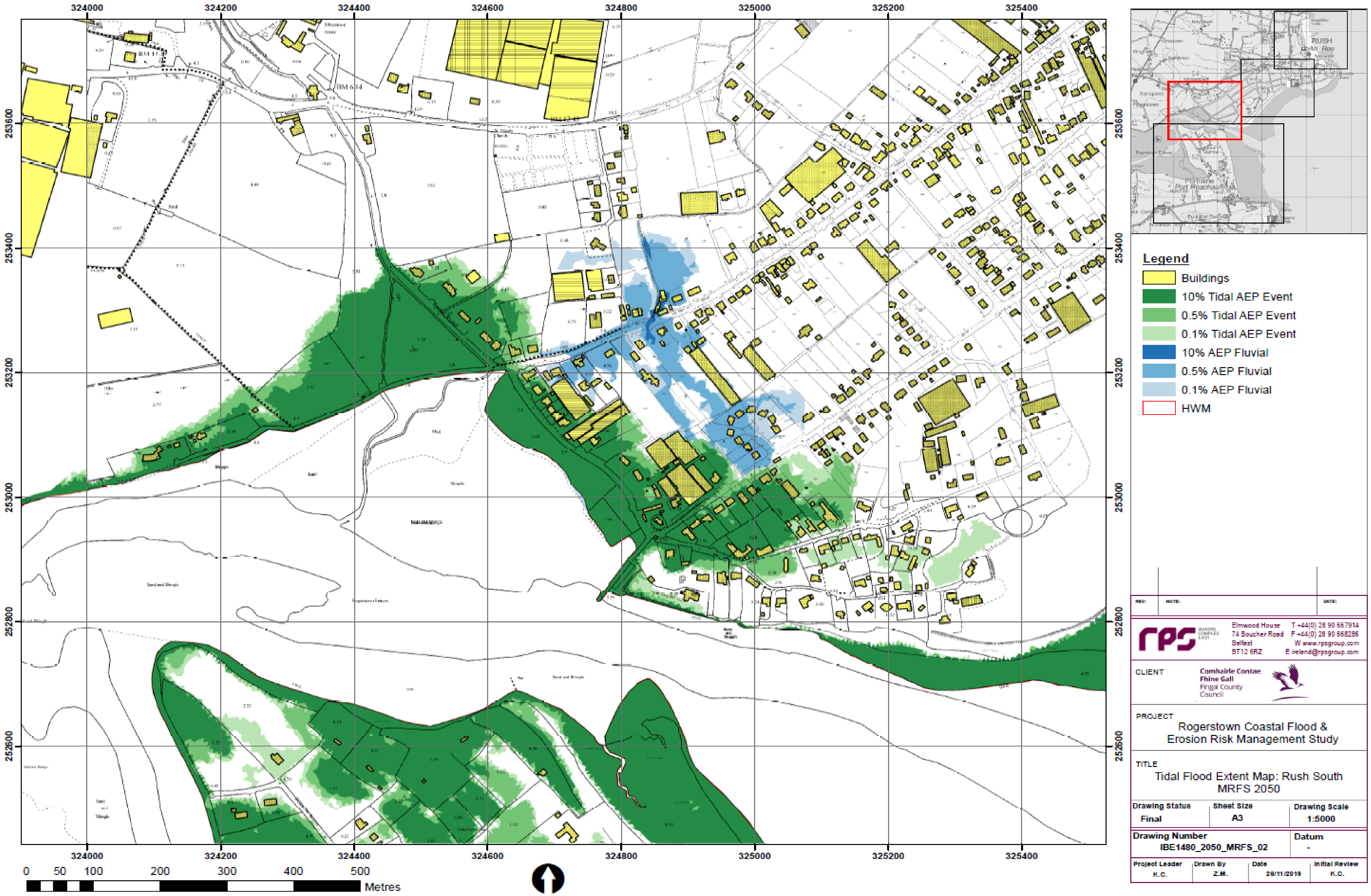

Figure 7.21: Tidal Flood Extent Map: Rush South (1) - 2050 Medium Range Future Scenario (i.e. +0.20m sea level rise and *c.*21m of coastal retreat at Rush Golf Club)

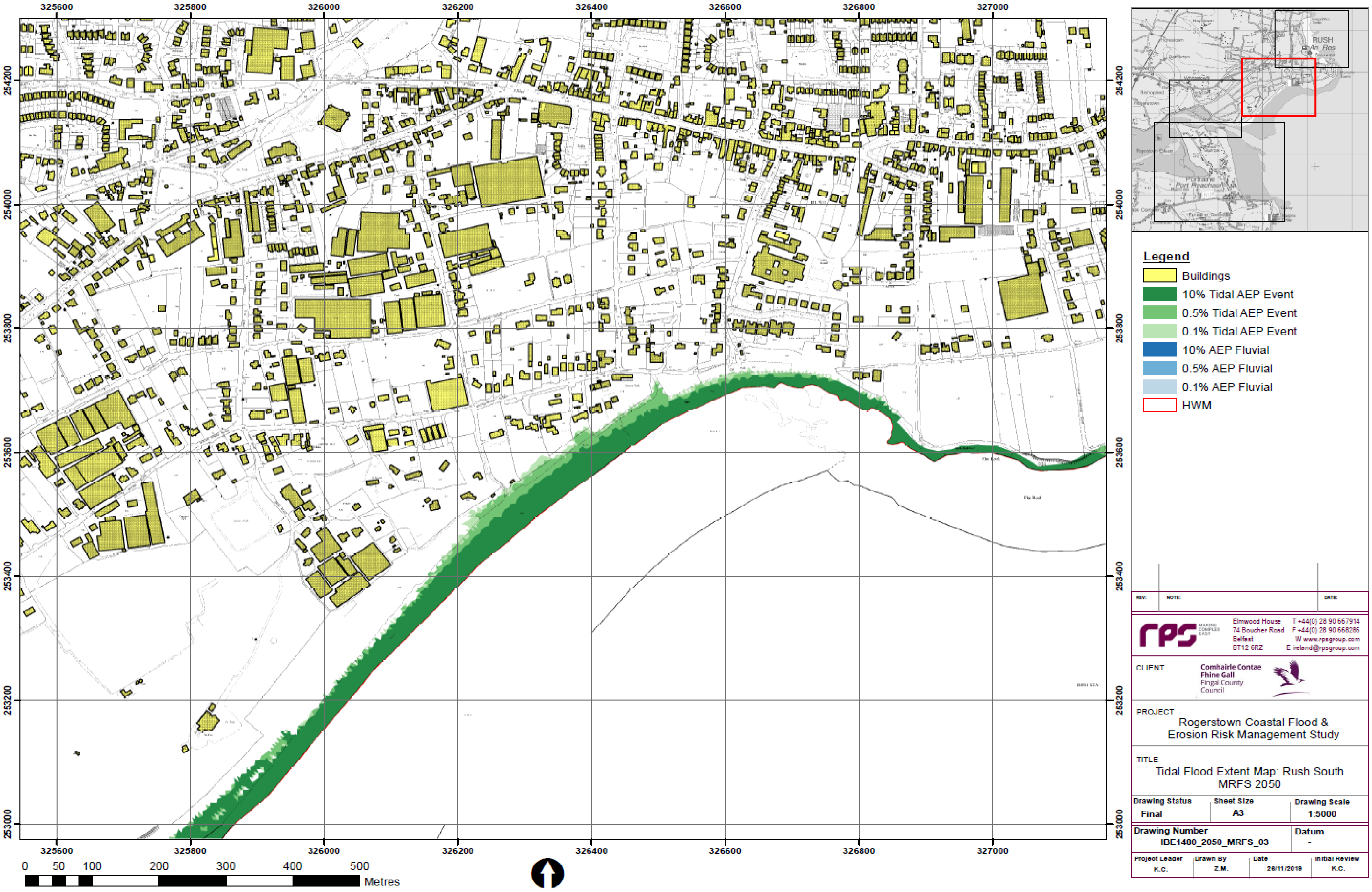

Figure 7.22: Tidal Flood Extent Map: Rush South (2) - 2050 Medium Range Future Scenario (i.e. +0.20m sea level rise and *c.*21m of coastal retreat)

Figure 7.23: Tidal Flood Extent Map: Rush North - 2050 Medium Range Future Scenario (i.e. +0.20m sea level rise and *c.*2m of coastal retreat)

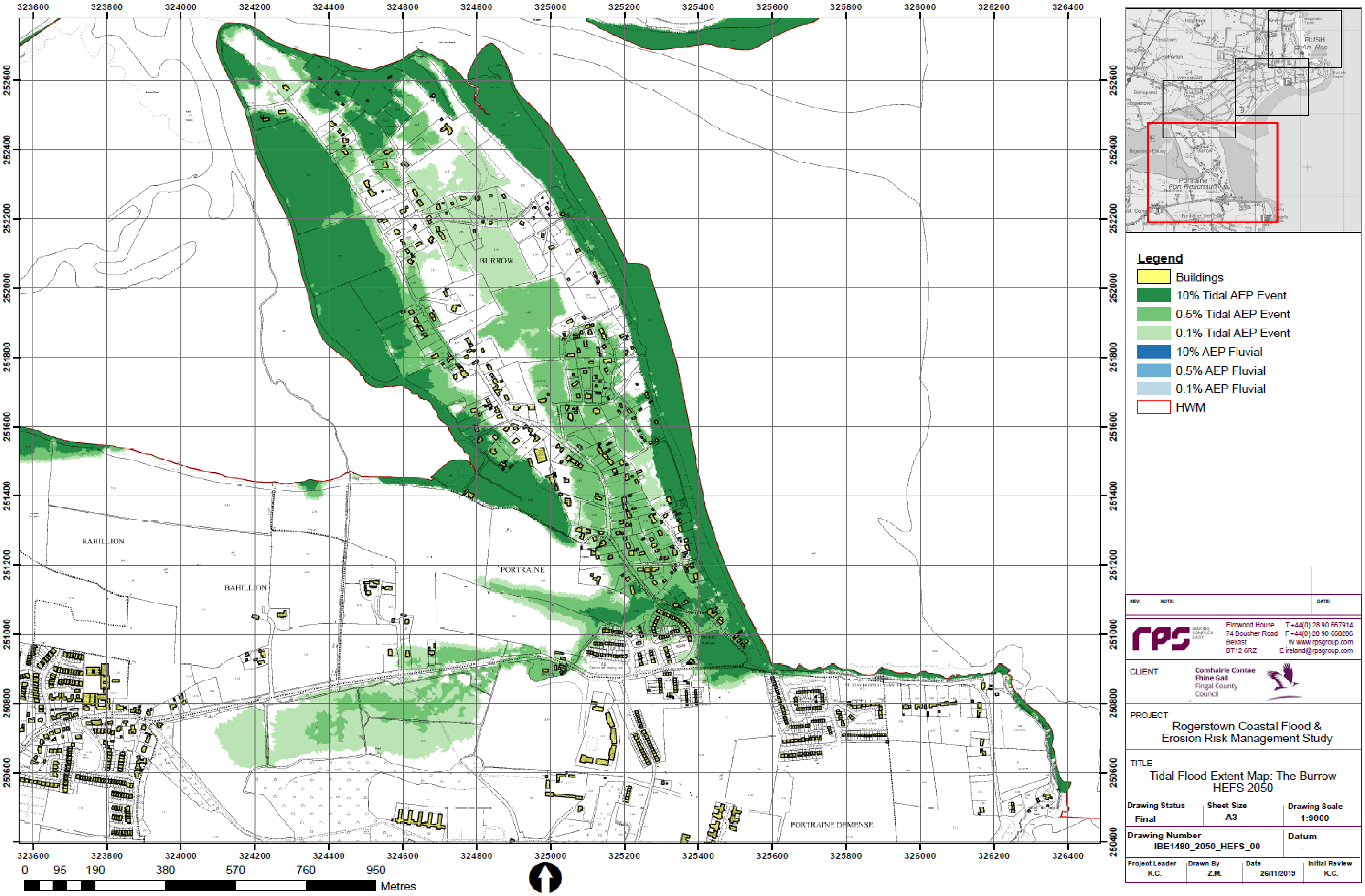

Figure 7.24: Tidal Flood Extent Map: The Burrow - 2050 High End Future Scenario (i.e. +0.33m sea level rise and *c.*39m of coastal retreat)

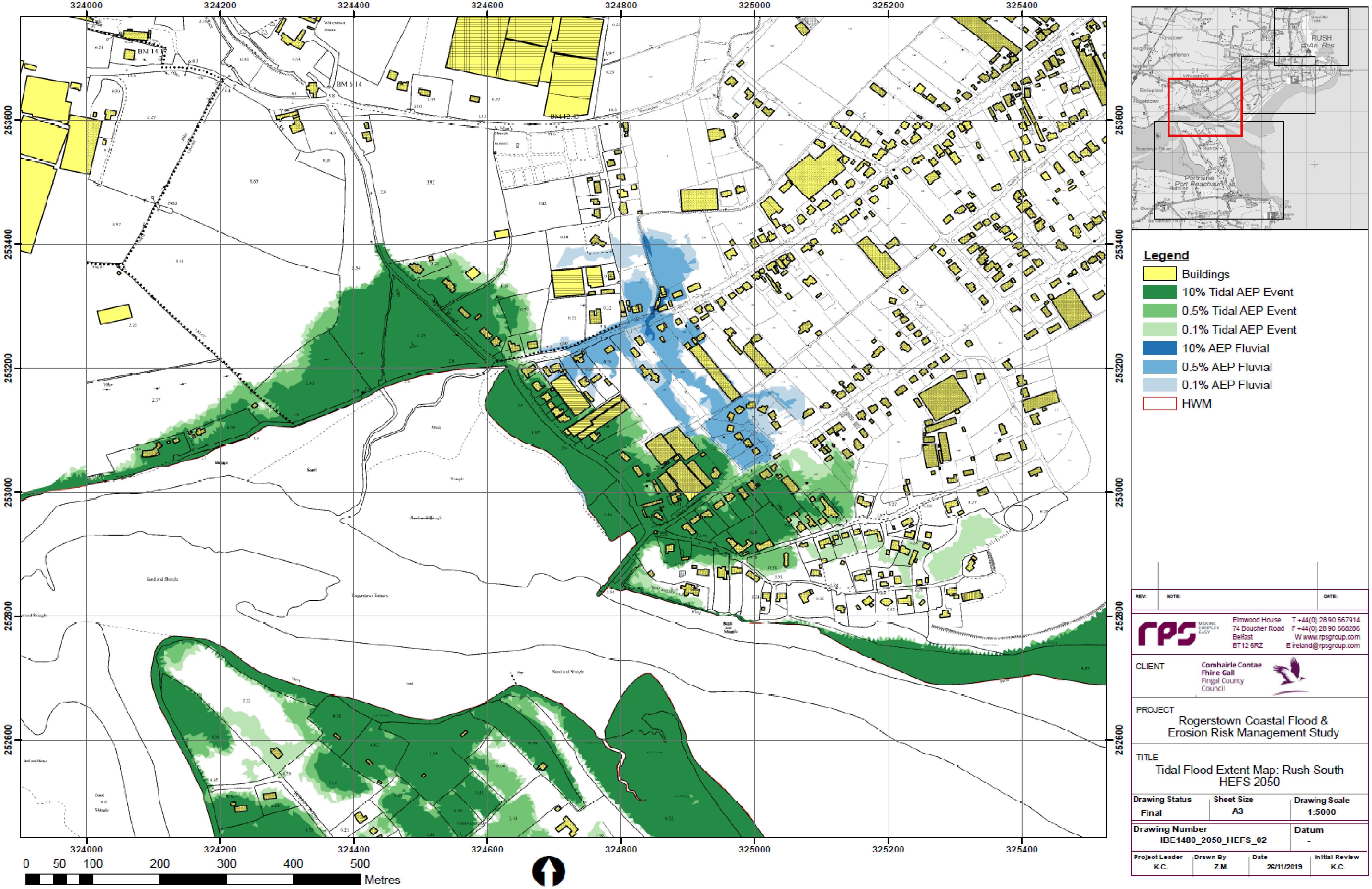

Figure 7.25: Tidal Flood Extent Map: Rush South (1) - 2050 High End Future Scenario (i.e. +0.33m sea level rise and *c.*28m of coastal retreat at Rush Golf Club)

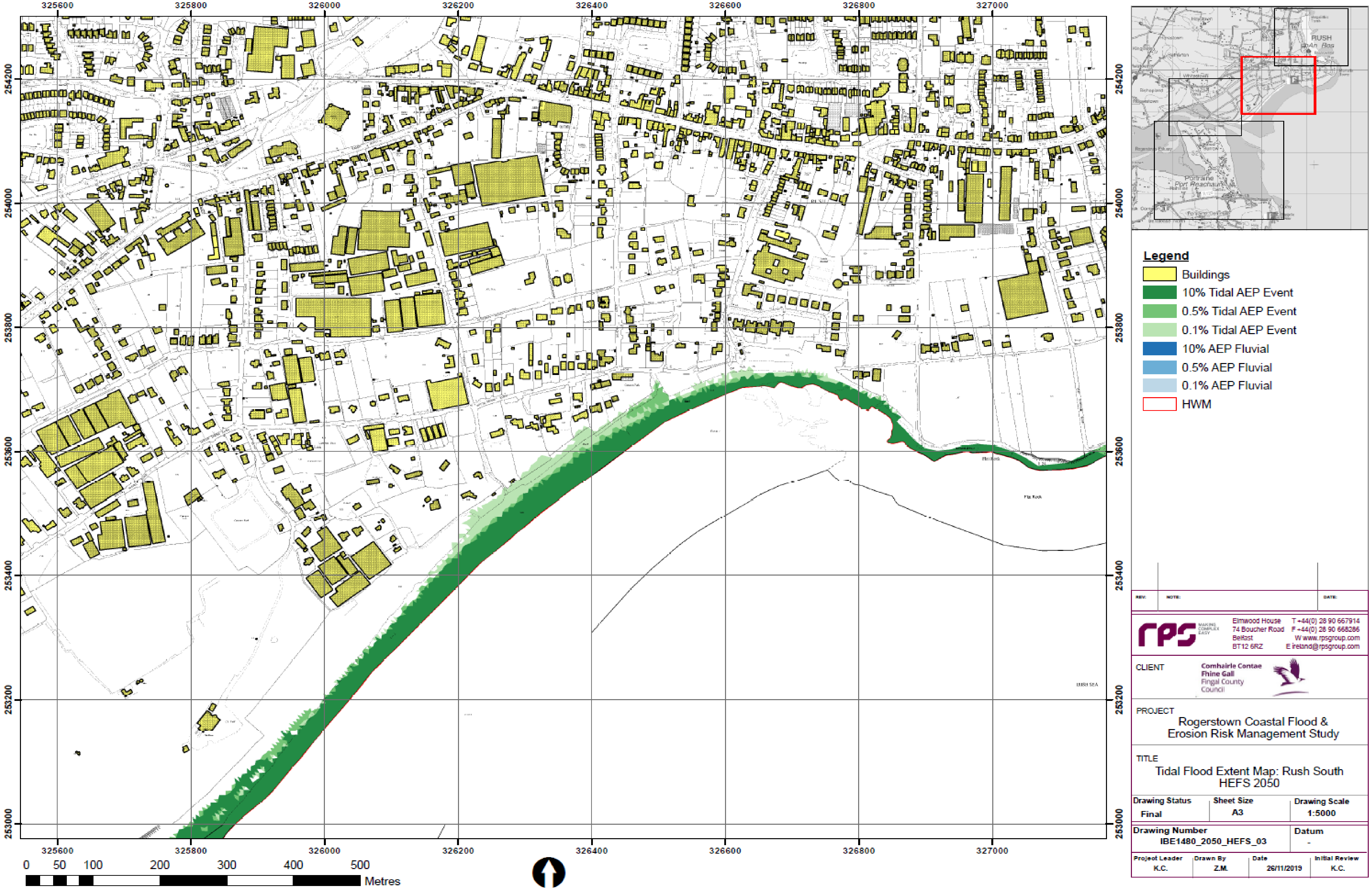

Figure 7.26: Tidal Flood Extent Map: Rush South (2) - 2050 High End Future Scenario (i.e. +0.33m sea level rise and *c.*28m of coastal retreat)

Figure 7.27: Tidal Flood Extent Map: Rush South (2) - 2050 High End Future Scenario (i.e. +0.33m sea level rise and *c*.4m of coastal retreat)

7.4.4 Flood Risk Assessment – 2100 based on MRFS & HEFS Conditions

To undertake a flood risk assessment for the 2100 epoch, the existing hydrodynamic model was further updated to account for the position of the shoreline at the Burrow, Rush South and Rush North based on the coastal change maps presented in Section 7.3.3 for both the Medium Range Future Scenario and High End Future Scenarios.

These updated models were subsequently used to assess flood risk for a range of return period events relevant to this study. These events included the corresponding sea level rise and wave overtopping values for each climate scenario. For reference, the extreme water levels and average overtopping rates used for this assessment are summarised in Table 7.8 below.

Table 7.8: Summary of flood risk assessment inputs for the 2100 water levels & coastal change

AEP event [%]	**MRFS**		**HEFS**	
	Water Level ODm [m]	**Overtopping at the Burrow** [L/s/m]	**Water Level** ODm [m]	**Overtopping at the Burrow** [L/s/m]
50	3.05	0.06	3.55	3.41
20	3.17	0.14	3.67	5.53
10	3.27	0.27	3.77	7.23
5	3.37	0.66	3.87	9.68
2	3.50	1.66	4.00	14.34
1	3.60	2.65	4.10	19.00
0.5	3.69	5.01	4.19	26.11

Figure 7.28 to Figure 7.31 illustrate the flood extents for the Rogerstown study area based on the 2100 MRFS climate scenario with corresponding erosion lines and extreme water levels with sea level rise. The figures illustrate the flood extents for the 1 in 10 year (10% AEP), 1 in 200 year (0.5% AEP) and 1 in 1000 year (0.1% AEP) return period storm events.

Similar plots have been presented in Figure 7.32 to Figure 7.35 for the 2100 HEFS climate scenario again with the erosion lines and extreme water levels with sea level rise that correspond to the 2100 HEFS epoch and climate scenario.

By comparing the figures for the 2100 MRFS and HEFS it will be seen that unlike the 2050 epoch, there are significant differences in the flood extents at both Rush South and the Burrow depending on the climate scenario. Even during a 10% AEP event during the 2100 epoch and HEFS climate scenario, most of the Burrow will be adversely impacted by flooding.

The number of properties which are expected to be at risk from flooding during the various return period events during the 2100 epoch under the MRFS and HEFS climate scenarios is summarised in Section 7.5.3 of this report.

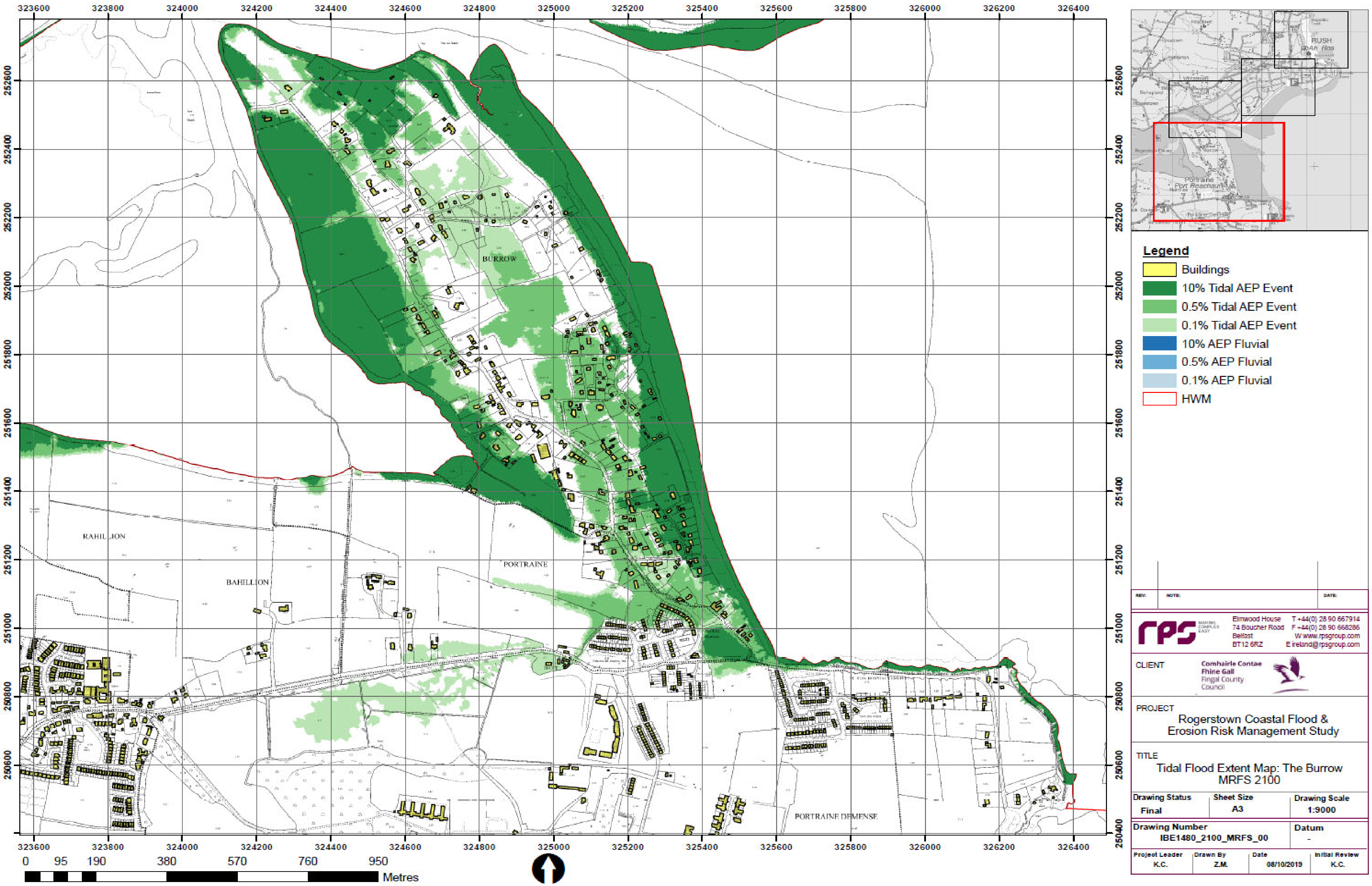

Figure 7.28: Tidal Flood Extent Map: The Burrow - 2100 Medium Range Future Scenario (i.e. +0.50m sea level rise and *c.*68m of coastal retreat)

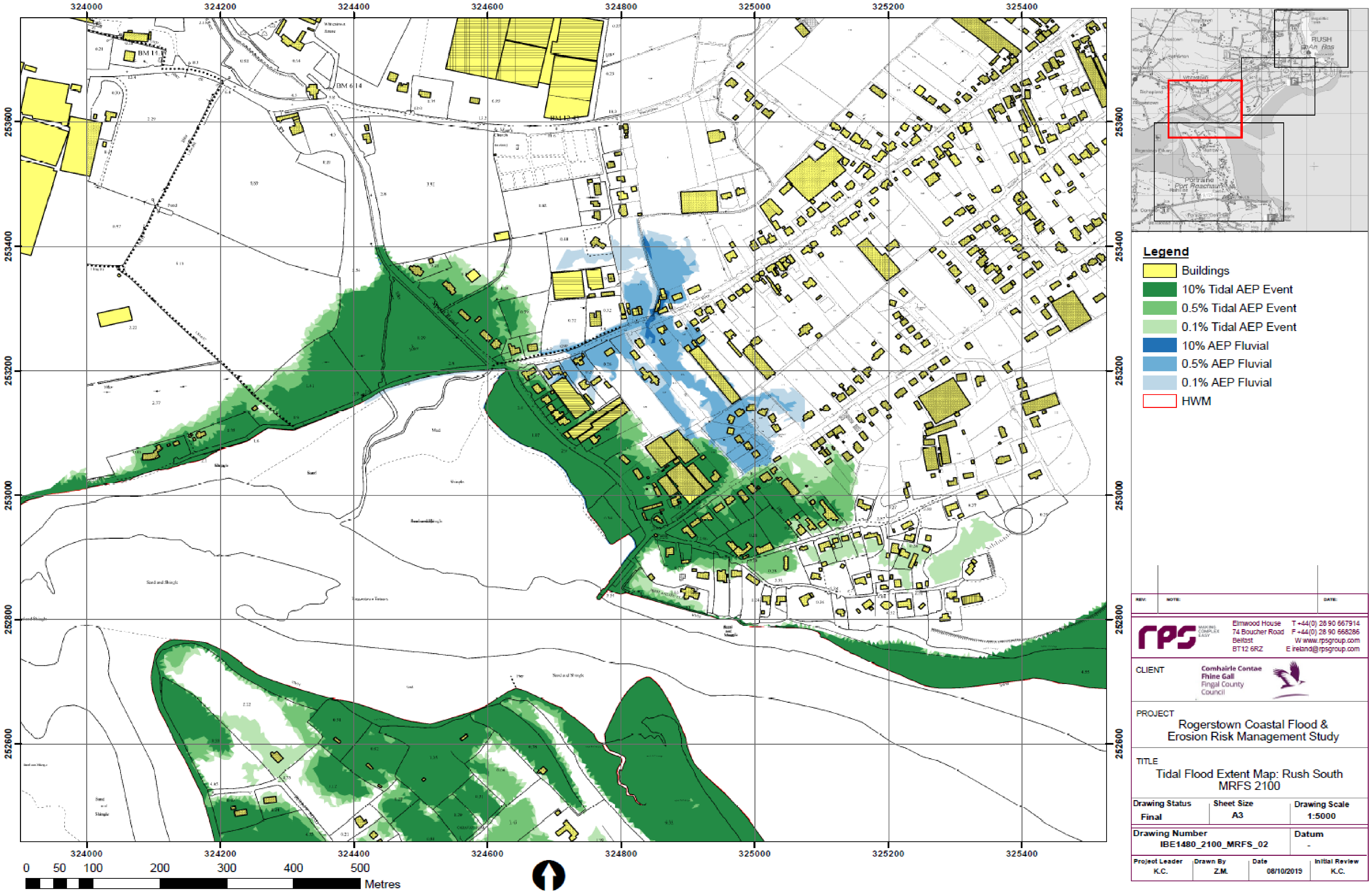

Figure 7.29: Tidal Flood Extent Map: Rush South (1) - 2100 Medium Range Future Scenario (i.e. +0.50m sea level rise and *c.*50m of coastal retreat at Rush Golf Club)

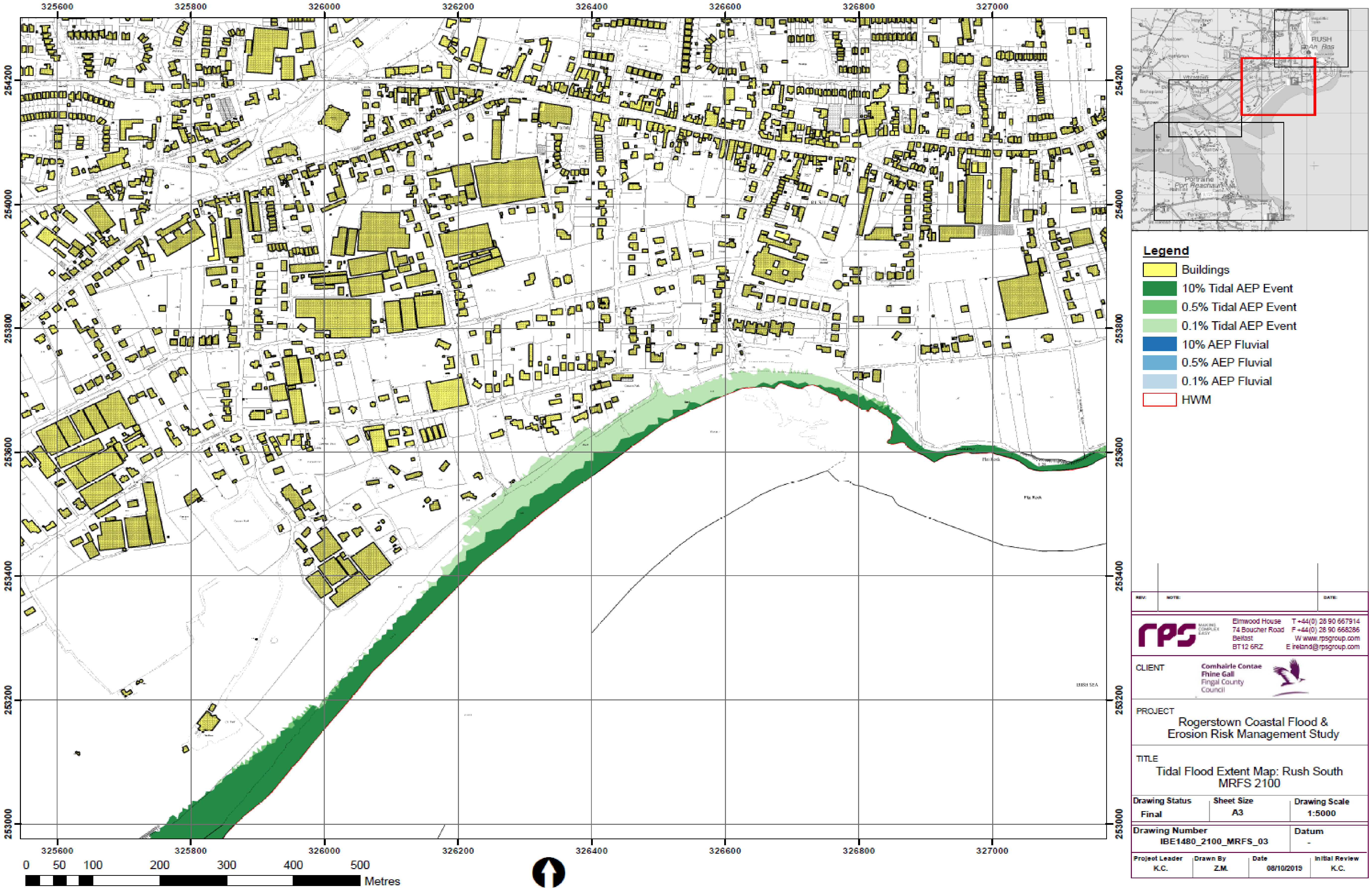

Figure 7.30: Tidal Flood Extent Map: Rush South (2) - Medium Range Future Scenario (i.e. +0.50m sea level rise and *c.*50m of coastal retreat)

Figure 7.31: Tidal Flood Extent Map: Rush North - 2100 Medium Range Future Scenario (i.e. +0.50m sea level rise and *c.*4m of coastal retreat)

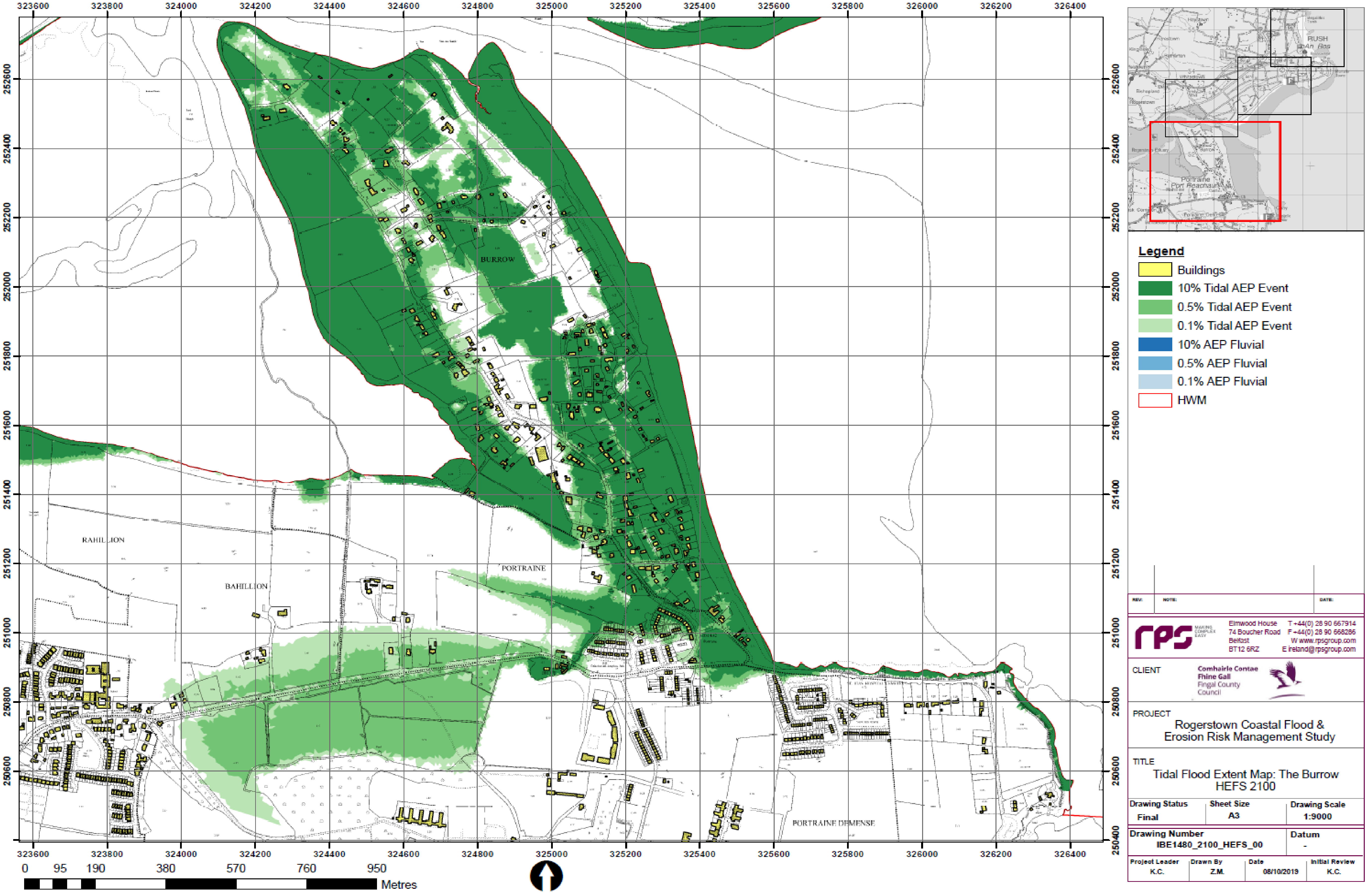

Figure 7.32: Tidal Flood Extent Map: The Burrow - 2100 High End Future Scenario (i.e. +1.00m sea level rise and *c*.88m of coastal retreat)

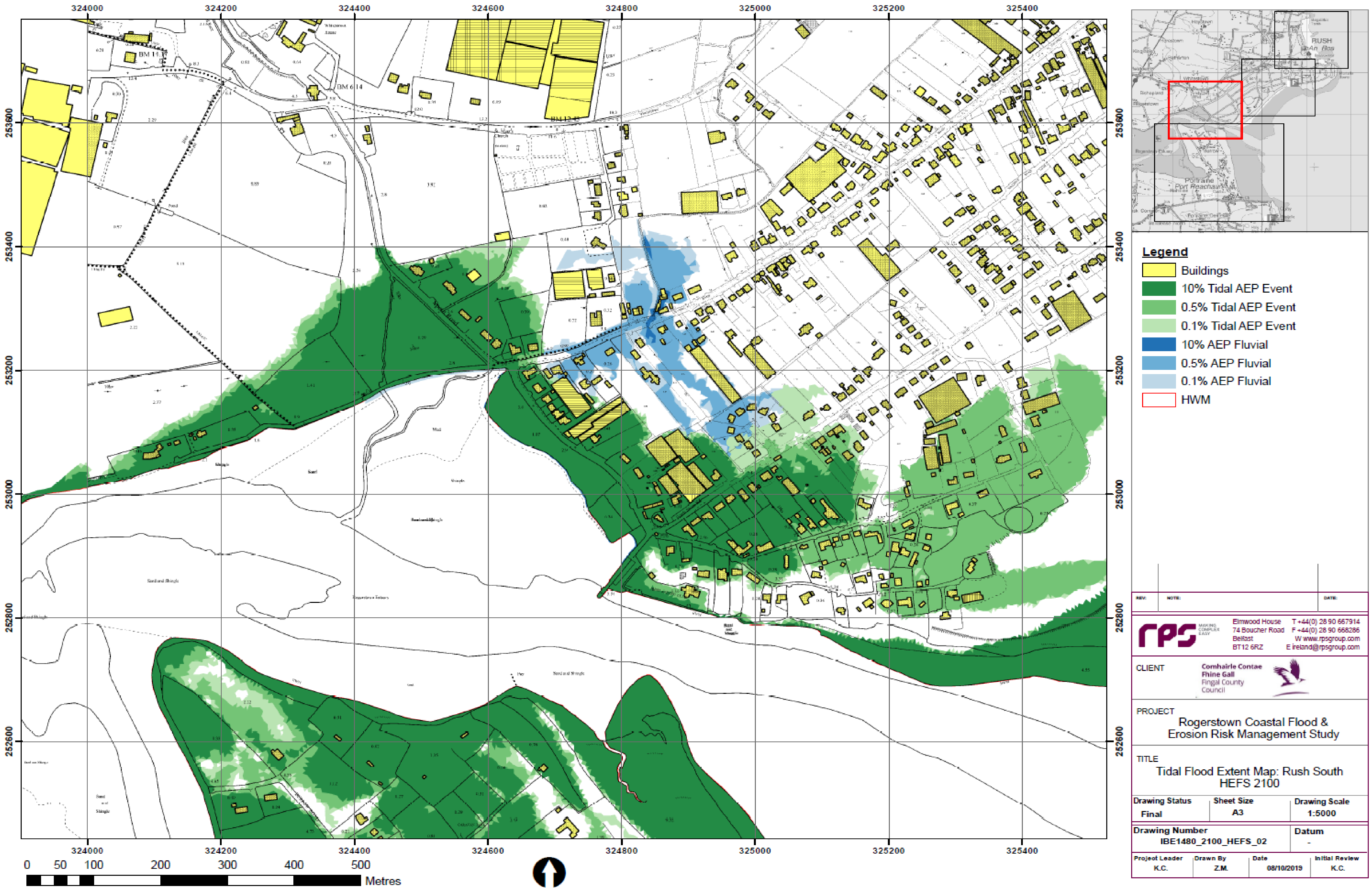

Figure 7.33: Tidal Flood Extent Map: Rush South (1) - 2100 High End Future Scenario (i.e. +1.0m sea level rise and *c.*64m of coastal retreat at Rush Golf Club)

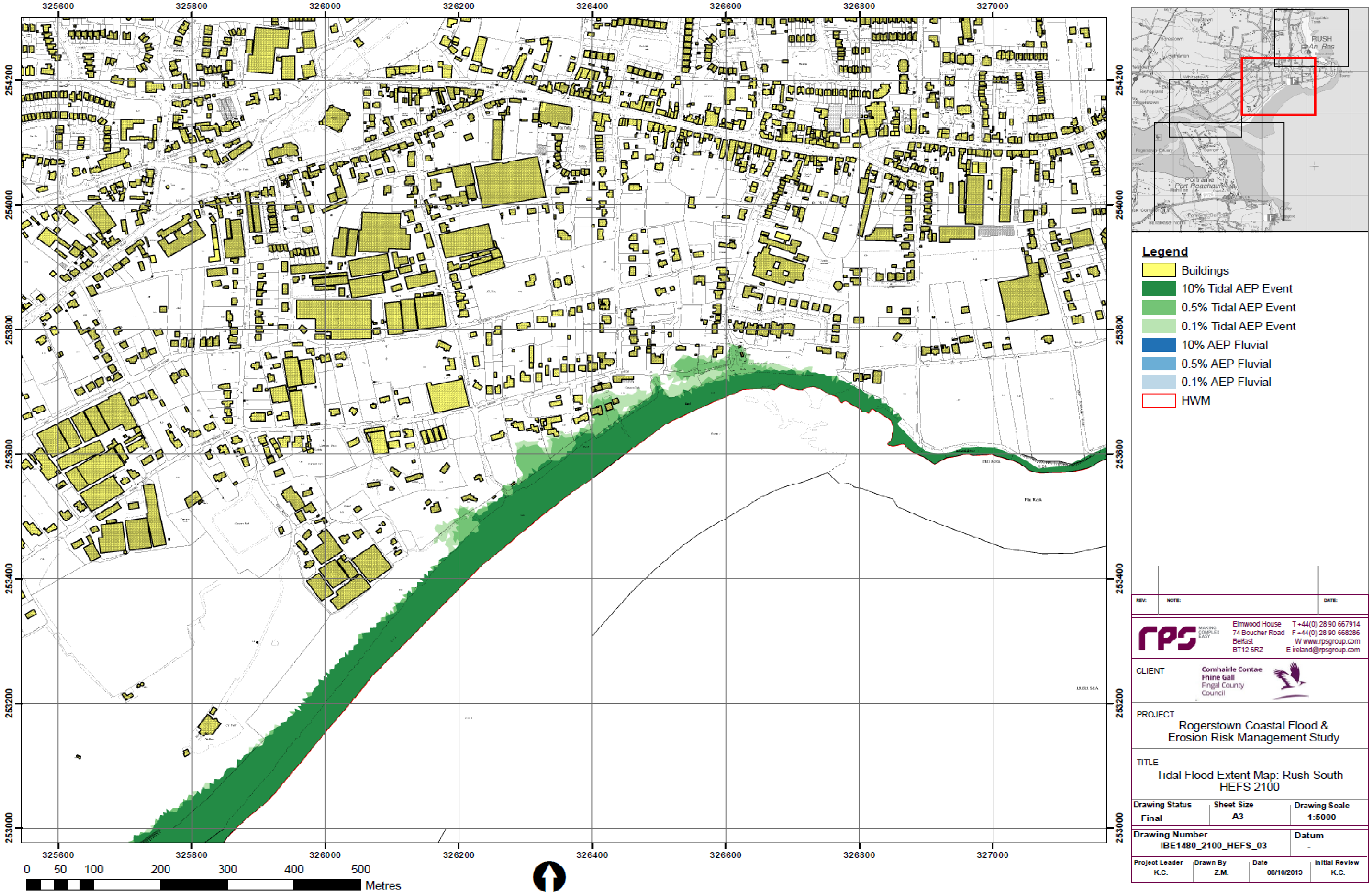

Figure 7.34: Tidal Flood Extent Map: Rush South (2) – High End Future Scenario (i.e. +1.0m sea level rise and *c.*64m of coastal retreat)

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Rogerstown Coastal Flood & Erosion Risk Management Study

TITLE
Tidal Flood Extent Map: Rush North
HEFS 2100

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Final	A3	1:5000

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IBE1480_2100_HEFS_04	-

Project Leader	Drawn By	Date	Initial Review
K.C.	Z.M.	08/10/2019	K.C.

Figure 7.35: Tidal Flood Extent Map: Rush North - 2100 High End Future Scenario (i.e. +1.0m sea level rise and *c.*9m of coastal retreat)

7.5 Assets at risk of Flooding

Based on the flood risk assessments presented in the previous sections of this report, RPS appraised the number of buildings which could potentially be at risk of coastal flooding. It should be noted that it was not possible to categorise building types as a property survey was not made available for this study. RPS have therefore simply referred to the number of buildings that could be affected by coastal flooding.

It is important to note that this appraisal assesses the number of buildings at risk from coastal flooding only, i.e. buildings affected by fluvial flooding have not been included.

The number of buildings potentially at risk of flooding was assessed for the three epochs and climate scenarios in Sections 7.5.1 to 7.5.3 of this report. This included the full suite of return period flood events for each climate scenario.

7.5.1 Present Day Flood Risk

The total number of buildings found to be at risk across the study area based on present day conditions is summarised in Table 7.9 and illustrated in Figure 7.36.

Based on present day conditions, up to 47 and 48 buildings were found to be at risk from coastal flooding at Rush south and the Burrow respectively. A total of 96 buildings were found to be at risk under a 1 in 1000 year return period event across the entire study area.

The main mechanism of flooding at the Burrow and Rush south was a combination of tide and surge activity (i.e. flood mechanism 1).

Table 7.9: Total number of buildings at risk from coastal flooding based on present day conditions

Scenario	**AEP event [%]**	**Buildings at Risk**			**Total Buildings**
		The Burrow	**Rush South**	**Rush North**	
Existing Extreme Water Level & no erosion	50	5	2	0	7
	20	9	4	0	13
	10	10	8	0	18
	5	14	11	0	25
	2	16	11	0	27
	1	19	34	0	53
	0.5	23	39	0	62
	0.1	48	47	1	96

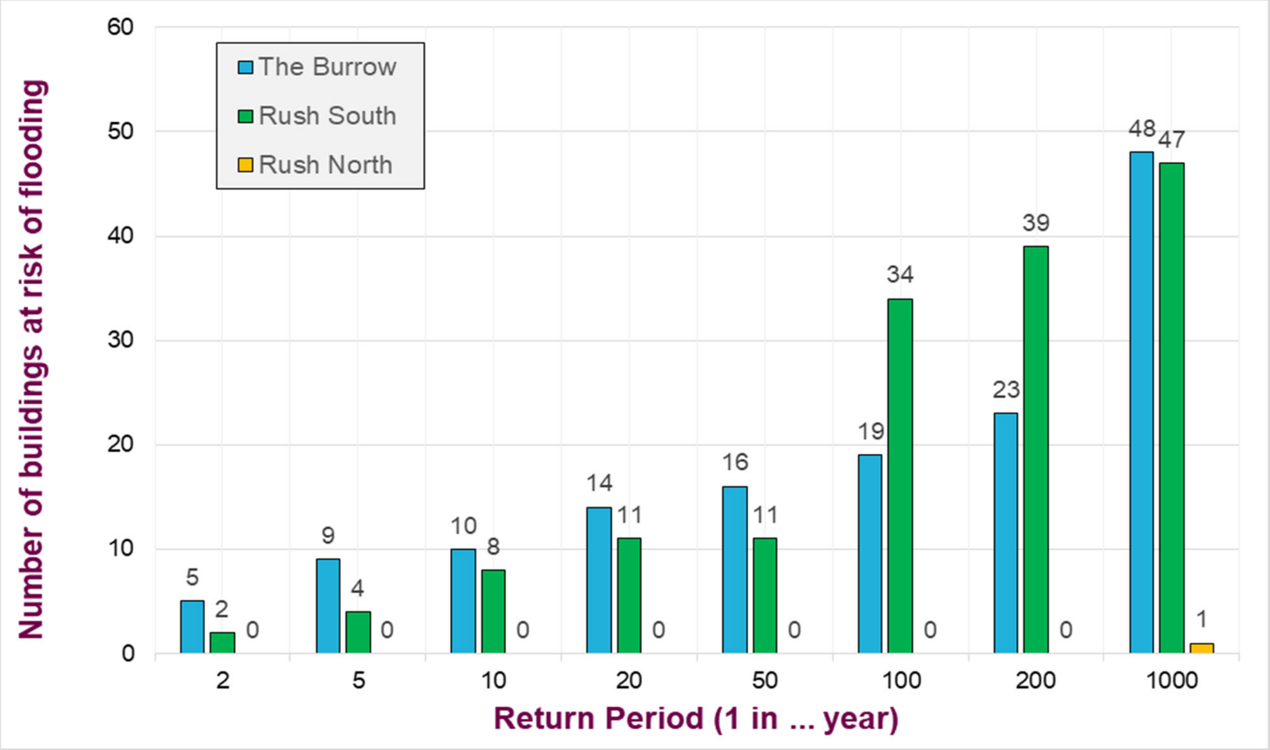

Figure 7.36: Number of buildings at risk of coastal flooding across the study areas during various return period flood events based on existing climate conditions and no erosion

7.5.2 Flood Risk by 2050

The total number of buildings found to be at risk of flooding based on the 2050 MRFS scenario is summarised in Table 7.10 and illustrated in Figure 7.37. Similar information for the 2050 HEFS is presented in Table 7.11 and Figure 7.38.

It will be seen from this information that as sea levels begin to rise due to climate change, the number of properties affected by flooding increases significantly. This increase is most prevalent along the Burrow where increased erosion rates are expected to create new flood routes into the hinterland.

The number of properties affected by flooding could increase from 48 to between 208 and 248 at the Burrow for a 1 in 1000 year event depending on future climate change. At Rush south, the number of properties affected by flooding is expected to almost double from 47 to *c.*70.

The main mechanism of flooding at the Burrow and Rush South remained a combination of tide and surge activity (i.e. flood mechanism 1).

Table 7.10: Total number of buildings at risk from coastal flooding by 2050 based on MRFS water levels and 2050 MRFS erosion extents

Scenario	**AEP event [%]**	**Buildings at Risk**			**Total Buildings**
		The Burrow	**Rush South**	**Rush North**	
Existing Extreme Water Level & 2100 erosion	50	21	8	0	29
	20	27	39	0	66
	10	29	41	1	71
	5	41	45	1	87
	2	72	50	1	123
	1	112	50	1	163
	0.5	148	54	1	203
	0.1	208	71	2	281

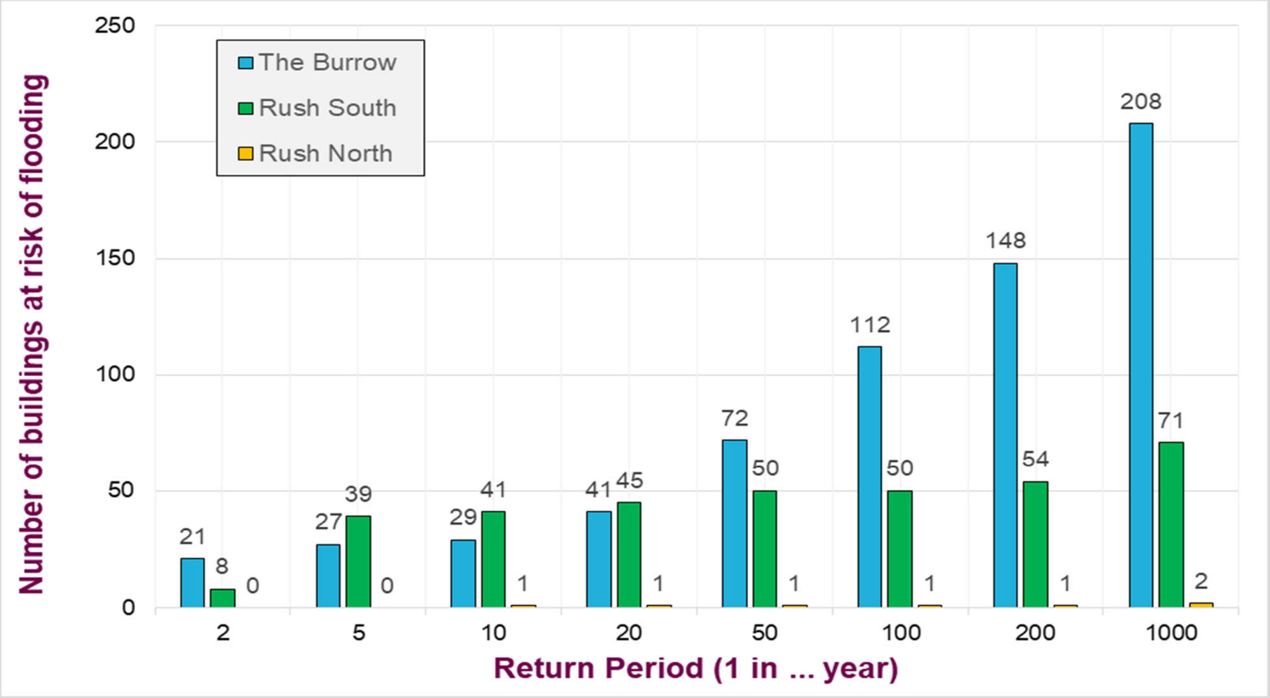

Figure 7.37: Total number of buildings at risk from coastal flooding by 2050 based on MRFS water levels and 2050 MRFS erosion extents

Table 7.11: Total number of buildings at risk from coastal flooding by 2050 based on HEFS water levels and 2050 HEFS erosion extents

Scenario	AEP event [%]	Buildings at Risk The Burrow	 Rush South	 Rush North	Total Buildings
Existing Extreme Water Level & 2100 erosion	50	30	28	0	58
	20	35	38	0	73
	10	39	41	1	81
	5	58	44	1	103
	2	103	50	1	154
	1	145	50	1	196
	0.5	163	53	1	217
	0.1	215	71	2	288

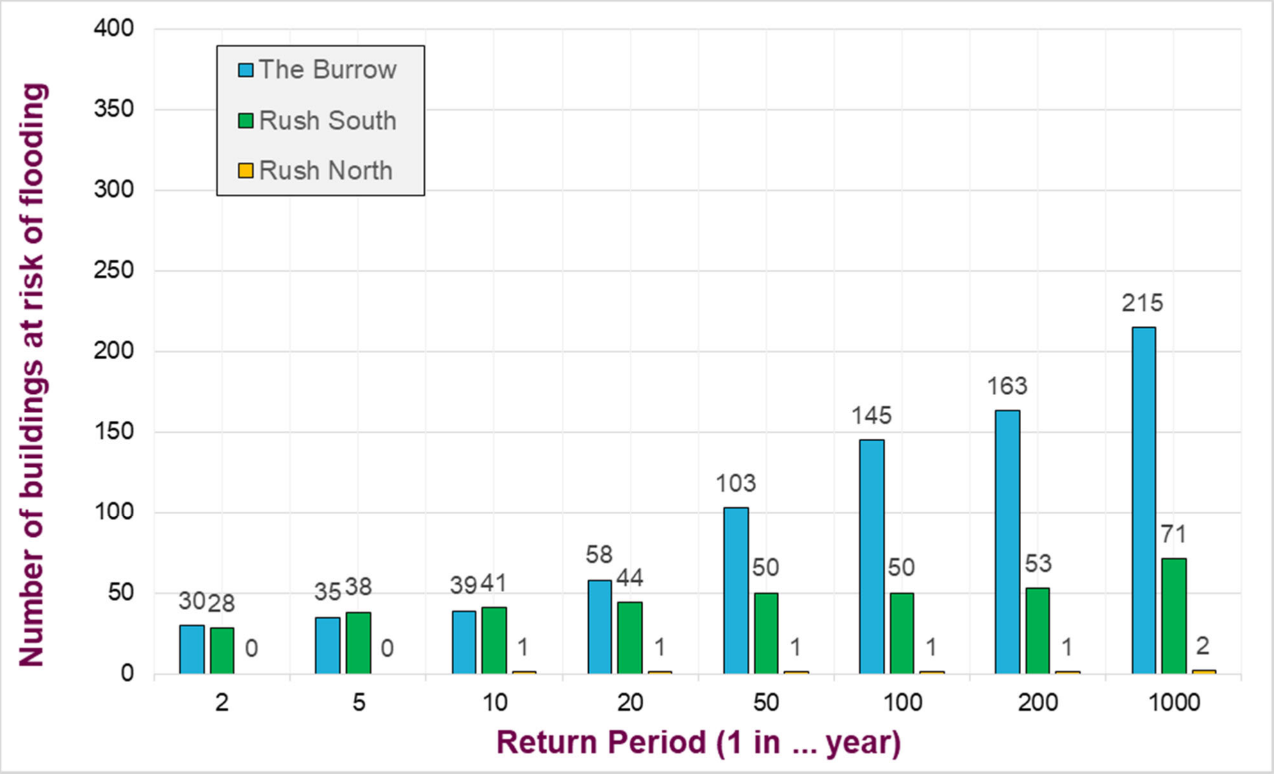

Figure 7.38: Total number of buildings at risk from coastal flooding by 2050 based on HEFS water levels and 2050 HEFS erosion extents

7.5.3 Flood Risk by 2100

The total number of buildings found to be at risk across the study area based on the 2100 erosion extent and MRFS scenarios is summarised in Table 7.10 and illustrated in Figure 7.39. Analogous information for the 2100 HEFS events is presented in Table 7.11 and Figure 7.37.

Relative to present day conditions, the number of properties affected by coastal flooding could increase by a factor of *c.*6 and *c.*2.5 across the Burrow and Rush South respectively, depending on the rate and magnitude of future sea level rise and coastal erosion.

The main mechanism of flooding at the Burrow and Rush South remained a combination of tide and surge activity (i.e. flood mechanism 1).

Table 7.12: Total number of buildings at risk from coastal flooding by 2100 based on MRFS water levels and 2100 MRFS erosion extents

Scenario	AEP event [%]	Buildings at Risk			Total Buildings
		The Burrow	Rush South	Rush North	
Existing Extreme Water Level & 2100 erosion	50	41	29	2	72
	20	49	39	2	90
	10	54	41	2	97
	5	73	45	2	120
	2	115	50	3	168
	1	157	50	4	211
	0.5	178	54	4	236
	0.1	248	72	5	325

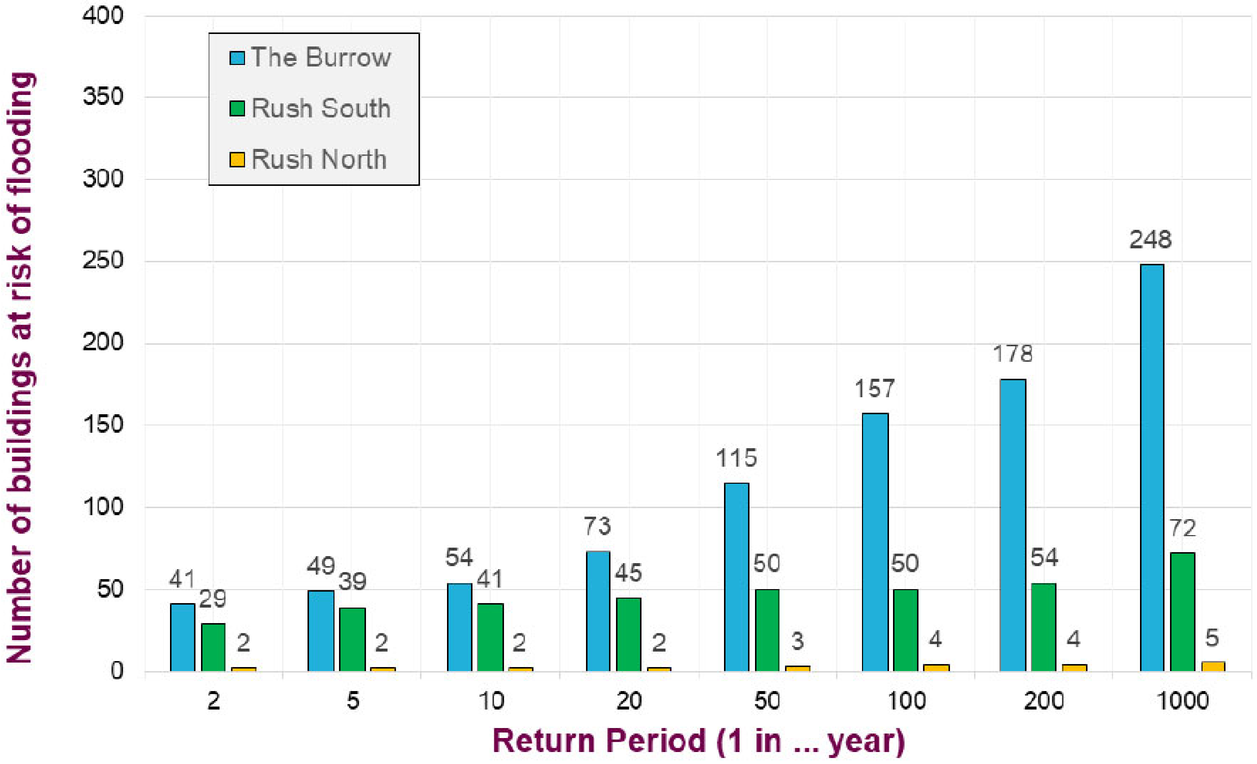

Figure 7.39: Total number of buildings at risk from coastal flooding by 2100 based on MRFS water levels and 2100 MRFS erosion extents

Table 7.13: Total number of buildings at risk from coastal flooding by 2100 based on HEFS water levels and 2100 HEFS erosion extents

Scenario	AEP event [%]	Buildings at Risk			Total Buildings
		The Burrow	Rush South	Rush North	
Existing Extreme Water Level & 2100 erosion	50	133	50	5	188
	20	167	52	5	224
	10	193	56	5	254
	5	206	62	6	274
	2	232	86	10	328
	1	252	103	10	365
	0.5	267	111	11	389
	0.1	286	123	13	422

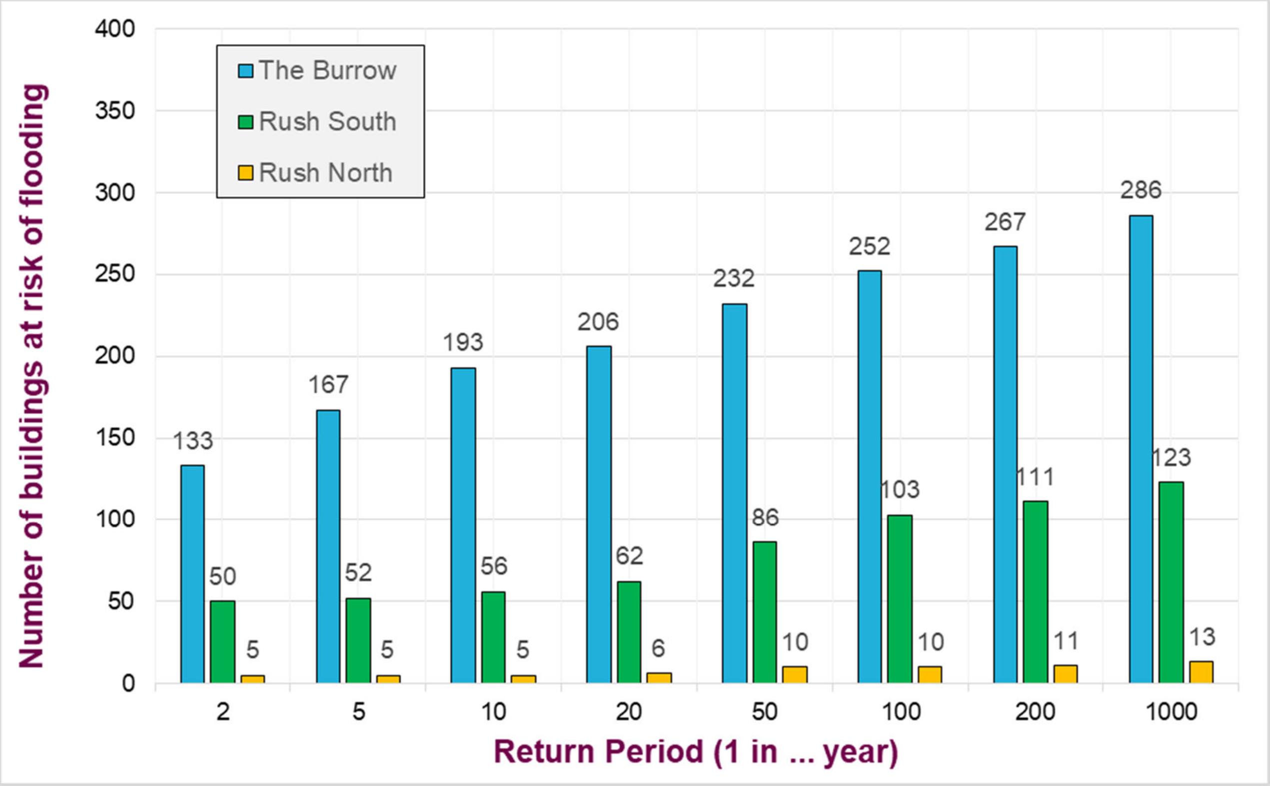

Figure 7.40: Total number of buildings at risk from coastal flooding by 2100 based on HEFS water levels and 2100 HEFS erosion extents

7.5.4 Summary of Properties at Risk of Flooding

RPS assessed the flood risk across the Rogerstown estuary area for a range of return periods, epochs and climate change scenarios using the hydrodynamic model described earlier in this report. Where appropriate, these flood models also accounted for wave overtopping.

A summary of the total number of buildings that could be at risk of coastal flooding based on the various scenarios assessed is illustrated Figure 7.41 below.

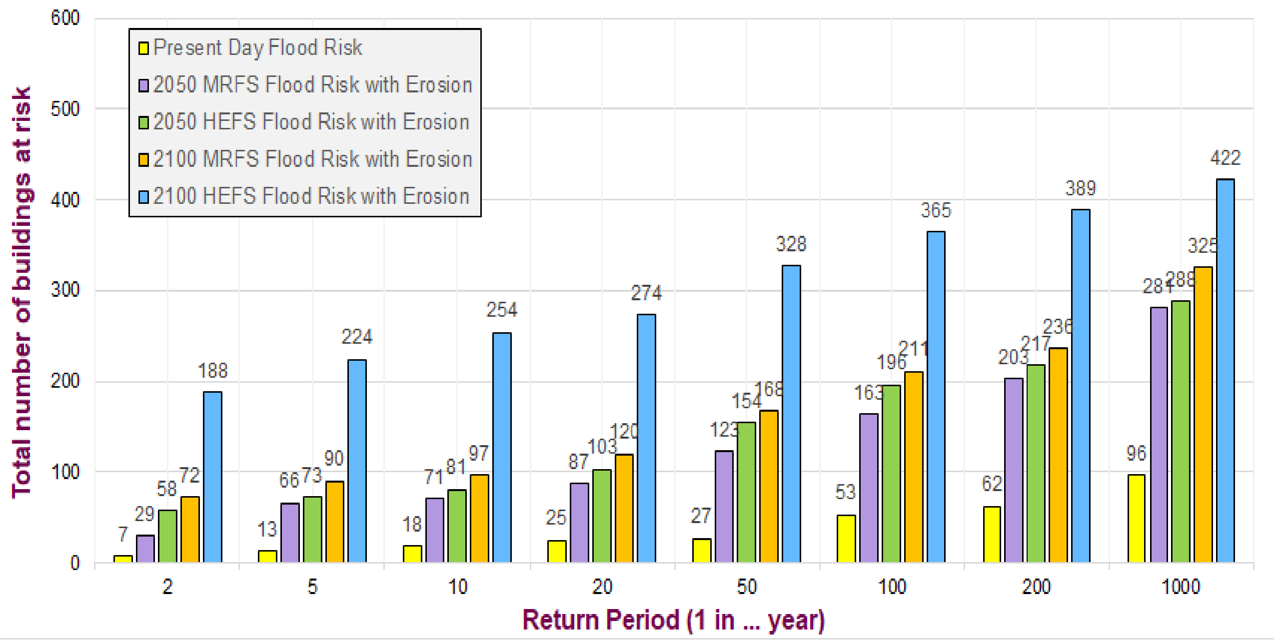

Figure 7.41: Total number of buildings at risk of coastal flooding across the entire study area based on various climate change and erosion extent scenarios

It is evident that there is a significant flood risk along at the Burrow and Rush south. Depending on future climate change and magnitude of future coastal erosion, the total number of buildings at risk of flooding across the entire study during a 1 in 50 year return period event could range between 27 and 328 buildings.

Depending on the future climate change and coastal erosion scenario, the number of buildings at risk of flooding under a 1 in 200 year return period event could increase by more than a factor of 6 from 62 to 389.

When compared to the number of buildings affected by coastal erosion it becomes clear that coastal flooding generally poses greater risk to the Rogerstown Estuary area over the long term.

However, it is important to note that coastal erosion of the existing dune system along the Burrow significantly enhances the coastal flood risk by creating additional flood routes.

Given these risks, it is imperative that an effective and sustainable CFERM plan is quickly developed and implemented at the Burrow and Rush south. The technical, economic and environmental assessment of a complete range of potential coastal management strategies is the focus an Optioneering report which accompanies this CFERM Assessment report.

8 CONCLUSION

In 2018 RPS were commissioned by Fingal County Council to assess the feasibility of a coastal defence scheme to reduce flood risk within the Rogerstown Outer Estuary area. Following Storm Emma and a succession of other arduous storm events, the scope of the study was expanded to ensure that the proposed scheme also mitigated the risk of future coastal erosion.

The objectives for this study were developed by the Office of Public Works (OPW) and specified in Schedule A.1 of the CFERM guidance. In context of these objectives, the purpose of this CFERM Assessment was report was to:

1. Review and assess existing information.
2. Identify information gaps & arrange for necessary additional field surveys.
3. Address surveys of existing coastal protection structures and other surveys.
4. Undertake an assessment of existing coastal processes and coastline evolution.
5. Prepare detailed current and future coastal change maps.
6. Prepare a detailed risk assessment.

The findings of this report, which are summarised in the following Sections, were subsequently used to inform an accompanying Optioneering Report that identified and assessed the technical, environmental and economic viability of potential Coastal Flood and Erosion Management (CFERM) options.

8.1 Summary of Historical Review

Using geo-referenced shoreline datasets, RPS assessed the rate of coastal change across the study area between 1973 and 2019. In summary, this assessment found that:

The Burrow

- Coastal change has historically been greatest along the Burrow.
- Between 1973 and 2000, the southern section of the Burrow advanced seaward by *c.*20m.
- Following Storm Emma and several other storms in 2018, sections of the Burrow retreated by more than 20m.
- Since the installation of the interim coastal protection works, i.e. the concrete Seabee units, there has been little movement of the shoreline immediately behind the units. However, erosion has continued to the north of these protection works.

Rush South

- The beach along Rush south has generally been accreting since 1973.
- Northern sections of this beach have in the past been protected by rock armour in this area. Much of this armour is now buried beneath sand which is evidence of sediment accretion in this area.
- Based on historical data, the beach at Rush south was found to be relatively stable with no significant erosion pressures.

Rush North

- The beach at Rush north is well protected due to its enclosed nature and has experienced modest levels of accretion (i.e. up to *c.*20. between 1973 and 2019).
- Some regions of this beach are protected by rock armour which was constructed to protect the carpark and the gas pipeline that comes ashore at this point.
- Based on historical data, the beach at Rush north was found to be stable and even accreting across many sections.

8.2 Summary of Coastal Processes Assessment

A comprehensive coastal processes modelling programme found the beach at Rush north to be dynamically stable under almost all conditions. At Rush south, waves from the north east and south east were found to maintain the sediment budget, with a small volume of material coming from along the Burrow.

Conversely, the Burrow was found to depend almost exclusively on sediment supply from the south east as the strong littoral currents coming from the Rogerstown estuary prevent the effective transfer of sediment between the two beaches.

The sediment transport regime along the Burrow is no longer in a state of dynamic due to a deficit in the sediment supply. As the supply of sediment to the beach is no longer proportional to the volume of sand leaving the beach, there are now increased erosion pressures along this coastline.

This shift has been attributed to the recent increase in the frequency and magnitude of storm events which have lowered beach levels and increased wave energy. Without sufficient long-term high-resolution data, it is not possible to determine if these events are unique or the beginning of a new long-term trend.

8.3 Summary of Coastal Erosion Assessment

The coastal erosion assessment was undertaken using industry standard software developed by the US Geological Society. This software utilises the principles of historical trend analysis and was used in conjunction with historical shoreline data from between 1973 and 2019. The assessment also accounted for the impact of future climate change.

In summary, this assessment found that

- At the Burrow, undefended regions of this shoreline could retreat up to *c.* 88m ±30m by 2100 and threaten up to 49 buildings depending on future climate change.
- At Rush south, regions of the beach could retreat by up to 64m ±30m whilst other regions of the beach could advance. No buildings were expected to be at risk from erosion at Rush south by 2100.
- At Rush north, the shoreline could continue to accrete, however depending on future climate change the shoreline in this region could also retreat by up to 9m which could threaten up to 9 building by 2100.

RPS are acutely aware that recent events indicate a potential “turning point” in the coastal processes along the Burrow and that the erosion rates calculated as part of the Historical Trend Analyses may not reflect recent observations. However, without sufficient long-term high-resolution data it is not possible to determine if these events are unique outliers or the beginning of a new long-term trend.

In line with best practice and guidance from relevant statutory authorities, RPS have estimated erosion rates using all available shoreline data in the Historical Trend Analyses. Despite this, a Sensitivity Analyses of this method found that average erosion rates could be up to x3 greater if historical data prior to 2013 was excluded.

8.4 Summary of Coastal Flood Risk Assessment

RPS assessed the flood risk across the Rogerstown estuary area for a range of return period events, epochs and climate change scenarios using industry standard techniques. Where appropriate, these flood models also accounted for wave overtopping.

In summary this assessment found that:

- There is a significant flood risk along at the Burrow and Rush South.
- Under present day conditions up to 23 and 39 buildings could be flooded at the Burrow and Rush south respectively during a 1 in 200 year return period flood event.
- Looking ahead, flood risk at the Burrow and Rush south will be sensitive to future sea rises caused by climate change. Even relatively modest increases in sea levels were found to significantly enhance flood risk.
- Depending on the future climate change and coastal erosion scenario, the number of properties at risk of flooding under a 1 in 200 year return period event could increase by more than a factor of 6 from 62 to 389 buildings.
- No significant flood risk was identified at Rush north.

This flood assessment used projected erosion extents and sea level rises to estimate flood risk across the study area. It is important to recognise that the actual coastal flood risk will be subject to future erosion and climate change and may therefore differ to the results presented in this report.

8.5 Concluding Remarks

In agreement with anecdotal evidence reported by statutory authorities and groups such as the Fingal Coastal Liaison Group, this CFERM Assessment concludes that the most pressing and immediate issue affecting the Rogerstown Estuary area is the substantial risk that coastal erosion poses to the local community.

Depending on future climate change, up to c.50 buildings were found to be at risk from coastal erosion by 2100 with many of these building at risk within the next few decades.

Furthermore, RPS are acutely aware that recent events indicate a potential “turning point” in the coastal processes along the Burrow and that rates of coastal erosion could be significantly greater than those reported in this study. However, without sufficient long-term high-resolution data it is not possible to determine if recent events are unique outliers or the beginning of a new long-term trend.

In the long term, when compared to the risk of coastal erosion, it is coastal flooding that generally poses the greater risk to the Rogerstown Estuary area. However, it is important to note that erosion of the existing dune system along the Burrow significantly enhances the coastal flood risk by creating additional flood routes.

Future climate change will undoubtedly pose the greatest challenge to the Rogerstown Outer Estuary area over the coming decades. It is highly likely that an increase in sea levels and changes in storm conditions will exacerbate existing erosion pressures along the Burrow and result in more frequent flooding of the Burrow and Rush south.

Given these risks, it is imperative that an effective and sustainable management plan is implemented at the Burrow and Rush South without delay. The technical, economic and environmental assessment of a complete range of potential coastal management strategies is the focus a CFERM Optioneering report which accompanies this CFERM Assessment report.

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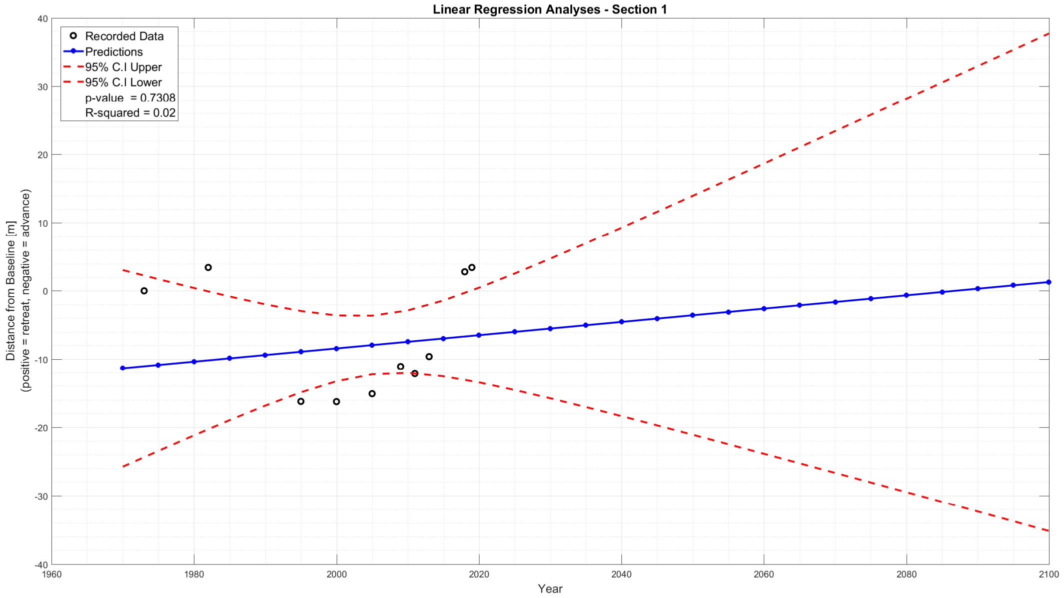
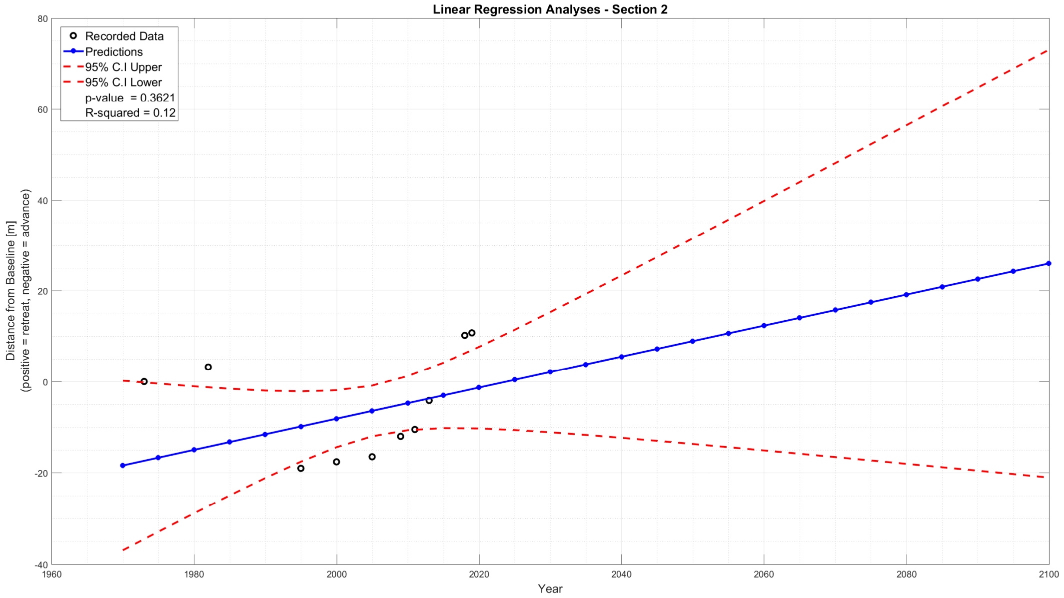
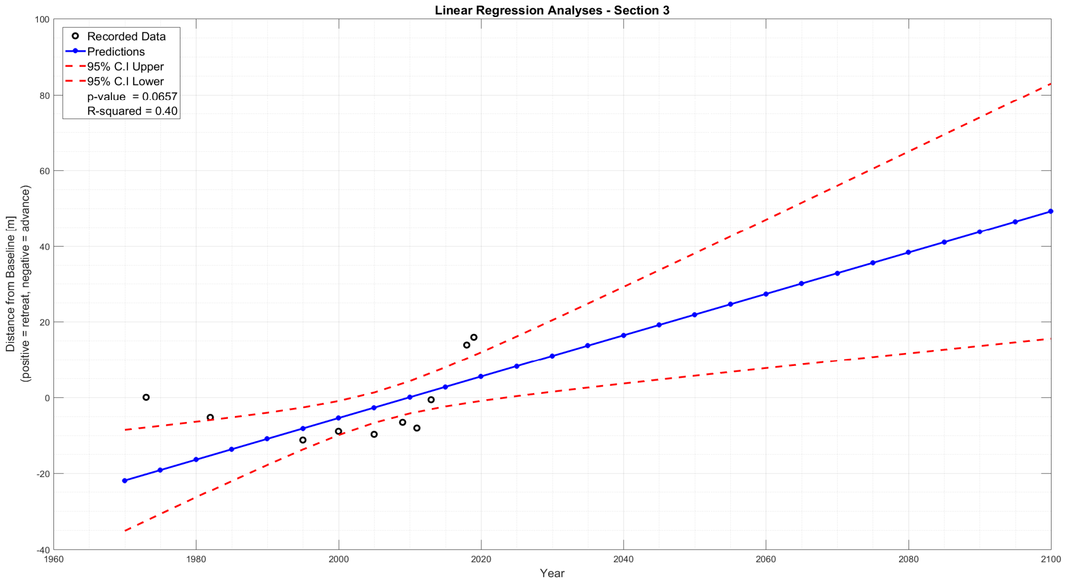
Appendix A

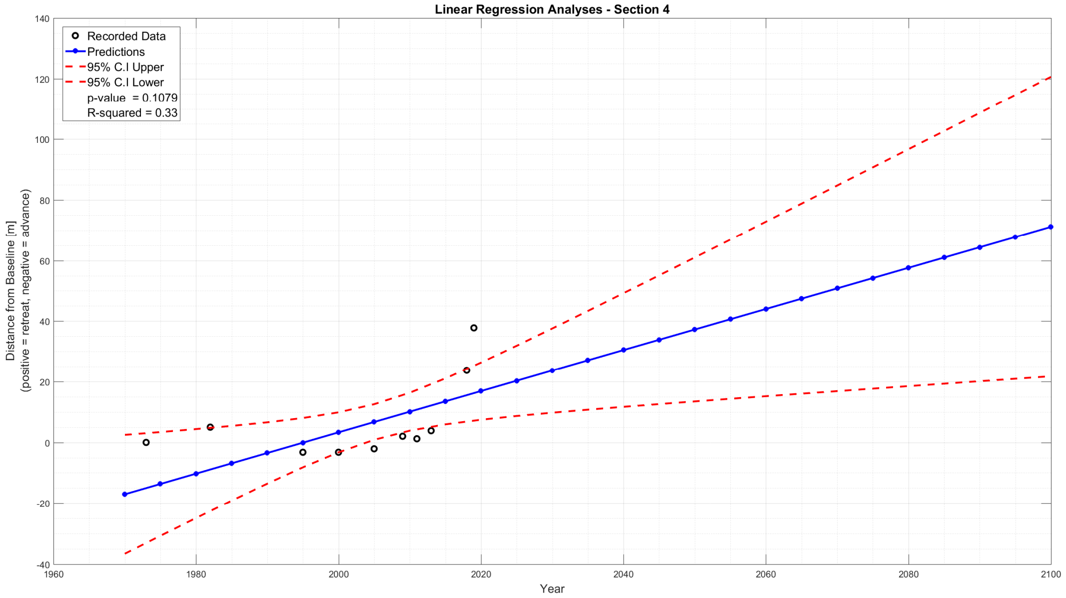
Coastal Change Assessment – Linear Coastal Change Regression Plots

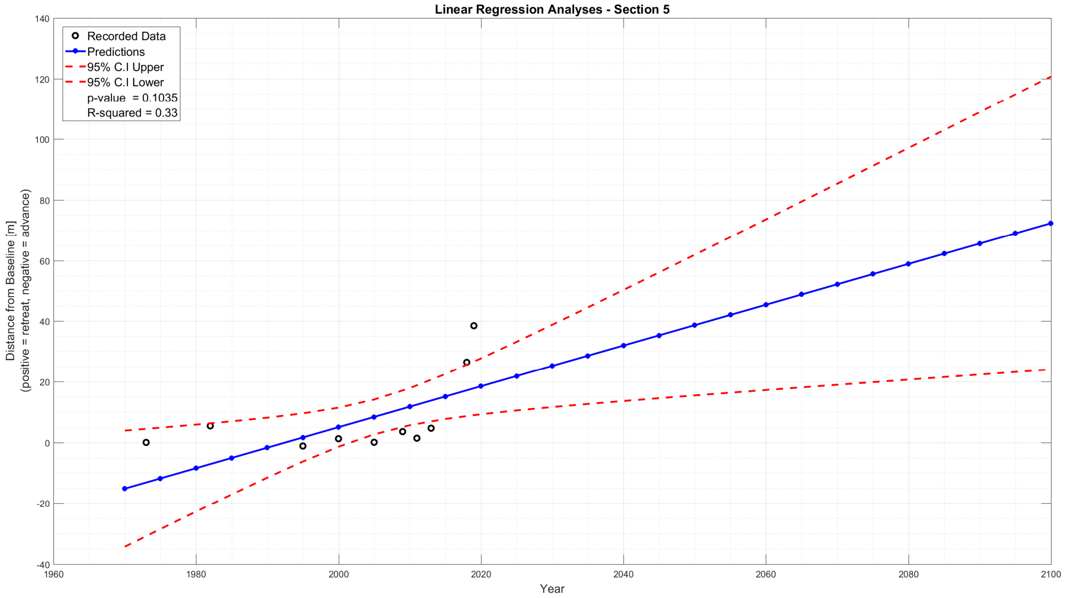
Study site: The Burrow

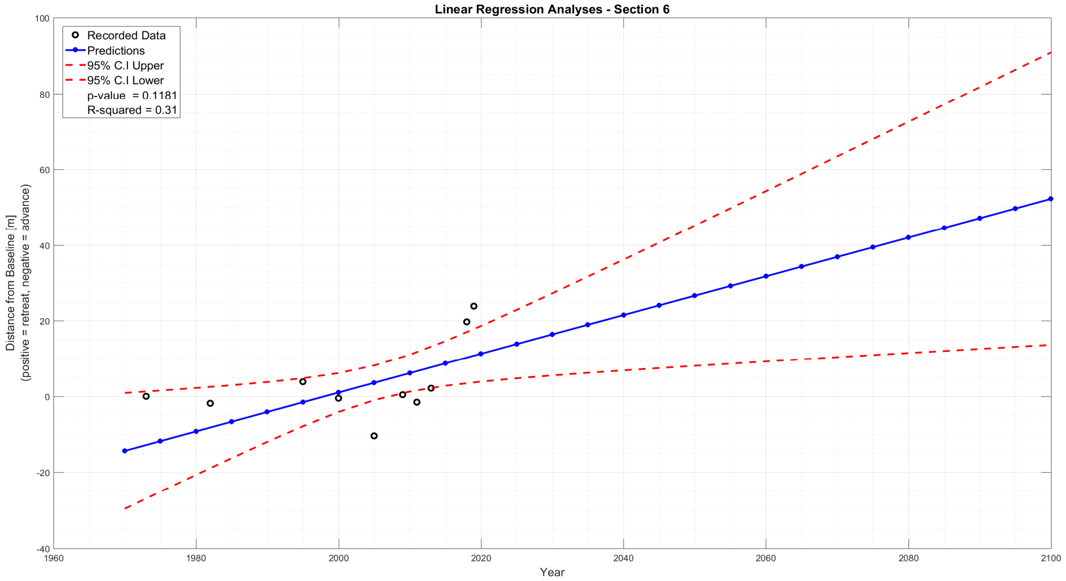

Linear Regression Analyses - Section 1
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.7308
R-squared = 0.02
Distance from Baseline [m]
(positive = retreat, negative = advance)
40
30
20
10
0
-10
-20
-30
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year

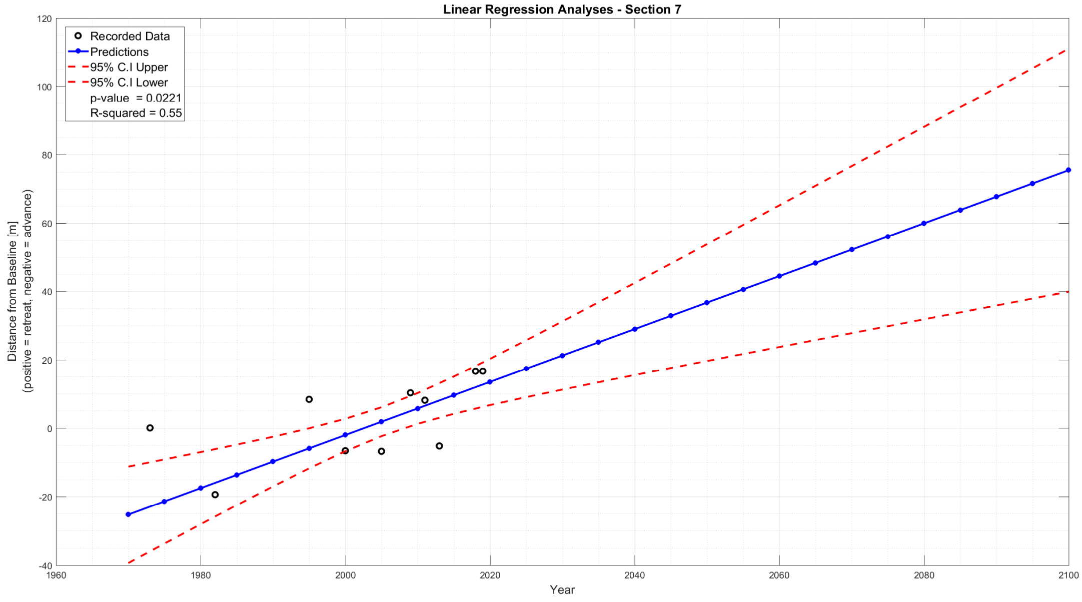

Linear Regression Analyses - Section 2
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.3621
R-squared = 0.12
Distance from Baseline [m]
(positive = retreat, negative = advance)
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year

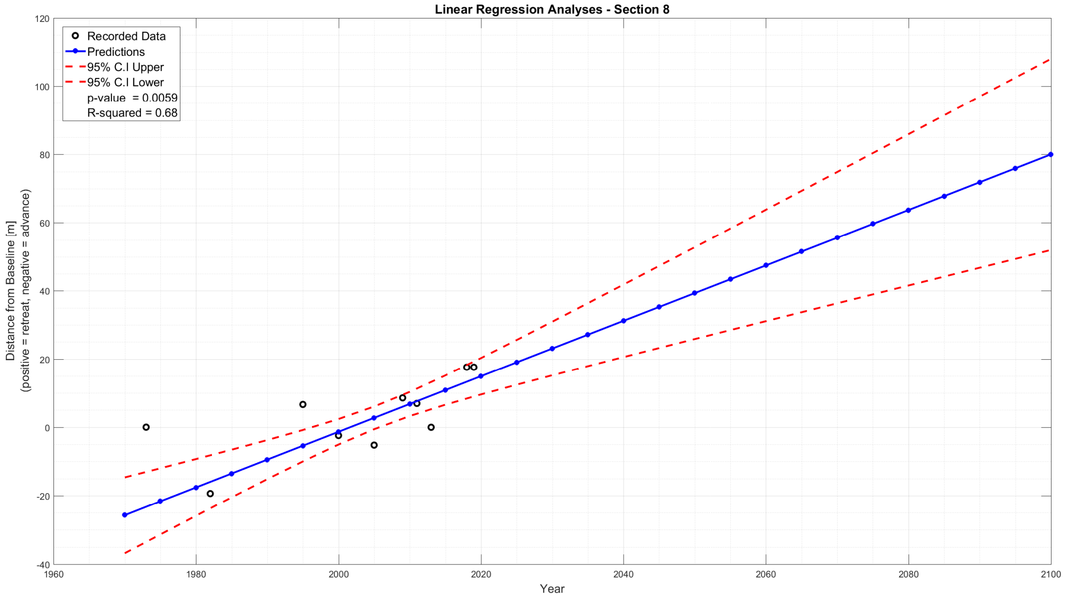

Linear Regression Analyses - Section 3
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0657
R-squared = 0.40
Distance from Baseline [m]
(positive = retreat, negative = advance)
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year

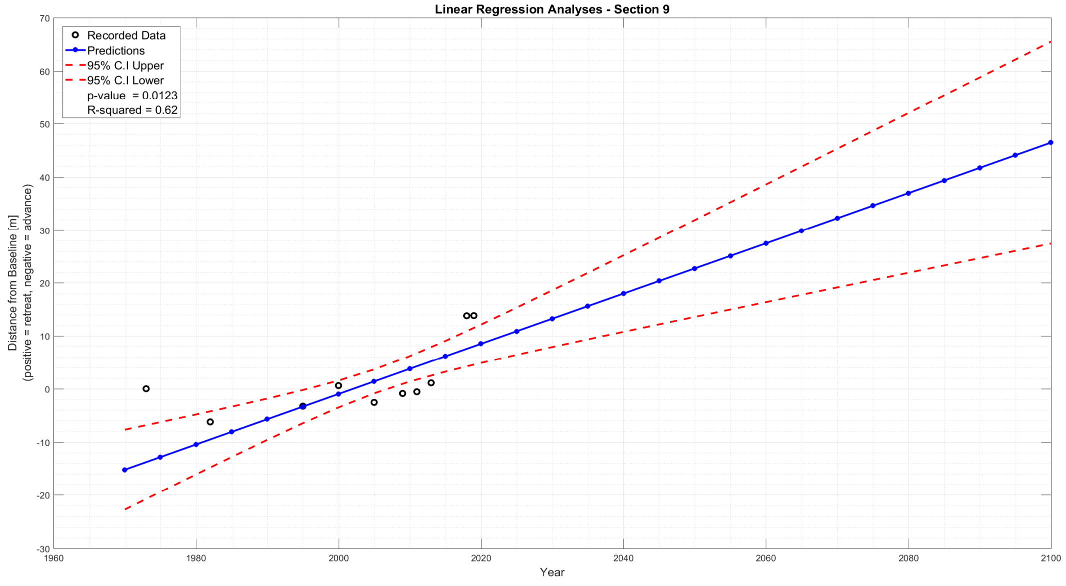

Linear Regression Analyses - Section 4
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.1079
R-squared = 0.33
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
140
120
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100

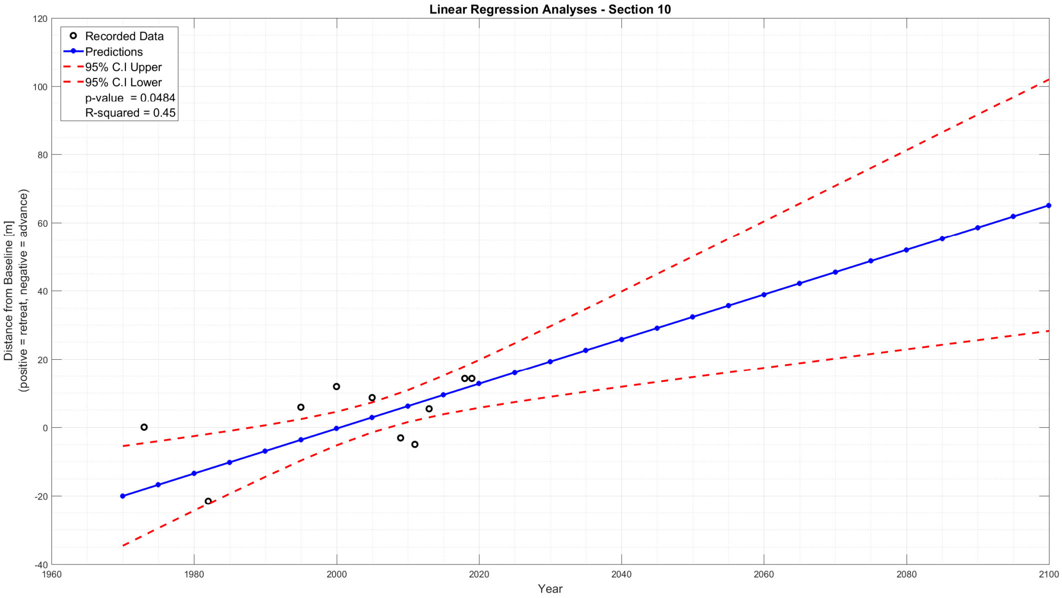

Linear Regression Analyses - Section 5
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.1035
R-squared = 0.33
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
140
120
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100

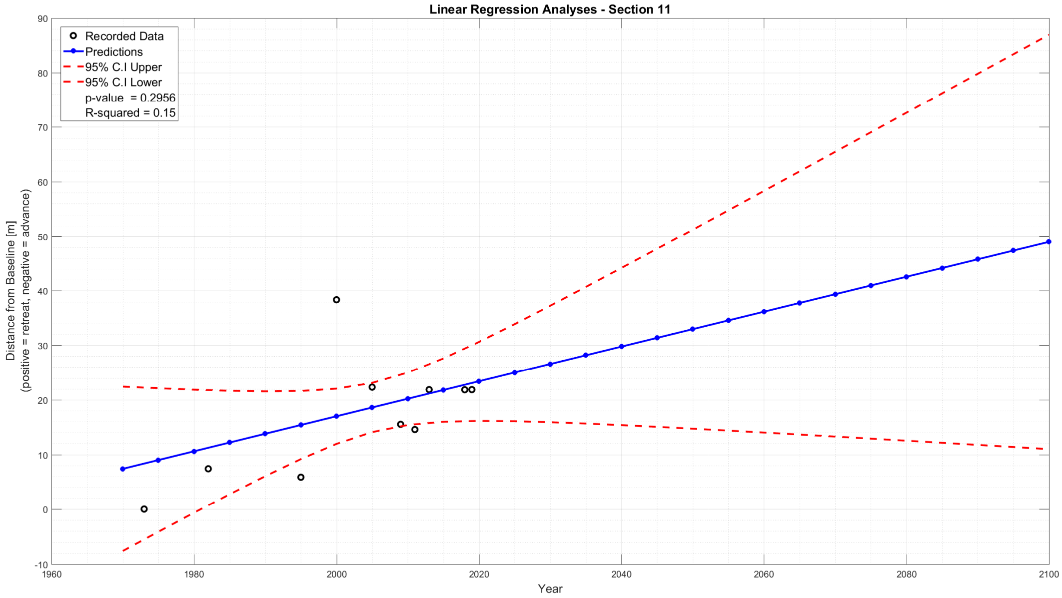

Linear Regression Analyses - Section 6
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.1181
R-squared = 0.31
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100

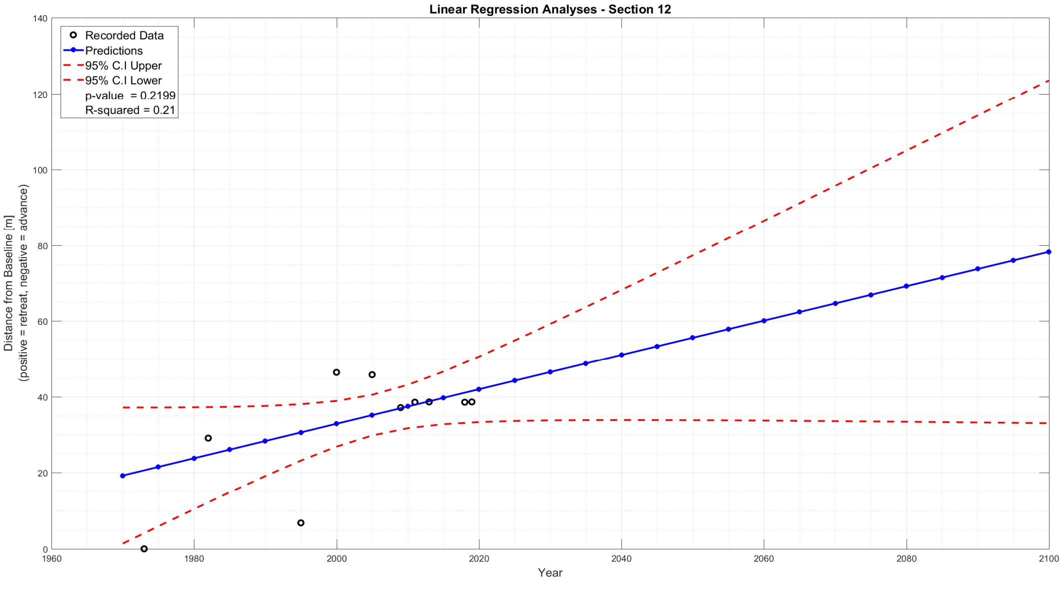

Linear Regression Analyses - Section 7
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0221
R-squared = 0.55
Distance from Baseline [m]
(positive = retreat, negative = advance)
120
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year


Linear Regression Analyses - Section 8
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0059
R-squared = 0.68
Distance from Baseline [m]
(positive = retreat, negative = advance)
120
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year


Linear Regression Analyses - Section 9
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0123
R-squared = 0.62
Distance from Baseline [m]
(positive = retreat, negative = advance)
70
60
50
40
30
20
10
0
-10
-20
-30
1960
1980
2000
2020
2040
2060
2080
2100
Year

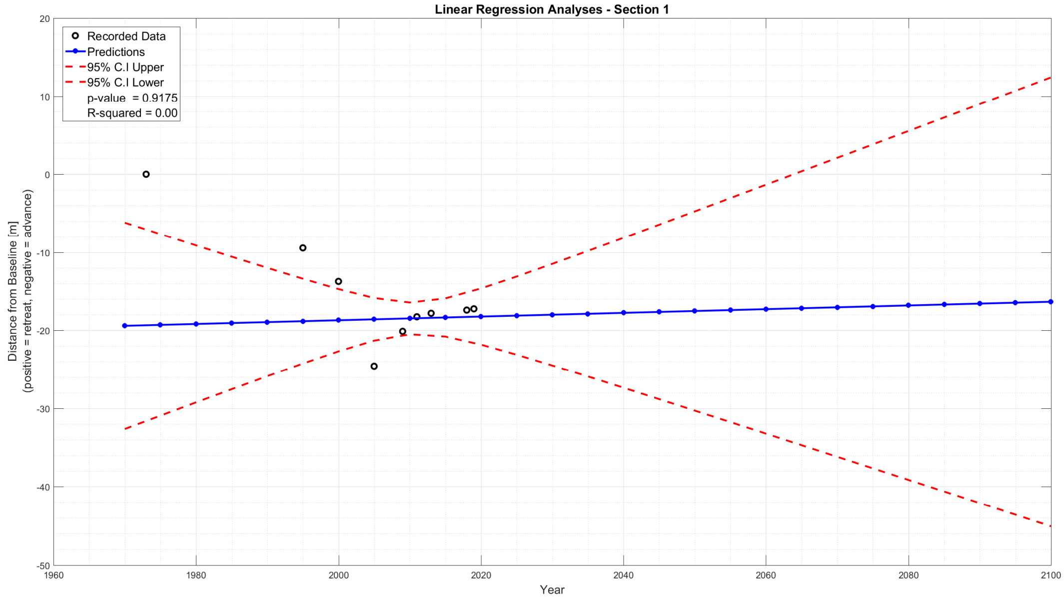

Linear Regression Analyses - Section 10
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0484
R-squared = 0.45
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
120
100
80
60
40
20
0
-20
-40
1960
1980
2000
2020
2040
2060
2080
2100

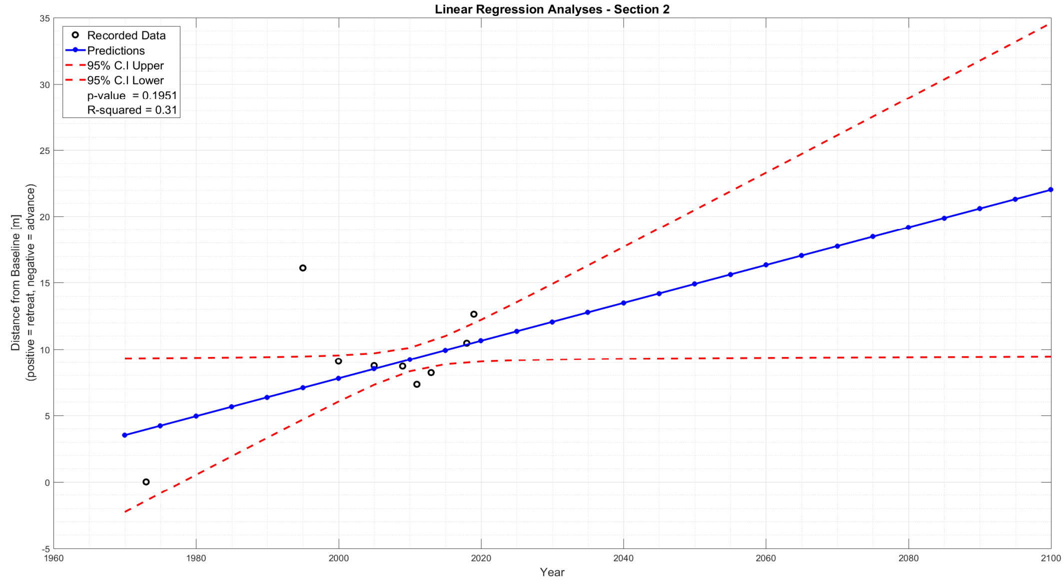

Linear Regression Analyses - Section 11
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.2956
R-squared = 0.15
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
90
80
70
60
50
40
30
20
10
0
-10
1960
1980
2000
2020
2040
2060
2080
2100

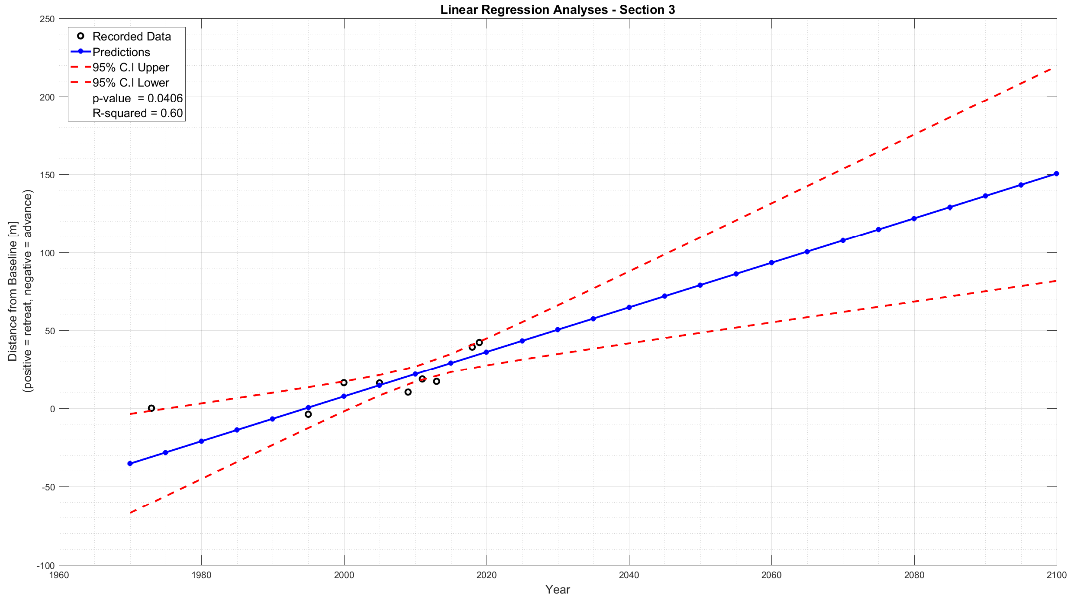

Linear Regression Analyses - Section 12
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.2199
R-squared = 0.21
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
140
120
100
80
60
40
20
0
1960
1980
2000
2020
2040
2060
2080
2100

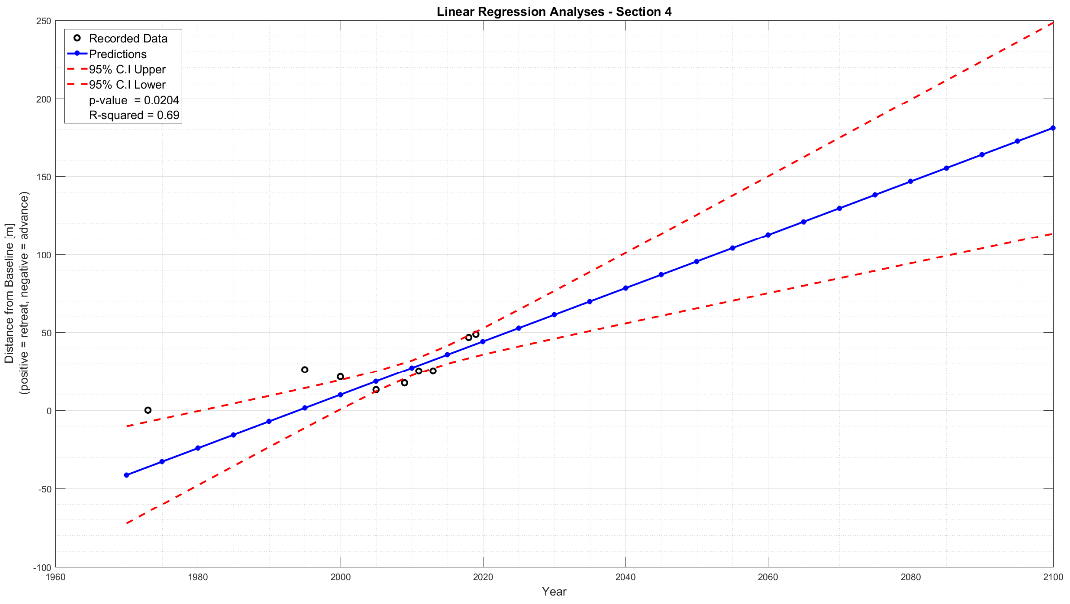
Coastal Change Assessment – Linear Regression Plots

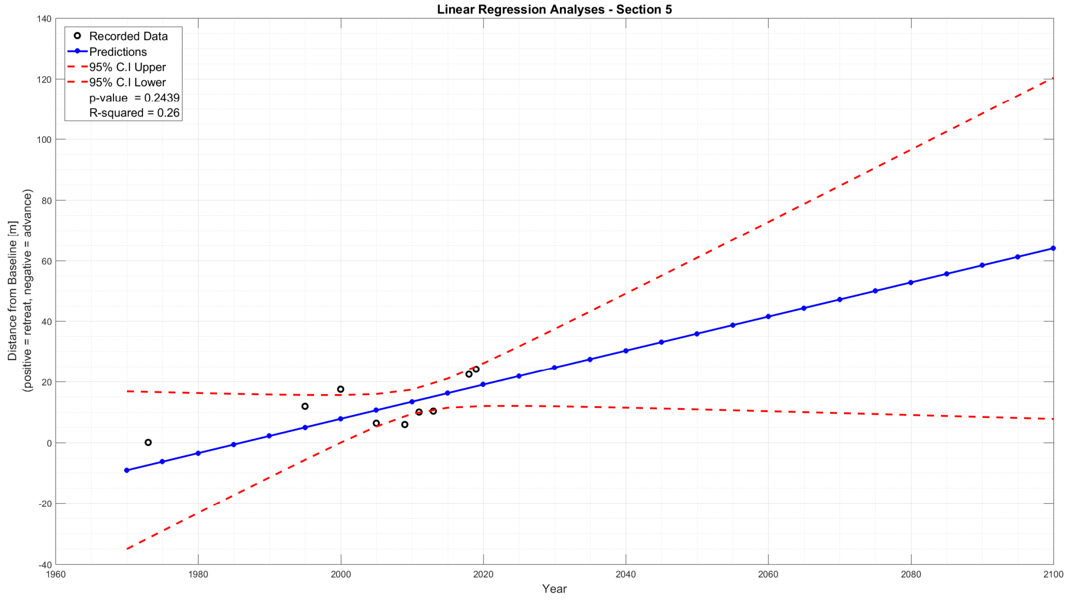
Study site: Rush South

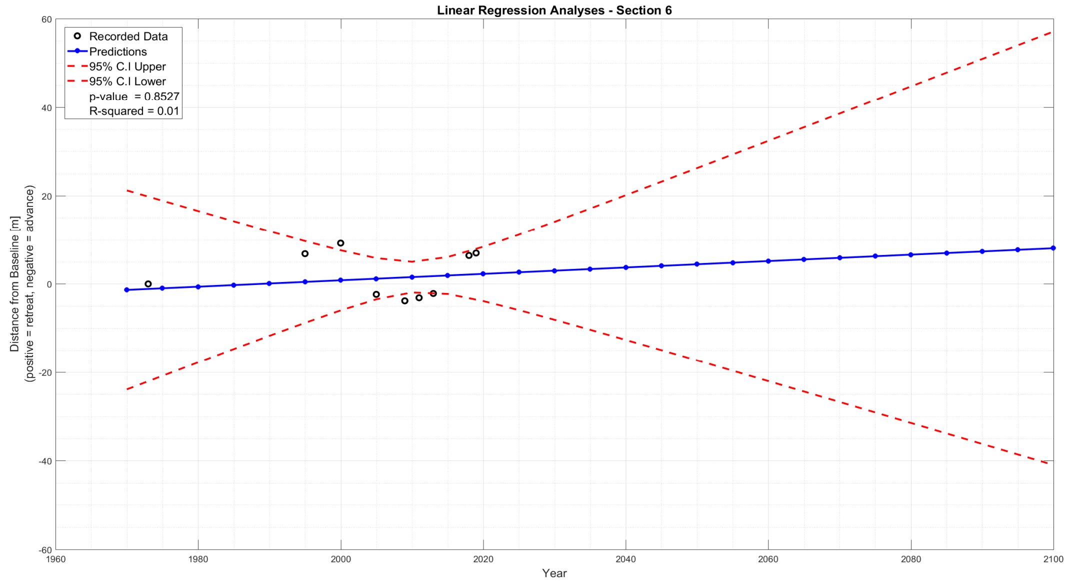

Linear Regression Analyses - Section 1
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.9175
R-squared = 0.00
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
20
10
0
-10
-20
-30
-40
-50
1960
1980
2000
2020
2040
2060
2080
2100

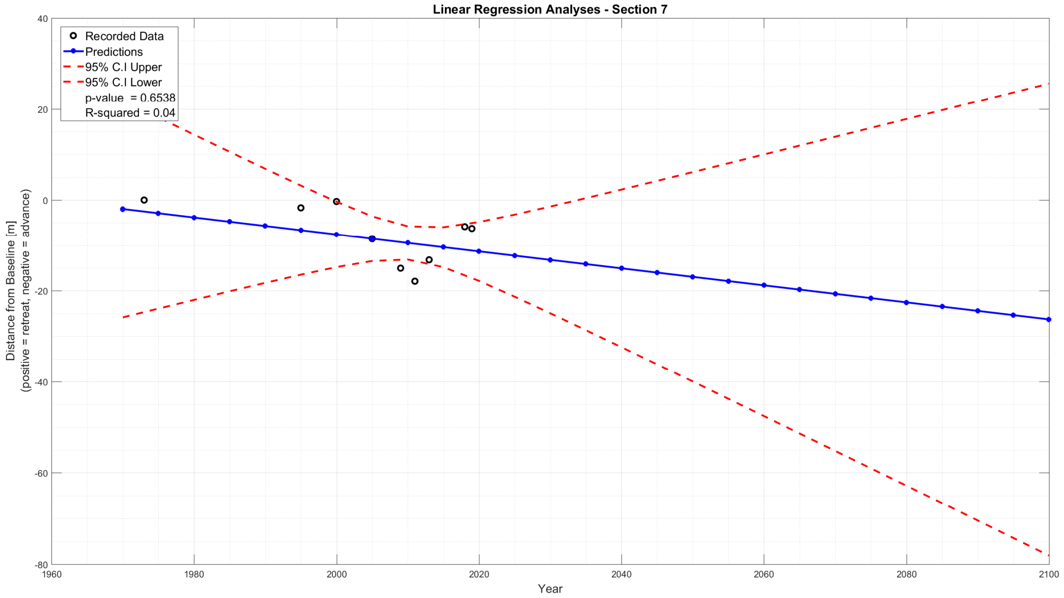

Linear Regression Analyses - Section 2
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.1951
R-squared = 0.31
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
35
30
25
20
15
10
5
0
-5
1960
1980
2000
2020
2040
2060
2080
2100

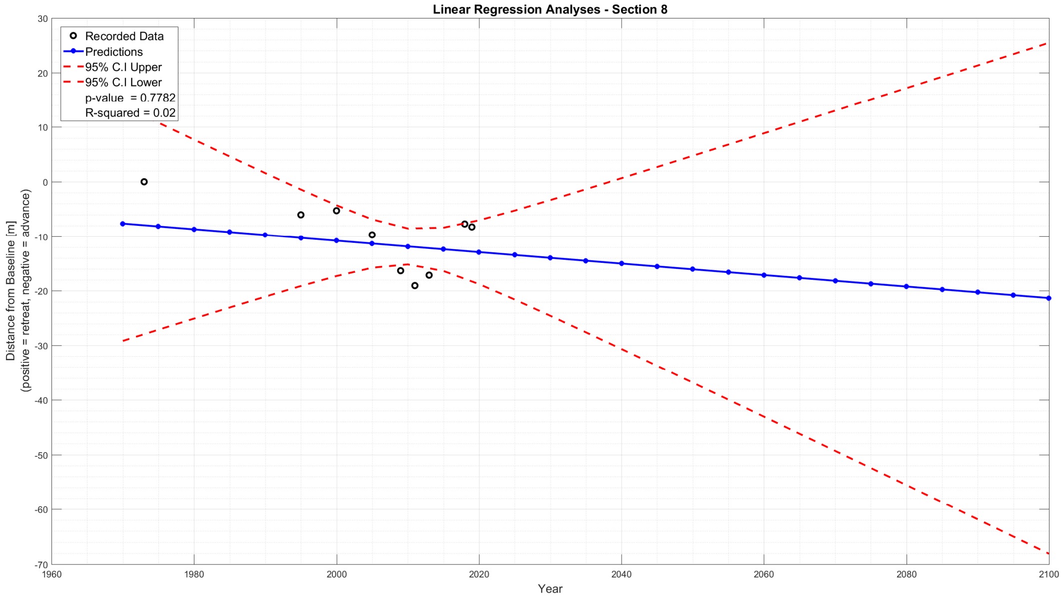

Linear Regression Analyses - Section 3
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0406
R-squared = 0.60
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
250
200
150
100
50
0
-50
-100
1960
1980
2000
2020
2040
2060
2080
2100

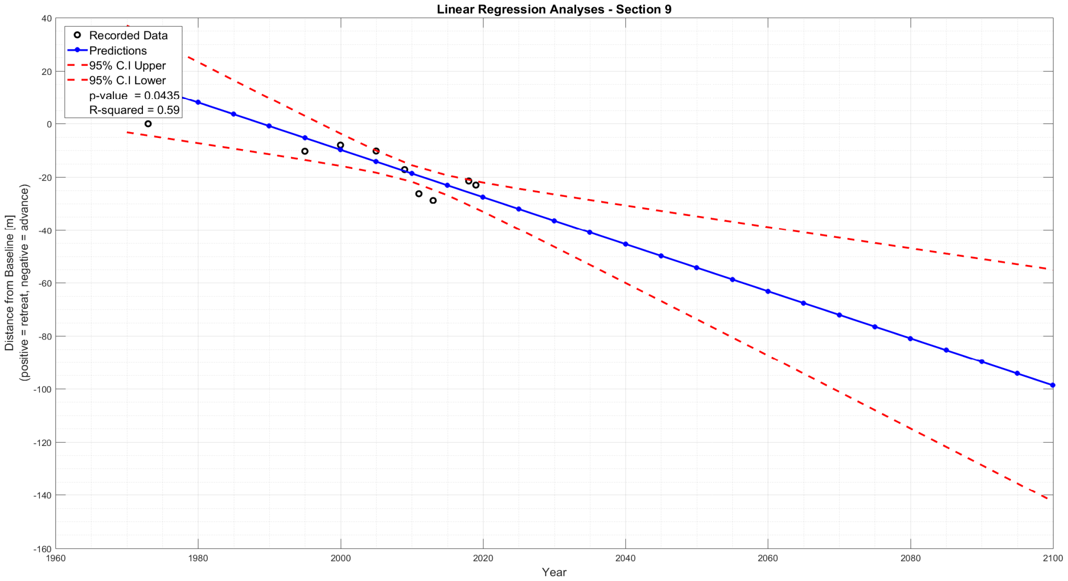

Linear Regression Analyses - Section 4

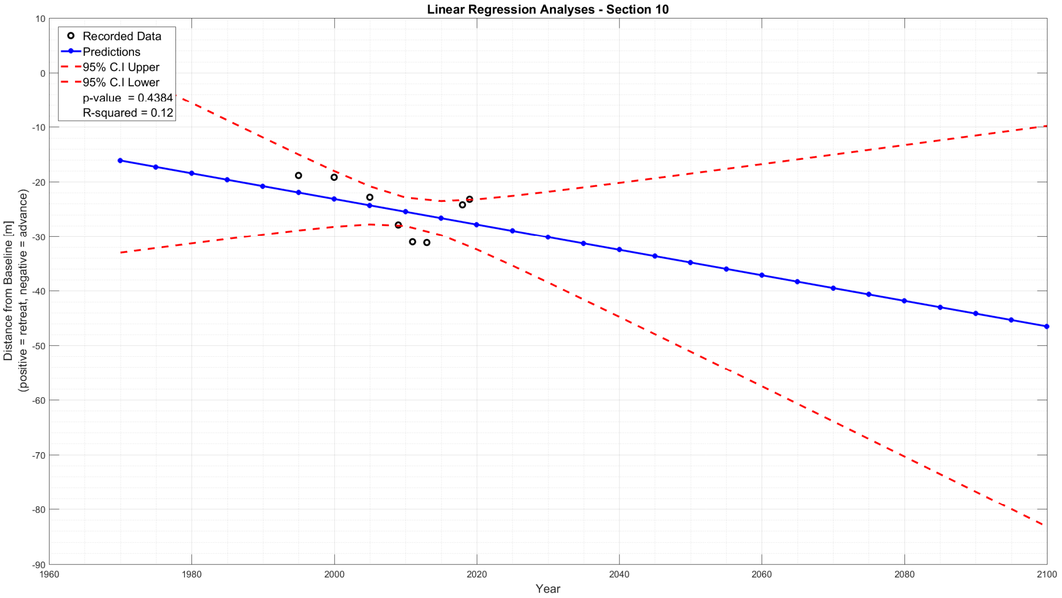

Linear Regression Analyses - Section 5

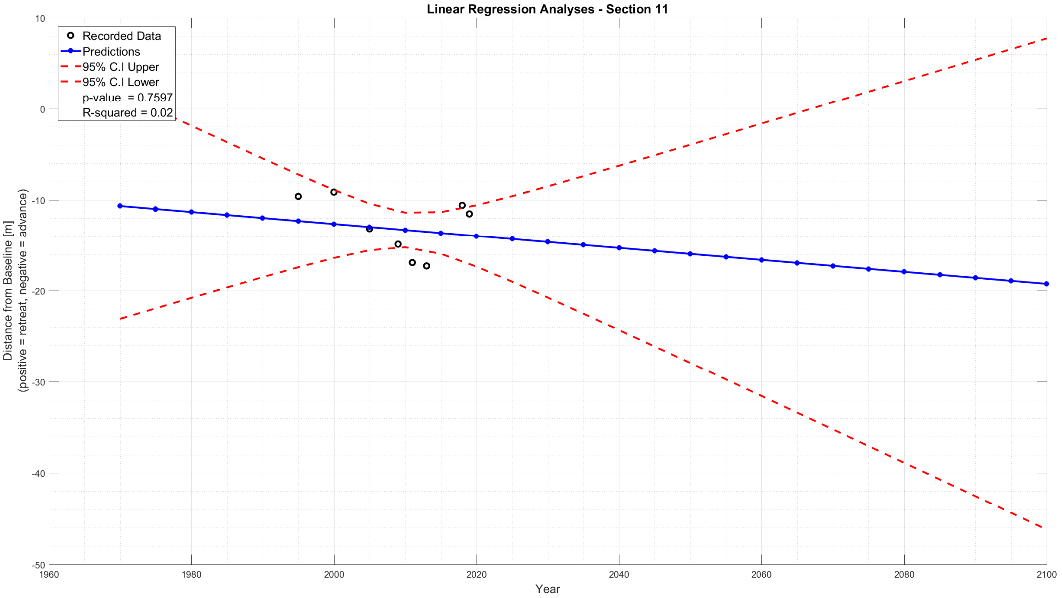

Linear Regression Analyses - Section 6


Linear Regression Analyses - Section 7
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.6538
R-squared = 0.04
Distance from Baseline [m]
(positive = retreat, negative = advance)
40
20
0
-20
-40
-60
-80
1960
1980
2000
2020
2040
2060
2080
2100
Year


Linear Regression Analyses - Section 8
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.7782
R-squared = 0.02
Distance from Baseline [m]
(positive = retreat, negative = advance)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
1960
1980
2000
2020
2040
2060
2080
2100
Year

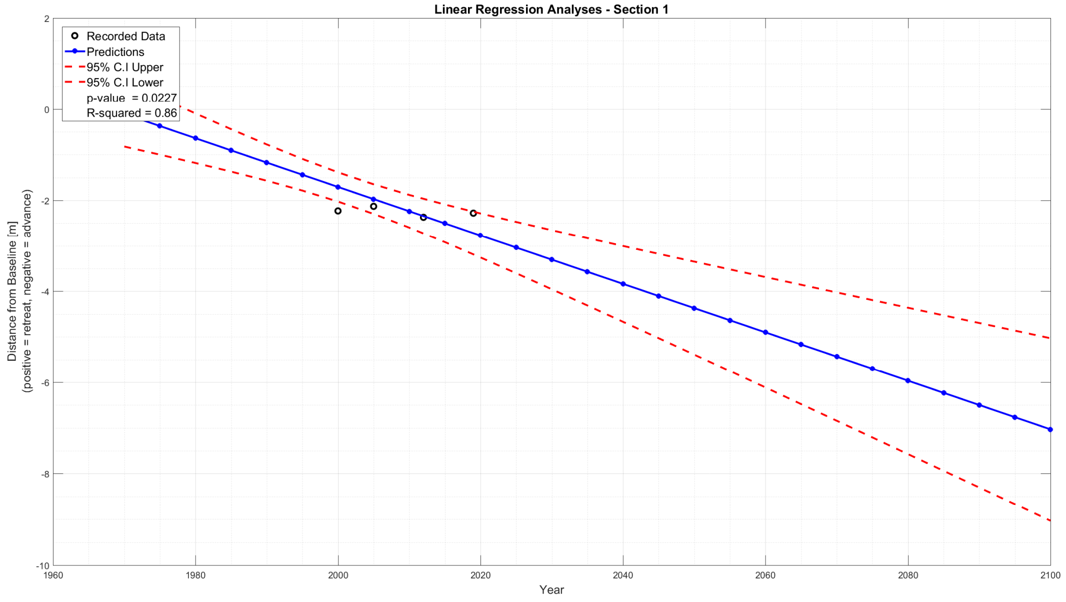

Linear Regression Analyses - Section 9
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0435
R-squared = 0.59
Distance from Baseline [m]
(positive = retreat, negative = advance)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
1960
1980
2000
2020
2040
2060
2080
2100
Year

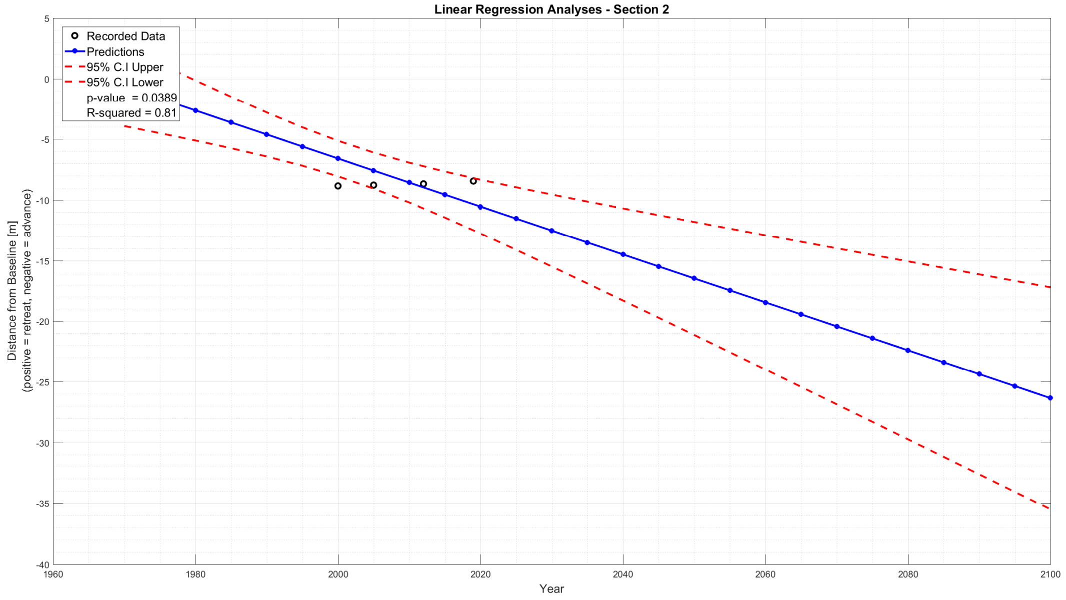

Linear Regression Analyses - Section 10
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.4384
R-squared = 0.12
Distance from Baseline [m]
(positive = retreat, negative = advance)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1960
1980
2000
2020
2040
2060
2080
2100
Year

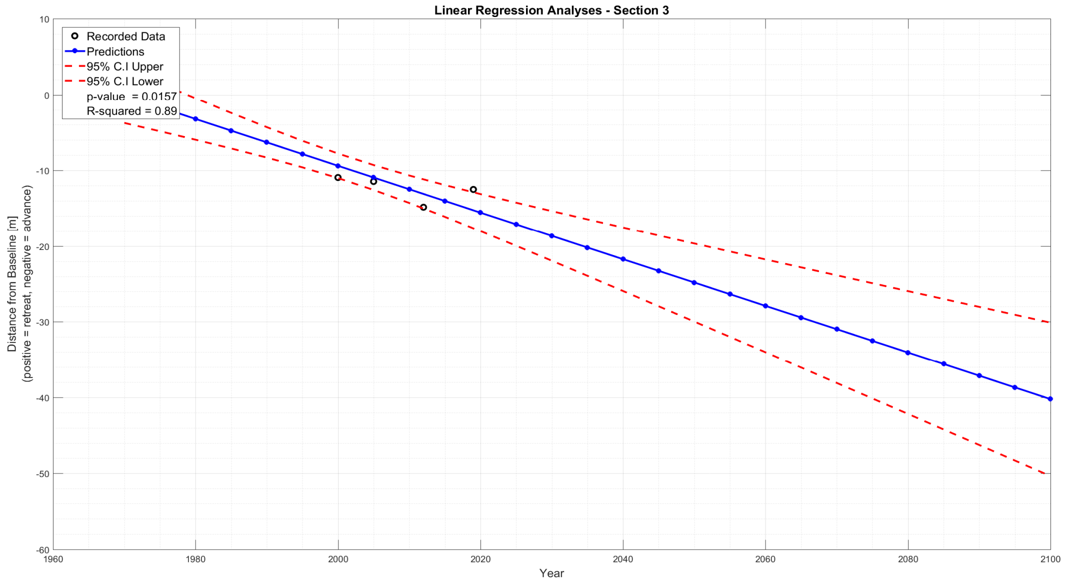

Linear Regression Analyses - Section 11
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.7597
R-squared = 0.02
Distance from Baseline [m]
(positive = retreat, negative = advance)
10
0
-10
-20
-30
-40
-50
1960
1980
2000
2020
2040
2060
2080
2100
Year

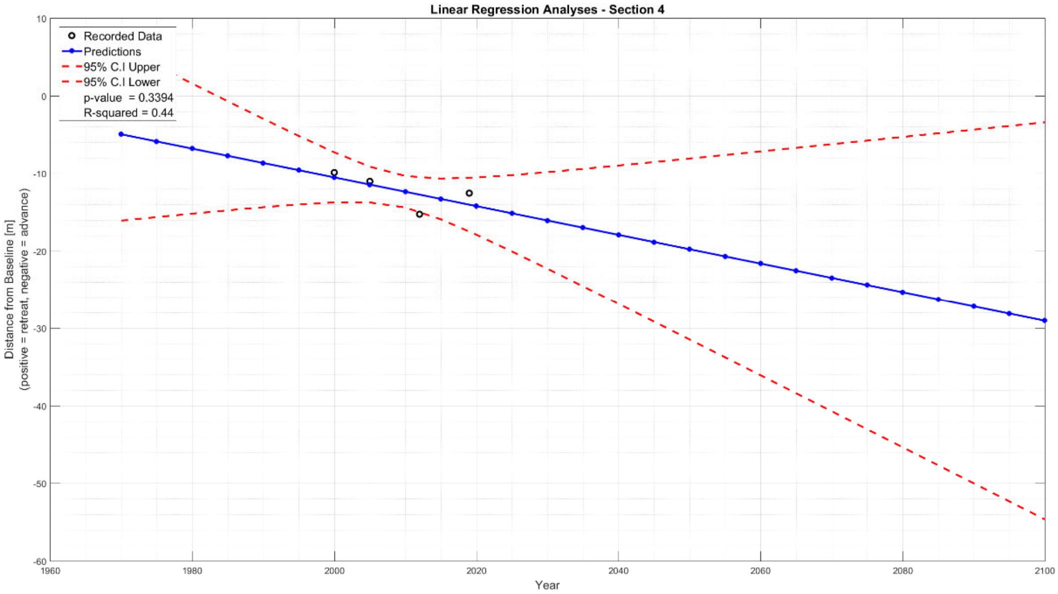
Coastal Change Assessment – Linear Regression Plots

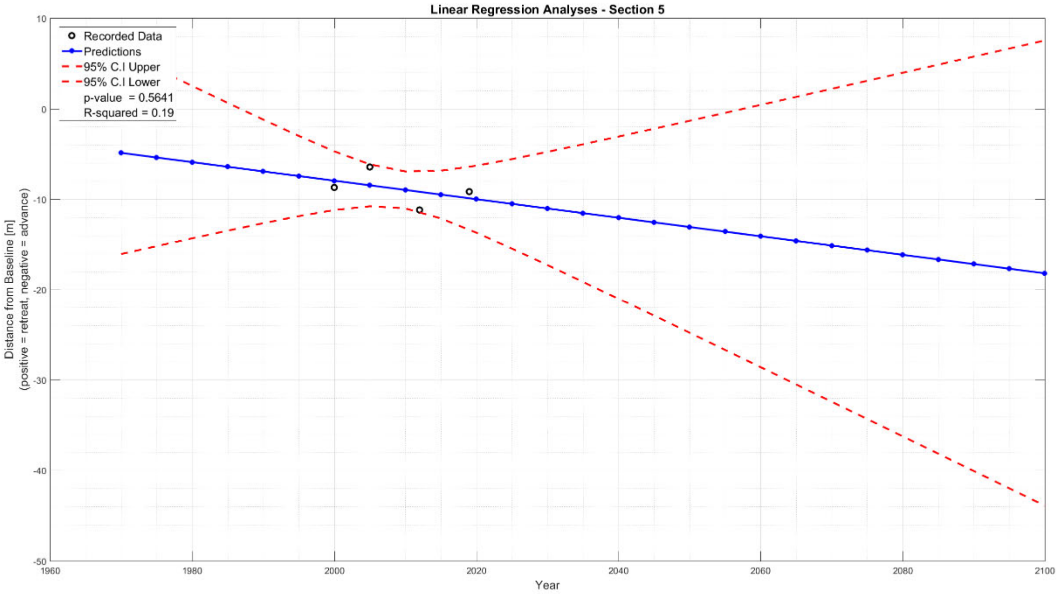
Study site: Rush North

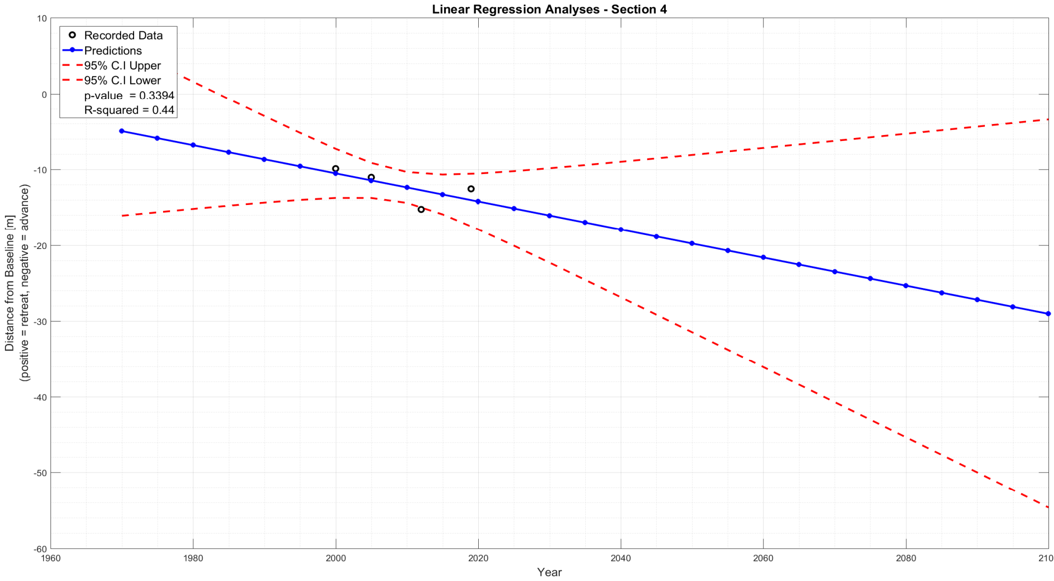

Linear Regression Analyses - Section 1
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0227
R-squared = 0.86
Distance from Baseline [m]
(positive = retreat, negative = advance)
2
0
-2
-4
-6
-8
-10
1960
1980
2000
2020
2040
2060
2080
2100
Year

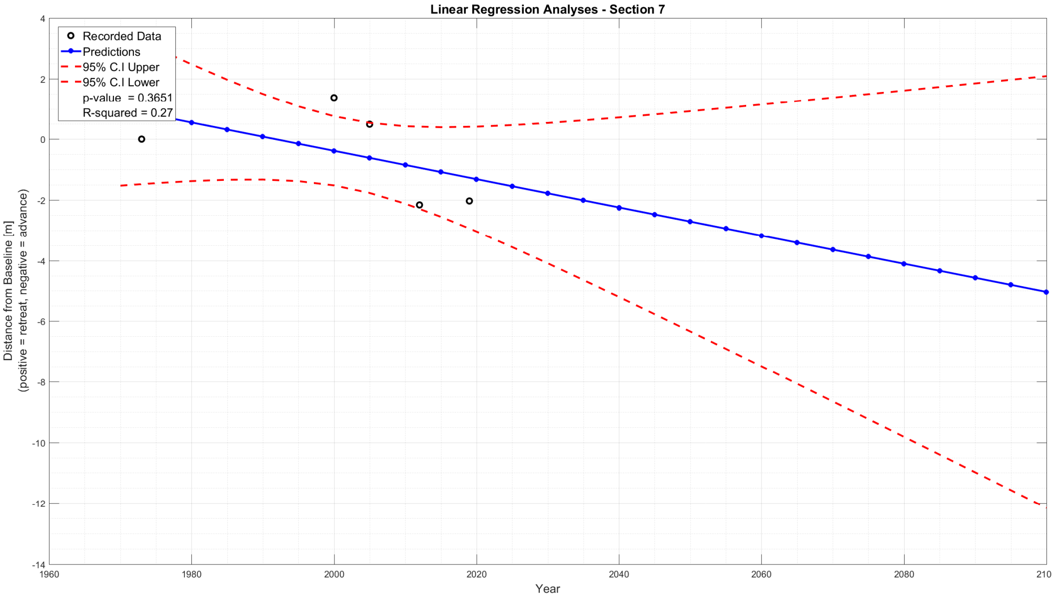

Linear Regression Analyses - Section 2
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0389
R-squared = 0.81
Distance from Baseline [m]
(positive = retreat, negative = advance)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
1960
1980
2000
2020
2040
2060
2080
2100
Year

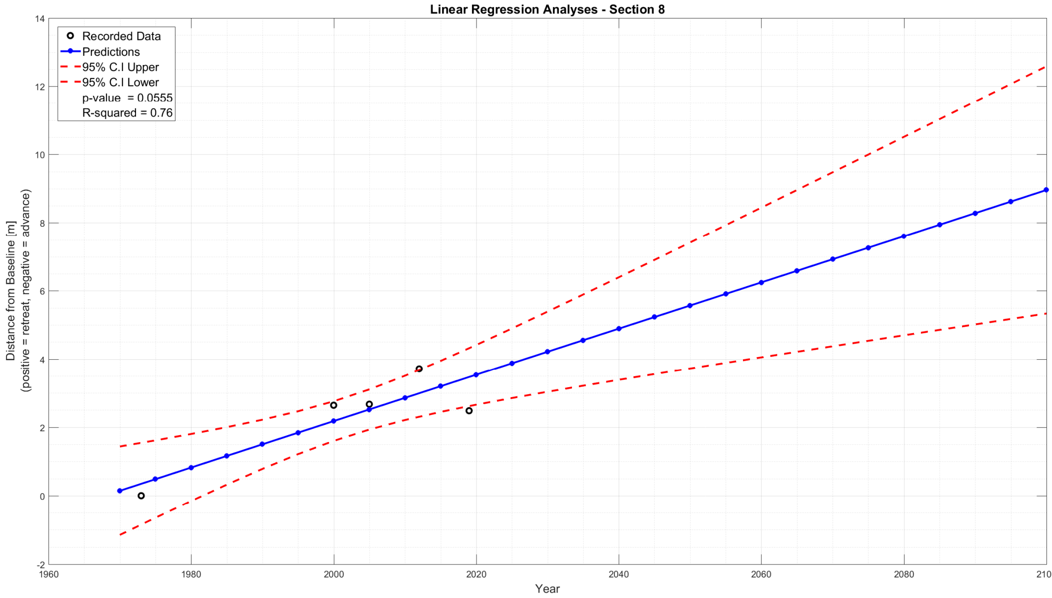

Linear Regression Analyses - Section 3
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0157
R-squared = 0.89
Distance from Baseline [m]
(positive = retreat, negative = advance)
10
0
-10
-20
-30
-40
-50
-60
1960
1980
2000
2020
2040
2060
2080
2100
Year

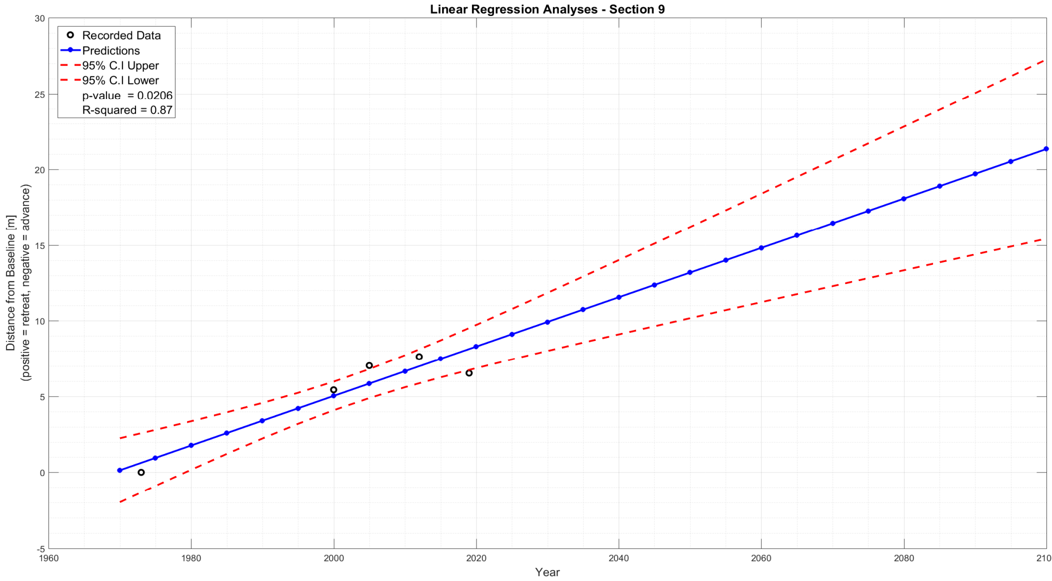

Linear Regression Analyses - Section 4
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.3394
R-squared = 0.44
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
10
0
-10
-20
-30
-40
-50
-60
1960
1980
2000
2020
2040
2060
2080
2100


Linear Regression Analyses - Section 5
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.5641
R-squared = 0.19
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
10
0
-10
-20
-30
-40
-50
1960
1980
2000
2020
2040
2060
2080
2100


Linear Regression Analyses - Section 4
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.3394
R-squared = 0.44
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
10
0
-10
-20
-30
-40
-50
-60
1960
1980
2000
2020
2040
2060
2080
2100


Linear Regression Analyses - Section 7
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.3651
R-squared = 0.27
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
4
2
0
-2
-4
-6
-8
-10
-12
-14
1960
1980
2000
2020
2040
2060
2080
2100


Linear Regression Analyses - Section 8
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0555
R-squared = 0.76
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
14
12
10
8
6
4
2
0
-2
1960
1980
2000
2020
2040
2060
2080
2100


Linear Regression Analyses - Section 9
Recorded Data
Predictions
95% C.I Upper
95% C.I Lower
p-value = 0.0206
R-squared = 0.87
Distance from Baseline [m]
(positive = retreat, negative = advance)
Year
30
25
20
15
10
5
0
-5
1960
1980
2000
2020
2040
2060
2080
2100

Appendix B
Coastal Change Sensitivity Analyses

1 COASTAL CHANGE SENSITIVITYANALYSES

1.1 Background

As reported in this document, the coastal change assessment for this study was undertaken using a Historical Trend Analyses (HTA) approach. RPS used this approach as it is well recognised that shoreline geometry and position are amongst the most useful indicators with which to evaluate changes in coastal regions. This approach is preferred over the use of storm induced dune erosion models for several reasons, including but not limited:

- Full morphological models such as XBeach, are generally designed to simulate dune erosion processes and to a much lesser extent, beach and dune recovery. As such, morphological models tend to over-predict beach and dune erosion.
- All models require input “boundary condition” data. However, as it is not possible to predict the frequency, timing and magnitude of future storm events between now and 2100, it is difficult to produce reliable input data for long term dune erosion models.
- Morphological models are very computationally demanding and can often take several days to accurately simulate a single 24hr storm event. Thus simulating 80+years of data would be difficult.

1.2 Limitations of the HTA Approach

Although the HTA approach was considered preferential to dune erosion modelling for the reasons outlined above, there are still several important factors that influence the predictive accuracy and uncertainty of erosion forecasts produced from HTA. These factors are outlined below:

Temporal span: It is important to use sufficiently long datasets to forecast future shoreline positions. This is because erosion/recovery cycles associated with severe storms can obscure underlying trends for decades. This presents a problem in an Irish context as piecemeal historical data is generally only available from 1970 onwards in Ireland.

Deselection of historical shorelines: A decision whether to deselect certain shoreline datasets is critical in determining a realistic historical erosion rate as certain historical shorelines may not be representative of the long-term trend. As an example, it may be prudent to exclude shoreline data recorded immediately after a particularly extreme storm event as this “outlier” event could skew the HTA.

Identifying turning points: A major problem in forecasting trends involves identifying turning points. With hindsight, turning points are clearly visible, but in real time these events can appear as outliers as opposed to the beginning of a new trend. This emphasises the need for frequent, high resolution survey data which is often lacking in Ireland.

1.3 Sensitivity of the HTA Approach

To highlight the sensitivity of the HTA approach to the deselection of shoreline data, RPS undertook a “forward HTA” assessment for beach section 3 along the Burrow which is illustrated in Figure 1.1 overleaf. The “reverse HTA” approach involved iteratively fitting a best fit line to more data in reverse chronological order of availability starting at 2019. The output from this analysis is illustrated in Figure 1.2.

As will be seen from Figure 1.2, the total coastal erosion from 2020 to 2100 varied from c.5m to c.240m depending on which shoreline data was included in the assessment. Based on this assessment, the maximum rate of erosion along this section of the beach could be c. 3m per year. This is significantly higher than the c. 1.3m per year long term average used to assess the erosion risk within the main report.

It is therefore important to recognise that the erosion rates presented within the main report may significantly under-estimate the actual rate of coastal retreat along the Burrow. Nevertheless, this CFERM Assessment has identified and characterised the serious and immediate threat posed by coastal erosion. The development of a long-term is the focus a CFERM Optioneering report which accompanies this CFERM Assessment report.

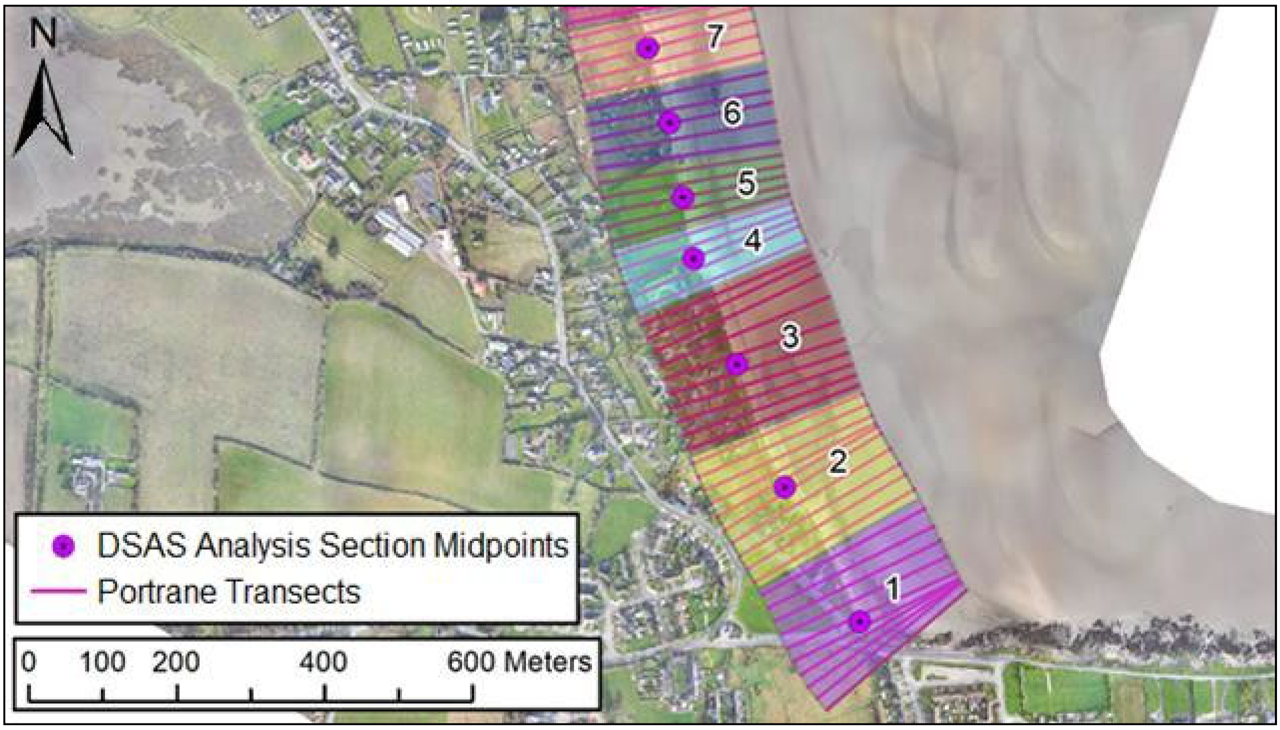


Figure 1.1: The Burrow beach split into sections for DSAS analysis

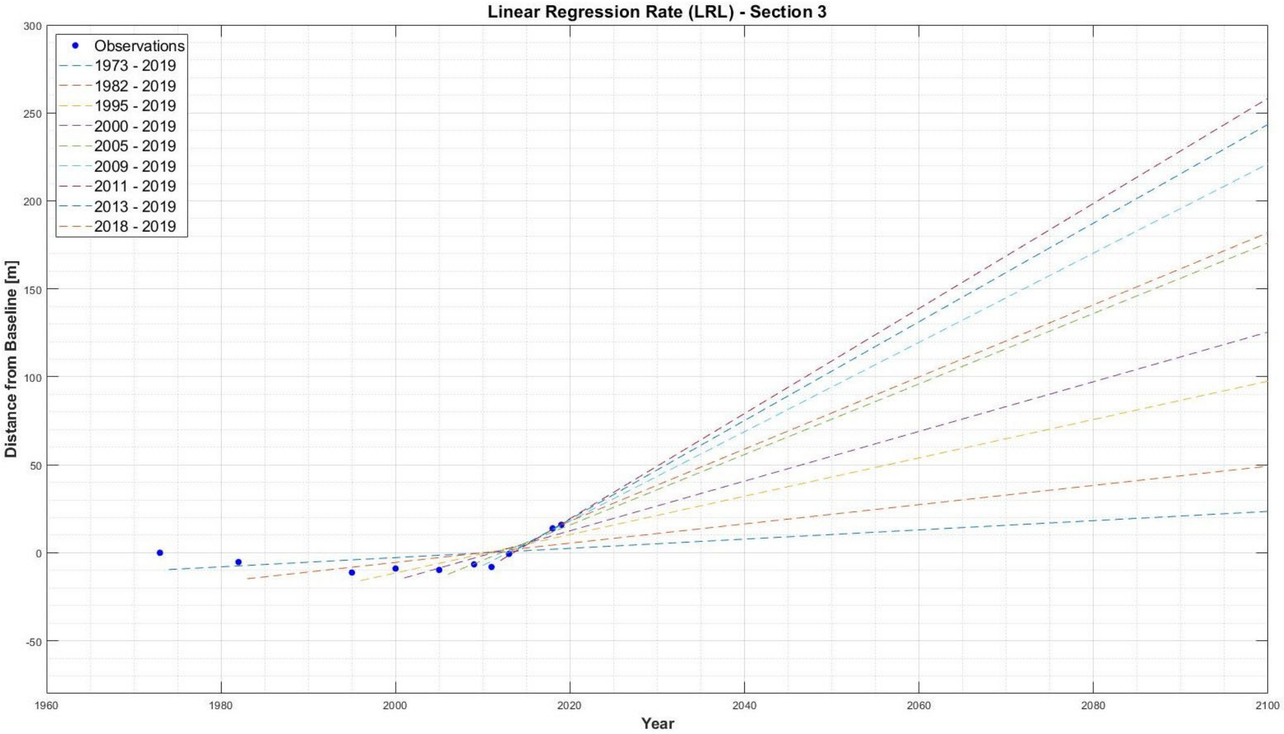


Figure 1.2: Example of a linear regression analyses undertaken along the Burrow at Section 3 using a reverse HTA approach for a range of different data groups