Report

Technical Group Overview Report

The Technical Summary of Impacts of Changing Risk at Fairbourne - Draft Issue for Internal Use Only

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Executive Summary

The[RJ1] aim of this Technical Overview Report is to collate the reporting which has been prepared by the Technical Group on behalf of the Fairbourne Moving Forward Project Board. Further information about the project and the work undertaken to date is available on the Fairbourne Moving Forward website:

http://fairbourne.info/

Referring to the source-pathway and receptor model, the work compiled within this overview reviews the various sources of flood risk, which are summarised below, along with the key reporting. The receptors within this model relate to the village and the individuals within it.

- **The open coast**
  Fairbourne Open Coast - Review of Geomorphology and Influence of Climate Change on Defence Management (Royal HaskoningDHV, 2018)
- **The tidal embankment to the north of the village**
  Rear Embankment Sensitivity of Defence Standard with Climate Change (Royal HaskoningDHV, 2017)
- **Fluvial (river) and surface water flood risk**
  Fairbourne Flood Risk Management Scheme Project Appraisal Report (PAR, 2011)
- **Ground water**
  Monitoring and characterisation of the hydrological environment at Fairbourne, Gwynedd April 2015 – August 2016 (Rigare Ltd, 2017; and)
  Update on hydrological monitoring at Fairbourne, Gwynedd, September 2016 to September 2017 (Rigare Ltd, 2017)

These sources are assessed in terms of their current risk, and the change in risk over time. A key date in the timeline is 2054. This is the projects' current planning horizon which was set back in 2014, and reflects the point in time where there is no longer a need to manage the defences. This timeline could be dramatically reduced id a significant storm is experienced. Actions (or management approaches) which would enable the risk to be modified at key points along this timeline, including potential cost implications are detailed where available. This will feed in to the **Coastal Adaptation Masterplan**, which is the vehicle for implementing the **Shoreline Management Plan**.

Current risk and changing risk

The existing defences mostly provide a T200 standard of protection. Speaking in terms of statistics, this suggests that the defences would be overwhelmed during a flooding event that would occur on average once in 200 years. There are however, a huge number of factors that influence an event of this magnitude.

Over time, and taking in to account the impacts of climate change, this standard of protection will reduce, and the receptors i.e. the village and the individuals within it, will become more at risk of flooding from smaller events, which would occur more frequently. This will, in part, be due to increased intensity of rainfall but more critically, the impacts of sea level rise and coastal erosion. Projections for how climate change will affect rainfall intensity and sea level rise in to the future, are based upon national guidance. These will be closely monitored, to test and modify the management approaches which will be outlined within the Coastal Adaptation Masterplan.

The review completed suggests that the most critical risk arises from the **open coast**, where continued investment will be required to maintain an adequate standard of defence through to the current planning horizon (2054). Works may also be required to maintain an appropriate standard of protection to the **tidal embankment** to the north of the village through to 2054. More major works would be required to both the **open coast** defences and the **tidal embankment** should the decision be made to defend beyond the current planning horizon. The review also highlights that the management approach to the **fluvial (river)**, **surface water** and **ground water** sources will also need to be adapted as we approach the planning horizon.

Modifying the risks and the associated cost

As indicated above, ongoing investment will be required to maintain an appropriate standard of protection for the village through to the planning horizon. These are estimated as being between £9million - £15million, based upon the High 95% climate change scenario. This climate change scenario is taken from national guidance. The Fairbourne Flood Risk Management Scheme Project Appraisal Report (PAR,2011), estimated that tidal flooding could result in approximately £70million worth of damages to Fairbourne. When compared to the estimated costs to maintain an appropriate standard of protection, this investment is considered as just.

The investment required to maintain the defences beyond the planning horizon (2054), increases significantly. This is because new defences would be required to the north and the tidal embankment would need to be raised. This would tip the balance between the cost associated with the potential damages, compared to the investment required.

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1 Introduction

1.1 Scope

Fairbourne is a community at the west coast of Wales. The permanent population of the town is estimated at about 500 and includes a high proportion of elderly residents. During the summer, the population increases up to approximately 3,000 (Fairbourne FRMS PAR, 2011).

Fairbourne is built on a low coastal plain. Figure 1-1 shows the village lying behind a shingle bank. The town is protected from flooding from the Mawddach estuary by a tidal embankment. Two rivers flow through the coastal plain; the Afon Henddol flows through the town with the Afon Morfa flowing through the low lying area to the north of the village.

Figure 1-1 General locations of Fairbourne including the beaches, tidal embankment and rivers (Afons)

The West of Wales Shoreline Management Plan (SMP) identified significant concerns over the medium to long term sustainability of the defences at Fairbourne. There is a clear need to maintain existing defences and reduce flood risk to the area over the short term and this remains the starting point for management.

However, primarily due to climate change, any major increase in protection, specifically with respect to dealing with the potential increase in ground water levels, flooding from rivers, flooding arising from failure or overtopping of the tidal embankment or failure and overtopping of the front facing sea defences, is likely to drive management down an unsustainable route. This would mean that the village would be ever more reliant on defences and therefore, increasingly vulnerable should any aspect of defence fail. It would also rely on significantly increased levels of funding into the future. For these reasons, the SMP identifies the need for change, with the intent that over the project planning horizon of 2014-2054, we move to a position that we no longer need to defend the village.

The present Fairbourne Moving Forward (FMF) project aims to develop how this process of change is managed. It is recognised that there are still important uncertainties that need to be addressed. In particular, the need for change is driven primarily by sea level rise. As such, an important aspect of the project is re-examining, in detail, how different aspects of defence will be influenced by climate change, and testing the high-level assumptions made within the SMP.

To this end, a series of studies have been undertaken to look at the implications of sustaining defences over the project planning horizon from 2014 up to 2054, examining:

- How defence standards (Standards of Protection (SoP)) might change under different climate change scenarios over the nominal 40-year planning horizon.
- What might then be required to maintain an acceptable SoP in terms of continued investment.
- The degree of flexibility in terms of the 40-year planning horizon; whether this is realistic or whether there may be scope for extending this period.

And also,

- Testing the assumptions within the SMP, that costs and risk would increase substantially if we do not plan for change now.

1.2 Objectives

This Technical Group Overview Report brings together the reporting prepared by the Technical Group on behalf of the Project Board, regarding the different sources of risk. It assesses the current risk, the changing risk over time and addresses actions to modify the risk, including where available the cost profiles to modify the risk. This work will feed into the development of the Coastal Adaptation Masterplan.

1.3 Referenced Reports

All risk factors have been considered through a range of previous reports. Figure 1-2 shows the Referenced Reports, categorised by risk. It also gives a short description of the contents of each report. The full Report References are denoted in Section 5.

The information in these previous reports are collated within the work and reports developed by the Technical Group. Further analysis has been undertaken with regard to the open coast, supported by work undertaken by the University of Wales (2017) and in relation to the flood risk from the estuary. Fluvial flows and rainfall were considered previously through the Fairbourne Flood Risk Management Scheme PAR (2011), with subsequent work having been undertaken on ground water, reported in the Monitoring and characterisation of the hydrological environment at Fairbourne, reports, by Rigare Ltd (2017), based on the monitoring data commissioned through the project.

Underpinning all this work are the projections of climate change provided by UK CP09. It is recognised that this information is due to be updated as UK CP18. This is discussed further in Section 2 of this overview. As new information becomes available, then this will be reviewed as part of the on-going delivery of the Masterplan. The way in which information has been presented in this report sets out the assumptions that have been made, such that implications associated with any change in climate change projections may be properly assessed.

1.4 Structure of this report

Section 2 summarises the baseline conditions developed within the various reports. These results aim to provide a comprehensive collation of our current knowledge of information for the area, together with an assessment of how conditions might change in the future with climate change.

Section 3 describes the current and future risk. The current Standard of Protection of the different defences is expanded upon, along with the vulnerability of the defences to future climate change. The section ends with an estimation of the potential damages due to flooding.

Section 4 describes the Management Response to the increasing future risk. First, the works required to the individual components of the defence system are examined. The review then draws this together, initially considering the implications in terms of long term defence by further testing the conclusions set out in the SMP2 that on-going long term management of the area would lead to an unsustainable situation. The review goes on to consider in further detail, the potential approach and investment profiles that are likely to be required to deliver flood protection over the Project Planning Horizon, considering also the uncertainties and potential range of costs that might be required to extend the Planning Horizon beyond 2054.

Importantly, within all this work, it is recognised that there may be some variation in terms of those actions and interventions that are identified. In particular, it is recognised that prior to undertaking any works in the future there would be the need to review what actions might be required and, specifically, the most effective form that such works would take. Even so, the description of works and the associated costs are considered to be realistic but should not be taken as a strict schedule of interventions. This would be picked up in developing the Masterplan and within the continuous process of review associated with managing the area into the future.

Primary Reports	Input Reports	Description
Fairbourne **Open Coast** - Review of Geomorphology and Influence of Climate Change on Defence Management (2018)	Flood and Coastal Erosion Risk Management (FCERM): Fairbourne Going Forward (2017)	*Assessment of change in Coastal Processes, based on beach profiles and aerial photographs*
	West of Wales Shoreline Management Plan 2 (SMP2 2012)	*Proposed management approach for the West of Wales*
	Friog Cliffs Study Project Appraisal Report (PAR 2015)	*Appraisal for the works at Friog Corner*
Fairbourne **Rear Embankment** sensitivity of defence standard with Climate Change (2017)	Fairbourne Flood Risk Management Scheme Project Appraisal Report (FRMS PAR 2011)	*Appraisal for the works at the Fairbourne tidal embankment and the river Afon Henddol*
	West of Wales Shoreline Management Plan 2 (SMP2 2012)	*Proposed management approach for the West of Wales*
	UK CP09 - Climate Projections (2009)	*Future projections for climate change*
Ground water Monitoring and characterisation of the hydrological environment at Faibourne, Gwynedd April 2015 to August 2016. Update on hydrological monitoring at Fairbourne, Gwynedd, September 2016 to September 2017 Rigare Ltd (2017)	Rigare, 2014. Scoping study on ground water level monitoring and hydrogeological characterisation of Fairbourne and environs, Gwynedd. Consultant report for Cyngor Gwynedd.	*Review and interpretation of available hydrological data to develop and refine the hydrological fiunctioning of the area.*
Fairbourne Flood Risk Management Scheme Project Appraisal Report (2011)	*Various Appendices included as part of this Project Appraisal Report*	*This document provided the information used within this report for the fluvial flood risk*

Figure 1-2 Referenced Reports

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2 Summary of Baseline Conditions

2.1 Risk factors

Flood and coastal erosion risk occurs at Fairbourne because of several interdependent factors. This may be described in terms of a source, pathway, receptor model, as shown in Figure 2-1.

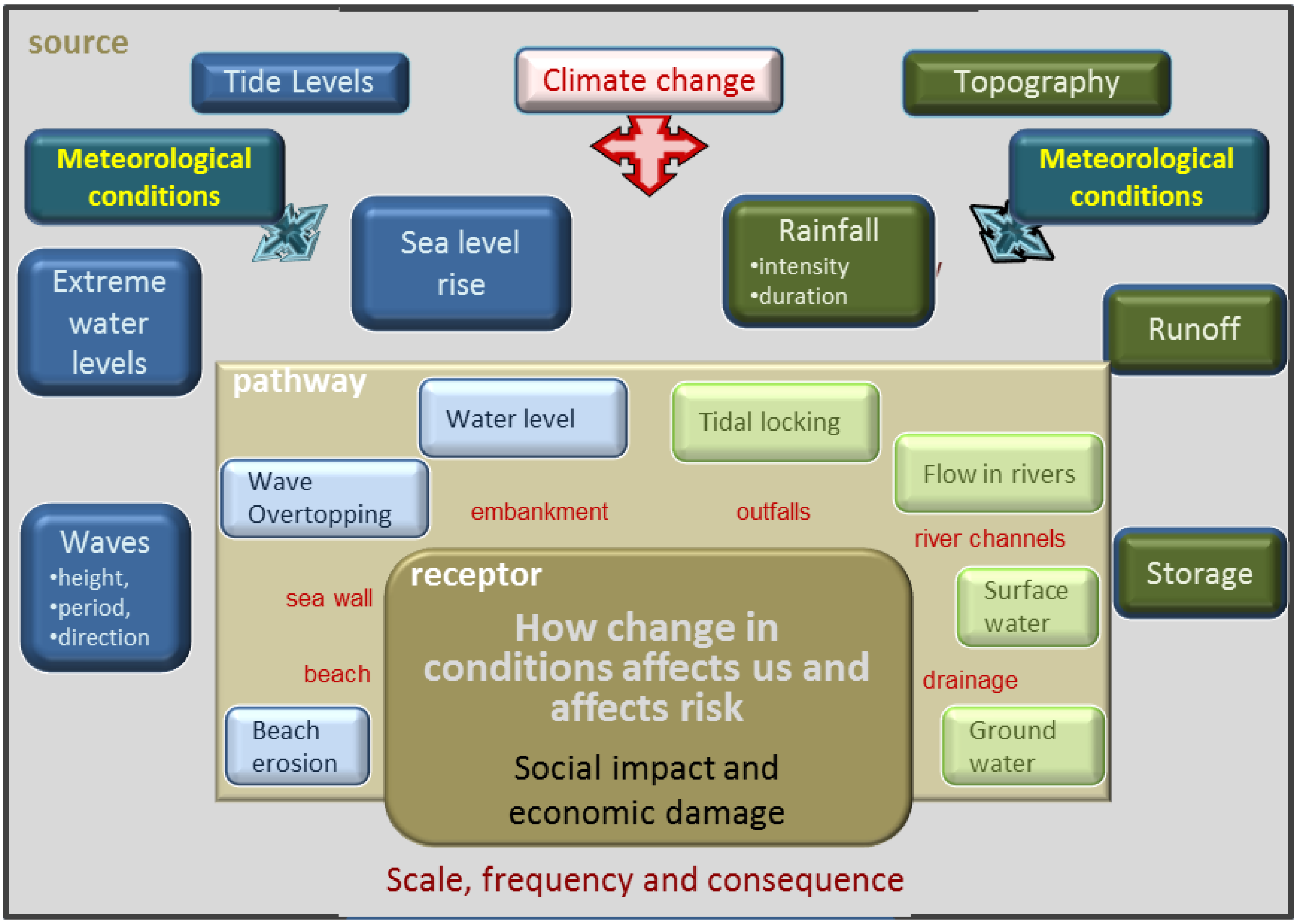

Figure 2-1 Source, pathway, receptor concept model

The degree of uncertainty associated with different factors identified above, is set out in more detail in a separate note that is being prepared by the Technical Group. The key uncertainties are highlighted in the text below. The main area of uncertainty is associated with the impacts of climate change and this is discussed briefly in the following sub-section. This section does not however consider that the timescales could be dramatically reduced should a significant storm event be experienced within the planning horizon. This will be developed further in the Coastal Adaptation Masterplan.

2.1.1 Impact of Climate Change

The main climate impacts in relation to risk at Fairbourne are the two core "source" factors of sea level rise and rainfall (duration and intensity), with a potential additional influence on the wave climate (storminess) and extreme water levels (surge events). The main reference source used throughout the Fairbourne

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Project to date has been the UK Climate Change Projections 2009 (UK CP09). This reference is currently being updated as UK CP18 but as yet this further information is not available[1].

There is strong evidence, from observation, that climate change is occurring, however, as set out in UK CP09, the key area of uncertainty is in terms of the rates of change. UK CP09 collates information from different climate models based on different future "world views" on emission scenarios, in developing a suite of projections. Climate change projections are, therefore, presented in terms of different scenarios (Low, Medium and High) with different confidence limits in terms of model results. For sea level rise, UK CP09 also identifies a worst-case H++ projection based on the potential ice cap melt conditions. This is described as a realistic condition that is unlikely to be exceeded. The range of predictions based on UK CP09 for sea level rise is shown in Figure 2-2.

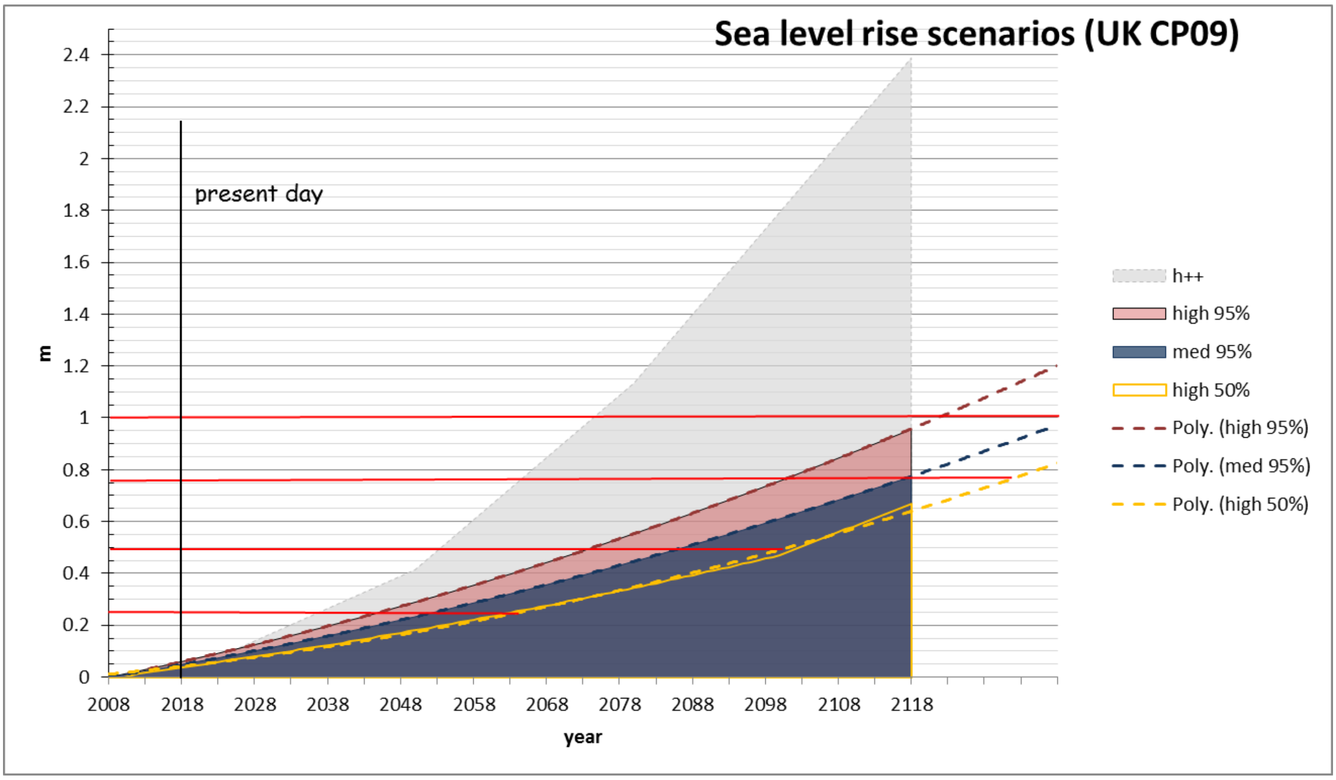

Figure 2-2 Projected sea level rise scenarios.

This approach to projections, while sensibly recognising the uncertainties, poses problems in terms of planning for the future in a deterministic manner. Typically, in long term planning, Natural Resources Wales (NRW) recommend the use of the High 95% scenario and this has been used as the baseline throughout the Fairbourne Project, although the Project also considers the possible implications in terms of time scales based on alternative projections.

This assessment of when incremental increases in sea level rise would occur, is shown in Table 2-1. This forms the subsequent basis for assessing change in risk throughout the review.

[1] As further information becomes available it is intended to revise, where necessary, information included within this review as part of the on-going process defined through the Masterplan.

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Table 2-1 Date of occurrence under different sea level rise scenarios.

UK CP09 scenarios	Med (95%)	High (50%)	High (95%)	H++
Sea Level Rise from 2008				
0.25m	2052	2063	2045	2037
0.5m	2086	2102	2074	2054
0.75m	2115	-	2099	2064
1m	-	-	2118	2074

With respect to rainfall, UK CP09 indicates significant seasonal variation, tending on average towards drier summers and wetter autumns and winters. The projections are shown in Table 2-2. Based on the reported 50% confidence level, rainfall, during the winter period, might be expected to increase by around 8% between 2020 - 2049, increasing to around 14% between 2049 – 2069 (the planning horizon currently extends to 2054), and increasing further by around 19% to 26% between 2070 - 2099.

Table 2-2 Percentage change in rainfall (UK CP09 Wales).

Scenario	Time period (range) 2020 - 2049			Time period (range) 2049 - 2069			Time period (range) 2070 - 2099		
	10%	**50%**	90%	10%	**50%**	90%	10%	**50%**	90%
Annual (high)	-5	**0**	+5	-6	**0**	+6	-7	**+1**	+9
Spring (high)	-6	**+1**	+8	-6	**+1**	+7	-4	**+2**	+8
Summer (high)	-26	**-10**	+10	-38	**-16**	+7	-50	**-26**	+4
Autumn (high)	-7	**+4**	+16	-5	**+6**	+20	-7	**+8**	+28
Winter (high)	-2	**+7**	+18	+1	**+14**	+31	+6	**+26**	+55
Winter (medium)	-2	**+8**	+21	+2	**+14**	+30	+4	**+19**	+42

The influence of these primary factors and those in relation to other influences of climate change are discussed below, in association with the discussion of specific aspects of the baseline conditions.

2.2 Source Conditions

2.2.1 Water levels

Present day and future tide levels at Barmouth are shown in Table 2-3Error! Reference source not found., together with extreme water levels taken from the EA boundary data set (base year 2008). All values are shown as m OD. Although there may be slight variation between the open coast and the estuary, the following values have been taken to apply in both locations.

Table 2-3 Water Levels (m OD) based on the High 95% climate scenario

		Astronomic Tide Levels (Barmouth)					Extremes (return period)*				
Time period		MLWS	MLWN	MHWN	MHWS	HAT	1 in 1	1 in 10	1 in 50	1 in 100	1 in 200
2008	Baseline extreme water levels	-1.74	-0.64	1.06	2.56	3.29	3.48	3.83	4.04	4.13	4.22
2018	Present day	-1.7	-0.6	1.1	2.6	3.4	3.5	3.9	4.1	4.2	4.3
2054	Planning horizon	-1.4	-0.3	1.4	2.9	3.6	3.8	4.2	4.4	4.5	4.5

Time period		Astronomic Tide Levels (Barmouth)					Extremes (return period)*				
		MLWS	MLWN	MHWN	MHWS	HAT	1 in 1	1 in 10	1 in 50	1 in 100	1 in 200
2068	50yrs from present day	-1.3	-0.2	1.5	3.0	3.7	3.9	4.3	4.5	4.6	4.7
2093	75yrs from present day	-1.1	0.0	1.7	3.2	4.0	4.2	4.5	4.7	4.8	4.9
2118	100yrs from present day	-0.8	0.3	2.0	3.5	4.2	4.4	4.8	5.0	5.1	5.2

*Notes: * This assumes no relative change in extreme water levels, MLWS = Mean Low Water Spring, MLWN = Mean Low Water Neap, MHWN = Mean High Water Neap, MHWS = Mean High Water Spring, HAT = Highest Astronomical Tide*

2.2.2 Wave Climate

2.2.2.1 Open coast

The offshore wave climate is dominated by waves centred around the southwest to west direction Figure 2-3, with typical maximum waves heights in the order of 5m (UoW 2017). The Central Cardigan Bay SMP1 (2004) indicates that the waves in Cardigan Bay are either locally wind-generated waves (typically with periods of less than 7 seconds), or swell waves generated outside the immediate area (typically with periods in excess of 9 seconds). Owing to the configuration of the area, swell waves generally approach from the southwest, through the St George’s Channel from the Atlantic. Some swell waves approach from the north, from the Irish Sea.

The extreme offshore wave heights (reported in UoW 2017) are indicted to be around 3.5m to 4m for a 1 in 1 year (T1) return condition, increasing to around 6m under the 1 in 100 (T100) year condition.

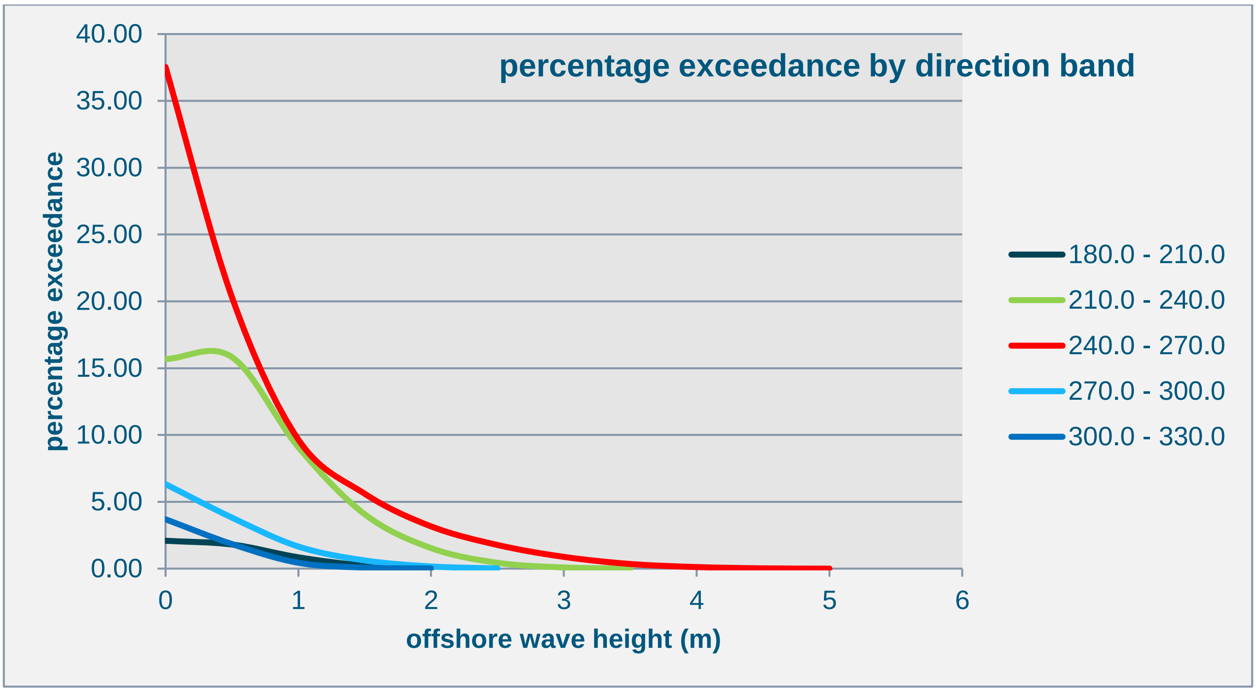

Figure 2-3 distribution of offshore wave height by direction

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Inshore, along the main frontage, wave heights are depth limited and are, therefore, determined by water levels. Typical wave heights over Mean High Water Spring (MHWS) tide conditions are around 2.1m to 2.2m at the beach (at 0m OD). Under a T1 water level condition, wave heights might typically increase to around 2.8m to 3.1m.

The recent analysis at Friog Corner also highlights the influence of reflected waves from the Friog Cliff line. This influence is seen as being most severe at the junction between the cliffs and the Friog Corner defence, where it was concluded that incident wave height might be increased by around 20%, reducing further to the north to around a 10% increase.

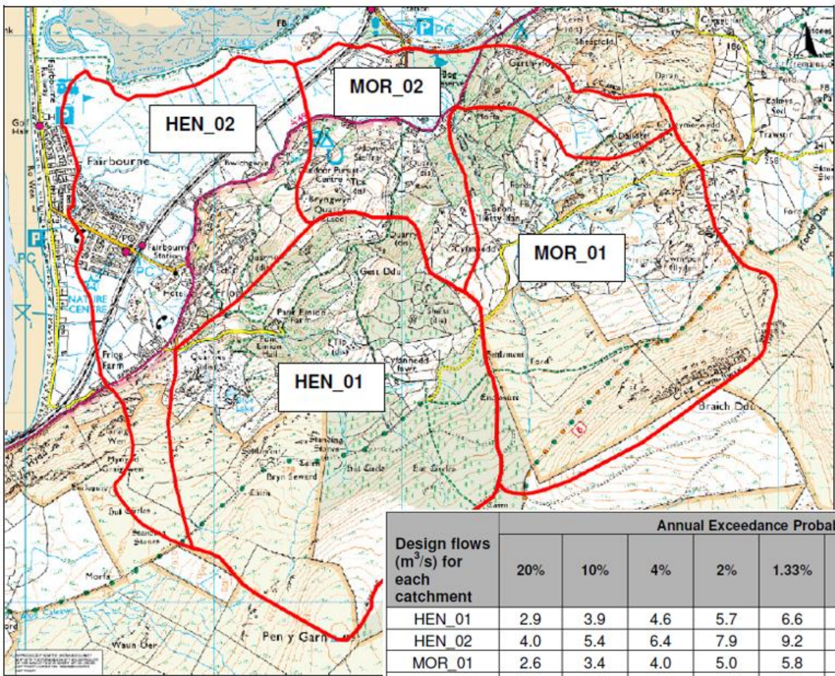
2.2.2.2 Estuary

Waves can be generated locally across the estuary, although there is no actual record of wave heights. In the assessment of the changing risk to the tidal embankment (the Embankment Technical Report, 2017), three different wave loading cases have been developed. These in part relate to possible conditions resulting in extreme water levels on the basis that such conditions would be associated with strong local winds. In assessing the potential risk of overtopping, these three wave loading conditions have been taken as:

- Lower wave loading: T10 water level with wave heights of 0.3 to 0.4m;
- Probable wave loading: T20 water levels with wave heights of 0.5m;
- Exceptional wave loading: T100 water levels, with wave heights between 0.75 and 1m.

2.2.3 Fluvial Inputs

The catchments of the Afon Henddol and Afon Morfa were divided into 4 sub catchments: The sub-catchments shown on
Figure 2-4 were determined as part of the modelling undertaken in developing the Fairbourne FAS PAR Hydraulic Modelling Report (April 2011), being revised based on OS Contours and LiDAR data.



Design flows (m^3/s) for each catchment	Annual Exceedance Probability							
	20%	10%	4%	2%	1.33%	1%	0.50%	0.1%
HEN_01	2.9	3.9	4.6	5.7	6.6	7.2	7.7	8.9
HEN_02	4.0	5.4	6.4	7.9	9.2	10.0	10.7	12.3
MOR_01	2.6	3.4	4.0	5.0	5.8	6.3	6.7	7.7
MOR_02	2.9	3.8	4.6	5.6	6.6	7.2	7.6	8.9

Figure 2-4 Catchment Boundaries and design flows for each sub catchment

Further details are provided in the Hydraulic Modelling Report included within the Fairbourne Flood Risk Management Scheme 2011 PAR. The report did consider the influence of climate change on this input data; taken as an increase of 20%, although the results of this are not recorded in the report. The impact of this is, however, reported in relation to peak flows and increased water levels within the discussion of the fluvial system. This is included within the following sub-section discussing the pathway conditions.

2.3 Pathway conditions

This section collates information on pathway conditions, as shown in Figure 2-1. Clearly, there is increased interrelationship between these aspects of the risk management system, most critically in terms of the interrelationship between ground water, surface water and fluvial flows and levels. However, in particular these aspects of the system will be further influenced by climate change and sea level rise, in terms of tidal locking.

The section starts, however, by considering coastal change, both the on-going change in geomorphology and erosion and how this changes with climate change. This coastal change impacts both directly on the integrity of defences at the shoreline and in terms of overtopping. Overtopping is also considered in relation to the tidal embankment, with consideration of potential for breaching of this defence. Should either the defence on the open coast or the tidal embankment fail, then this would independently open the whole area to widespread flooding.

2.3.1 Coastal Change

Based on the initial baseline assessment carried out by the University of Wales, a further study has been carried out into how the coast might continue to change in to the future. In developing this, it is suggested that the coast may be seen as two interdependent geomorphological units:

- To the north, the area is seen as being controlled very strongly by the influence of the estuary. This modifies the movement of sediment and is typically seen as being quite stable (despite significant short term variation).
- Over the southern half of the area, the coast adopts a more embayed shape. This area, extending down to Friog Corner has a history of erosion.

There is a transition between these two units, where to the south there is erosion and to the north some history of accretion. Considering this in detail, there is good evidence that as the southern embayment deepens, so this area of transition effectively moves north. This means that areas may change over time from accreting to eroding.

Coupling this with the influence of sea level, it has been possible to assess how the shoreline as a whole might be expected to change over time. This is set out in Figure 2-5**.** The following critical aspects of this behaviour are described below:

- That the transition between erosion and accretion will progress north at a rate of around 30m/yr. This will reduce as the influence of the estuary becomes the more dominant control further to the north;
- Over the southern part of the frontage the erosion is occurring as a result of a loss of sediment supply from further south;
- It has been assumed that underlying rates of erosion caused by this lack of sediment will, therefore, remain effectively the same in areas already effected by erosion but will be modified in any area that transitions from accretion to erosion. These changes are necessarily estimates based on judgement; and

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- That sea level rise will result in increased erosion and pressure on the coast to set back (in land) and as such, an allowance for erosion due to sea level rise has been superimposed on the underlying rates of erosion.

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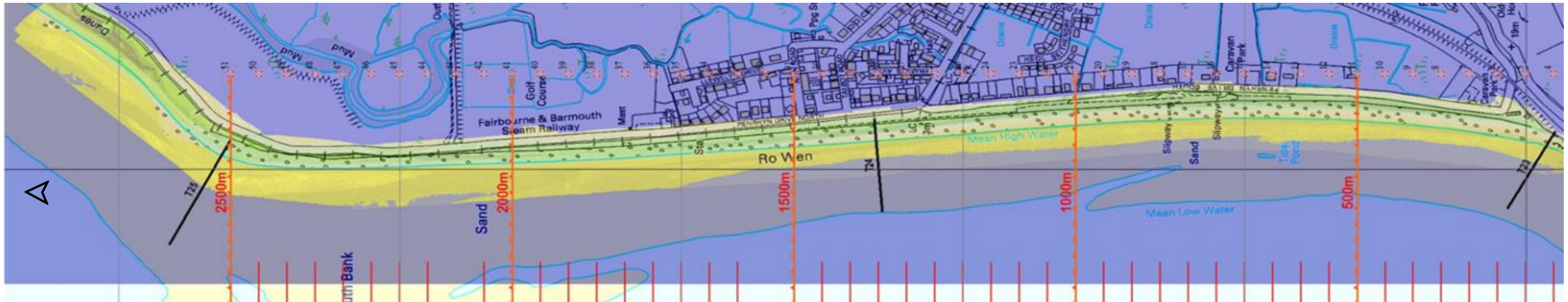

	1	2	3	4	5	6	7	8
defence	Shingle bank		Shingle bank and crest wall					rock
Ridge width (at T200) (m)		27	35	32		37	32	
Set back of defence (m)		22	24	22		12	15	
Present day 2017								
Upper beach behaviour	Acc.	Stable	Accretion	Erosion				
Erosion rate	+0.1 MHWN	-0.006 5m OD	+0.56 5m OD	+0.2 5m OD	-0.7 MHWN	-0.28 5m OD	-0.3 5m OD	-0.34 MHWN
2027 (no increase due to SLR)								
behaviour								
Erosion rate		+0.3	+0.3	-0.2		-0.3	-0.3	-0.34
Change (m)		+3	+4	0		-3	-3	
To 2045 (additional 1.5m erosion due to 0.25m SLR (high 95%))								
behaviour								
Erosion rate		+0.6	-0.1	-0.3		-0.3	-0.3	-0.34
Change (m)		+10	+4	-6		-10	-10	
To 2074 (additional 3m erosion due to 0.5m SLR (high 95%))								
behaviour								
Erosion rate		+0.4	-0.2	-0.3		-0.3	-0.3	-0.34
Change (m)		+22	-4	-18		-22	-22	

Figure 2-5 Summary of Potential Coastal Change with time – accretion in green and erosion in red

These processes may be summarised in the following way:

- The frontage comprises two principal, interrelated geomorphological zones:
    - The shallow embayment covering the southern half of the frontage; and
    - The northern section of the open coast which is strongly influenced by the behaviour of the estuary and the estuary outer banks.
- Over the southern section of the frontage, there is clearly seen to be a decreasing supply of sediment, particularly from the shoreline running out along the Friog Cliffs and beyond to the southwest;
- This has had a major influence, most strongly felt in terms of the shingle bank and at present in the area of the Friog Corner. With continued movement of shingle north along the Fairbourne frontage, this lack of sediment supply has meant that Friog Corner has become increasingly vulnerable. This situation is made worse as a result of the reflected wave action from the Friog Cliffs, tending to move sediment away to the north;
- Over the rest of the frontage, the analysis of beach change shows quite clearly a differential pattern of drift. Particularly over the more northern sections, there are areas where shingle tends to accrete, while in other areas the upper back shoreline remains relatively stable, or erodes;
- It is concluded that the balance of erosion and accretion will change over time. Areas in front of the northern part of the Village Beach where accretion is currently observed, may well start to erode in the future. Similarly, areas further north, where the frontage appears to be relatively stable, may start to accrete in to the future;
- It is further concluded, that while the analysis of past beach profiles provides an important baseline from which to develop an understanding of change, it is not possible to project past rates forward as an indication of change in the future;
- Typically, over the southern part of the frontage, it is predicted that the back shoreline might erode by some 3m over the next 10 years but that this erosion might have increased to around 22m by 2074;
- Over the northern section of the Village frontage, there may be a continuing trend of accretion over the next 5 to 10 years. This frontage is likely then to start to erode, such that by 2074 erosion is predicted to be in the order of 18m;
- At the far northern end, it seems probable that the corner between the open coast and where the backshore curves around to form the Ro Wen Spit, there is likely to be increased accretion (benefiting from erosion along the open coast); and
- These influences have a major impact on the vulnerability of the defences.

2.3.2 Wave Overtopping (Open Coast)

Wave overtopping can influence risk in two principal ways:

- **By direct damage to the structure** typically occurring at levels of 1 to 10 l/s/m to grass covered embankments and at levels of 50 to 200 l/s/m for embankments with protection to the crest and back face. Erosion of the crest and back face tend to be the critical criteria in failure of an embankment; and

- **By direct flooding due to the water level in the hinterland[2]**. In the case of Fairbourne flooding might occur initially to the lower area to the south of the village, between the village and Friog Corner. With increased flow over the defences, water would spread into the village and through to

[2] It is highlighted that failure of the defence would create a different risk exposing the area of the village to widespread flooding on lower water level conditions.

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the larger low-lying area to the rear (northwest) of the village. This is indicated in Figure 2-6, showing present day estimates of flood extent under different return period events due to overtopping.

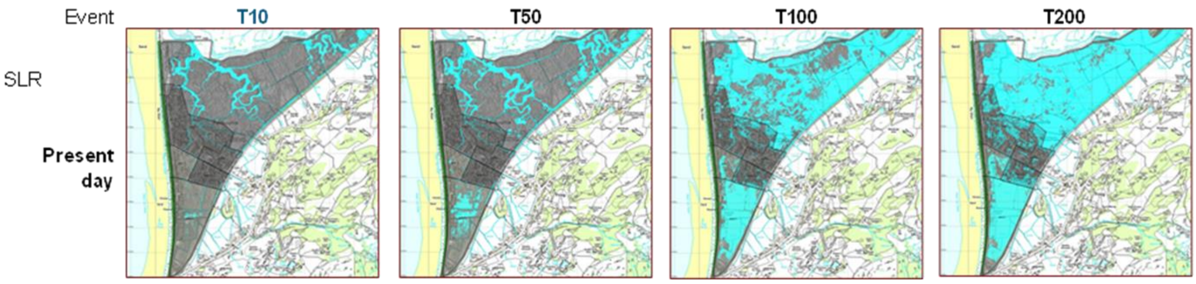

Figure 2-6 Present-day flood extent

During the 2014 storms, the area between Friog Corner and Fairbourne village was flooded, resulting in damage to the revetment. Studies of Friog Corner (Friog Corner PAR, 2015 and the Royal HaskoningDHV Open Coast Study, 2018) show that waves are reflected from the Friog Cliffs, such that the wave heights increase typically by a factor of 1.2. Royal HaskoningDHV completed an outline design for the works to the revetment in 2017. A Ground Investigation to inform detailed design was procured in January 2018, with the detailed design to follow.

2.3.3 Wave Overtopping and Embankment Breach (Tidal Embankment)

The key reports for the risks regarding the tidal embankment are the Embankment Technical Report and Summary (Royal HaskoningDHV, 2017), and the Fairbourne FRMS PAR (2011) (Figure 1-2).

Similar to the open coast, there are two mechanisms that could result in flooding and flood damage to the village:

- The risk of **overtopping of the existing embankment** (improved and strengthened in 2013/ 2014). This assumes that the embankment does not fail and that the potential risk arises purely from overtopping. Overtopping rates higher than 33 l/s/m result in flooding to the village;
- The risk of **failure of the embankment** (a breach situation) where the area behind the embankment is flooded as a result of water flowing through the embankment. Embankment failure is possible with overtopping rates higher than 10 l/s/m. Hence, the embankment failure is the limiting scenario. This aligns with the SMP2 assessment.

An assessment of potential overtopping has been made, based upon the possibility of severe wave height conditions as set out above in Section 2.2.2. Figure 2-4 sets out the results of this under present day conditions.

Table 2-4 Overtopping conditions for the embankment

		Wave height 0.75m		**Wave height 1m**	
Return period	Still water level	**Run-up level**	**Discharge l/sec/m**	**Run-up level**	**Discharge l/sec/m**
T50	4.09m OD	5.4m OD	4.5	5.5m OD	7
T100	4.18m OD	5.5m OD	8	5.6m OD	12
T200	4.27m OD	5.6m OD	13	5.7m OD	32

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Damage could potentially occur to the embankment under the higher wave height, combined with the T100 water level. More typically initial damage might occur on a T200 water level and 0.75m wave height, with an increased risk of failure and possibly direct flood impact damage to the village if a 1m wave were generated across the estuary. In conclusion, the existing tidal embankment is considered to have both an Serviceability Standard of Protection (sSoP) and Ultimate Standard of Protection (uSoP) in the order of return period of 1 in 200.

With sea level rise, overtopping would increase over time. This is summarised in Figure 2-5 in relation to run-up levels based on the analysis undertaken within the embankment report. The present crest level of the tidal embankment is 5.2m OD.

Table 2-5 Change in run-up level with sea level rise

SLR	0.25m *(2046*)*				0.5m *(2074*)*				0.75m *(2099*)*				1m *(2118*)*			
Wave height range (m)	0.2	0.3-0.4	0.5-0.75	0.75-1.0	0.2	0.3-0.4	0.5-0.75	0.75-1.0	0.2	0.3-0.4	0.5-0.75	0.75-1.0	0.2	0.3-0.4	0.5-0.75	0.75-1.0
MHWS	3.2	3.4	3.5	3.8	3.5	3.7	3.9	4.2	3.8	3.9	4.2	4.5	4.0	4.2	4.5	4.9
T10	4.4	4.6	4.9	5.2	4.6	5.2	**5.5**	**5.4**	5.0	**5.6**	**5.9**	**6.2**	**5.4**	**5.9**	**6.2**	**6.4**
T50	4.7	4.8	5.2	**5.4**	4.8	**5.4**	**5.7**	**5.6**	**5.6**	**5.9**	**6.1**	**6.4**	**5.8**	**6.1**	**6.4**	**6.6**
T100	4.7	5.2	**5.2**	**5.5**	5.2	**5.5**	**5.8**	**5.7**	**5.7**	**5.9**	**6.2**	**6.6**	**5.9**	**6.2**	**6.6**	**6.9**
T200	4.8	**5.3**	**5.3**	**5.6**	**5.3**	**5.6**	**5.8**	**5.8**	**5.8**	**6.0**	**6.3**	**6.6**	**5.9**	**6.3**	**6.6**	**7.0**

Notes: all levels in m OD.

** years are based on UK CP09*

Figure 2-7 shows the relationship between overtopping rates, water levels and wave heights in relation to flood risk to the village (Serviceability Standard of Protection) and failure risk of the embankment (Ultimate Standard of Protection).

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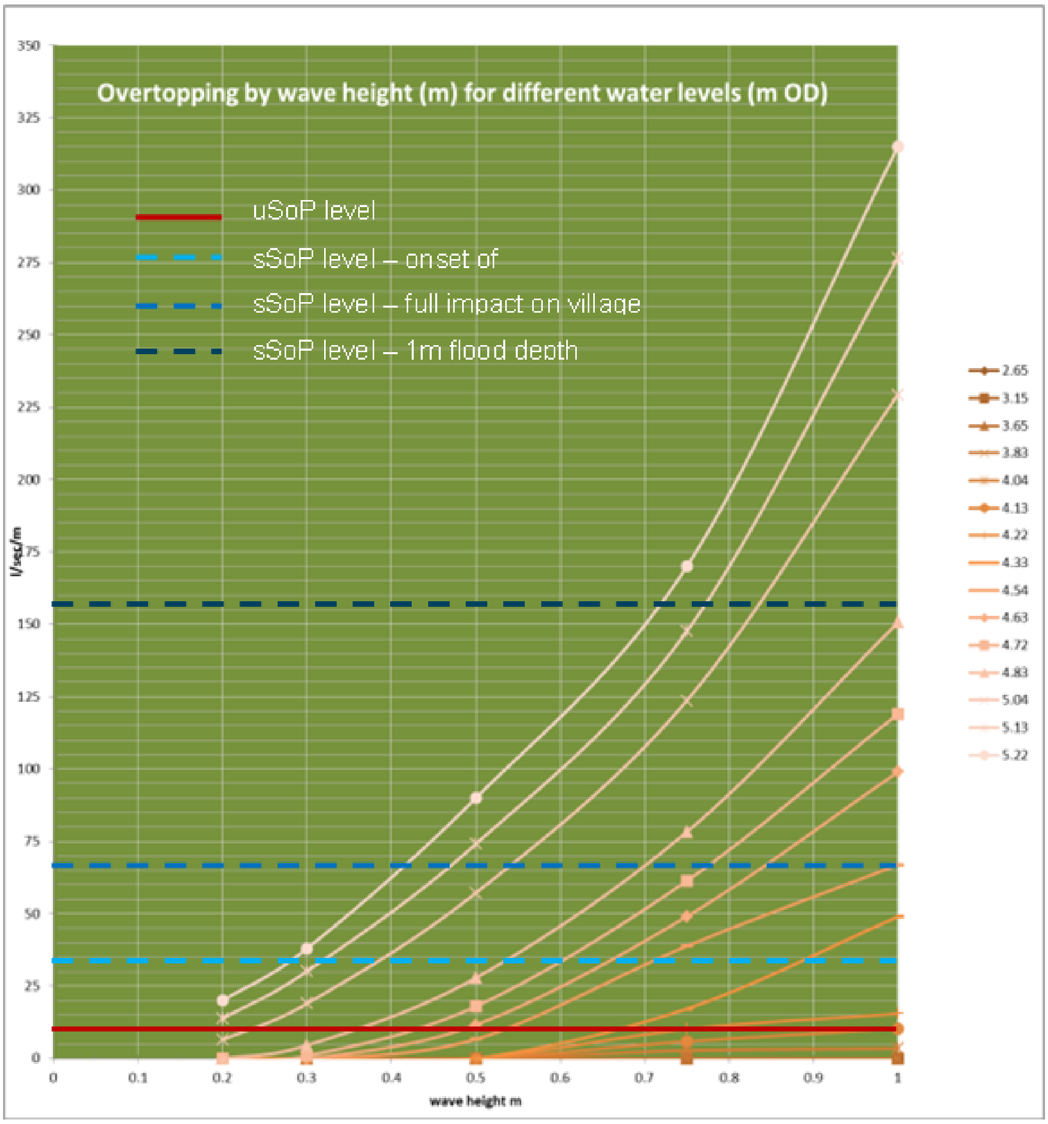

Figure 2-7 Overtopping rates by water level and wave heights

A critical uncertainty associated with this analysis, in addition to that of the rate of sea level rise, is the actual wave exposure along the tidal embankment. This will require review as further information becomes available.

2.3.4 Ground water system

Rigare Ltd were commissioned by Gwynedd Council to establish and monitor ground and surface water levels. Initial results were analysed by Rigare Ltd based on data collected from April 2015 through to August 2016. While the data set at present is relatively limited, the report sets out the preliminary findings. It is intended to continue with this monitoring as part of the on-going review of risks associated with the village. The results of the study provide further insight in to the relationship between the fluvial management system (discussed below) and, with respect to this, the relationship between tidal influences and tidal locking.

The local hydrometric monitoring network comprises both stilling wells (monitoring surface water in ditches) and dipwells (collecting data on the shallow ground water levels). The network is shown in Figure 2-8.

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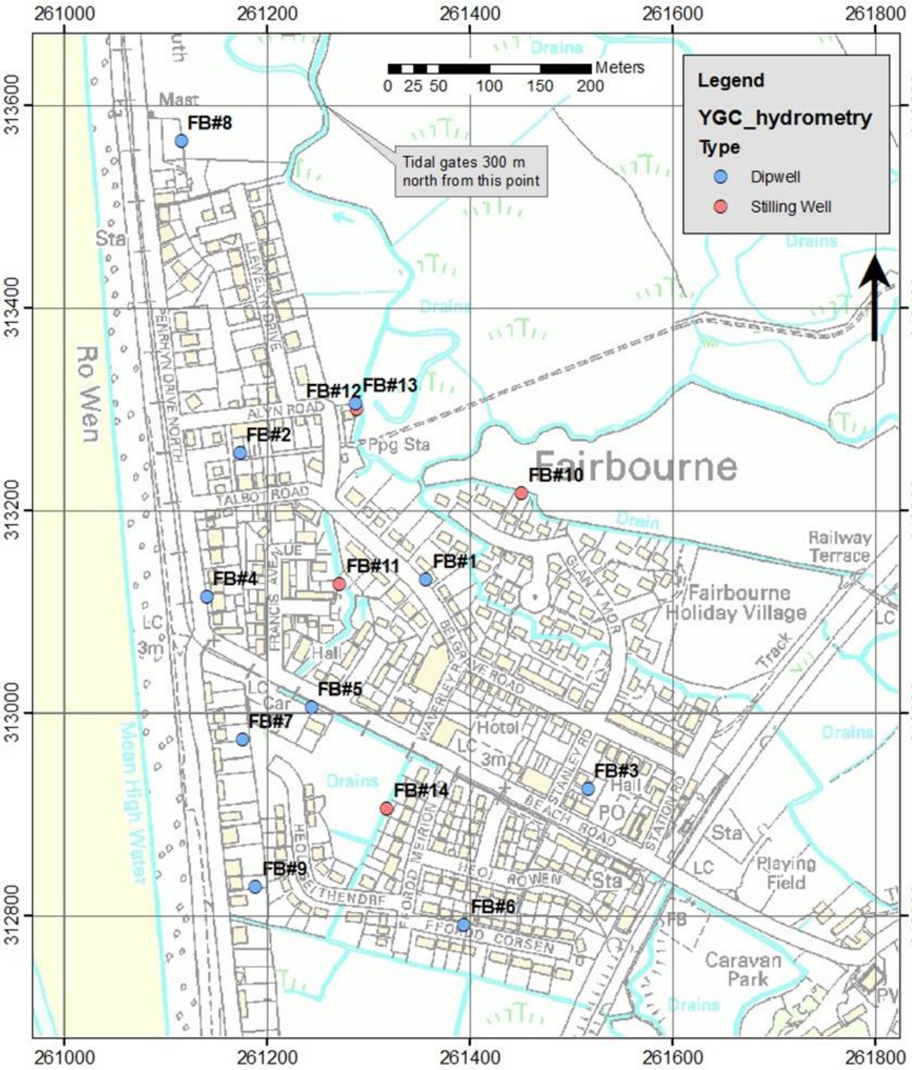

Figure 2-8 The local hydrometric network

The analysis is supported by on-going collection of rainfall data and data related to tidal levels recorded at Barmouth.

The report highlights the important relationship between ground water and surface (and fluvial) water levels, developing a preliminary concept model for the area. It is shown that ground water levels, i.e. the level of the water table beneath residential areas, exhibits a seasonal progression, in line with that recorded for surface water, with higher levels during the late-autumn, winter and early spring. At all of the dipwell locations, the highest sustained groundwater level is the level at which relatively rapid shallow lateral flows to the ditch network, by flow over the surface or within shallow drainage infrastructure (drains, etc), is initiated.

Operation of this rapid shallow lateral flow mechanism is only possible because water levels in the ditch network are generally at least 0.8 m below the maximum sustained groundwater level. If surface water levels rise to the same level as the maximum sustained groundwater level, both will rise in tandem thereafter, almost certainly causing flooding to the land surrounding the ditch network.

It is noted that this came close to happening during December 19th/20th 2015 during the monitoring period demonstrating that it is a real risk. Depending on the temporal distribution and intensity of rainfall, any flooding would probably be short-term as the ditch network would quickly remove excess water when ditch water levels subsided.

Groundwater levels in a small number of dipwells, which are located in central, western Fairbourne, near to the sea wall, exhibit subdued responses to tidal fluctuations; the mechanisms which leads to these responses is currently uncertain.

In summary the key findings of the report are set out below.

- Surface water levels are universally, and unsurprisingly, sensitive to rainfall. There appears to be a lag of around one day between the incidence of rainfall and its effect of surface water levels, which suggests perhaps that the effect is caused mainly by slightly delayed runoff from the inland catchment. It is not unusual for surface water levels to rise by over 0.5 m after a relatively common rainfall event of c. 15 mm. The 27.4 mm event on 19th December 2015 caused the water level at FB#12 to rise by around 0.8 m.
- Surface water levels are also sensitive to the tidal fluctuation of sea level; this is shown by the short-term 'noise' on each of the hydrograph lines. The sensitivity appears to vary positively with absolute water level at any one stilling well; when water levels were low during the early-autumn 2015 twice-daily water level fluctuations caused by the tide were extremely muted, but when water levels were high during winter 2015-6 the twice-daily fluctuations at FB#12 were approaching 0.5 m (Figure 3.1-3). This would be expected because;
    - lower ditch flows during the summer mean that the available storage volume in the ditch channel is filled more slowly when the tidal gates are shut, and
    - there might be freeboard in the ditch when water levels are low, between the monitoring point and the tidal gates, meaning that some time will elapse before the water "backs-up" the ditch from the tidal gates to the monitoring point.
- The detailed groundwater level responses are quite variable, but a common overall response can be identified, in that when there was significant rainfall over a prolonged period, during the November, December and early-January (2015 – 2016) period in Table 2-6, groundwater levels rose until they peaked at a more-or-less constant level (highest sustained level). This behaviour is almost certainly caused by groundwater levels rising to the point where they are 'controlled', relatively close to the local ground surface, by either flow over the ground surface or, more likely, flow in shallow surface water drainage infrastructure. Groundwater levels frequently rise above the highest sustained level, in response to rainfall events, but only briefly. The variation in ground water is shown in Table 2-6.

Table 2-6 Highest sustainable ground water level (HSGWL) and lowest ground water level (LGWL) Fig 3-2-1 Rigare ltd (2017)

Dipwell	Est. HSGWL (mAOD)	Ground Surface (mAOD)	HSGWL (mBGL)	LGWL (mAOD)	LGWL (mBGL)
1	2.20	2.36	0.16	1.41	0.95
2	2.40	2.46	0.06	0.94	1.52
3	2.40	2.52	0.12	1.77	0.75
4	2.55	2.75	0.20	1.34	1.41
5	1.50	?*	?	0.99	?
6	2.25	2.55	0.30	1.67	0.88
7	2.40	2.49	0.09	1.03	1.46
8	3.05	3.10	0.05	1.05	2.05
9	2.00	2.18	0.18	1.51	0.67
13	1.35	1.57	0.22	0.58	0.99

*Notes: * Dipwell completed below ground surface – measurement to be taken during next download*

- the highest sustained groundwater levels at all of the dipwells are all with 0.3 m (30 cm) of the ground surface; at four of the dipwells they are between 0.1 and 0.2 m of the ground surface, and at three dipwells they are within 0.1 m of the ground surface.
- Whilst the highest sustained groundwater levels in Table 2-6, in relation to the ground surface, are perhaps surprisingly high, it is worth noting that this has probably been a characteristic of the hydrological system for a long period of time, and therefore that it is sustainable under current conditions.

2.3.5 Fluvial system

The key report for the fluvial risk the Fairbourne Flood Risk Management Scheme PAR (2011) (Figure 1-2).

There are two main rivers draining the land surrounding Fairbourne; the Afon Henddol and the Afon Morfa (Figure 1-1). The Afon Henddol and Afon Morfa drain in a north westerly direction to the Mawddach Estuary and discharge through tidal outfalls within the Fairbourne tidal embankment. The Afon Henddol flows through the village. Prior to undertaking the recent improvement works, the model calculations (Fairbourne FRMS PAR, 2011) showed that both Afon Henddol and Afon Morfa began overtopping during a 1 in 2 AEP flood event, resulting from an under-capacity channel and limited floodplain.

The new works are understood to have comprised the construction of a new diversion channel, new local defences, replacement of the tidal outfalls and implementation of a small flood storage area. These works are shown in Figure 2-9 and were designed to provide a T200 standard of protection.

The Fairbourne FRMS PAR (2011) indicates that the Afon Henddol, flowing through the village, responds quickly to rainfall due to its small catchment size and adjacent steep sided high ground to the south of the village. These factors increase the fluvial risk with increasing rainfall. The hydraulic model was used to determine the optimal storm duration that would maximise the flooding within the study area. A range of storm durations were investigated under 1% AEP event conditions and it was found that a 10 hour storm produced the largest flood extent. The timing of the hydrograph peaks was subsequently adjusted to coincide with the tide locking period to provide a worst case scenario.

It is noted that from the surface water monitoring data (Section 2.3.4) that there appears to be a lag of around one day between the incidence of rainfall and its effect of surface water levels. The significance of this is uncertain in terms of the model results presented in the Fairbourne FRMS PAR (2011).

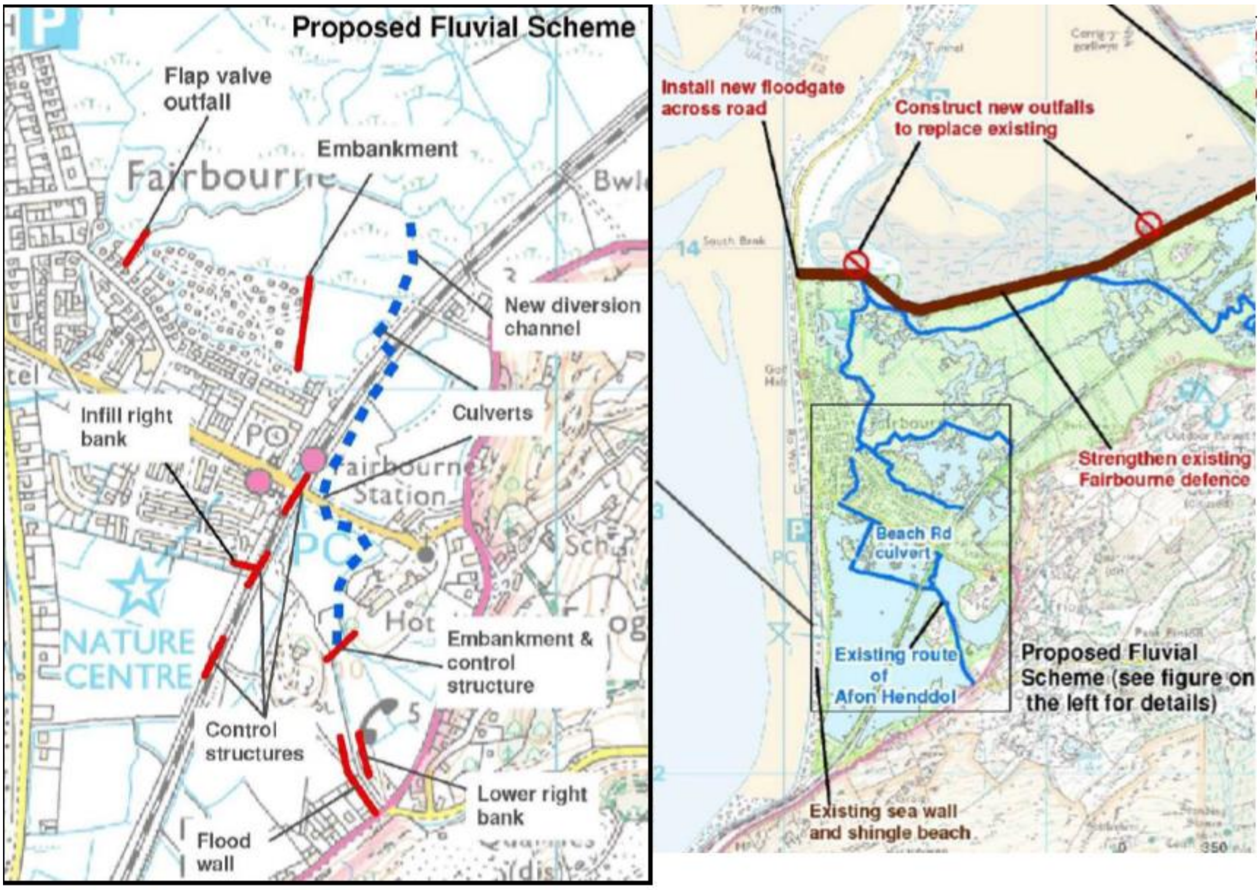

Figure 2-9 Measures proposed by the Fairbourne FRMS PAR, 2011 to reduce fluvial flood risk

As part of the analysis, as a sensitivity test, inflows were increased by 20% (equivalent to possible change due to climate change). This resulted in the mean peak water level in the Afon Henddol rising by 60mm on average with a maximum of 130mm.

The Fairbourne FRMS PAR (2011) provides results from the model at various locations within the fluvial system with the improved system. A comparison has been undertaken of three such points with locations where surface water has been monitored. While these points may not coincide precisely, the comparison is still felt to be valid. The monitoring points taken are FB12, FB11 and FB14 as shown in Figure 2-8. The corresponding model points and comparison of results are shown in Table 2-7. Monitoring data is taken for the significant rainfall event associated with the 19th Dec 2015. The modelled condition was for a T100 event.

Table 2-7 Comparison of monitoring with Fairbourne FRMS PAR, 2011 model results

Location	FB 12	FB 11	FB 14
	HEN01 0771d	HEN01 0939	HEN02 0060
Monitored level 19/12/2015	1.6m OD	2m OD	2.1m OD
Modelled level T100	2.17m OD	2.19m OD	2.21m OD

This tends to confirm that the event was relatively significant based on the water levels at FB11 and FB14, however, there appears to be some discrepancy when comping levels at FB12. It is not known whether the diversion relief channel was activated during the event.

2.3.6 Influence of Tidal Locking

The Fairbourne FRMS PAR (2011) modelling report records that water levels in the watercourse are very sensitive to the backing up effect that occurs when the tidal outfall is shut and the watercourse is not able to drain.

FURTHER DETAILS ARE AWAITED FROM Rigare Ltd

3 Current and future risk

3.1 Discussion of defence system

From the above assessment of source and pathway conditions, it may be seen that, while there are critical areas of interaction between the principal components of flood risk (e.g tidal locking associated with increased rainfall), the different sources and pathways of flood risk pose different levels of risk over different time periods. It has to be stressed, however, that failure or exceedance of design conditions with respect to any specific flood pathway results in impacts on the common receptor, i.e flood risk to the village.

Over the short term it is the open coast which poses the greatest risk at present, principally due to the condition and vulnerability of the defence at Friog Corner.

In terms of the open coast and the tidal embankment the main risk arises due to failure of the defences (i.e failure of the structural integrity of the defence with the potential for breaching to occur). Such failure would result in an immediate and substantial reduction in the standard of defence provided to the village. If maintained (and reinforced as necessary) but not raised, these structures would continue to provide a higher standard of protection (compared to the failed condition) but this standard of protection would reduce over time due principally to sea level rise (i.e increased overtopping).

Subsequent to the works undertaken to the fluvial system, the risk directly related to fluvial flooding has been significantly improved. Over the longer term, however, with increased rainfall during the winter months, this standard of protection will reduce. Potentially more crucial, will be the influence of tidal locking, both on the fluvial, surface and ground water systems. While over the short to medium term this is not seen to be critical, over the longer term, particularly in terms of the interaction between the surface water levels and the potential impact on ground water, this risk pathway could have an increasing impact on the village and the infrastructure supporting village life.

To a degree, therefore, the different flood risk pathways may be considered separately, recognising that potential damages arising from any risk pathway will affect the village as a whole.

The following sections consider specifically the different areas of vulnerability and standards of protection provided by each aspect of defence. Section 4, then considers the implications of this in terms of potential management response.

3.1.1 Existing Standard of Protection

The existing Standards of Protection (SoP) are presented below:

- The Open Coast Study (Royal HaskoningDHV, 2018) concluded that at present, and on the assumption that the weakness at Friog Corner is addressed in the short term, the defences provide generally a T200 SoP to the village.
- The Embankment Technical Report (Royal HaskoningDHV, 2017) concluded that at present the tidal embankment provides around a T200 SoP to the village. Under exceptional conditions wave heights between 0.75 and 1m might be generated (the upper wave loading case), reducing the SoP to a T100 level.
- The measures in the Fairbourne FRMS PAR (2011) in relation to fluvial risk have been implemented. It is estimated that the measures provide a T200 SoP to the village against fluvial flooding.

- Ground water levels are shown to be high and the most obvious source of flood risk at Fairbourne is a large (sustained and/or intense) rainfall event which causes water levels in the ditch network to rise close to the ground surface, such that in turn, the rapid shallow lateral flow mechanisms, which transfer water to the ditch network, would be unable to operate. However, this appears to have been a sustainable feature of the hydrology of the area over the longer-term, with only local impacts.

Summarising this present situation, it is assessed that:

- There are 430 properties at risk of tidal flooding during a 1:200 (0.5%) AEP flood event, due to a breach in the existing tidal embankments or open coast defences (Fairbourne FRMS PAR, 2011); and
- There are also 58 properties at risk from fluvial flooding from the Afon Henddol during a 1 in 200 AEP flood event. No properties are identified as being at risk from fluvial flooding from the Afon Morfa (Fairbourne FRMS PAR, 2011).

3.1.2 Defence Vulnerability to Climate Change

3.1.2.1 Open coast

The Open Coast Study (Royal HaskoningDHV, 2018) draws the following conclusions regarding the changing flood risk related to climate change:

- With 0.25m sea level rise, purely from wave overtopping of the defences, the SoP provided to the village potentially reduces to around a T50 level;
- Associated with this, is the risk of defence failure or breach. Again, but this time due to either increased wave overtopping or erosion, with 0.25m sea level rise (nominally by year 2045), some sections of defence might become vulnerable to failure;
- Over time, clearly, both due to the risk of increased overtopping and erosion, defences become more vulnerable. With 0.75m sea level rise (nominally by year 2099), the SoP to the area, without any improvement to defences could be at a T1 level; and
- Due to continued erosion, the most immediately vulnerable sections of defence are at Friog Corner and along the southern section of defences between Friog Corner and the main Village area. The study has mapped this vulnerability by area, over time, as is shown in Figure 3-1.

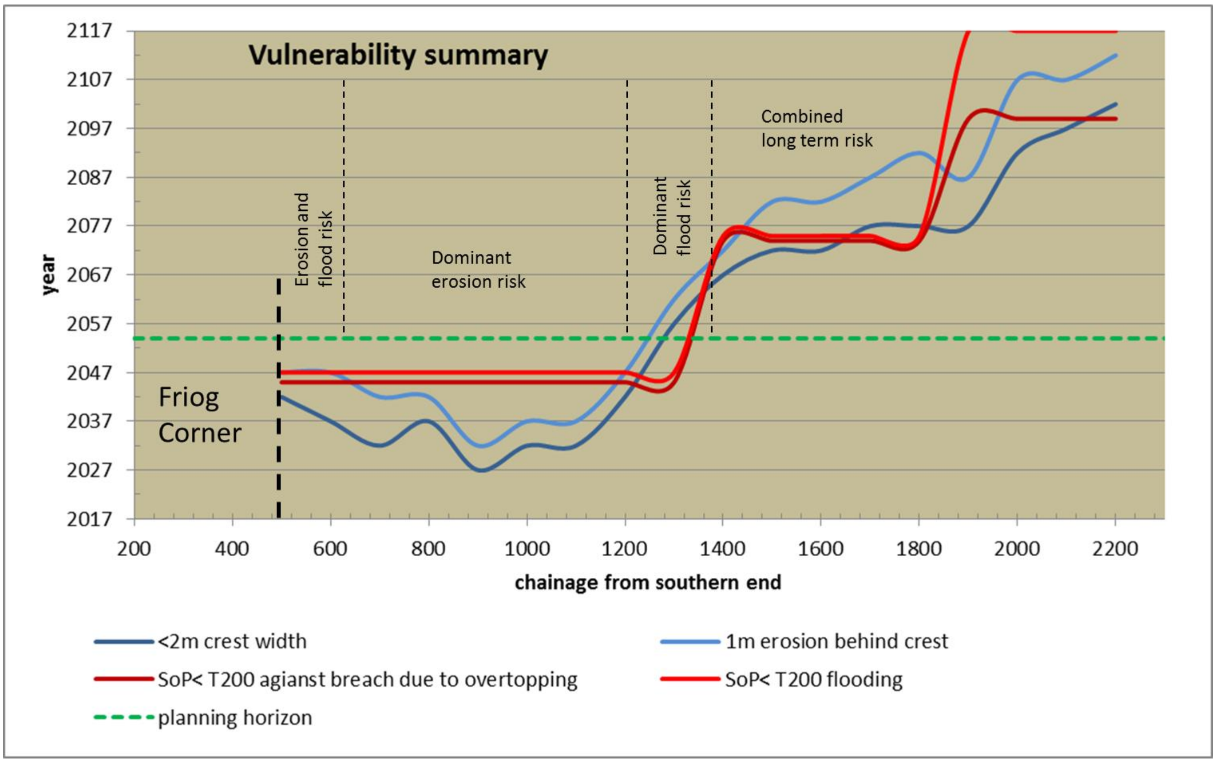

Figure 3-1 Combined critical risk pathway by length along the frontage. The chainage location is shown in Figure 2-5.

3.1.2.2 Tidal Embankment

Table 3-1 shows the assessment of the change in Standard of Protection (SoP) provided by the existing embankment for incremental increases in sea level under different wave loading cases (wave loading cases described in section 2.2.2). The table shows that the Standard of Protection at present is T200 and the limiting scenario is potential failure of the embankment, rather than overtopping and flooding.

The table also shows that, under the probable wave loading scenario, the embankment provides a T75 SoP while sea level rise remains below 0.5m, which is considered a minimum Standard of Protection. Under the upper wave loading scenario, the SoP related to potential failure is likely to reduce to a T75 with 0.25m SLR.

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Table 3-1 Change in Standard of Protection (SoP) for potential failure, onset of flooding, flooding of the village and catastrophic flooding, with Sea Level Rise (SLR) and different wave loading cases

SoP loading assessment	uSoP (potential failure)			Assuming no Failure								
				sSoP (onset)			sSoP (full village)			sSoP (catastrophic)		
	Lower loading SoP	Probable loading SoP	Upper loading SoP	Lower loading SoP	Probable loading SoP	Upper loading SoP	Lower loading SoP	Probable loading SoP	Upper loading SoP	Lower loading SoP	Probable loading SoP	Upper loading SoP
Present day	T200	T200	T100	T200	T200	T200	T200	T200	T200	T200	T200	T200
0.25m SLR	T200	T200	T75	T200	T200	T100	T200	T200	T200	T200	T200	T200
0.5m SLR	T200	T75	T20	T200	T200	T100	T200	T200	T200	T200	T200	T200
0.75m SLR	T150	T20	T10	T200	T150	T75	T200	T200	T75	T200	T200	T100
1m SLR	T20	T5	T2	T100	T50	T20	T100	T50	T20	T150	T75	T25

The Embankment Technical Report concludes that:

- There is a reasonable expectation that the existing embankment would continue to provide a minimum SoP (to a T75 level) through to 2054 (the planning horizon of 40 years) without the need for major works to improve the structure. This would critically depend on actual rates of sea level rise and on the present assumptions as to wave loading.

3.1.2.3 Fluvial System

The Fairbounre FAS PAR (2011) Hydraulic modelling report asssessed the potential flood risk associated with developement of the recent scheme, considering the T100 condition allowing for increased rainfall over a 50 year period. This assessment of the extent of flooding is shown in Figure 3-2, together with the initial assessment of flood risk extent prior to the development of the scheme under similar conditions.

The Fairbourne FRMS PAR (2011) notes, however, that the water levels in the Afon Henddol are very sensitive to the backing up effect, that occurs when the tidal outfall is shut and the watercourse is not able to drain. This has the potential to reduce the efficiency of the scheme over the longer term. This is an aspect of risk that would need to be considered further in development of the Masteran. However, based on the existing information provided in the PAR, it has been assessed, at this stage, that over the Project Planning Horizon (2014 – 2054), accepting that the standard of protection may reduce to a T100 SoP no further improvement would be required. It is only beyond this period of time that further works would then be necessary, with the potential for fluvial drainage to be pumped.

3.1.2.4 Surface and Ground Water

Based on the preliminary results of the ground water level monitoring, the critical threshold in terms of vulnerability might be around the point where sea level rise is in excess of 0.5m. It has been assessed that at such a point in time, there might be a back-up in surface (fluvial) water such that this starts to constrain the shallow ground water drainage. This would then have the consequence that ground water might, more regularly, and over a longer period of time, reach critical levels such that surface water flooding might occur over a wider area under heavy rainfall conditions.

There is some indication that areas close to the sea front might also be influenced more strongly by sea level rise. However, this needs further examination as a more extensive data set is available.

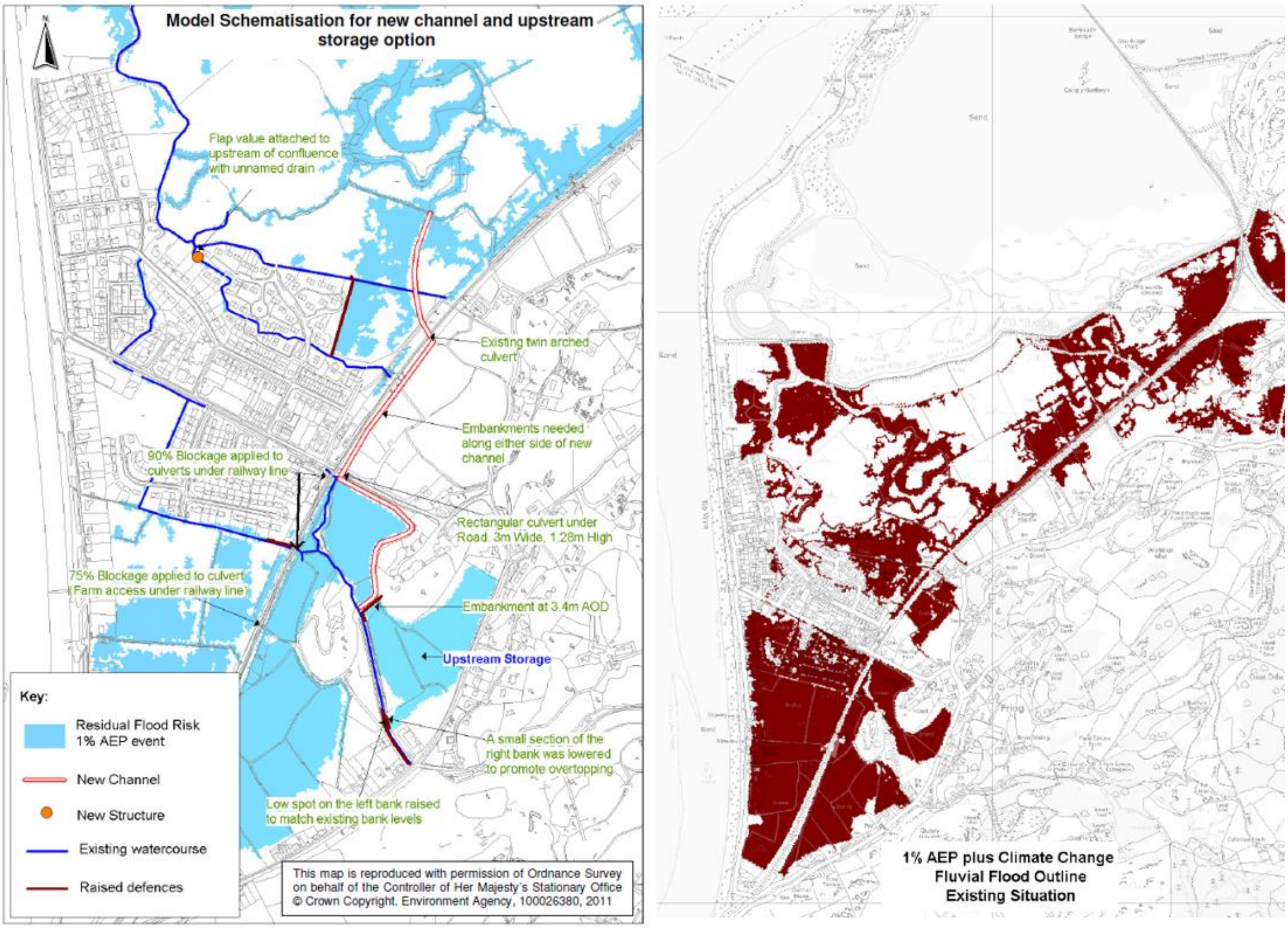

Figure 3-2 Fluvial flood outlines for an T100 flood event with climate change (extracted from Fairbourne FRMS PAR 2011)

3.2 Summary of combined future risk

There is an on-going problem of erosion of the open coast, principally effecting the southern half of the frontage at present. This is likely to continue and will be made substantially worse with sea level rise, increasing the risk to the village.

With sea level rise, there would be a decreasing standard of protection afforded to the village by the tidal embankment over the medium term. This risk may be localised over the medium term.

In both these cases the risk substantially increases beyond the Project Planning Horizon and in both cases the risk has the potential to affect the whole area of the village.

The risk directly associated with the fluvial system is likely to be more localised and has over the medium term (50 years) been considered in developing the design for the recent improvements. Associated with this, however, is the potentially more widespread impact of change within the general surface and ground water systems. This, based on the limited period of monitoring data, is more likely not to substantially impact of the area over the medium term but would need to be resolved if the area were defended in to the long term.

3.3 Potential damages

3.3.1 Discussion of existing information

The Fairbourne FRMS PAR (2011) estimated the Present Value benefits of the (currently implemented) mitigation measures, with a 100 year appraisal period. Table 3-2 shows that the benefits considering tidal flooding are about £70M. While the analysis was undertaken assuming a breach condition of the tidal embankment, the Fairbourne FRMS PAR (2011) states it is reasonable to assume that a breach of the open coast defence would give rise to similar flood conditions, with similar consequences in terms of damages.

Table 3-3 shows that the benefits of the Fairbourne FRMS PAR (2011) measures considering fluvial flooding are about £3M.

Table 3-2 Summary of Present Value damages and benefits for tidal flooding (Fairbourne FRMS PAR, 2011)

	Damage (PVd)	Damage Avoided	Benefits (PVb)	Key non-monetarised Benefits
Option T1 – Do Nothing	70,044	0	0	
Option T2 – Do Minimum	60,830	9,214	9,214	
Option T3 – Strengthen	27	70,017	70,017	

Table 3-3 Summary of Present Value damages and benefits for fluvial flooding (Fairbourne FRMS PAR, 2011)

	Damage (PVd)	Damage Avoided	Benefits (PVb)	Key non-monetarised Benefits
Option F1 – Do Nothing	3,430	0	0	
Option F2 – Do Minimum	1,271	2,159	2,159	
Option F3 – Bypass channel (1 in 100yr SoP)	309	3,122	3,122	Reduces risk of limited maintenance issues within the system, as floodwater taken away from village.

3.3.2 Assumptions made with respect to economic assessment

The main area of damages occurs as a result of catastrophic flooding as a result of a breach in either the open coast defences or the tidal embankment. As such, in determining the above damages, the majority of damages are taken in terms of "write off" values associated with properties, rather than annual averages damages associated with occasional flooding. The damages are not therefore determined based on either the probability of event occurrence or on the change in the standard of protection.

In considering the vulnerability of the defence system, it has been assessed that the critical mechanism for flooding would still be on the assumption that overtopping would cause failure. While it is recognised that if works were undertaken to reinforce rather than raise defences there would still be some residual risk of flooding (due to threshold exceedance), this is not the critical issue in terms of damages.

In developing this report, therefore, it may reasonably be assumed that, while there would be some relatively minor residual damages from residual flood risk, the critical level of damages would remain the same, for the open coast and embankment, at a level of £70M. Because these damages are "write off" values, the value remains the same in real terms, whether do nothing defence occurred now or at some time in the future. Based on this assumption, therefore, the benefit in terms of defence may be assessed in terms of the discounted Present Value delay.

If works were undertaken now, as a result of an imminent risk of failure (such as exists in the case of Friog Corner), then the level of benefits may be determined in terms of the extended period of time before these same damages might occur, in the future, as a result of failure in some other component of the defence system.

In taking this approach, based on the fixed baseline damages of £70M, it is possible to assess the benefits in terms of different stages of work necessary to secure the area. At the strategic level of this overview, and obviously looking forward to the potential need for works over any period of time, the cumulative cost of defence has to be taken in comparison with the discounted benefit that might be derived from such works.

It is recognised that the same approach cannot be taken in relation to fluvial or surface water flooding. This would require a more detailed assessment of the probability of flooding under any given event. The assessment, however, recognises that ultimately the critical risk, certainly over the Project Planning Horizon is in relation to the open coast and flood risk from the tidal embankment. Without these two defence systems in place, there would be little justification for taking other forms of flood risk management. As such, while other aspects of defence management would need to be assessed in more detail as the risk arises, it is reasonable to assume that some form of action might be required in the future if the main risk pathways have been addressed.

4 Management Response

4.1 General Discussion

From the above information, it may be concluded that at present (and assuming works are undertaken to address the immediate issues faced at Friog Corner), the defence system provides a good Standard of Protection; typically addressing protection under T200 conditions for all principal sources of risk. It is noted that ground water at present can, on rare events, come close to the surface but that shallow drainage does allow this to dissipate quite rapidly into the surface water system. This may have very local consequences but is a situation that has been on-going historically.

Over time, and with climate change, the situation will change, in part due to the increased intensity of rainfall but more critically due to sea level rise and the on-going changes at the coast (as a result of underlying change in sediment supply). The change in coastal dynamics imposes increased pressure due to erosion, while sea level rise impacts on:

- Overtopping at the open coast (with increased risk of defence failure in addition to basic flooding due to overtopping);
- Increasing risk of overtopping of the tidal embankment (particularly in terms of potential damage and breach of the defence structure); and
- Increasing risk of tidal locking with the associated influence on the surface drainage system and ground water.

These influences, therefore, tend to support the conclusions set out within the SMP2, that over time the defence of the area will require significantly greater investment in risk management and that the village would become increasingly vulnerable to failure of any component of the present system.

The SMP2 provided a preliminary assessment of how the need for management might change over time, concluding that significant change in approach and investment might be required as sea level rise reached a level of around 0.5m. This has now been considered in more detail through the work undertaken by the Technical Group, refining this assessment in relation to the different risk pathways.

This work, drawn together in this review, shows that the most critical area of risk comes from the open coast, where it is anticipated that continuing works will be required over the next 15 to 40 years to address the increasing threat. Over the slightly longer term, and still within the nominal 40 year planning horizon (2014 to 2054), it is likely that some works will be required to maintain the Standard of Protection associated with the tidal embankment. Both in relation to the open coast and the embankment, these more immediate works would only provide defence over the short to medium term, with the need for more major works to be undertaken beyond that.

The review also concludes that, in the longer term there is likely to be the need for a different approach to management of the fluvial, surface and ground water systems.

This is all summarised in Figure 4-1, updating the assessment provided within the SMP2, based on timescales associated with the High 95% sea level rise scenario.

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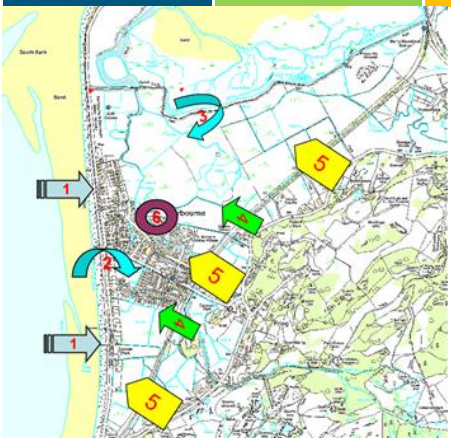
Sea Level Rise (m)	**0**	**0.25**	**0.5**	**0.75**	**1**
Year (based upon High 95% climate change projection)	*2018*	*2045*	*2074*	*2099*	*2118*
Coastal change	*No increase in net erosion*	*Erosion southern shoreline and start of erosion to village frontage*	*Southern shoreline 22m erosion, village 18m erosion.*		
Wave overtopping and erosion at the open coast	*T200 SoP, Friog corner works*	*T50 SoP, some sections of defence might become vulnerable to failure, works on southern section required.*	*New defence to the northern section will be required.*	*Defence needs to be raised further.*	
Wave overtopping and tidal embankment breach	*T200 SoP*	*Reduction to about T75 SoP, local strengthening required.*	*Embankment needs to be raised.*	*Embankment needs to be raised further*	
Tidal locking			*Potential impacts of surface water and ground water*		
Ground water system	*Low risk*	*Low risk*	*Pumping*		
Fluvial System	*T200 SoP*	*Reducing SoP*	*Improvements required.*		
Residual risk					



[RJ2]*Figure 4-1 Changing Risk overview*

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A more detailed summary of this is provided in Sub-Section 4.2 below with respect to individual components of the defence system. The review then draws this together, initially considering the implications in terms of long term defence, by further testing the conclusions set out in the SMP2 that on-going long term management of the area would lead to an unsustainable situation.

Cost profiles for continued defence of all risk pathways are considered and this is related to the potential damages identified in Section 3.3.2 of this review. This is considered below in Sub-Section 4.3.

The review goes on then to consider in further detail the potential approach and investment profiles that are likely to be required to deliver flood protection over the Project Planning Horizon, considering also the uncertainties and potential range of costs that might be required to extend the Planning Horizon beyond 2054. This is discussed and set out in Sub-Section 4.4.

4.2 Defence Component Analysis

4.2.1 Coastal Defence

Within the planning horizon, works need to be carried out to reduce the risks at the section from Friog Corner to South Beach. Figure 4-2 shows the typical works that might be required to deliver an acceptable SoP for defence up to 2054 (within the planning horizon). In the Open Coast Study, two outline design profiles have been developed along the open coast section:

- A **full revetment**, where the beach has already been substantially lost. The outline costs are estimated at around £9.6m;
- **Crest defence**, providing shorter term protection to existing defence. The outline costs are estimated at round £8.4m.

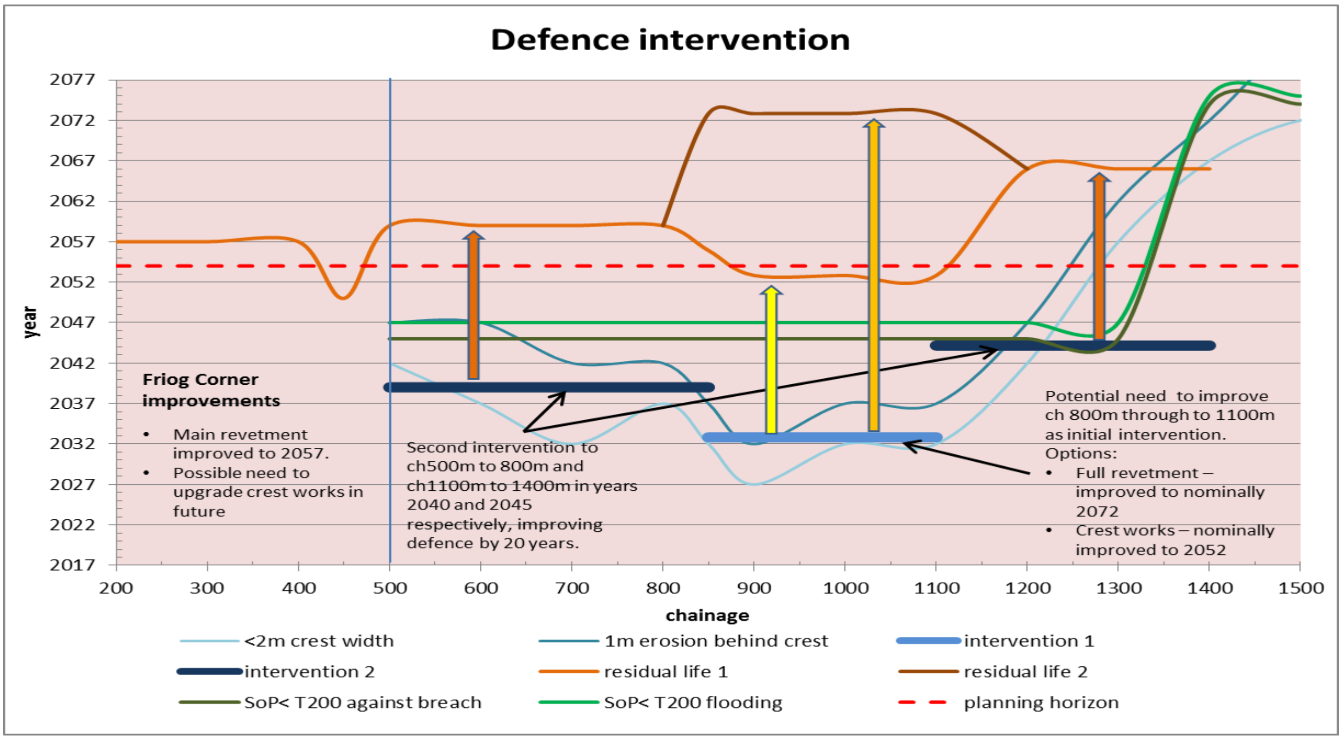

Figure 4-2 Timescale for future interventions. The chainage location is shown in Figure 2-5.

Critically the choice between options to specific lengths depends on how management might be taken forward into the future. If as set out above the aim is to maintain defences up to the Planning Horizon but not necessarily beyond, then this would influence the level of defence provided at any point in time.

Over the longer term, beyond the planning horizon, all defences in the southern section would need to be raised and reinforced. The outline net cost estimate indicates that these extra works amount to £21M. In addition, also by around 2070 there would be an increased risk both from overtopping and erosion over the northerly section of defence, between chainage 1400m and 2200m. The outline additional cost estimate for the works on the northern section is about £14.5M. In to the future, to maintain defences and an acceptable standard of protection over 100 years from present, there would be the need for further works.

4.2.2 Tidal Embankment

The Embankment Technical Report (Royal HaskoningDHV, 2017) concludes that in principal, the assessment made in the SMP2 is valid in identifying that, around the level of 0.5m sea level rise, significant improvements would be necessary purely to maintain a minimum Standard of Protection (T75) to the village. Depending on the climate change scenario, works within the planning horizon (up to 2054) might cover:

- Local strengthening of the embankment; and
- Full length improvements.

In the case of UK CP09 Med 95%, works are likely to be localised (**local strengthening**), given that there is only the need to maintain an acceptable SoP over a few years. The estimated costs for these works are £150k - £200k.

In the case of the UK CP09 Med 95% (upper loading case) and H++ (probable loading case) it might be possible to only undertake local strengthening to the embankment where there has been identified specific weakness, in order to maintain a reduced but still acceptable standard of defence through until 2054. This would critically depend on the degree of possible wave damage.

It may however, be necessary, in the case of the High 95% climate scenario, to raise the embankment over its full length (**full length improvements**), given that the defence might become vulnerable, potentially, some ten years before the Planning Horizon in year 2054. Works might typically involve strengthening of the embankment against wave damage and increasing the height of the embankment by up to 1.3m. The estimated costs for these works are £4M - £4.5M.

Over the longer term, if management were continued beyond the Planning Horizon, more substantial works would be required, by raising the embankment to higher levels. The design level of the embankment is currently set at 5.2 mOD, over the longer term there would be the need to raise the defence to 6m OD (Med 95% climate scenario and probable wave loading) up to 8.1m OD (H++ climate scenario and upper wave loading). The outline cost estimates for these options ranges from £11M up to £25.5M.

As with the open coast, there would be the need to raise the embankment still further to provide protection over a 100 year period.

As with the open coast the approach to management over the shorter term would depend on the plan for management in to the future. Towards the end of the Planning Horizon Period, it might only be necessary to undertake more minor works, such as some raising of the embankment. If it were planned to extend management in to the future then more major investment might be required, justified over a longer time period.

4.2.3 Fluvial, Surface and Ground Water

FURTHER DETAILS ARE AWAITED FROM Rigare Ltd

4.3 Response in long term management with Climate Change

Critical to the assumptions made within the SMP2 is that there would be a substantial increase needed in investment in defence, alongside the concern that such improvements in defence would set in motion an expectation of further works into the future. This may be considered in further detail based on the evidence presented above.

On the basis of long term management, the general cost profile would be as set out in Figure 4-3. This shows the need for works, principally in relation to the open coast over the short term, with the increase in costs occurring into the future. In undertaking works through to 100 years in the future, it has been taken that works in the future would all be designed to a standard that would provide protection typically over the following 50 years.

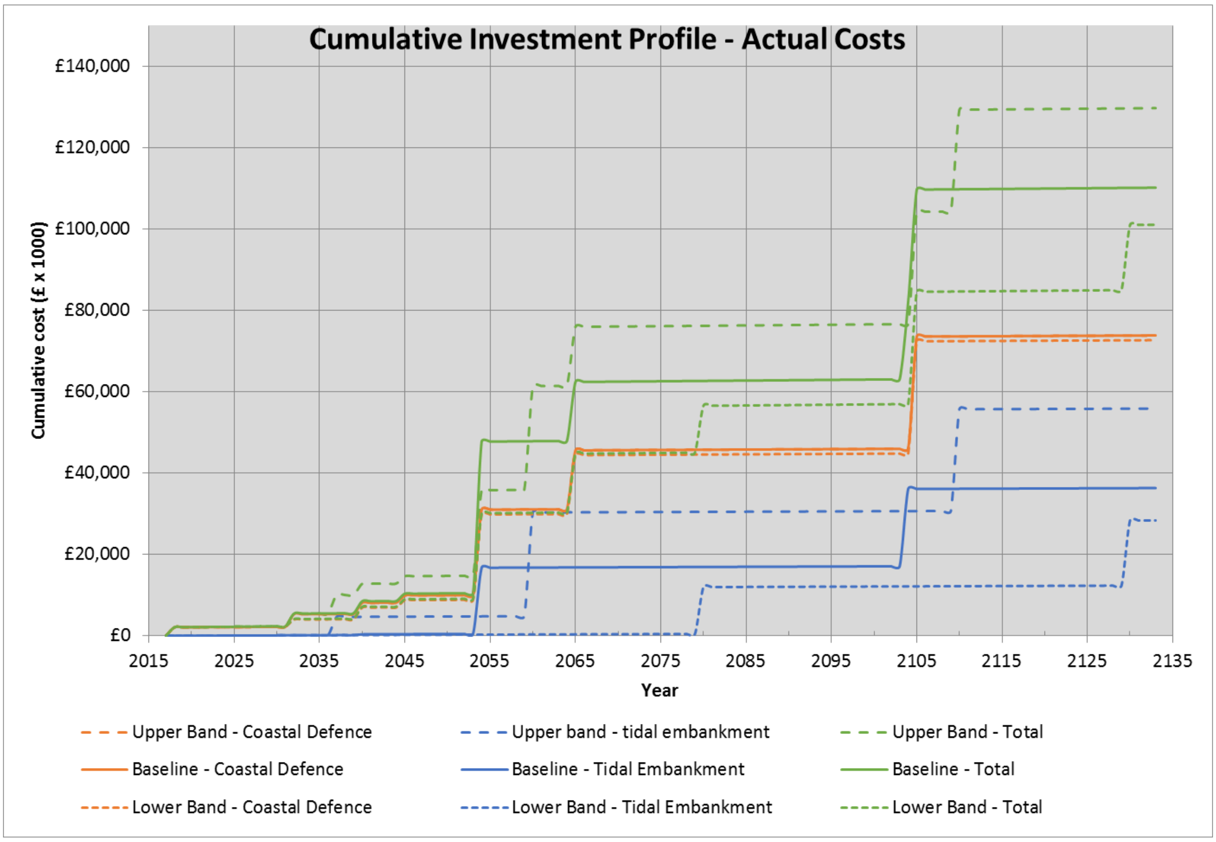

Figure 4-3 Long Term Cost profile for required long term works. The baseline is based on High 95% climate scenario

This cost profile shows that the maintaining the minimum Standard of Protection will cost around £10M within the Project Planning Horizon (subject to additional works potentially required in relation to the

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embankment). Beyond 2054, the costs increase significantly, initially as a result of further works to the coastal defence and the need to raise the embankment beyond its current 50 year design life. By around 2065 the northern section of the coast is also likely to need to be defended. The combined works, together with costs to address surface and ground water, increases the cumulative costs to about £64M, to provide protection through to around 2105. If extended to cover the full 100 years (and assuming continued defence for a further 50 years (to around 2155) then the total cumulative costs would rise to around £115M.

It should be noted that there is greater uncertainty associated with costs for the embankment due to the greater direct influence of sea level rise. This is reflected in the shift in costs in relation to when different degrees of sea level rise are realised. I.e. under the lower cost profile, based on the UK CP09 Med95% climate change scenario with lower wave heights, the cost for raising the embankment might possibly be delayed until 2079. Under the high cost profile, based on UK CP09 H++ scenario, some costs might be expected to occur in 2036, with further improvement costs in 2060 and again in 2110. While costs along the open coast are sensitive to sea level rise, the main driver is when defences become vulnerable to erosion. In many ways, there is greater uncertainty associated, more locally, at the open coast in the earlier years depending on when local areas might be affected.

Table 4-1 provides further detail of this outlie schedule based on the UK CP09 high 95% climate change scenario. The costs shown in the table include for on-going maintenance costs over the period between when works are undertaken and when further works are carried out. Present Value costs (PVc) are also shown, discounting costs to a present day baseline.

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Table 4-1 Costs with time based on High 95% climate scenario

Time period (year)	Open coast		Tidal embankment		Fluvial/ surface ground water		Outline economic assessment assuming incremental improvements over time in response to change in conditions.					Short description of works
	Cost (£k)	PVc (£k)	Cost (£k)	PVc (£k)	Cost (£k)	PVc (£k)	Total PVc (£M)	Discounted delayed damages PVd (£M) Without scheme	Discounted delayed damages PVd (£M) With scheme	PVb £M	BCR	
2018	2,223	2,122	120	94	198	157	2.4	70	43.2	27	11.3	• Improvement to Friog Corner
2032	3,170	1,887	53	27	106	56	2.0	43.2	32.8	10.4	5.3	• coastal Intervention 1 (fig 4-2)
2040	2,760	1,250	245	109	66	28	1.4	32.8	27.7	5.2	3.7	• coastal Intervention 2 (i) plus crest wall, (Fig. 4-2) • local strengthening tidal embankment
2045	1,860	709	60	22	119	44	0.8	27.7	24.2	3.5	4.5	• coastal Intervention 2(ii) (Fig 4-2)
Summary of cost to 2054	**10,013**	**5,968**	**478**	**252**	**489**	**285**	**6.5**	**70**	**24.2**	**45.8**	**7.1**	**Total estimated works to provide defence to 2054**
2054	21,098	7,063	16,625	5,514	[GJ(3] 145	42						• Coastal works to Friog and southern section of frontage. • Raising tidal embankment.
2065	14,975	3,576			515	82						• Coastal works to northern section of Village area
Summary of cost to 2105	**36,073**	**10,639**	**16,625**	**5,514**	**660**	**124**	**16.3**	**24.2**	**8.2**	**16.0**	**0.98**	**Total estimated works to provide defence from 2054 to 2105**
2105	28,100	3173	22,140	2,946	686	46						• Raise coastal defence over full length in line with sea level rise (50 yrs.). • Raise tidal embankment over full length in line with sea level rise (50 yrs.).
Summary of cost to 2105	**28,100**	**3173**	**22,140**	**2,946**	**686**	**46**	**6.2**	**8.2**	**2.4**	**5.8**	**0.94**	**Total estimated works to provide defence beyond 2105 based on 50 yr. design life.**

Figure 4-2 also includes an outline strategic economic assessment for future management. This indicates that over the short term, based on the delay in damages (benefits), there is a strong economic argument for continued defence to an acceptable standard of protection to the village. This has been assessed for both individual phases of work and over the whole planning horizon, through to 2054.

Individual stages of work are assessed in terms of the cost of each phase considered in relation to the delay in terms of damages until the next phase of works might be anticipated. Clearly at each phase, there would need to be further consideration of the actual extent of works, the detailed approach that might be required, considered in relation to the risk and the potential benefits that would be derived. This would also need to consider the history of maintenance and the forward projection of maintenance. At present maintenance is based on estimates included in previous reports such as the Fairbourne FRMS PAR (2011).

Looking further ahead, clearly there is greater uncertainties, not least in terms of the acceleration in the rate sea level rise. Over a ten year period, at present, sea level rise might be in the order of 30mm. In the future, over a ten year period in 2105, sea level might rise by around 110mm. This is taken in to account, basing costs for works on those works necessary to provide a 50 year design life.

Under the baseline UK CP09 scenario, it may be seen that the economic justification for works substantially reduces, such that the benefit cost ratio (BCR) for works potentially in 2054 is less than unity (0.98), and that further into the future the BCR continues to reduce (0.94 by year 2105).

It should be noted that damages are based on avoidance of catastrophic failure, taking capped values for assets at risk (as explained in Section 3.3.2). No allowance has been made for more incidental flood damages (as seen in 2014). As such no allowance has been made for residual flooding due to exceedance of the design standard. With accelerating sea level rise into the future, towards the end of any 50 year design life period, there would be increasing risk of an event exceeding the design criteria.

Within the Masterplan, consideration has to be given to the management response should, at any time, a catastrophic exceedance of design standard occur. This has to be linked to other factors associated with the progress towards broader adaptive management, not least in terms of flood warning and response to a flooding incident.

The overall conclusion from the above assessment supports the higher level assessment made in the SMP2. In line with this, a further assessment has been undertaken in relation to the initial short to medium term period during which defences would be maintained. This considers the key risks in terms of the investment profile.

4.4 Assessment of Management Requirements over the Project Planning Horizon

Within the Project Planning Horizon, maintaining the minimum Standard of Protection can be justified based on flood damage of about £70M. In this section the costs are detailed further. This review is done based on a baseline and including a lower and upper cost band. An overview of the costed scenarios is given in Table 4-2.

Table 4-2 Overview of costed scenarios

	Coastal Defence	Tidal Embankment	Ground water/fluvial
Governing factors	The principal risk is associated with erosion in the short term. Limited sensitivity based on type of response.	Critical to rates of sea level rise and associated uncertainty over wave exposure. Critical to timing and degree of embankment raising.	Relatively low initial risk based on monitoring. Principal factor on tidal locking.
Upper Band	Assume need for revetment at intervention points.	UK CP H++, high cost.	Generally covered in system maintenance costs.
Baseline	Assume need for revetment at intervention points (as above).	UK CP High 95%, average cost profile.	Generally covered in system maintenance costs.
Lower Band	Limited crest works.	UK CP Med 95%, low cost profile.	Generally covered in system maintenance costs.

Figure 4-4 shows the cost profile with lower and upper band. The profile shows that the actual costs within the Project Planning Horizon are estimated between £9M and £15M. The main risk would be in relation to works that might be required to the tidal embankment should sea level rise be higher than anticipated. It should be noted that, based on the H++ scenario, this is described as possible but unlikely, especially over the short to medium term. The range of the total Present Value costs is £5M - £8M.

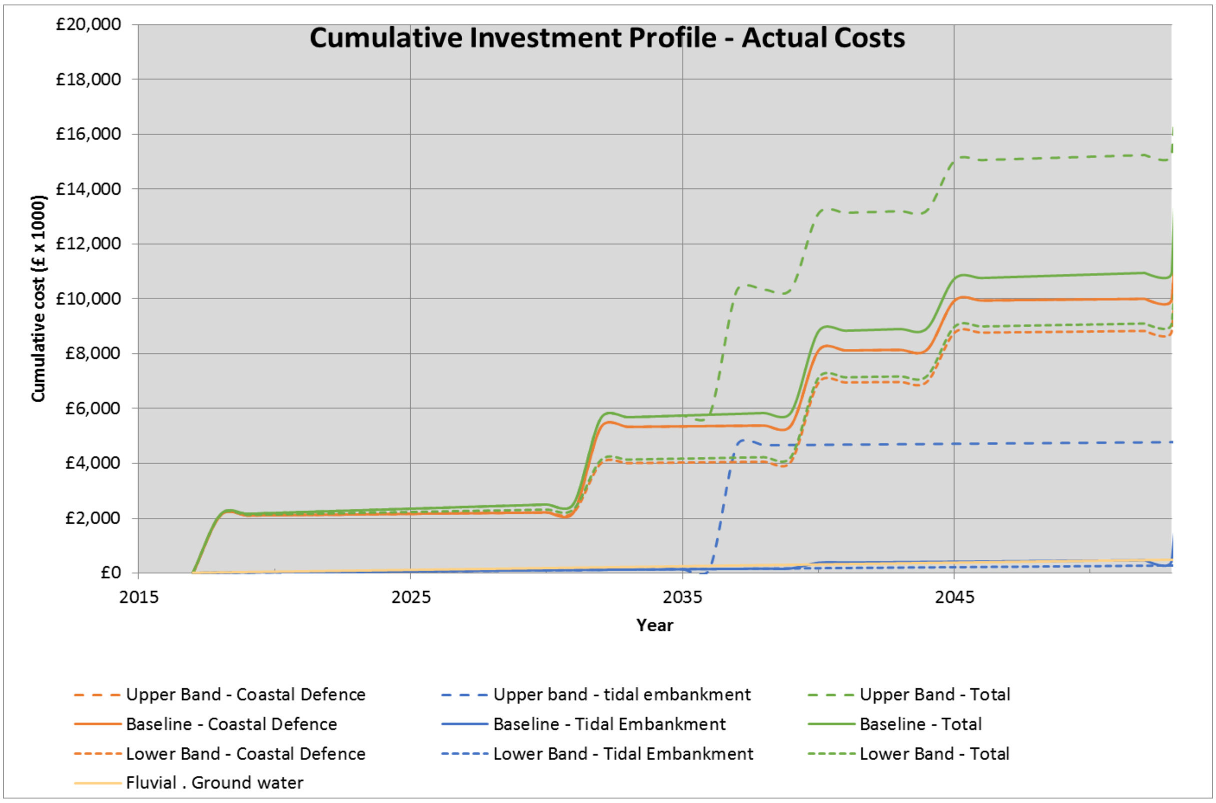

Figure 4-4 Cost profile for Planning Horizon, with upper and lower bands

The above assessment provides a collation of all information developed from the work undertaken by the Technical Group and this information will be used in development of the Masterplan.

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