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Dyddiad / Date: 16th April 2018

Councillor Ramesh Patel
C/O Member Services
County Hall
Atlantic Wharf
Cardiff
CF10 4UW

Annwyl/Dear Councillor Patel

Environmental Scrutiny Committee - 6th March 2018

Thank you for your letter dated 14th March 2018 regarding comments and observations received from Environmental Scrutiny Committee. I have now had an opportunity to consider your questions and am able to advise as follows:

<u>Coastal Risk Management Programme</u>

Comment

The Committee supports the plan to improve coastal flood defences between Rover Way in the west and Lamby Way in the east. They feel that it is vital to ensure that the large number of homes and businesses in the area are properly protected against coastal erosion and future potential flood risks. They believe that working with Welsh Government to deliver the scheme is a positive thing and feel that developing the outline business case has been a thorough process that has assessed eight shortlisted options. The Committee looks forward to seeing this scheme progress and would like to have the opportunity to review the detailed plans for option 6 (Improve 4) once they have been completed in the next phase of the process.

Response

I am grateful for the Environmental Scrutiny Committee's support for the Coastal Risk Management Programme. I will ensure we will provide updates at key milestones in the delivery programme to Environmental Scrutiny on this key strategic project for Cardiff.

Cardiff Council will continue to work closely with Welsh Government throughout the process of detailed design and construction.

Comment

The Committee understands that the primary purpose of the new coastal flood defence scheme will be to protect an area of Cardiff from flooding and to prevent further coastal erosion. However, as discussed in the meeting it would be a very positive thing if the new coastal flood defence scheme could be designed to support wildlife in the area and allow for a range of leisure opportunities, for example, walking. Members. therefore, have asked if you could look at these options and do what you can to build them into the design process

Response

Welsh Government's Coastal Risk Management Programme promotes the incorporation of multiple benefits into the scheme design and there is an appetite for the delivery of multiple benefits. The brief for detailed design will highlight the multiple benefits identified during stakeholder workshops undertaken as part of the Outline Business Case and there will be consideration of these during the detailed design process. Incorporation of the All Wales Coast Path is an example of a multiple benefit identified.

Comment

Table 2 of the draft Cabinet report set out a series of eight shortlisted options. As the recommendation is to proceed with 'Improve 4' financial details were only provided for this option. While the Committee supports your judgement it would like to see the costings for all of the other options included in Table 2.

Response

Please find attached the full Outline Business Case and the economic appraisal for the options. Please note the assessment of options was against environmental implications as well as costs.

Comment

The Committee was told that Welsh Government along with the Council had agreed 'Improve 4' as the best way to proceed based on financial implications and a number of other considerations. I would be grateful if you could supply the Committee with the narrative provided by Welsh Government that identifies the other considerations applied in the making their decision.

Response

There has been no formal correspondence received from Welsh Government to date. Following the Council's application for funding, as part of the Coastal Risk Management Programme, Welsh Government will provide formal correspondence.

Comment

At the meeting a Member asked if sufficient modelling had been undertaken to assess the impact that creating the scheme would have on other nearby coastal areas. It was suggested that some modelling work had been carried out, however, Members felt that the response lacked detail. I would be grateful if you could provide the Committee with any coastal modelling information that you have on the proposed implementation of the scheme.

Response

A significant amount of modelling was undertaken as part of the Outline Business Case. The Model User Report is attached for reference. The document provides a detailed record of the hydraulic model constructed for the Coastal Risk Management Programme Outline Business Case. The report provides details of the Quality Assurance and validation checks, and the modelling results.

Member Brieifng Note: New Burial Space

I am delighted to hear that the Scrutiny Committee are supportive of the proposal to develop a new cemetery in Cardiff North on the A469 and that the Members recognise the importance of Cardiff being able to establish a burial ground to serve the City over the long term.

The location is favourable due to a number of reasons including the logical view taken by the Committee relating to its close proximity to the existing site at Thornhill. This means that the facility will not need additional buildings such as offices or a depot as the site will be serviced from Thornhill Cemetery, which is only 600 meters away. Not only does this keep development costs down it also ensures that we can maximise the amount of land we use for burial space and have a lesser impact on landscape and the natural environment.

Various other sites were considered by the service area when looking for available land throughout the City. An appendix summarising a number of these sites is attached. You will note that there are numerous reasons for the sites being deemed unsuitable such as access issues, high water table, residential usage/concerns or views that the sites would be more suited to an alternative use such as housing. In view of these comments made at an early stage and in consultation with colleagues in planning, no detailed costings were sought for any of the sites.

The Committee view on phasing the works are acknowledged and this option was originally provided if funding for the whole of the infrastructure could not be identified. I am however pleased to report that the necessary funding for the whole project has been secured and subject to planning approval, all of the infrastructure works for the primary site will be completed as part of a single contract. This will include installation of all roads and paths throughout the site as well as the car park and toilet block.

Some concerns have been raised as part of the consultation exercise undertaken by myself with the various political parties and those members representing the Lisvane and Llanishen wards. The concerns relate specifically to the future of the current tenant of the site and if his business will be negatively affected, (which I am confident that it will not be) and concerns around the site being within the Green Wedge and whether this creates any issues. The matters all fall within the planning process and any affected group or individual will be permitted to raise concerns in the appropriate way. In addition to this, a 28-day statutory consultation period will be implemented in April 2018 as part of the planning process to ensure that the Planning Committee can consider the views of all affected parties.

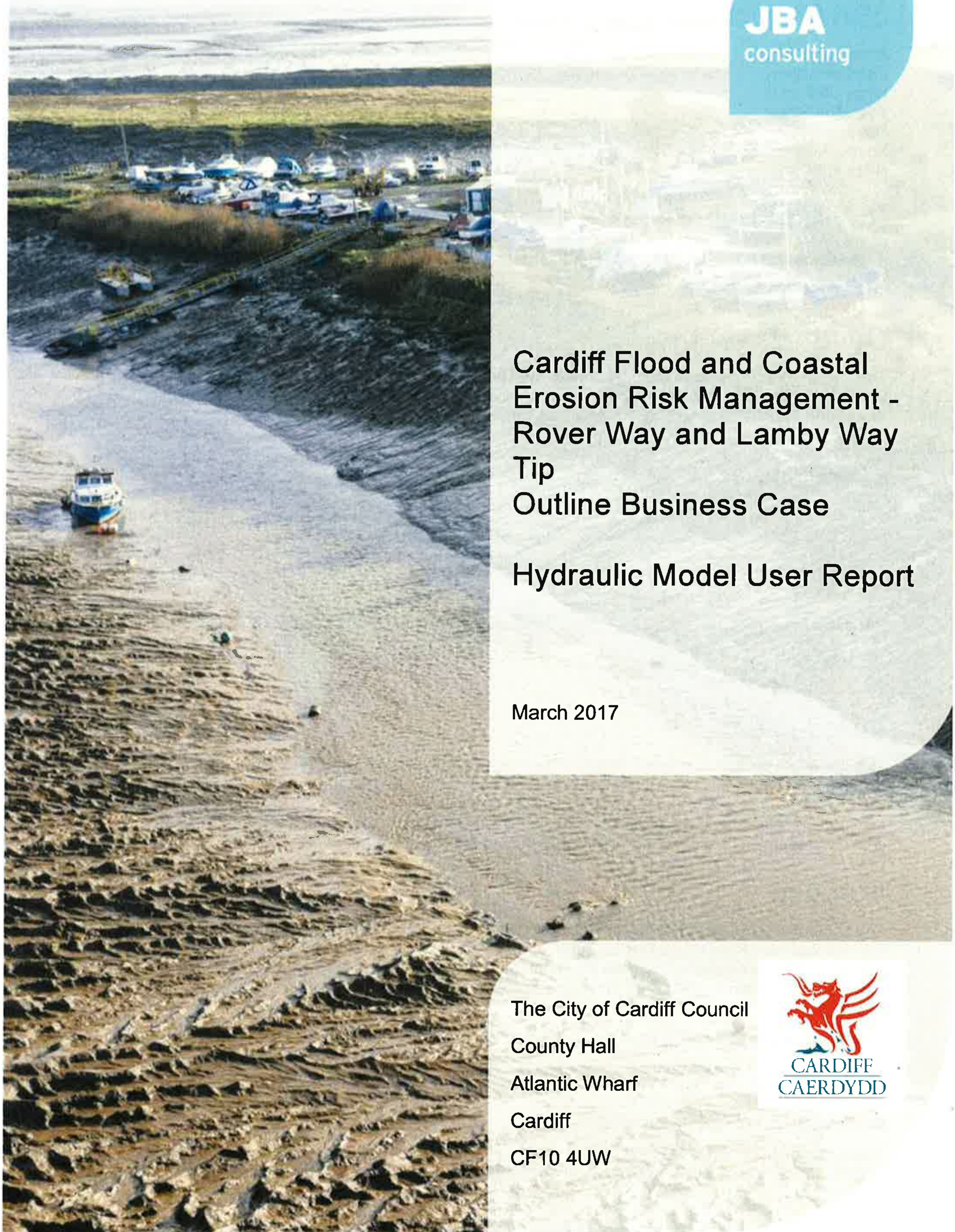
A number of environmental assessments and surveys are ongoing as part of the planning application process and I would be happy to share these with the Scrutiny Committee once they are all completed.

I hope the above is of assistance.

Yn gywir
Yours sincerely

Cynghorydd / Councillor Michael Michael
Cabinet Member for Clean Streets, Recycling & Environment /
Aelod Cabinet dros Strydoedd Glân, Ailgylchu a'r Amgylchedd

JBA consulting



Cardiff Flood and Coastal Erosion Risk Management - Rover Way and Lamby Way Tip Outline Business Case

Hydraulic Model User Report

March 2017

The City of Cardiff Council
County Hall
Atlantic Wharf
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Revision History

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V1.0 / 31 March 2017		David Brain

Contract

This report describes work commissioned by The City of Cardiff Council, in a letter dated 21/10/2016. The City of Cardiff Council's representative for the contract is David Brain. Amelia Wright and Paul Redbourne of JBA Consulting carried out this work.

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Introduction

This document provides a detailed record of the hydraulic model constructed for the Cardiff Coastal Risk Management Programme Outline Business Case, incorporating both Rover Way and Lamby Way Tip. This report also provides details of the QA and validation checks, and the modelling results. It complements the information in the main Outline Business Case report, which gives more general information on the model, the study area, and the objectives of the commission.

Purpose

This document provides a detailed record of the hydraulic model constructed for the Cardiff Coastal Risk Management Programme Outline Business Case and has been prepared for The City of Cardiff Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to The City of Cardiff Council.

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Abbreviations

AEP .... Annual Exceedance Probabilities
CCC .... The City of Cardiff Council
DSM .... Digital Surface Models
DTM .... Digital Terrain Models
EurOtop .... European Overtopping Manual
LIDAR .... Light Detection and Ranging
MB .... Mass Balance
OBC .... Outline Business Case

JBA consulting

1 Introduction

1.1 Project introduction

The City of Cardiff Council (CCC) commissioned JBA Consulting to undertake an Outline Business Case (OBC) to develop a business case for the flood and erosion protection of Cardiff. The OBC combines the areas of Rover Way and Lamby Way Tip. The objectives of the commission have been divided into three phases. The first stage includes the build and development of a hydraulic model for simulations of the required return periods and scenarios, upon which flood maps and an initial economic appraisal can be made. From this, phase two objectives were to model the shortlisted options to aid a more detailed investigation. To address the main objective of the construction and running of a hydraulic model, a 2D hydraulic model using TUFLOW was developed. This modelling package was chosen as it allows for efficient calculation of the channel conveyance, the impact of any structures to be addressed and the routing of overland flows across the floodplain.

1.2 Study area

The Rover Way and Lamby Way Tip study areas are located to the east and west, respectively, of the Rhymney River, Cardiff. At these coastal locations, the flows of the Rhymney River play no part in the flood risk, which is solely of tidal influence from the Severn Estuary. Therefore, the primary focus is on the lower catchment which experiences negligible fluvial flow. Despite being of different flood cells, the two areas share similarities and technical challenges, thus the sites have been combined into a single flood cell for hydraulic modelling purposes. Consequently, a single 2D TUFLOW tidal inundation model has been constructed to address the main objectives as summarised above. The full model domain is shown in Figure 1-1.

1.3 Shortlisted scenario options

There are three main scenario options for the Rover Way and Lamby Way Tip study area. These shortlisted scenarios include do nothing, do minimum, and improve.

1.3.1 Do nothing scenario

A baseline scenario was required for the economic appraisal in order to assess the benefits of the flood protection options. This represents a 'do nothing' scenario based on the present-day conditions of Cardiff with no intervention in the natural processes. This was modelled to include breaches to the areas which are most at risk. The current standard of protection of defences is compromised with the impact of climate change, under which the existing defence assets are not sufficient to prevent flooding to Cardiff in the future.

1.3.2 Do minimum scenario

The first option scenario is the do minimum scenario. This will involve light rock armour along the coast to delay erosion for 20 years. Although no additional formal works will be undertaken, the current defence will be maintained through patch and repair along the fluvial sections of defence. This means that the standard of protection will remain as it is presently, and overtopping of the defences may occur in the future with rising sea levels.

1.3.3 Improve scenario

The second option considered is the improve scenario. This incorporates options which have been designed to the 0.5% AEP standard of protection. The coastal defences and at risk areas of the fluvial defences are raised to prevent any breaching. Also, the tidal overtopping rates have also been modified with the design development. All sub-options within the improve scenario have been modelled as one option. Therefore, all of the improve options have the same benefits and damages, but with differing costs for each scheme. The details of each sub-option within the improved scenario are given below:

- Improve 1: Rock option along the coast and along Lamby Way roundabout;
- Improve 2: Sheet piling option along the coast and rock option along Lamby Way roundabout;
- Improve 3: Concrete wall option along the coast and rock option along Lamby Way roundabout;

- Improve 4: Rock option along the coast and sheet piling along Lamby Way roundabout;
- Improve 5: Sheet piling option along the coast and sheet piling along Lamby Way roundabout; and
- Improve 6: Concrete wall option along the coast and sheet piling along Lamby Way roundabout.

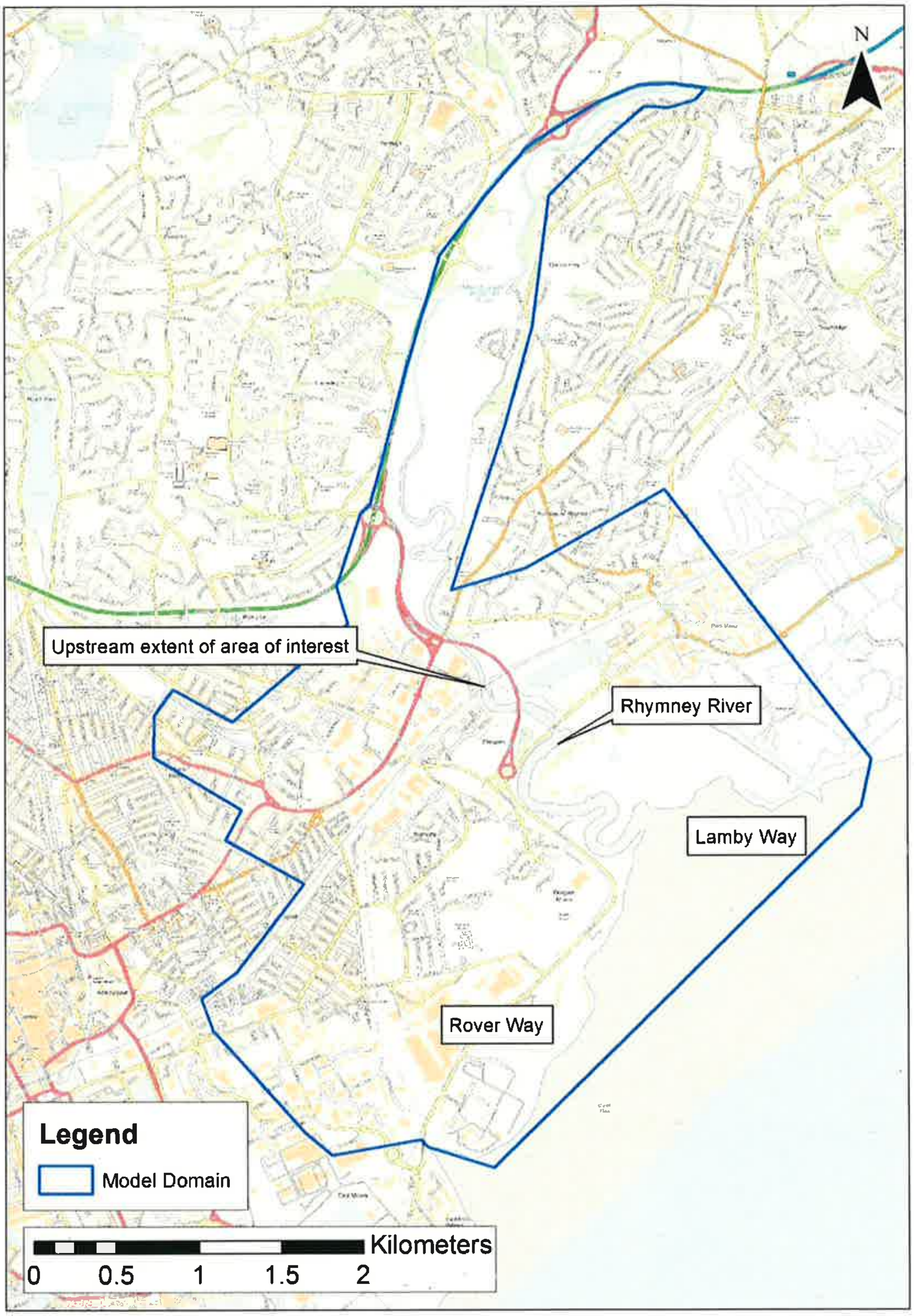


Figure 1-1 Full extent of the model domain

1.4 Project Reporting

This model user report provides a technical overview of the modelling undertaken and applied assumptions as well as an overview of model results for each scenario and the limitations.

This document is split into the following sections:

Chapter 2. Modelling approach - provides details of the available data and an overview of the modelling approach adopted;

Chapter 3. Model development - summarises the schematisation of the model for Cardiff;

Chapter 4. Topographic modification - provides details of topographic modifications which were applied to the model;

Chapter 5. Flood defences - provides details of the flood defences included in the model and how they were modelled and removed from the undefended model;

Chapter 6. Wave conditions - summarises the wave transformation and overtopping which were applied to the model;

Chapter 7. Sensitivity analysis - provides details of the sensitivity testing undertaken on the model;

Chapter 8. Model performance, limitations, assumptions, and uncertainty - provides details of any issues encountered;

Chapter 9. Model runs - provides details of the design runs carried out for this study; and

Chapter 10. Model results - summarises the model results, looking at flood mechanisms and the extent of flood risk.

2 Modelling Approach

2.1 Available Data

Item	Comments
Existing models	Prior to the construction of this model, there were no pre-existing models incorporating the Lamby Way and Rover Way areas of interest.
Channel cross-section	The model is 2D only, and thus no channel cross-sections have been incorporated.
Topographic survey	Prior to the model build, there was no pre-existing survey datasets available. As a result, a topographic survey was undertaken in December 2016 by Storm Geomatics Ltd, under the direction of JBA Consulting. This was undertaken in accordance with the EA National Standard Technical Specifications, in which the flood level or top of bank crest level was surveyed every 10m along the defence line. This dataset was checked in-house and was incorporated into the model in an appropriate manner. Further details of this can be found in section 4.
LIDAR and other topographic data	Digital Surface Models (DSM) and Digital Terrain Models (DTM) were provided at 1m and 2m resolutions for the entire model extent. The latest available LIDAR was used in the model, with three datasets used: 1m DTM of coastal areas, 1m DTM wider coverage and 2m DTM full coverage. All LIDAR data was provided my Natural Resources Wales. The latest LIDAR was flown on 25th January 2016. Due to the quantity of LIDAR data available, preference was given to the most recent high quality data. The most recent 1m DTM coastal area dataset was stamped on top of the 1m DTM wider coverage, which in turn was stamped over the coarser 2m DTM full coverage. This removed all areas of no data (ie, holes) within the LIDAR. Checks on the DTM were undertaken in order to identify any issues with the LIDAR filtering. This check was essential to verify that the model grid accurately represented the ground conditions. Such inspection did not result in the need for LIDAR modifications due to appropriate filtering of the DSM dataset in DTM.
Map data	OS MasterMap and 25k and 50k raster data was provided by CCC for the study area.
Hydrological assessment	This was not undertaken due to no fluvial element within the model, as a result of the study area's flood risk being solely of a tidal influence.
Tidal assessment	A Mean High Spring tide (MHWS) curve for Cardiff was obtained from the Admiralty Total Tide software and corrected from Chart Datum to Ordnance Datum with a value of -6.3m. Based on this data, tide curves were generated for a series of events. A range of events were selected covering a variety of annual exceedance probability (AEP) flood events and with varying amounts of climate change. For the tidal inundation model, tide curves were generated for the following 32 runs: • 50% AEP event, applying 2017 sea levels (ESL: 7.48mAOD); • 10% AEP event, applying 2017 sea levels (ESL: 7.70mAOD); • 5% AEP event, applying 2017 sea levels (ESL: 7.81mAOD); • 2% AEP event, applying 2017 sea levels (ESL: 7.96mAOD); • 1.33% AEP event, applying 2017 sea levels (ESL: 8.04mAOD); • 1% AEP event, applying 2017 sea levels (ESL: 8.10mAOD); • 0.5% AEP event, applying 2017 sea levels (ESL: 8.23mAOD); • 0.1% AEP event, applying 2017 sea levels (ESL: 8.63mAOD); • 50% AEP event, applying 2037 sea levels (ESL: 7.60mAOD);

- 10% AEP event, applying 2037 sea levels (ESL: 7.82mAOD);
- 5% AEP event, applying 2037 sea levels (ESL: 7.93mAOD);
- 2% AEP event, applying 2037 sea levels (ESL: 8.07mAOD);
- 1.33% AEP event, applying 2037 sea levels (ESL: 8.15mAOD);
- 1% AEP event, applying 2037 sea levels (ESL: 8.22mAOD);
- 0.5% AEP event, applying 2037 sea levels (ESL: 8.35mAOD);
- 0.1% AEP event, applying 2037 sea levels (ESL: 8.75mAOD);
- 50% AEP event, applying 2067 sea levels (ESL: 7.81mAOD);
- 10% AEP event, applying 2067 sea levels (ESL: 8.03mAOD);
- 5% AEP event, applying 2067 sea levels (ESL: 8.14mAOD);
- 2% AEP event, applying 2067 sea levels (ESL: 8.28mAOD);
- 1.33% AEP event, applying 2067 sea levels (ESL: 8.36mAOD);
- 1% AEP event, applying 2067 sea levels (ESL: 8.43mAOD);
- 0.5% AEP event, applying 2067 sea levels (ESL: 8.56mAOD);
- 0.1% AEP event, applying 2067 sea levels (ESL: 8.96mAOD);
- 50% AEP event, applying 2117 sea levels (ESL: 8.23mAOD);
- 10% AEP event, applying 2117 sea levels (ESL: 8.45mAOD);
- 5% AEP event, applying 2117 sea levels (ESL: 8.56mAOD);
- 2% AEP event, applying 2117 sea levels (ESL: 8.71mAOD);
- 1.33% AEP event, applying 2117 sea levels (ESL: 8.79mAOD);
- 1% AEP event, applying 2117 sea levels (ESL: 8.85mAOD);
- 0.5% AEP event, applying 2117 sea levels (ESL: 8.98mAOD); and
- 0.1% AEP event, applying 2117 sea levels (ESL: 9.38mAOD).

The extreme sea level dataset (EA, 2011) of still water design sea level estimates from the UK coastline was used to obtain sea level estimates at Cardiff. These estimates are provided for a baseline year of 2008, and have been updated to take into account sea level rise to 2017 levels. 2017 was adopted as the base year for this project, as is the year in which much of the model development and testing were undertaken, and is the year in which the OBC will be presented to Welsh Government.

Climate change scenarios for a range of agreed epochs (2017, 2037, 2067, and 2117) were assessed by applying the current climate change estimates (EA, 2016). The updated 2017, 2037, 2067 and 2117 extreme sea level estimates are provided in Table 2-1.

Table 2-1 Extreme sea level estimates at Cardiff

Event (% AEP)	2017 Extreme Sea Levels (mAOD)	2037 Extreme Sea Levels (mAOD)	2067 Extreme Sea Levels (mAOD)	2117 Extreme Sea Levels (mAOD)
50	7.48	7.60	7.81	8.23
10	7.70	7.82	8.03	8.45
5	7.81	7.93	8.14	8.56
2	7.96	8.07	8.28	8.71
1.33	8.04	8.15	8.36	8.79
1	8.10	8.22	8.43	8.85
0.5	8.23	8.35	8.56	8.98
0.1	8.63	8.75	8.96	9.38

The present day astronomical tide and 0.5% AEP even tide curves, along with the surge profile, are shown in Figure 2-1.

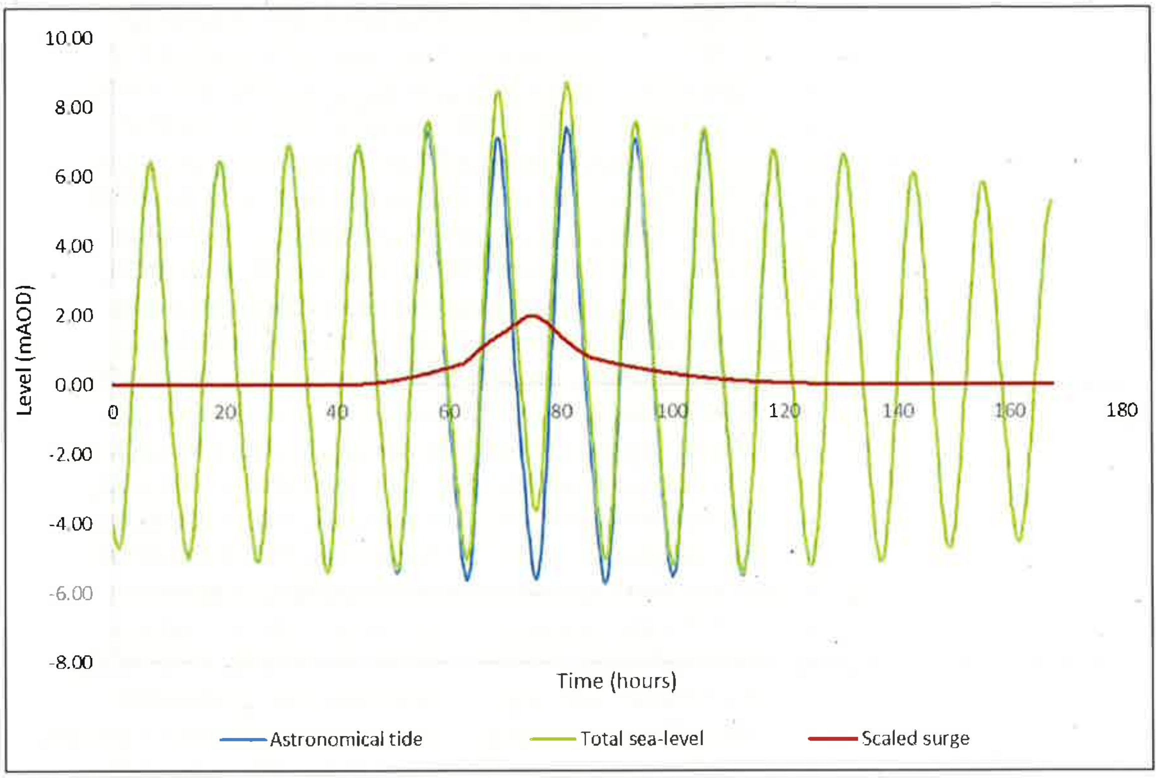


Figure 2-1 Full tide curves for Cardiff, along with comparison of the astronomical tide and the impact of the scaled surge.

2.2 Model Schematisation

Item	Notes	Comments
Software used	TUFLOW 2D Model version 2016-03-AD	A 2D TUFLOW model was developed for the study area, incorporating the Rhymney River and Roath Brook watercourses. This meets the specifications of the project scope and the standards required by NRW. The project requires assessment of flood risk and the flood hazard across the model domain, with the production of baseline scenarios and subsequent flood maps. The model was also required to form the basis for initial flood damage values and the longlist options to be proposed. From this, the baseline model was developed to assess a do minimum and do something scenarios across the same AEP events. The use of 2D modelling is preferred to allow overland flow routes to be represented. A 1D element is not required due to the lack of hydraulic structures within the model domain.
Grid size selection	5m grid resolution	The model has a grid size of 5m. Such resolution allows for a good level of detail without being detrimental to run times due to the size of the model domain. It also removed the potential need for multiple domains within the model.
Model proving	Via sensitivity analysis	After discussions with the internal model reviewer and the Project Director, it was decided that sensitivity testing would be undertaken on: • The hydraulic roughness, by altering the

		Manning's n roughness coefficient; • Stage-discharge (HQ) outflow boundaries; and • The tidal boundary. These model parameters were assessed for the 0.5% AEP with 100 years' climate change (2117) baseline model scenario, with the tidal boundary assessment undertaken for the 0.5% AEP present day event also.

3 Model Development

3.1 Boundary conditions

Item	Comments	
Model domain	The model domain extends from the Cardiff coast in the south, to just beyond the tidal influence zone at the A48 Eastern Avenue bridge over the Rhymney River. The tidal boundary is located parallel to the coastline. The model domain was tied into high ground where appropriate, and appropriate outflow boundaries applied where this was not possible. The model study area is 12.4km^2. The main areas of interest are Rover Way and Lamby Way Tip in the southern section of the model. The model domain and boundary conditions are shown in Figure 3-1.	
Outflow boundary	Tidal	The tidal boundary was applied in a southwest to northeast orientation parallel to the coastline. It is a level-time (HT) hydrograph based on tide curves generated specifically for this study. The model was run for 31 hours, allowing for a total of three tidal cycles wo be run within each simulation.
	Rhymney River	The Rhymney River was represented within the model using an open 2D channel approach. As the model only extends to the maximum tidal influence, a stage-discharge (HQ) boundary was applied at the A48 Eastern Avenue bridge over the Rhymney River to allow water out of the model if the tidal influence were to propagate further with climate change. This was applied in the 2D domain with a channel slope of 0.0002 used to automatically generate a stage-discharge relationship using the TUFLOW software.
	Roath Brook	The Roath Brook was represented as an open 2D channel within the model. As the model did not extend for the full reach of the Roath Brook, a stage-discharge (HQ) boundary was applied at Pen-y-Lan Road to allow flow out of the model. This was applied in the 2D domain with a channel slope of 0.0167 used to automatically generate a stage-discharge relationship using the TUFLOW software.
	Pwll-Mawr	The eastern extent of the model domain at Pwll-Mawr had a stage-discharge (HQ) boundary applied perpendicular to the B4239 Wentloog Avenue where it meets Parkway. The boundary was required due to the vast extent of the low-lying floodplain which extends beyond Wentlooge. This was applied in the 2D domain with a channel slope of 0.0025 used to automatically generate a stage-discharge relationship using the TUFLOW software.
	Railway line	A stage-discharge (HQ) boundary was applied to the railway line to the west of the model, to allow for water to dissipate out of the model over low topographic elevation. This was applied in the 2D domain with a channel slope of 0.005 used to automatically generate a

		stage-discharge relationship using the TUFLOW software.

Hydraulic roughness used	There are no 1D components within this model, thus only manning's n roughness coefficients were required for the 2D domain. A generalised value of 0.3 was applied for the Manning's n coefficient value across the entire area. Key floodplain features were then identified using OS MasterMap data to provide a more physically reasonable representation of these features, such as roads, vegetation, gardens and pathways. OS MasterMap data was compared to aerial imagery to check the accuracy of the data was fit for purpose across the study region. Manning's n values were assigned based on the feature code attribute of OS MasterMap, for example, where the feature code was 10172, this value represented roads in OS MasterMap and was given a Manning's n value of 0.020. 2D Manning's n roughness coefficients were selected based on previous modelling experience and internal JBA guidance, and are provided in Table 3-1.

Table 3-1 Manning's n roughness values used in the model.

Material Code	2D Manning's n	Comment/ Example
999	0.05	Typical value for 2D domain
10021	0.30	Buildings
10053	0.05	Gardens
10054 & 10217	0.05	General surface and unclassified land
10056	0.03	Fields
10062	0.05	Glasshouse
10089	0.04	Inland water
10093	0.045	Landform (combined manmade/natural landforms)
10096	0.04	Landform (Slope-Man made landform)
10099	0.05	Landform (Cliff-Natural Landform)
10111	0.08	Trees and dense vegetation
11119, 10123 & 10183	0.025	Tracks and paths
10172	0.02	Roads
10185 & 10193	0.06	Structures
10203 & 10210	0.044	Tidal water
1000	0.10	Roughness stability amendment

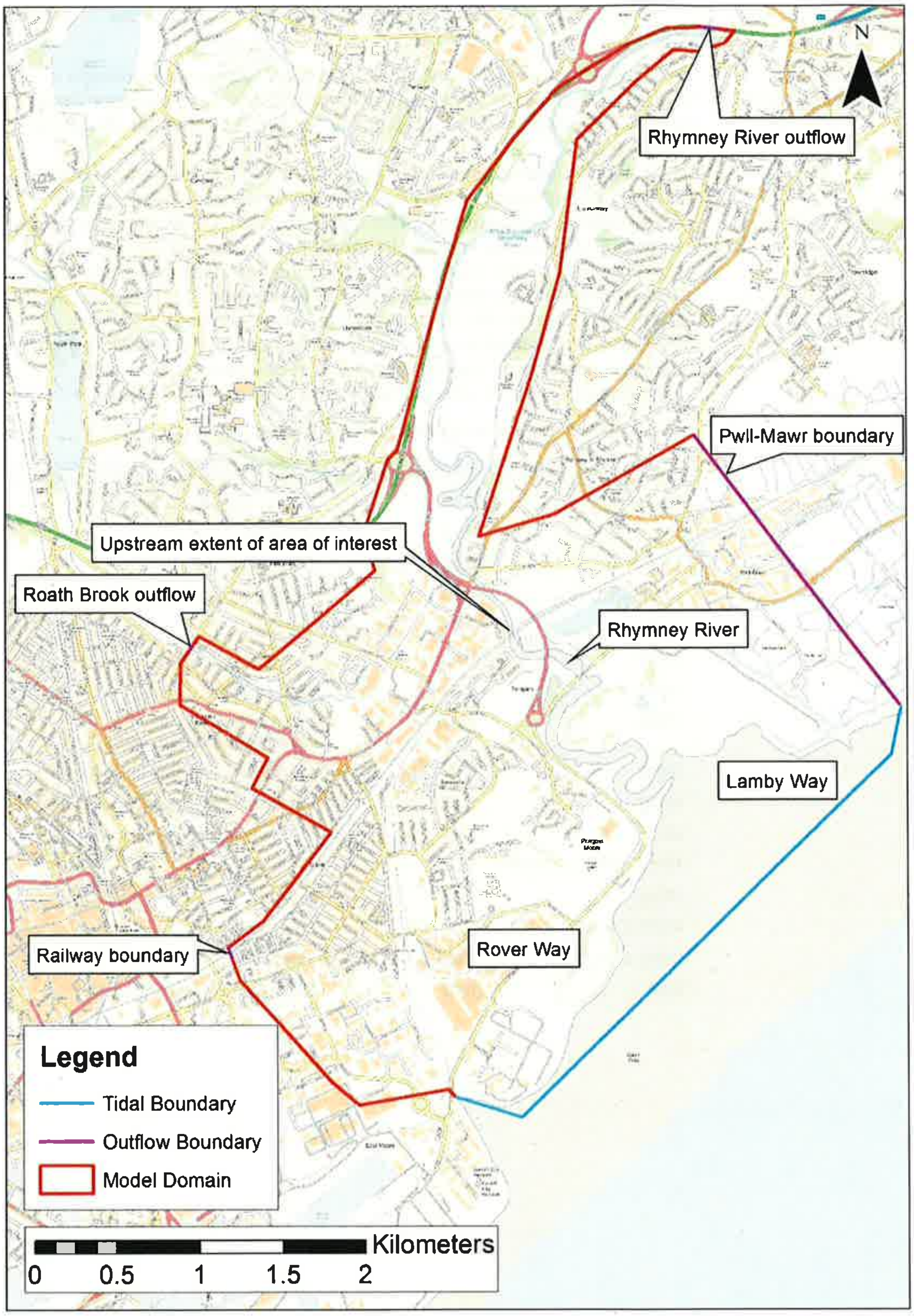


Figure 3-1 Model boundary conditions

4 Topographic modifications

A series of topography modifications were applied to the model to modify the grid to enable a more detailed representation of floodplain features and additional modifications to represent different scenarios in line with climate change impacts and those outlined in the Geomorphological Report as an appendix of the OBC. This section provides details of these modifications.

Topography modification command	Purpose of command
2d_zsh_neg_depths	This z-shape layer was used to address a section of negative depths as a result of the LIDAR. The LIDAR fix was parallel to a section of the current defence on the eastern bank of the Rhymney River, just north of Lamby Way. Any section of this z-shape layer over the current defence crest will have been overwritten by the topographic survey data.
2d_zln_RB_CDF_002	To the north of the study area there is a current scheme for the protection of Roath Brook which is not present in the LIDAR. As a result, a z-line was created to represent this new scheme as it may also impact the flood risk to the study area.
2d_zpt_topo_CDF_021 2d_zln_topo_CDF_002	As mentioned in section 4, a topographic survey of the defence crest height was undertaken throughout the study area. This was represented in the model via the use of a z-point layer and a z-line layer.

4.1 Breaches

In order to fully represent the impact of climate change on the risk of flooding and coastal erosion, the use of breaches was adopted within the model. A total of six breaches have been applied to the model, activated due to erosion risk or when water level exceeds that of the minimum defence height at the location. They have been applied as variable z-shapes with the option of 'MIN NO MERGE'. In accordance with appropriate guidance, the breach period is 30 minutes which commences one hour prior to the peak water level of the peak tidal cycle. Once breached, the topographic area affected will remain at this breached level for the remainder of the model simulation. Additional breach properties are provided in Table 4-1 and Table 4-2, and the breach locations are shown in Figure 4-1.

Table 4-1 Breach location and properties

Breach	Breach Location	Section Location	Type of Risk	Breach Level (mAOD)
2d_vzsh_breach_region_CDF_021	Rover Way coast	1	Erosion	8.00
2d_vzsh_breach1_CDF_021	Rover Way coast	1/2	Erosion	7.85
2d_vzsh_breach2_CDF_021	Rover Way; outside of first Rhymney meander	2	Flood	6.90
2d_vzsh_breach3_CDF_021	Rover Way; outside of second Rhymney meander	3	Erosion	8.00
2d_vzsh_breach4_CDF_021	West of Rhymney; north of Lamby Way	4	Flood	6.90
2d_vzsh_breach5_CDF_021	East of Rhymney; north of Lamby Way	5	Flood	6.70

Table 4-2 Breach activation rules and commencement

Breach	Activation	First Event Activated
Main breach	Always activated due to erosion risk	2017 50% AEP
1	Always activated due to erosion risk	2017 50% AEP

2	Once water levels exceed 8m, as the height assumed as the boundary between the sheet piles and the overlying earth embankment	2017 1.33% AEP
3	Always activated from 2037 due to erosion risk	2037 50% AEP
4	Activated when water levels exceed the level of minimum defence height	2017 0.1% AEP
5	Activated when water levels exceed the level of minimum defence height	2037 0.1% AEP

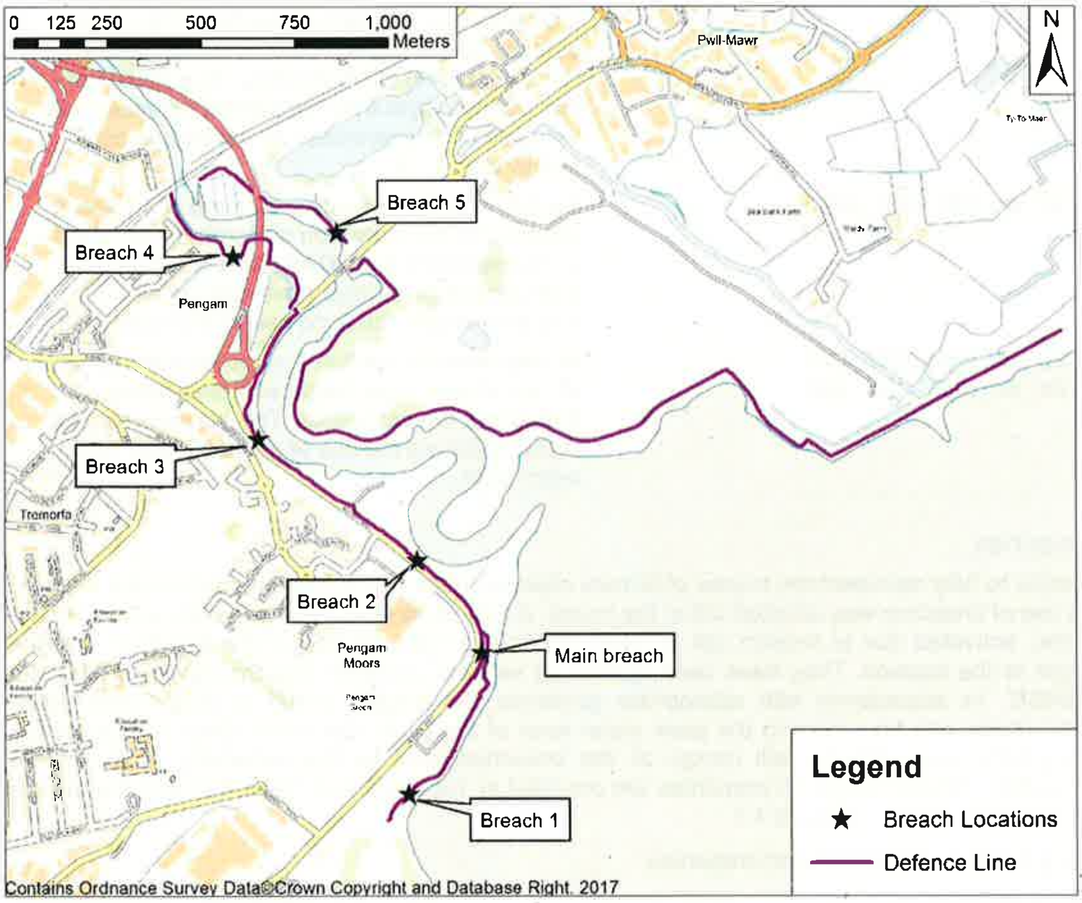


Figure 4-1 Breach locations within the model

The breaches were used in combination, creating a series of scenarios which were applied to different epochs and flood events. Table 4-3 and Table 4-4 shown the setup of breach scenarios for the do nothing and do minimum scenarios respectively. The breach scenarios are as follows:

- Br1 - main breach and breach 1;
- Br2 - main breach, breach 1 and breach 2;
- Br3 - main breach, breach 1, breach 2 and breach 4;
- Br4 - main breach, breach 1, breach 2, breach 3, breach 4 and breach 5;
- Br5 - main breach, breach 1 and breach 3;
- Br6 - main breach, breach 1, breach 2 and breach 3;
- Br7 - main breach, breach 1, breach 2, breach 3 and breach 4; and
- Cbr - main breach and breach 1 (nb: this is the same as Br1).

No breaches were simulated during the improve scenarios.

Table 4-3 Breaches for each event for the do nothing scenario

Year	50% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP	0.1% AEP
2017	Br1	Br1	Br1	Br1	Br2	Br2	Br2	Br3
2037	Br5	Br5	Br5	Br6	Br6	Br6	Br7	Br4
2067	Br5	Br6	Br6	Br7	Br7	Br7	Br4	Br4
2117	Br6	Br7	Br4	Br4	Br4	Br4	Br4	Br4

Table 4-4 Breaches for each event for the do minimum scenario

Year	50% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP	0.1% AEP
2017	-	-	-	-	-	-	-	-
2037	Cbr	Cbr	Cbr	Cbr	Cbr	Cbr	Cbr	Cbr
2067	Br5	Br6	Br6	Br7	Br7	Br7	Br4	Br4
2117	Br6	Br7	Br4	Br4	Br4	Br4	Br4	Br4

5 Flood defences

Rover Way and Lamby Way currently have a degree of protection as a series of defences which include earth embankments, rock armour and wave return walls. To provide an up-to-date representation of the formal defences along the coastline and the Rhymney River, a topographic survey was undertaken in December 2016. Storm Geomatics Ltd carried out this survey under the direction of JBA Consulting. This was undertaken in accordance with the EA National Standard Technical Specifications, in which the flood level or top of bank crest level was surveyed every 10m along the defence line. This dataset was checked in-house.

Within the model, the formal flood defences are a series of z-points and z-lines, superseding the LIDAR elevations, and is illustrated in Figure 5-1.

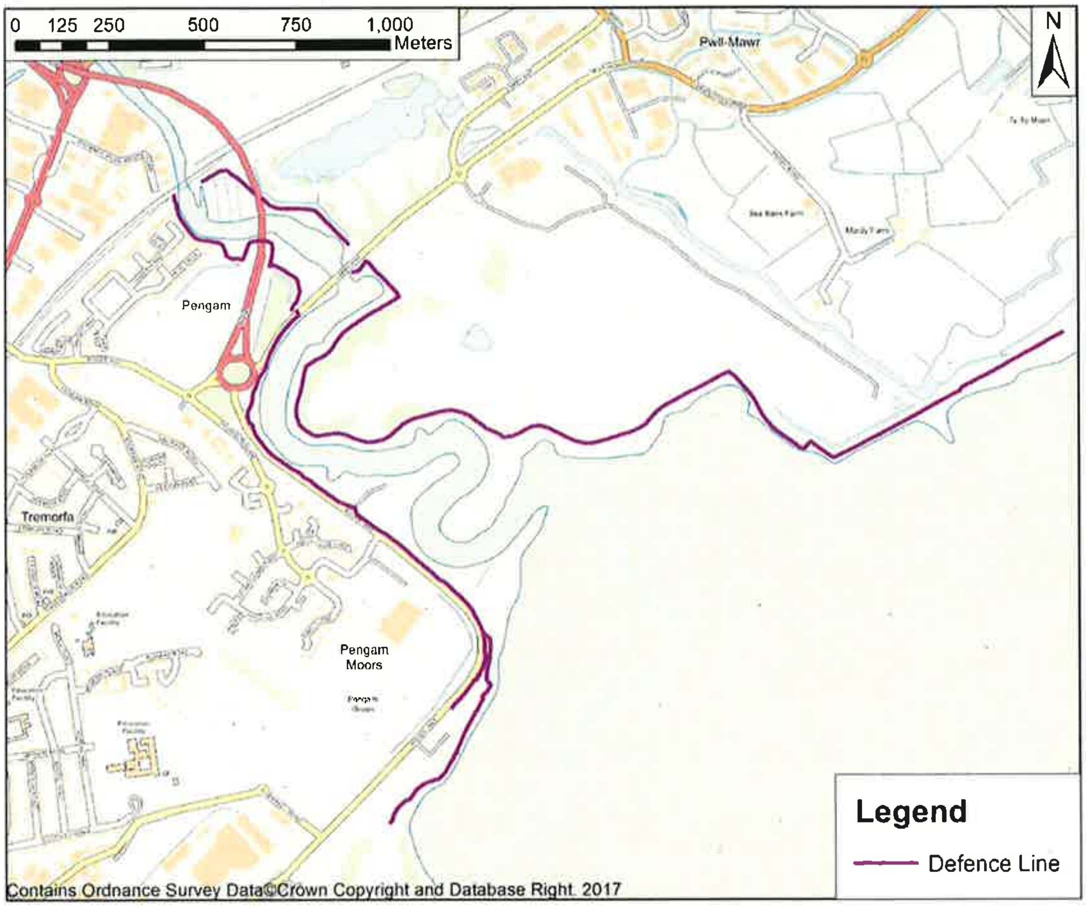


Figure 5-1: The formal flood defence line

5.1 Do nothing scenario

For the do nothing scenario, the formal defence line as taken from the topographic survey of crest heights was used.

5.2 Do minimum scenario

The formal defences for the do minimum scenario are the same as that of the do nothing scenario, as that lineated from the topographic survey of defence crest height.

5.3 Improve scenario

The current formal defence line, as provided by the crest topographic survey, was read into the model. Additional z-lines were created to represent the standard of protection to which the improve scenario was designed to. This superseded the current formal defence line, and is shown in Figure 5-2.

For the improve scenario, the proposed coastal defence was raised to a 0.5% AEP with 100 years' climate change (ie 2117) standard protection. A series of z-lines representing areas of increase fluvial defences along the Rhymney River were also incorporated into the model to override the current defence heights. This was to remove the presence of any low points along the existing defences to improve the protection of the study area from flood, and erosion, risk. A total of approximately 1,045m was altered, with 950m of this being raised to the 0.5% AEP with 100 years' climate change (ie 2117) standard protection, at 8.98mAOD. The remaining 95m was tied into the height of the existing defences either side of the low point.

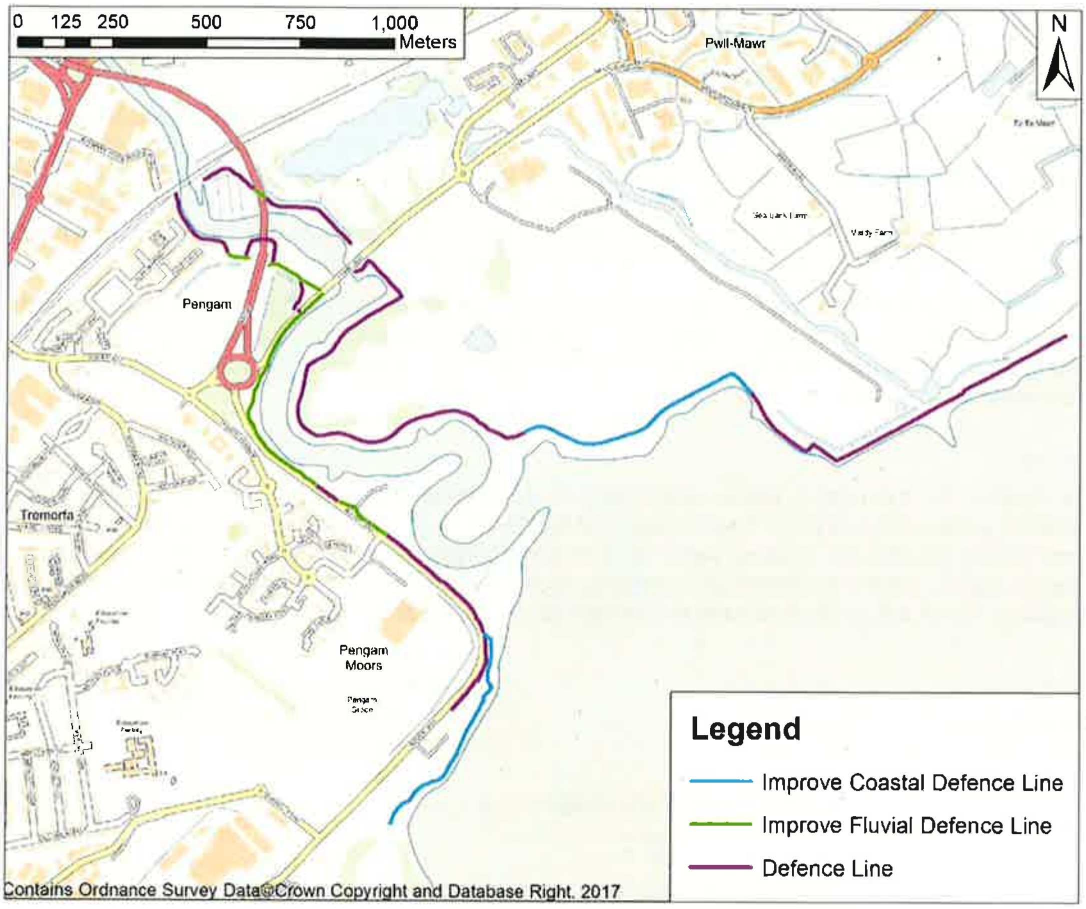


Figure 5-2 Present day defence line with superimposed coastal and fluvial defence lines for the improved option

6 Wave conditions

6.1 General

Modelling of the flood risk in coastal areas requires consideration of the different sources of flood risk. This is mainly from still water flooding from tide and surge conditions and flood risk from waves overtopping the coastal defences. The latter occurs even when the still water levels are lower than the defence crest heights. The coastal frontage of Rover Way and Lamby Way is protected by a series of defences which include earth embankments, rock armour and wave return walls. Due to the height of the defences and the nature of topography, the primary source of flood risk is from waves overtopping the defences or the failure and breaching of the defences.

Overtopping or breaching of the defences will result in floodwaters spreading into the industrial and residential areas of Tremorfa and Rumney. To help understand this flood risk, several modelling tools were used. Offshore waves were transformed into the nearshore using a wave transformation model. Wave overtopping modelling was undertaken to calculate volumes of wave overtopping based on the nearshore wave heights, and flood inundation modelling was applied to simulate flood inundation from both extreme still water level flooding and wave overtopping volumes.

Wave overtopping must be calculated separately as no single model is capable of simulating both still water flooding and wave overtopping. This section provides an overview of the various assumptions that have been made for the wave overtopping process, and the methodology followed specifically for this study.

6.2 Method

The method for calculating wave overtopping is a multistage process within the coastal flood modelling system (Figure 6-1). The modelling of the flood risk from wave overtopping can be broken down into six key stages; offshore water level and wind analysis, joint probability analysis, defence schematisation, wave transformation modelling, wave overtopping calculations and flood inundation modelling. Each will be discussed in the remainder of the chapter.

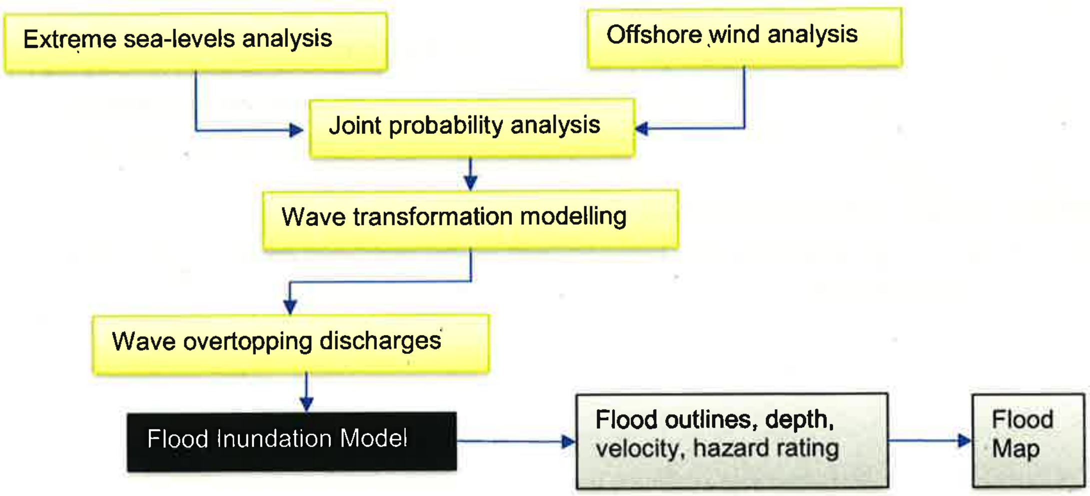
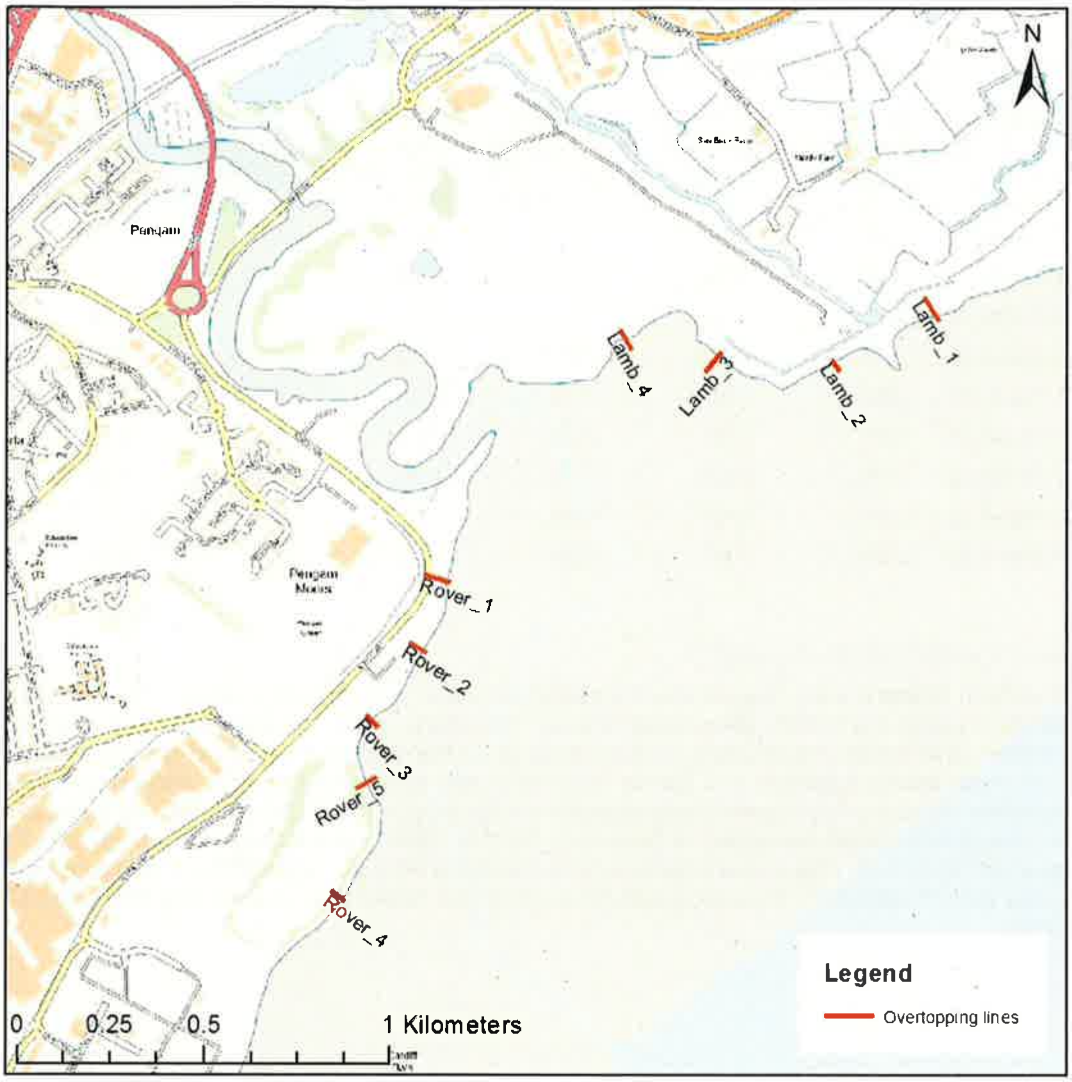


Figure 6-1: Coastal flood modelling system architecture

6.3 Defence schematisation

There are approximately 1.5km of defences on either side of Rhymney River. A total of nine defences were schematised for the wave overtopping calculations, with four to the east of the Rhymney River for Lamby Way and five to the west for Rover Way (Contains Ordnance Survey data © Crown copyright and database right 2017

Figure 6-2). These defences are in the form of earth embankments and rock armour with wave return walls. Schematisation of defence profiles was required for calculating wave overtopping discharge rates during the wave overtopping calculations stage. However, it is also used at the wave transformation stage, as it defines the locations of where the nearshore wave conditions are required.



Contains Ordnance Survey data © Crown copyright and database right 2017

Figure 6-2: Schematised defences

The defences were separated into nine separate stretches that have a similar wave overtopping risk. The defence profiles were separated based on defence type, crest level, facing angle and foreshore topography.

This study applied the Neural Network methodology to calculate the wave overtopping discharge rates, the details of which are outlined in the European Overtopping Manual (EurOtop). The Neural Network tool in EurOtop was developed by the European CLASH programme and uses a large database of results from physical modelling tests to derive a solution based on complex defence profiles. The schematisations of the nine defences describe the components of the profile using the parameters required by the Neural Network tool. The key components required for the Neural Network methodology for each of the nine defence profiles are provided in Table 6-1. The defence profiles were based on surveyed defence cross sections where available and high resolution LIDAR where not available. New survey was procured as part of this project as is discussed in more detail in section 5.

Table 6-1: Lamby and Rover Way defence information

Defence	Toe level (mAOD)	Berm level (mAOD)	Slope downward from berm (cot ad)	Slope upward from berm (cot au)	Armour crest level (mAOD)	Crest level (mAOD)
1 (Lamb_1)	2.90	6.85	2.11	2.04	10.43	10.43
2 (Lamb_2)	3.00	5.80	6.43	1.84	9.60	9.60
3 (Lamb_3)	2.70	-9.00	3.00	3.00	9.70	9.70
4 (Lamb_4)	3.10	6.40	3.64	5.13	10.30	10.30
5 (Rover_1)	3.80	6.80	7.33	2.96	9.50	9.50
6 (Rover_2)	2.00	7.40	7.41	1.00	9.40	9.40
7 (Rover_3)	3.10	8.00	6.12	3.57	9.40	9.40
8 (Rover_4)	3.90	6.40	6.80	0.40	8.90	8.90
9 (Rover_5)	2.00	7.50	6.04	3.33	8.90	8.90

6.4 Wave transformation modelling

To transform offshore wave heights into the nearshore zone, wave transformation modelling was undertaken using the SWAN (Simulating Waves Nearshore) wave model. SWAN is a third-generation wave model incorporating complex physics for the description of nearshore processes. It is an open source package (no licence required) used widely for research and commercial applications, developed by internationally recognised experts at the Delft University of Technology1. An existing SWAN model developed by Deltares in 2011 for NRW was used within this study, which is shown in Figure 6-3. This model extends around the entire offshore region of the Welsh coastline and was further refined for the output locations along the Rover Way and Lamby Way coastal defences.

1 SWAN User Manual, SWAN Cycle III version 40.81, Delft University of Technology, 2010

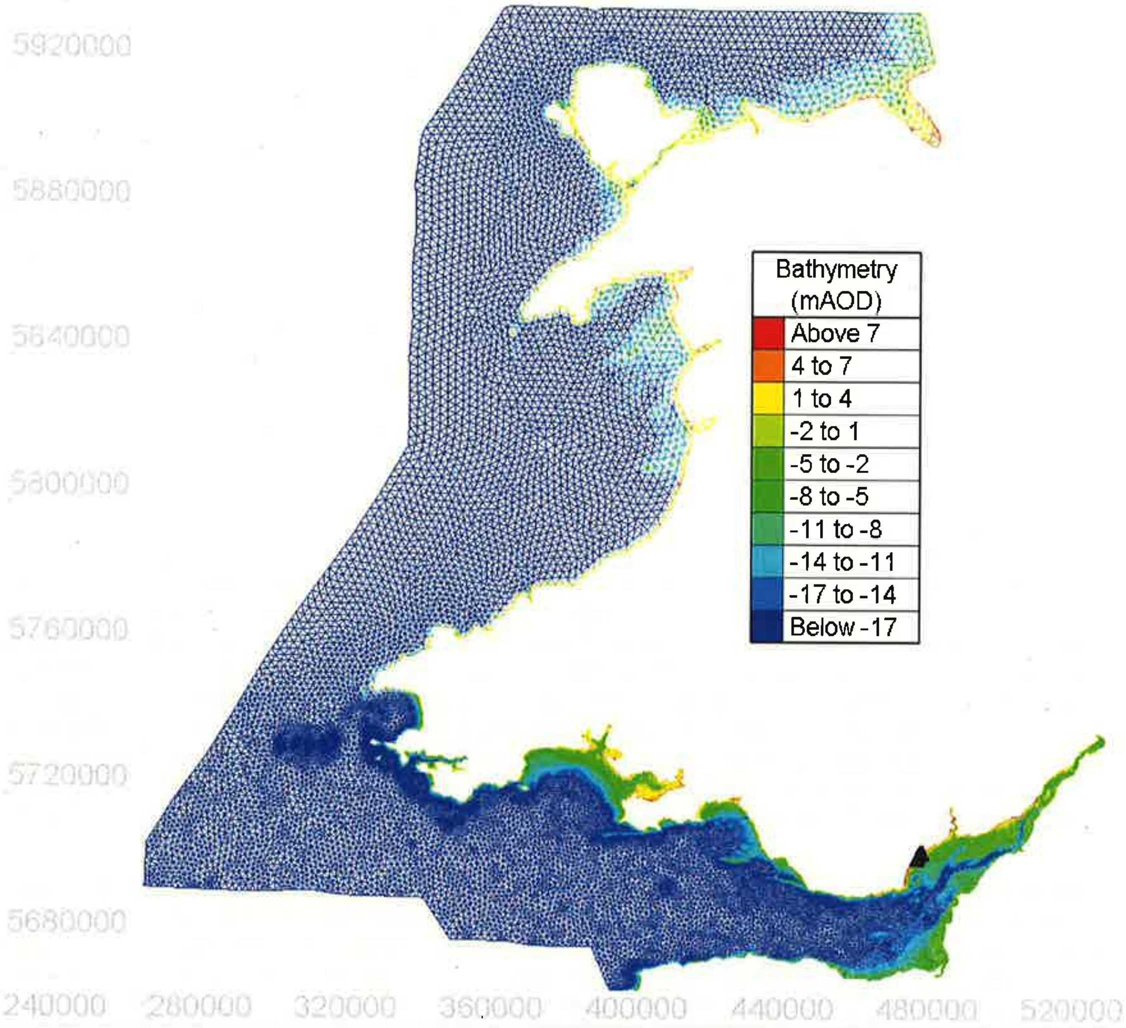


Figure 6-3: Wave transformation model used for this study area

6.4.1 Bathymetry

The offshore bathymetry was extracted from the existing Wales Coastal Model mesh (converted from MSL to ODN by subtracting 0.25m across the domain). The mesh was improved in the nearshore, where the bathymetry was merged with 2016 1m DTM LIDAR flown at low tide to a minimum elevation of -4m AOD. When merging the bathymetry, a gap was left between adjacent datasets, to allow for a smooth transition when interpolating.

6.4.2 Toe depths

The wave model results were extracted near the coastline, and are presented in Table 6-2. All differences between the Neural Network toe depth and model mesh depth are less than 0.1m, and thus the toe locations are deemed suitable. The toe outputs are located at model mesh nodes; hence, the mesh value equals the bathymetry value at this point.

Table 6-2: Comparison of neural network toe depths to depths at mesh extraction points

Toe	Neural Network toe depth (mAOD)	Model Mesh depth (mAOD)	Difference (m)
1	2.90	2.90	0.00
2	3.00	3.00	0.00
3	2.70	2.70	0.00
4	3.10	3.10	0.00
5	3.80	3.80	0.00
6	2.01	2.00	-0.01
7	3.10	3.10	0.00
8	3.87	3.90	0.03
9	2.00	2.00	0.00

6.4.3 Model boundary conditions

To force the wave transformation model, the boundary conditions were calculated through a joint probability analysis. The joint probability analysis used the Defra desk-based approach and was completed for a univariate extreme analysis of wind from the Met Office Wave Watch III (WWIII) wind point 625 near Flat Holm island. This was combined with the water levels at Cardiff from the coastal flood boundary (CFB) chainage point 408. The joint probability analysis calculates the probability of the source variables, in this case, water levels and wind data, occurring simultaneously and thus creating a situation where flooding may occur. The WWIII wind point was the same as used in previous studies and the data was split into direction sectors with univariate analysis of the wind data undertaken to analyse the winds from the west, south-west, south, south-east and east directions.

The desk study approach requires as input, high and extreme values of each of the two variables, together with a simple representation of the dependence between the two. A list of pre-computed combinations of alternative AEP events and levels of dependence are then used to derive the required AEP event. A limitation to this approach is that it is quite general, being neither site-specific nor variable-specific, as the pre-computed variables are expressed in terms of the marginal (single variable) AEP events for each of the two variables.

The variable-pairs used in these calculations are wind and total tide level. The dependence between these two variables was derived using the desk study Best Practice Guide FD2308, which provides dependence maps giving estimates of dependence between different variable-pairs covering most of the UK. The FD2308[2] dependence maps provide a Rho value of 0.3 for the dependence between winds speed and surge in the Severn Estuary. The report does not provide data for the dependence between total water level and wind speed, instead the dependence for surge was used as this is the dominant variable during flood events.

As laid out in the Best Practice Guide FD2308, the following steps outline the joint probability desk based approach required for this study:

- The total tide levels were derived;
- The wind speeds were derived;
- The dependence between the tide levels and the wind speeds estimated using the Best Practice Guide FD2308;
- The required joint AEP events were set (50%, 20%, 10%, 5%, 2%, 1.33%, 1%, 0.5%, 0.1% AEP events);
- Climate change simulations were required for 2037, 2067 and 2117;
- The appropriate tables for the level of dependence and AEP event were selected;
- The listed joint exceedance extremes were converted from the marginal AEP events to actual values.

2 Defra/Environment Agency (2005). Use of Joint Probability in Flood Management. A guide to best practice

The software tool provided by the Best Practice Guide FD2308 which reproduces the desk study approach calculated the final joint probability extreme events, requiring as input:

- The marginal extreme for the two variables
- The dependence between the two variables
- The desired joint exceedance events.

Table 6-3 shows the joint exceedance AEP events selected to be used in the Wales model update.

Table 6-3: Joint Probability joint exceedance AEP event results with minimum and maximum wind speeds and water levels used for each direction centre.

AEP %	Wind speed (m/s)										Max Water Level (mAOD)
	E		S		SE		SW		W		
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
50	7.71	10.56	10.34	13.52	8.23	11.44	11.71	14.47	12.47	15.98	7.51
20	7.71	10.56	10.34	13.52	8.23	11.44	11.71	14.47	12.47	15.98	7.64
10	9.61	12.09	12.47	15.19	10.37	13.24	13.56	15.76	14.82	17.90	7.73
5	10.43	12.62	13.38	15.76	11.30	13.90	14.35	16.14	15.83	18.57	7.84
52	10.43	12.62	13.38	15.76	11.30	13.90	14.35	16.14	15.83	18.57	7.99
1.33	10.43	12.62	13.38	15.76	11.30	13.90	14.35	16.14	15.83	18.57	8.07
0.10	10.43	12.62	13.38	15.76	11.30	13.90	14.35	16.14	15.83	18.57	8.12
0.50	10.43	12.62	13.38	15.76	11.30	13.90	14.35	16.14	15.83	18.57	8.26
0.10	12.00	13.62	15.09	16.79	13.13	15.18	15.69	16.77	17.78	19.84	8.65

A total of 1,262 model simulations were completed for the five different direction sectors, nine events and three climate change scenarios.

6.4.4 Water level grids

A variable water level grid was used within the model to enable an accurate prediction of the depth of water at each of the toe output locations for all the modelled simulations. The water levels were calculated from the closest Class-A tide gauge located at Newport. The State of the nation[3] water level equation was used:

The water level at a point *i* meters east of Newport (wl_i) is given by

$$wl_i = xl_N + y_i$$

Where (wl_N) is the water level at Newport relative to the ordnance datum,

$$y_i = 0.000295d^2 + 0.0386d \qquad for \quad wl_N > 7.519m$$

$$y_i = \frac{wl_N}{7.519}\left(0.000295d^2 + 0.0386d\right) \qquad for \quad wl_N \leq 7.519m$$

and,

$$d = \left(\frac{Easting_i - Easting_N}{1000}\right)$$

$$d_{\min} = -12.0 \ , \ d_{\max} = +36.0$$

An example water level grid is shown in Figure 6-4.

3 Environment Agency (2015). State of the Nation flood risk analysis. HR Wallingford.

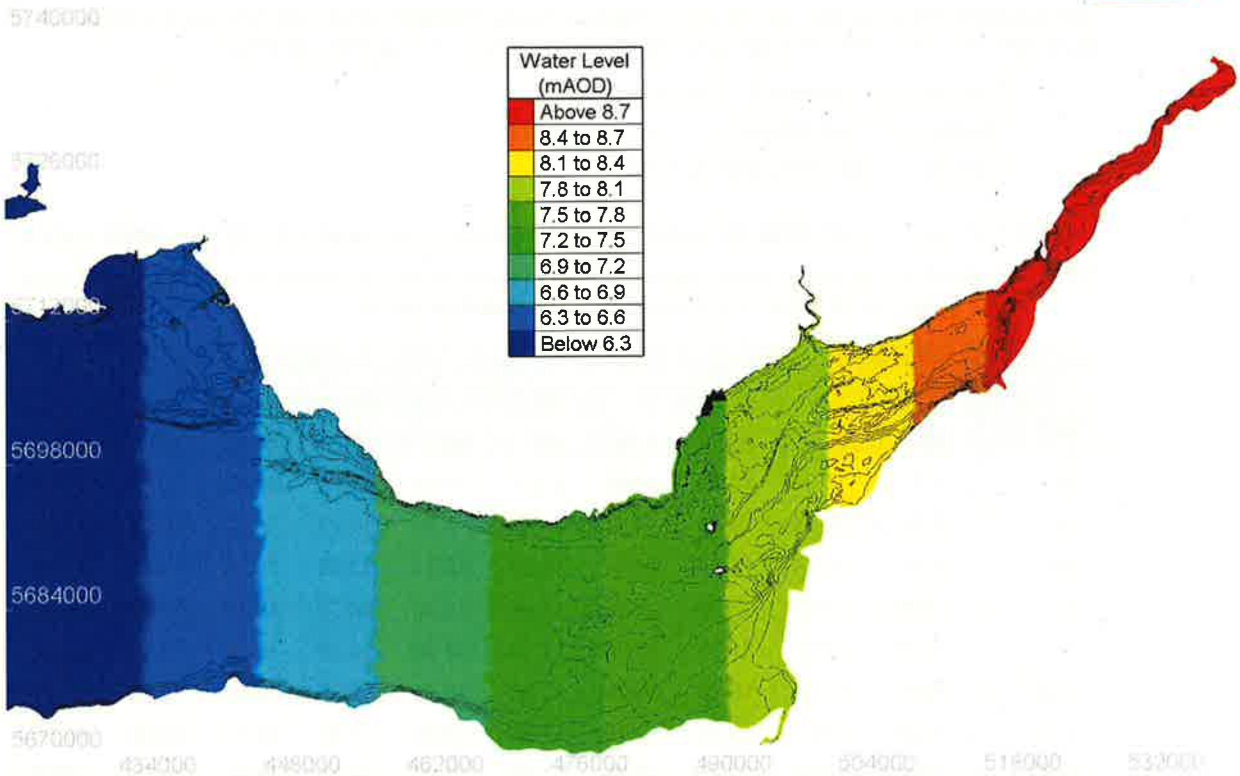


Figure 6-4: Variable water level grid

6.4.5 Wave overtopping calculations

The wave overtopping method calculates a wave overtopping discharge, quantified by the parameter 'q', in m³/s/m. The method outlined in the European Overtopping Manual[4] (EurOtop) has been used to calculate the wave overtopping discharges for this project. This manual includes three different methods and associated guidelines for the prediction of wave overtopping for different structure types. For this study, the Neural Network approach was used as it provides the most suitable methodology to rapidly assess complex multi-component defence structures such as many of the defences in the study area. The Neural Network model uses nearshore wave characteristics at the toe of a defence structure, defence geometry and sea-level data to quantify a mean overtopping discharge rate. This rate is expressed in terms of litres per second, per metre length of defence (l/s/m).

The mean wave overtopping discharges were calculated for the 1,262 simulations made up of the joint probability combinations of water levels and wind speeds for the five direction sectors, nine events and three climate change epochs. The wave overtopping was calculated using the nearshore wave conditions from the results of the wave transformation model simulations along with the defence structure parameters identified from the defence schematisation. For each event the maximum wave overtopping rates were identified and the conditions that produced this overtopping were taken forward to calculate timeseries of overtopping across a tidal cycle.

6.4.6 Tide curves

To enable the calculation of the wave overtopping across a tidal timeseries, tide curves were required for the nine modelled events and the three climate change scenarios. A design tidal graph is a time-series that quantifies how sea-levels are expected to change through time during an extreme event. It is these design tidal graphs which are used to drive the still water component of the flood inundation model at its offshore boundaries and used to calculate timeseries of wave overtopping rates. Creation of design tidal graphs requires three principal sources of information: an extreme sea-level estimate for the event of interest; a design surge shape, and; a design astronomical tide.

4 EurOtop (2010) "Wave Overtopping of Sea Defence and Related Structures: Assessment Manual", Overtopping Course Edition, November 2010. HR Wallingford.

The sea-levels that were used in the derivation of the design tidal graphs were based on the Coastal Flood Boundary (CFB) data that was updated with an additional 9 years of sea-level rise data to update from the 2008 base dataset to 2017.

The CFB report details how to combine an underlying astronomical tidal series and a design surge profile. Both the astronomical tidal series and the surge profile were based on the closest Class A tide gauge site at Newport. The underlying tide was exported from predictions based on harmonic analysis of the tide gauge data and calculated by the Admiralty Total Tide Software. The design surge profile was taken directly from the CFB study data.

As an example, the present-day design tidal graph derived for a 0.5% AEP event for Newport is shown in Figure 2-1.

A time series of wave overtopping volumes for each event (50%, 20% 10%, 5%, 2%, 1.33%, 1%, 0.5% and 0.1% AEP) was then derived. In cases where the still water level is at or above the defence crest, resulting in a zero or negative freeboard, the wave overtopping volumes have been adjusted to avoid double counting the volume of water overtopping the defence from wave action with that from still water flooding.

6.4.7 Climate change

In addition to present day extreme still water level events, climate change scenarios projected to 2037, 2067 and 2117 were modelled based on Adapting to the Climate Change: Advice for FCERM Authorities 2016 guidance.

Sea level rise estimates were based on the latest UKCP09 sea-level change guidance[5] using the medium emission 95th percentile scenario. The increases for sea level rise are shown in Table 6-4.

Table 6-4: UKCP09 medium emissions scenario sea level rise estimates, metres per year (2117 base year)

SLR projected to 2037 (m)	SLR projected to 2067 (m)	SLR projected to 2117 (m)
0.12	0.32	0.75

Linked with the changes in predicted sea levels, offshore wind speed and wave height allowances (increases) are provided within the UKCP09 guidance for two epochs which are noted below:

- 1990 to 2055 +5%
- 2056 to 2117 +10%.

An increase of 10% to both offshore wind speed and wave height was applied for this study.

As this project is based on UKCP09 guidance it is not inline/suitable to be used with planning. The latest National Planning and Policy Framework (NPPF) guidance should be used for this.

6.4.8 Assumptions

The behaviour of waves in the nearshore and surf zone is highly complex and the subject of detailed research. Due to this, a number of assumptions were made to represent wave overtopping at the model boundary for the appropriate design conditions. Firstly, for the purposes of a flood inundation model, it is unnecessary to incorporate details of individual wave processes but rather to represent worst case conditions.

The most important assumption is that wave conditions, remain consistent throughout the progression of the tidal time series. This approach is appropriate for modelling design events as it simulates the conditions at the boundary of the model where extreme tides, surge levels and waves occur at the same time. Changes in overtopping rates are therefore a result of the changing water level conditions rather than any changes in the incident wave conditions. Environment Agency Flood and Coastal Risk Management Modelling Guidance recommends modelling wave action over a 12-24-hour period, as the waves will then diminish as the storm moves and the wind changes direction. It was assumed that the storm continues with constant wind speeds and direction for the entire progression of the tidal curve, concurrent with the wave action.

5 http://ukclimateprojections.defra.gov.uk/

6.5 Wave overtopping results

The wave overtopping results for the existing defences are summarised in Table 6-5.

Table 6-5: Existing defences wave overtopping rates

Wave overtopping discharge (Qm $l^3/s/m$)									
Epoch	Toe 1	Toe 2	Toe 3	Toe 4	Toe 5	Toe 6	Toe 7	Toe 8	Toe 9
Present day	0	2.835	0	0.0167	0.0586	0.0578	0	0.4142	0.0314
	0.0050	4.761	0	0.0240	0.1611	0.1258	0	0.8595	0.0813
	0.0074	6.202	0	0.0213	0.2540	0.1944	0.0070	1.0940	0.1182
	0.0169	5.581	0.0093	0.0554	0.4954	0.4453	0.0165	1.7700	0.2887
	0.0522	28.65	0.0384	0.1366	2.3380	2.5780	0.0547	3.6640	1.0880
	0.0895	42.22	0.0832	0.2158	4.3120	4.0690	0.0843	4.7920	1.8510
	0.1282	54.11	0.1403	0.2966	6.1680	5.5300	0.1242	5.4540	2.5400
	0.3155	95.78	0.4956	0.6939	18.270	11.740	0.4039	9.7300	6.8400
	1.6840	148.8	3.3610	3.2850	98.050	54.480	5.0330	12.560	11.160
2037	0.0053	4.618	0	0.0241	0.1065	0.1031	0	0.8117	0.0503
	0.0075	6.933	0	0.0318	0.2906	0.2224	0.0058	1.1590	0.1293
	0.0107	8.903	0	0.0281	0.4545	0.3408	0.0111	1.4490	0.1868
	0.0293	16.74	0.0154	0.0711	0.9223	0.7209	0.0243	2.4230	0.4881
	0.0903	41.25	0.0775	0.2177	3.8750	3.8350	0.0798	4.6370	1.8010
	0.1550	59.78	0.1705	0.3488	7.0190	6.1460	0.1305	5.8620	2.9430
	0.2212	75.65	0.2854	0.4834	9.8250	8.3510	0.2201	7.5780	3.9250
	0.5364	128.8	0.9504	1.1400	22.090	17.650	0.7345	10.140	9.6600
	2.6060	197.8	5.1180	5.0500	131.80	56.780	8.2460	12.940	14.730
2067	0.0112	8.612	0	0.0407	0.3204	0.2561	0.0045	1.3740	0.1283
	0.0179	13.91	0.0117	0.0609	0.6593	0.6631	0.0134	1.9990	0.3401
	0.0298	17.06	0.0171	0.0721	1.3770	1.1030	0.0254	2.4470	0.4989
	0.0799	17.06	0.0547	0.1723	2.6910	1.7540	0.0564	4.0500	1.3050
	0.2529	39.21	0.3113	0.4846	9.3820	8.5290	0.2761	6.8040	4.1320
	0.4299	55.07	0.6497	0.7996	16.310	13.540	0.5625	8.7490	6.3580
	0.6357	101.3	1.1030	1.1920	22.230	17.910	0.9279	9.8230	8.0730
	0.8604	166.6	1.7040	1.8000	45.580	35.060	2.0910	11.060	10.390
	5.4840	268.7	9.4290	10.660	151.50	44.640	8.7700	197.043	185.99
2117	0.0787	16.85	0.0524	0.1650	2.8880	1.8660	0.0549	4.0780	1.1470
	0.1253	51.25	0.1210	0.2924	5.4490	5.2280	0.1046	5.3070	2.4580
	0.2210	65.78	0.2204	0.4355	7.9400	6.9040	0.2243	6.2060	3.3370
	0.5063	65.78	0.7399	0.9373	16.660	9.3950	0.6780	9.7310	6.7090
	0.9794	156.6	1.9980	1.7990	45.920	23.470	2.1490	10.690	10.400
	1.6760	156.6	3.7580	3.0680	70.290	34.000	4.0830	11.210	10.660
	2.2920	156.6	5.3090	4.2090	88.270	38.430	5.5840	11.560	10.770
	4.4440	213.7	10.180	8.3080	130.40	55.190	6.8370	204.17	190.79
	21.020	320.8	10.180	41.680	195.90	69.830	11.600	712.19	699.40

6.5.1 Wave overtopping for improve scenario proposed defences

Following the calculation of wave overtopping for the existing defences, the wave overtopping rates were also calculated for the proposed defences as part of the long list options appraisal. The defences were re-schematised to include the rock armour, increased crest heights and wave walls for the different options. Wave overtopping rates were calculated for a fixed crest height of 9.98m and then adjusted at 0.1m increments by plus 0.1-0.3m and minus 0.1-0.8m to determine the crest elevation required to achieve tolerable discharge rates as follows:

- All defences maximum tolerable discharge of 1l³/s/m for a 50% AEP event;
- Defences 5-7 (Rover 1-3) maximum tolerable discharge of less than 4l³/s/m during the 0.5% AEP plus climate change SLR to 2117;
- Defences 1-4 (Lamb1-4) and 8-9 (Rover_4, Rover_5) maximum tolerable discharge of less than 30l³/s/m during the 0.5% AEP plus climate change SLR to 2117; and
- The final defence elevations and overtopping rates for the rock armour, wall and sheet pile options are presented in Table 1-5 for the 0.5% AEP in 2117.

Table 6-6: Crest heights and overtopping discharges during a 0.5% AEP with SLR to 2117 for the defence options of rock armour and wave return walls/capped sheet piling

Defence	Rock Armour Defence crest (mAOD)	Rock Armour Overtopping discharge for the 0.5% AEP 2117 (l³/s/m)	Wall/Sheet pile Defence crest	Wall/Sheet pile Overtopping discharge for the 0.5% AEP 2117 (l³/s/m)
1	9.38	26.5	9.88	15.9
2	9.38	25.3	9.98	21.4
3	9.38	20.2	9.88	19.9
4	9.38	25.0	9.98	21.0
5	9.88	3.4	10.18	3.5
6	9.98	3.1	10.28	2.9
7	9.98	3.6	10.18	3.8
8	9.38	28.1	9.88	17.7
9	9.38	8.3	9.78	10.2
Note: The schematisations and hence the overtopping rates for the wave return wall and the capped sheet pile are the same.				

It can be seen from Table 6-6 that the rock armour with the lower crest elevations, is most effective at keeping the overtopping rates low.

7 Sensitivity analysis

It was decided after discussions with the internal reviewer and the project director to undertake sensitivity testing that looked at three of the model parameters: Manning's n roughness coefficients, and the 2D stage-discharge (HQ) outflow and tidal boundary conditions. There model parameters are considered to have the greatest influence on the model outputs, and were therefore chosen for testing.

Parameter	Variance
Manning's n roughness coefficient	±20% change in roughness applied to the 2D domain
Stage-discharge (HQ) Outflow boundaries	±20% change in slope value (used to generate HQ curve)
Tidal boundary	±0.3m confidence intervals for the 0.5% AEP event

All sensitivity analysis was undertaken on the 0.5% AEP flood event with 100 years' climate change, with additional tidal boundary testing on the present day 0.5% AEP event. Therefore, the testing was undertaken on model run version 030, acting as the do nothing design model run for these events. The former event incorporates breach scenario four, whilst the latter incorporates breach scenario two.

7.1 Manning's n roughness coefficients

Hydraulic roughness values of the floodplain are represented by specifying a Manning's n roughness coefficient within the 2D domain. The value of the Manning's n roughness coefficient varies throughout the model and is based on established reference texts. The OS MasterMap data supplied by CCC was used to define roughness characteristics in the 2D floodplain. Each key land use type was then assigned a Manning's n roughness coefficient. The 2D floodplain roughness values have been varied by ±20%, with the sensitivity tests has been undertaken using the 0.5% AEP 2117 event scenario.

The results of the Manning's n roughness coefficient sensitivity testing showed that:

- A reduction in the Manning's n roughness coefficients resulted in an increased flood extent and increased flood levels. This is due to the lower roughness meaning there is less resistance to overland flow, therefore allowing the propagation of floodwater further into the floodplain; and
- An increased in the Manning's n roughness coefficients resulted in a slightly reduced flood extent and decreased flood levels in the study area. The higher roughness acts as resistance to the propagation of flood water therefore reducing the extent.

As can be seen in Figure 7-1, the change in flood extents as a result of the alteration to Manning's coefficients is not significant. There are some localised impacts in the Moorland Park area and to the Avenue retail park just north of the study area, but the sensitivity test does not result in any additional areas to be at risk of flooding.

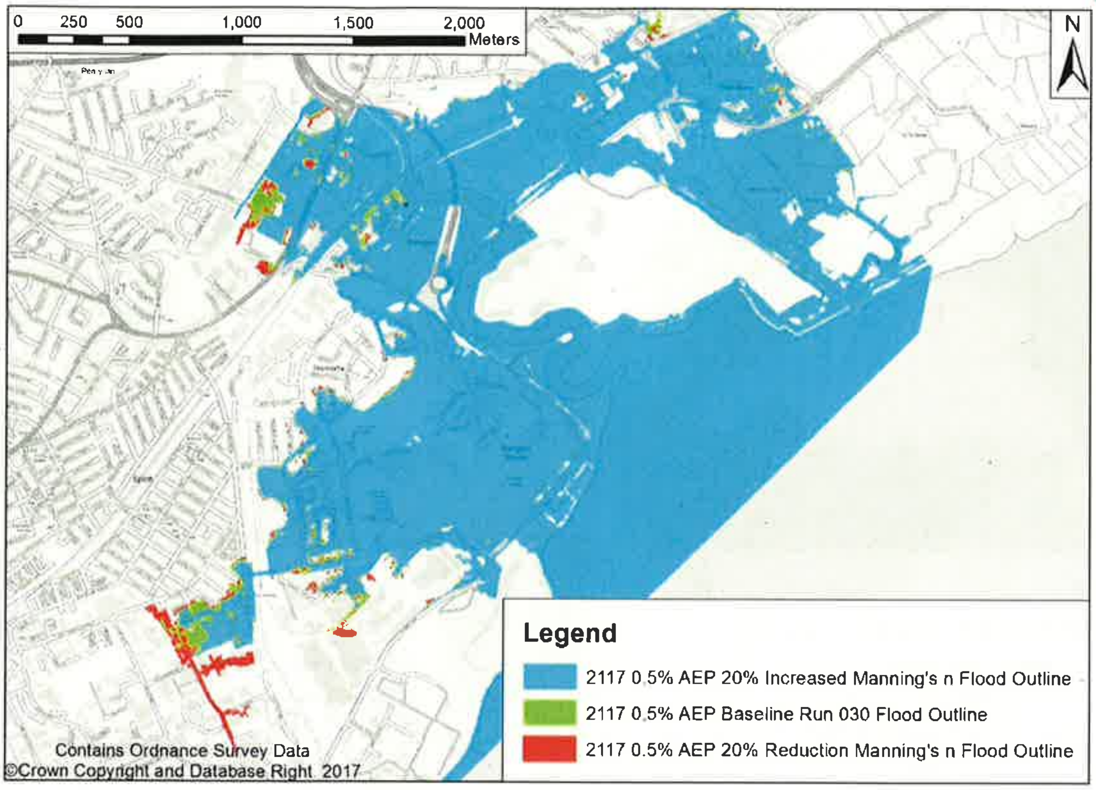


Figure 7-1 Manning's n sensitivity testing results showing changes to flood extents

7.2 Stage-discharge (HQ) outflow boundary

There are a total of four stage-discharge (HQ) boundaries located along the model boundary. These boundary conditions have been included within the model to allow floodwater to flow out of the model and prevent any 'glass-walling' occurrence. The HQ boundaries had been input into the model during the development phase; within the final model three of the four HQ boundaries are no longer utilised so they have no influence on the model results. The only HQ boundary that does allow water to exit the model is located along the Eastern boundary at Pwll-Mawr, perpendicular to the B4239 Wentloog Avenue where it meets Parkway. The HQ curve has been automatically generated in TUFLOW based on the slope gradient of 0.0002. For the purpose of the sensitivity assessment, this slope value has been amended by ±20%. The sensitivity tests have been undertaken using the 2117 0.5% AEP event scenario.

The results of the model sensitivity testing showed that:

- The HQ boundaries have minimal impact on the model results, with identical flood extents between the baseline run 030 and the two sensitivity tests of increasing and decreasing the HQ boundary slope values;
- Figure 7-2 shows the water level grid comparisons, of which highlights that the 20% reduction in slope value (right-hand side) has resulted in localised reductions in water level of up to 4cm to the eastern extent of the model; and
- A 20% increase in the slope value of the HQ boundaries results in localised increases of water level of up to 5cm to the eastern extent of the model, as shown on the left-hand side of Figure 7-2.

This sensitivity test has shown that the application of the HQ slope value does not have a significant impact on the model results or flood risk to the study area.

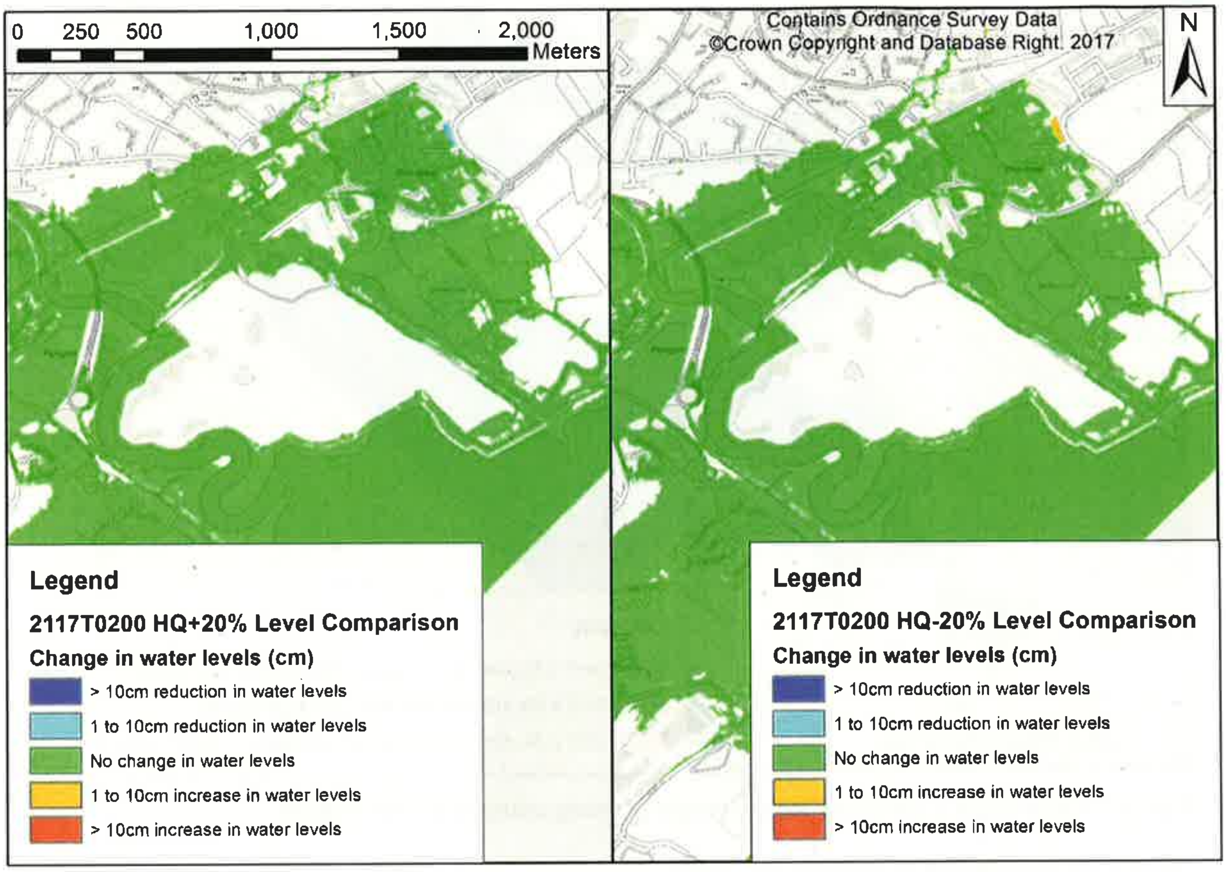


Figure 7-2 HQ boundary sensitivity testing results showing water level grid comparisons

7.3 Tidal boundary

The tidal boundary curves have been amended by ±0.3m for both the present day and 2117 0.5% AEP event simulations. A value of 0.3m was chosen as this is the recognised confidence intervals for the 0.5% AEP event. It was decided to test two events as the present day (2017) 0.5% AEP event shows very little flooding, and therefore assessing both events will allow for the quantification of the influence of the boundary condition at the two extremes of the design event spectrum.

The sensitivity results are presented in Figure 7-3, and can be summarised as showing that:

- For the present day 0.5% AEP event, increasing the tide curves by 0.3m result in some localised increases on flood extent around Tremorfa and the area bounded by Rover Way, the A4232 and the Beaufort Square housing estate. Additional localised increases occur to the retail parks along Newport Road just north of the study area. This can be seen in the top map of Figure 7-3;
- A 0.3m decrease to the tide curves in the present-day 0.5% AEP event, shows a decrease in the flood extents around Tremorfa, and around the railway line to the north of the study area;
- For the 0.5% AEP event with 100 years climate change (ie, 2117), the effect of changing the tidal boundary conditions by ±0.3m is more significant, as shown in the bottom map within Figure 7-3. Increasing the tidal curves by 0.3m increases the flood extent at Rumney, Tremorfa, the Beaufort Square housing estate and the retail parks along Newport Road just north of the study area. Additionally, new areas are encroached by floodwaters, at East Moors and the area bounded by Rover Way, the A4232 and the housing estate; and
- A 0.3m decrease to the tide curves in the 0.5% AEP in 2117, reduces the flood extent, with the greatest localised impacts at Rumney, Tremorfa and to the north of the study area and adjacent. Flooding under these tidal boundary conditions has resulted in no flooding to the Beaufort Square housing estate.

This sensitivity test suggests that the model results are very sensitive to the application of the tidal boundary conditions. Current guidance has been adopted, with tide curves and climate change based on UKCP09 values. However, it is worth noting that there is uncertainty in the sea levels and the confidence intervals on the extreme sea level dataset are 0.3m for the 0.5% AEP event which has been adopted; for the 0.1% AEP event the confidence interval is 0.5m so it is likely the results for 0.1% AEP will be more significant.

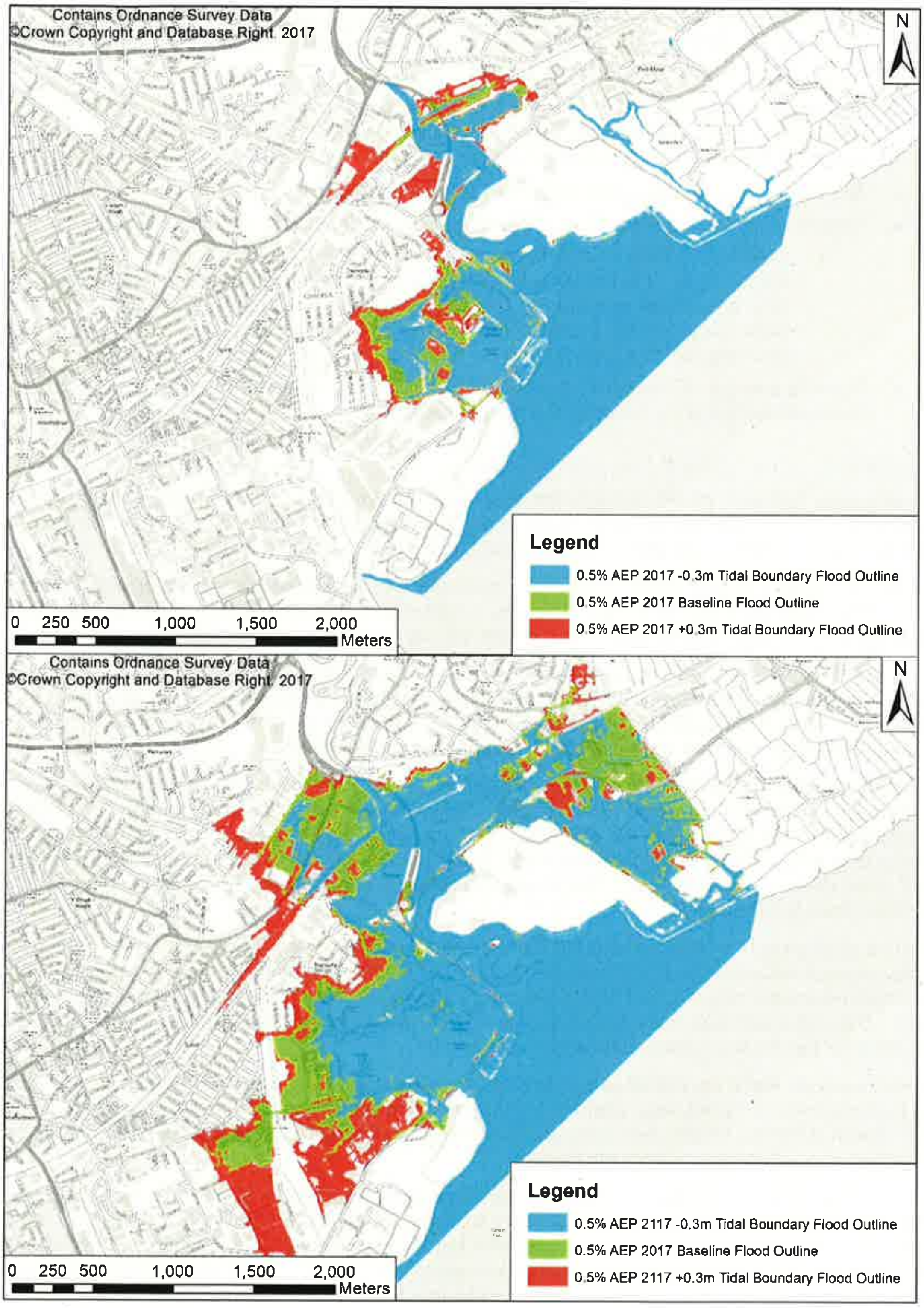


Figure 7-3: Tidal boundary ±0.3m sensitivity flood outline comparison

8 Model performance, limitations, assumptions, and uncertainty

8.1 Model performance

This section provides an overview of the performance of the hydraulic model. This has focused on the do nothing 0.5% AEP design event simulations including both the present day and future scenarios. The model performance is summarised below:

- The model mass balance is within the typically acceptable ±1% range for all of the climate change scenarios, with a peak mass balance of up to -0.26% during the 0.5% AEP 2117 event. This occurs during the initial model time-step;
- All model run scenarios run stably with a 2D time-step of 2 seconds;
- There is one warning in the TUFLOW message layer prior to the simulation beginning;
    - WARNING 2089 - Object ignored. Looking for first Line, Polyline or Region in 2d_loc layer. It is not clear where this warning has been derived from as there is only one object specified in the 2d_loc file and the dom_check file is shown to encompass the full model domain correctly. This warning has been disregarded as it was felt it had no bearing on the model outputs; and
- There is a single 2D negative depth identified within the 0.5% AEP 2117 event, there are no negative depths for the other 0.5% AEP events.

8.2 Limitations, assumptions and uncertainty

Developing a hydraulic model requires the application of simplifications and generalisations. As such, a number of assumptions were made when during the build and development of the model. This can lead to model uncertainties and subsequent limitations of the results.

The key input data for this model is the tide curve data, generated using peak water levels based on UKCP09 estimated sea level rise. There is a high degree of uncertainty regarding future sea level rise and the results generated by the model directly reflect this uncertainty.

The LIDAR used to set the base topography in the 2D model domain is an additional source of model uncertainty. The bare earth DTM was filtered to remove the presence of buildings and vegetation. The LIDAR data used in this study is at 1m and 2m resolution. This was reviewed, and noted LIDAR filtering errors were corrected through the use of Z-shapes.

Detailed topographic survey data has been collected, providing top of bank elevations throughout the study area at 10m increments. This was collected by Storm Geomatics in December 2016. Also included within this survey was the collection of 12 beach profiles that were used within the wave overtopping calculations. The surveyors noted that due to safety reasons the beach profiles were only taken up to the Estuary mud. This has led to potential uncertainty with the wave overtopping volumes input into the model.

The choice of breach locations is another form of uncertainty with the model outputs. The breaches have a considerable impact on the modelled flood risk. The location and threshold for the modelled breaches were determined based on the geomorphology assessment, asset condition, and defence level. It is assumed that these breaches are appropriate based on the available data but their influence on the results does lead to some uncertainty.

Other limitations within the model lie with the uncertainties in the wave overtopping estimations and the fact that there is no drainage element incorporated into the model. Additionally, all formal flood and erosion defences have been input into the model as topographic modifications as do not factor in any permeability of the defence structures.

General modelling assumptions relate to the selection of various parameters within the model, for example, the roughness values used within the model or the tidal boundary conditions. After discussions with the internal model reviewer and the Project Director it was decided to sensitivity test the manning's n roughness coefficients, the stage-discharge (HQ) boundary conditions and the tidal boundary. Details of the sensitivity test can be found in Section 0, and summarise below:

- A 20% reduction in 2D manning's n roughness coefficients resulted in an increased flood extent the ground surface provided less resistance allowing the floodwater to propagate further throughout the model extent. The opposite occurred during the increased roughness test which resulted in a smaller flood extent due to the higher roughness restricting the propagation of floodwater;

- The stage discharge (HQ) sensitivity test has been undertaken that amended the slope value by ±20%. This change in slope alters the TUFLOW automatically generated HQ curve. The 20% reduction saw a very localised area of decreased water levels of up to 4cm to the eastern extent of the model. A 20% increased resulted in up to 5cm increase in the same localised area; and
- The model results were shown to be very sensitive to the application of the tidal boundary. The flood extents changed considerably for both the 2017 and 2117 event scenarios. This impact was expected and it is acknowledged that there is uncertainty in climate change estimations used to calculate the sea levels used at the tidal boundary. The confidence intervals on the extreme sea-level dataset are 0.3m for the 0.5% and 0.5m for the 0.1% AEP events.

9 Model runs

A series of model runs were undertaken to assess the flood risk and flood hazard posed by tidal flooding to the Rover Way and Lamby Way Tip study area. The following sections describe the model scenarios and events that were modelled.

9.1 General procedures for model runs

Prior to running the hydraulic model, a clear folder structure needs to be set-up. This was taken directly from the TUFLOW guidance. The most straightforward approach is to save the "TUFLOW" folder contained with the "Model" folder, into 'C:\CARDIFF\' which was created on the user computer C drive. All folders are made sure to be uncompressed, with care taken to preserve the original folder structure. By setting up the folder structure in this way, when the model is run both the results and the check files will be saved in their respective TUFLOW folders on the C drive as the .tcf file references these locations.

9.2 Explanation of file types

.tgc = TUFLOW Geometry Control file

.tcf = TUFLOW Control File

.tbc = TUFLOW Boundary Condition file

.tef = TUFLOW Event File

.tmf = TUFLOW Material File

bc_dbase = boundary conditions database file

9.3 Tidal design "Do Nothing" scenario event runs

Run Reference:	CDF_030_~s1~_~e1~ (s1 = scenario e1 = event) CDF_040_~s1~_~e1~ (s1 = scenario e1 = event) Run 040 incorporates additional breach scenarios, incorporating breach 3.	
Purpose of Runs:	To model tidal flood events using the defended tidal model.	
TUFLOW: 2016-03-AD-w64	File names:	
	CDF_030_~s1~_~e1~.tcf CDF_040_~s1~_~e1~.tcf	CDF_024.tgc CDF_040.tgc
	CDF_022.tmf	CDF_021.tbc
	TIDAL_Events_CDF_021.tef	bc_dbase_CDF_026.csv
Notes:	Storm surge has been applied to tidal design curves.	
Run Time:	Model event duration: 31 hours	
AEP event(s)	50% AEP (2017, 2037, 2067, 2117) 10% AEP (2017, 2037, 2067, 2117) 5% AEP (2017, 2037, 2067, 2117) 2% AEP (2017, 2037, 2067, 2117) 1.33% AEP (2017, 2037, 2067, 2117) 1% AEP (2017, 2037, 2067, 2117) 0.5% AEP (2017, 2037, 2067, 2117) 0.1% AEP (2017, 2037, 2067, 2117)	
Boundary Conditions:	(HT) Tidal boundary orientated East-West (HQ) Stage-Discharge boundaries to allow floodwater out of model domain	
Run Settings:	All parameters were left as default.	
Comments on results:	2016 0.5% AEP Final MB Error = -0.00%; Peak MB Error = -0.11%; Max negative depth warnings: 0. (Run version 030) 2116 0.1% AEP Final MB Error = -0.03%; Peak MB Error = -0.26% Max negative depth warnings: 1. (Run Version 030)	

9.4 Tidal design "Do Minimum" scenario event runs

Run Reference:	CDF_030_~s1~_~e1~ (s1 = scenario e1 = event) CDF_036_~s1~_~e1~ (s1 = scenario e1 = event) CDF_040_~s1~_~e1~ (s1 = scenario e1 = event) Run 036 is the 'Do Minimum' scenario for the 2017 and 2037 events. For additional climate change events (ie, 2067 and 2117) the 'Do Nothing' model schematisation Run 030 and Run 040 has been adopted.	
Purpose of Runs:	To model tidal flood events using the defended tidal model.	
TUFLOW: 2016-03-AD-w64	File names:	
	CDF_030_~s1~_~e1~.tcf CDF_036_~s1~_~e1~.tcf CDF_040_~s1~_~e1~.tcf	CDF_024.tgc CDF_036.tgc CDF_040.tgc
	CDF_022.tmf	CDF_021.tbc
	TIDAL_Events_CDF_021.tef	bc_dbase_CDF_026.csv
Notes:	Storm surge has been applied to tidal design curves.	
Run Time:	Model event duration: 31 hours	
AEP event(s)	50% AEP (2017, 2037, 2067, 2117) 10% AEP (2017, 2037, 2067, 2117) 5% AEP (2017, 2037, 2067, 2117) 2% AEP (2017, 2037, 2067, 2117) 1.33% AEP (2017, 2037, 2067, 2117) 1% AEP (2017, 2037, 2067, 2117) 0.5% AEP (2017, 2037, 2067, 2117) 0.1% AEP (2017, 2037, 2067, 2117)	
Boundary Conditions:	(HT) Tidal boundary orientated East-West (HQ) Stage-Discharge boundaries to allow floodwater out of model domain	
Run Settings:	All parameters were left as default.	
Comments on results:	2016 0.5% AEP Final MB Error = -0.00%; Peak MB Error = -0.11%; Max negative depth warnings: 0. (Run version 036) 2116 0.1% AEP Final MB Error = -0.03%; Peak MB Error = -0.26% Max negative depth warnings: 1. (Run version 030)	

9.5 Tidal design "Improved" scenario event runs

Run Reference:	CDF_039_~s1~_~e1~ (s1 = scenario e1 = event)	
Purpose of Runs:	To model tidal flood events using the defended tidal model.	
TUFLOW: 2016-03-AD-w64	File names:	
	CDF_039_~s1~_~e1~.tcf	CDF_039.tgc
	CDF_022.tmf	CDF_039.tbc
	TIDAL_Events_CDF_021.tef	bc_dbase_CDF_039.csv
Notes:	Storm surge has been applied to tidal design curves.	
Run Time:	Model event duration: 31 hours	
AEP event(s)	50% AEP (2017, 2037, 2067, 2117) 10% AEP (2017, 2037, 2067, 2117) 5% AEP (2017, 2037, 2067, 2117) 2% AEP (2017, 2037, 2067, 2117) 1.33% AEP (2017, 2037, 2067, 2117) 1% AEP (2017, 2037, 2067, 2117) 0.5% AEP (2017, 2037, 2067, 2117) 0.1% AEP (2017, 2037, 2067, 2117)	
Boundary Conditions:	(HT) Tidal boundary orientated East-West (HQ) Stage-Discharge boundaries to allow floodwater out of model domain	
Run Settings:	All parameters were left as default.	
Comments on results:	2016 0.5% AEP Final MB Error = -0.01%; Peak MB Error = -0.11%; Max negative depth warnings: 0. 2116 0.1% AEP Final MB Error = -0.03%; Peak MB Error = -0.26% Max negative depth warnings: 1.	

10 Model results

This section provides an overview of the model outputs in terms of the flood mechanisms and severity of flooding impacting the Rover Way and Lamby Way Tip study area. For the purpose of this section the model results discussed are from the 0.5% AEP event for the present day and full range of future climate change scenarios. This section has been split into three sub-categories that covers each of the main modelled scenarios:

- 'Do Nothing'
- 'Do Minimum'
- 'Do Something'

10.1 'Do Nothing' scenario

The 'Do Nothing' scenario is the representation of the present-day conditions throughout the study area. The model schematisation for the 'Do Nothing' scenario has incorporated the current bank elevations and formal flood defences. Depending on the epoch, different breach scenarios were used to represented the situations in which the defences would fail without any maintenance or repairs. The breaches used for the 0.5% AEP event are as follows: (1) breach scenario 2 for 2017, (2) breach scenario 7 for 2037, and (3) breach scenario 4 for 2067 and 2117. These breaches and the low points within the current defence line are the main flow paths, allowing the water to propagate from the sea or the Rhymney River channel into the land and spread as overland flow.

Figure 10-1 shows the results for the 0.5% AEP events under the do nothing scenario.

In the present day 0.5% AEP event, much of the flood risk to the Lamby Way Tip study area is contained within surface water storage capacity: Rumney drainage channels and the Parc Tredelerch lake. Additional flooding to the east of the Rhymney River is due to the waves overtopping the existing defence line. Much of the flood risk during this event is located at Tremorfa, including the Pengam Moors areas. This is a result of wave overtopping, and breaches along the coastline and at the first meander loop of the Rhymney River, with floodwater propagating inland and flow paths following areas of lower elevation. Rover Way and the Rover Way traveller and Western Power sites are also at risk of flooding in the 0.5% AEP event, as is the area of land situated between Lamby Way and the A4232 to the west of the Rhymney River. A small amount of flooding may also occur at the railway lines to the north of the study area.

With 20 years' climate change, the 0.5% AEP flood extent increases from that of the present day. Floodwater propagates further in the Rumney area, although are still constrained within the drainage channels, and along the northern railway line. In this modelled simulation, the main additional flooding occurs due to water propagating through the breach 3 at the second meander loop, which poses a flood risk to the north of Tremorfa and the Rover Way highway.

The 2067 and 2117 0.5% AEP flood extents show further flood water propagation, partly as a result of all breaches being activated. In 2067, the main increase in flood risk is to Rumney/Trowbridge, in which floodwater overtops the drainage channel banks and the lake at Parc Tredelerch. Flood water encroaches on the business park in this area. Additional flooding to Tremorfa and the railway at the northern boundary of the study area is evident, and floodwater also propagates from the railway onto Avenue Retail Park on Newport Road. There is a significant difference between the 2067 and the 2117 event. Floodwaters propagate further through Tremorfa, and into Splott through the Muirton Road underpass. In this event the majority of the Beaufort Square housing estate is at risk of flooding, as is the wider extent of the retail parks along Newport Road, with Roath Brook marking the maximum extent of the flood risk to the north. Floodwaters also propagate from the Rumney drainage channels and eastwards from the Parc Tredelerch lake, increasing the spatial flood risk of Rumney and Trowbridge, to include the entirety of the business park and Pwll-Mawr. Much of the Rover Way and Lamby Way highway infrastructure within the study area is also at risk of flooding in the 0.5% AEP event in 2117.

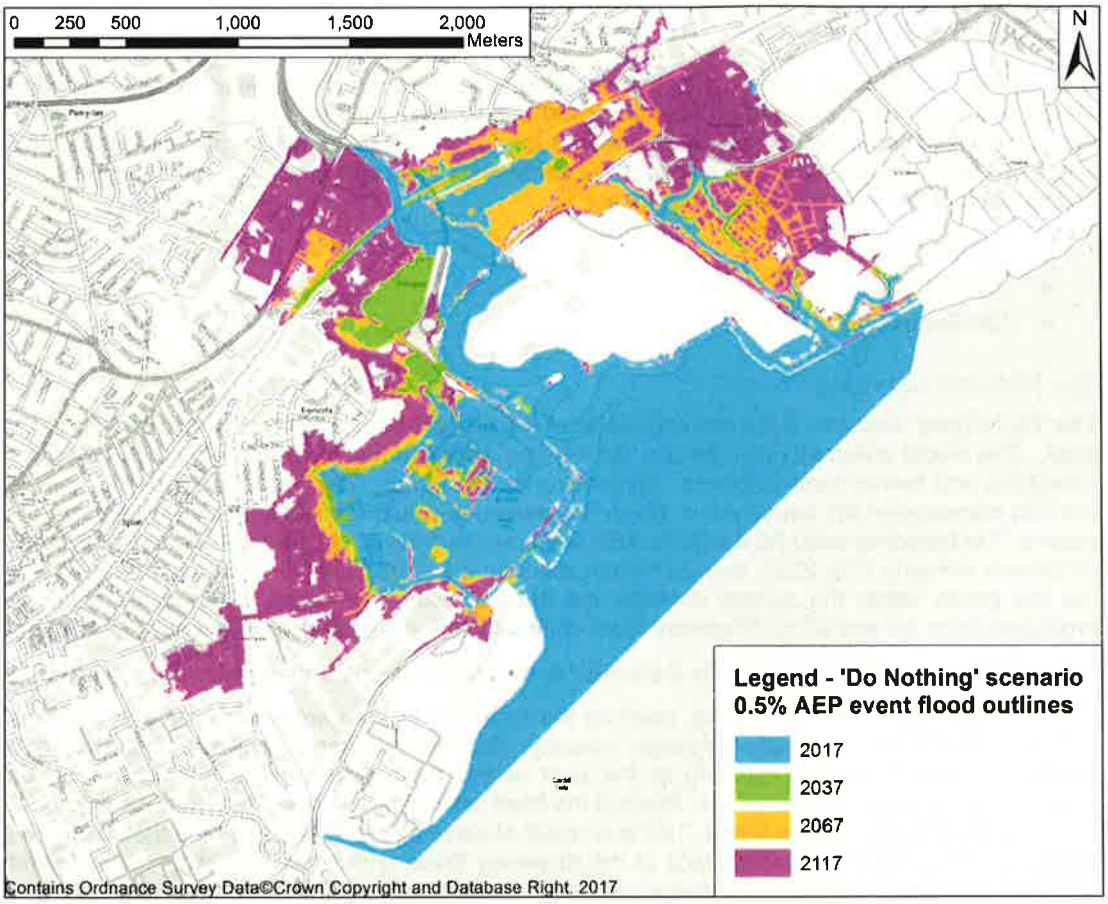


Figure 10-1 Flood outlines for the do nothing 0.5% AEP event across all modelled epochs

10.2 'Do Minimum' scenario

The 'Do Minimum' scenario is the representation of maintaining the present-day defence conditions throughout the study area. This will involve light rock armour along the coast to delay erosion for 20 years. Although no additional formal works will be undertaken, the current defence will be maintained through patch and repair along the fluvial sections of defence. Therefore, in the present day, no breaches will occur, with only the main breach and breaches 1 and 3 being activated in 2037. For years 2067 and 2117, the breach scenarios are the same as the do nothing scenario. Figure 10-2 shows the results for the 0.5% AEP events under the do minimum scenario.

Under the do minimum scenario, the flood extent of the present day 0.5% AEP event covers south Tremorfa, specifically Pengam moors, Rover Way, and the Rover Way traveller and Western Power sites along the coast at Rover Way. The flood water overtops the coastal defences at low points, and the extent is exacerbated by the additional overtopping applied to the model. The flood water propagates along the areas of low elevation, including that of the Rover Way highway. Parc Tredelerch lake and the drainage channels of Rumney are also filled. The same event with 20 years climate change has a large flood extent within the Tremorfa area. This is due to the coastal breaching which will occur due to coastal erosion along the Rover Way coastline. Additional flooding occurs due to the propagation of floodwater along the railway line marking the north of the study area. The flood extents for 2067 and 2117 are considerably larger and are identical to that of the do nothing scenario. This is due to maintenance and patch and repair of the current defences only being sustainable for 50 years. With 100 years' climate change, flood water propagates from all breaches into Tremorfa, Splott, Beaufort Square housing estate, and Roath. Out of bank flooding also occurs along the Rhymney River and the Rumney drainage channels, resulting in flooding to Rumney and Trowbridge also. Critical areas of housing developments, business parks and retail parks are at a 0.5% AEP event flood risk. In this event, critical infrastructure is at flood risk, including of Rover Way, Lamby Way, the A4232 roundabout, and the railway line to the north.

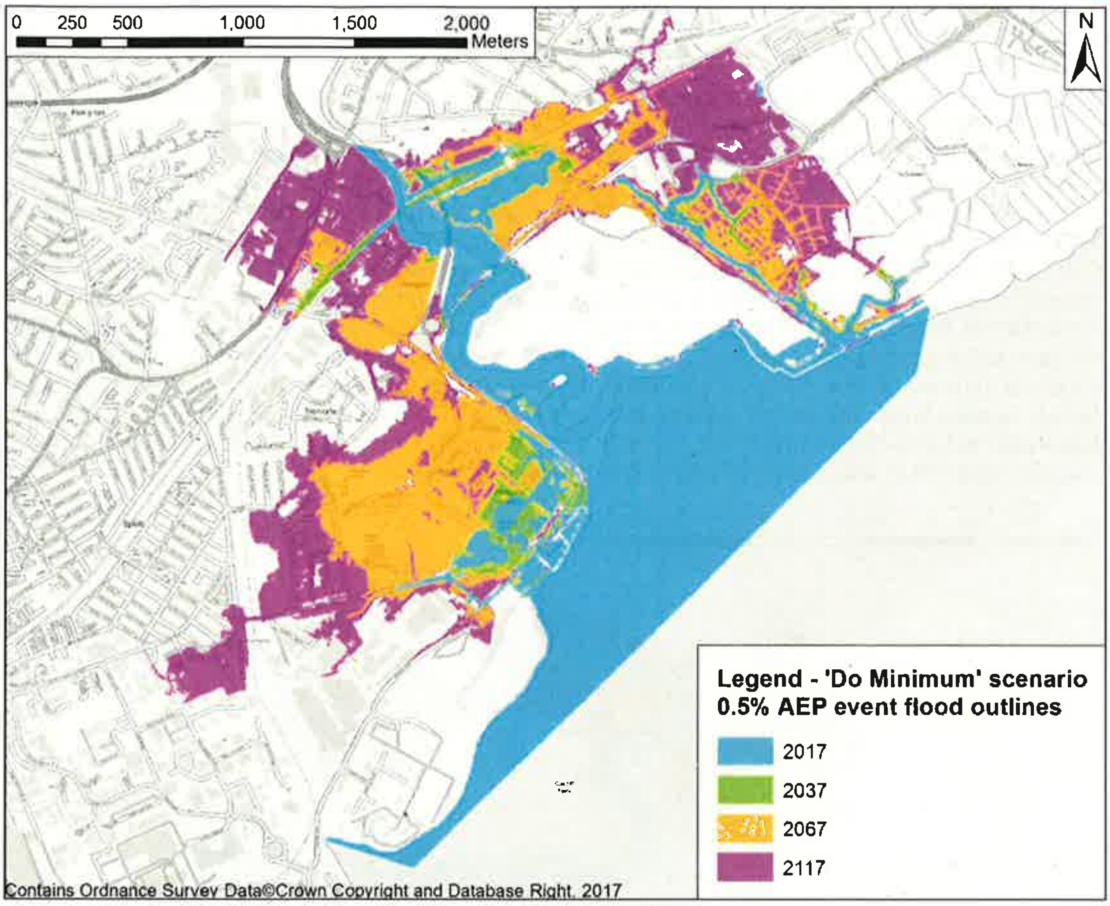


Figure 10-2 Flood outlines for the do minimum 0.5% AEP event across all modelled epochs

10.3 'Improve' scenario

The improve scenario incorporates options which were designed to the 0.5% AEP standard of protection. The coastal defences and at risk areas of the fluvial defences are raised to prevent any breaching, and thus are all unbreached scenarios. All sub-options within the improve scenario have been modelled as one option. Any overtopping of the defences was due to the water levels and coastal overtopping, and not due to manually input breaches, due to protection measures suggested. Figure 10-3 shows the results for the 0.5% AEP events under the improve scenario.

For the present day 0.5% AEP food event, there is minimal flooding to the Rover Way and Lamby Way Tip study area. There is some out of channel flooding of the Rhymney, although this flood water is prevented from propagating due to the defence line. There is some flooding to the railway line marking the north of the study area and floodwater within the drainage channels in the Rumney area. Additionally, there appears to be some coastal flooding on both sides of the mouth of the Rhymney River. As there are no breaches, manually applied or otherwise, within this model simulation, this is due to the applied wave overtopping. The resulting floodwater in these areas may not be a realistic representation. It is important to note that the overtopping may be an overestimation, and also that the model does not incorporate permeability of the defences or any drainage element into the model. The 2037 0.5% AEP event flood extent does not increase greatly, although floodwaters do propagate further down the railway line. The Rover Way and Lamby Way highways remain outside of the flood risk area, as does the roundabout connecting the two roads with the A4232.

With 50 years' climate change, the defence line within the improve scenario prevents most flooding in the 0.5% AEP flood event. Tremorfa is not at risk of flooding, and nor is main development within Rumney. Floodwater propagates into the Parc Tredelerch from out of bank flooding of the Rhymney River, in areas where the still water level exceeds the defence level. However, floodwater is contained within the lake in Parc Tredelerch and does not propagate into the business park. Additional flood water overtops the defence to the south of the Beaufort Square housing estate, but again this does not extend very far and does not pose a risk to any residential or non-residential properties. The 2067 0.5% AEP event, does however see some flood risk to part of the Avenue Retail Park on Newport Road, just north of the study area.

The improve option was designed to a 0.5% AEP standard of protection in 100 years time. In this event, flood risk remains negligible to Tremorfa. Where the flood extent has extended from the 2067 event to the 2117 event, this has been floodwater propagating further from the areas previously identified in the 2067 event. Within the study area, the flood risk now incorporates the north-eastern area of the Beaufort Square housing estate and the business park in the Rumney/Trowbridge area. Within the Beaufort Square housing estate, the majority of the area at risk only has a depth of up to 0.3m, with depths up to 0.5m on small sections of the roads within the estate. It is standard that a 300mm threshold is applied before a property is considered flooded, and thus the risk is minimal. Furthermore, this housing development is relatively new and will incorporate sufficient flood defence measures that comply with planning, and thus this small section of flood defences is not within our scope to improve. At the northern boundary of the study area, the 0.5% AEP event in 2117 sees further spatial flood risk to the railway line, especially to the east. Beyond this boundary, the floodwater extends further into Roath up to Roath Brook, although is limited to the wider area of the Avenue Retail Park and additional retail units along Newport Road.

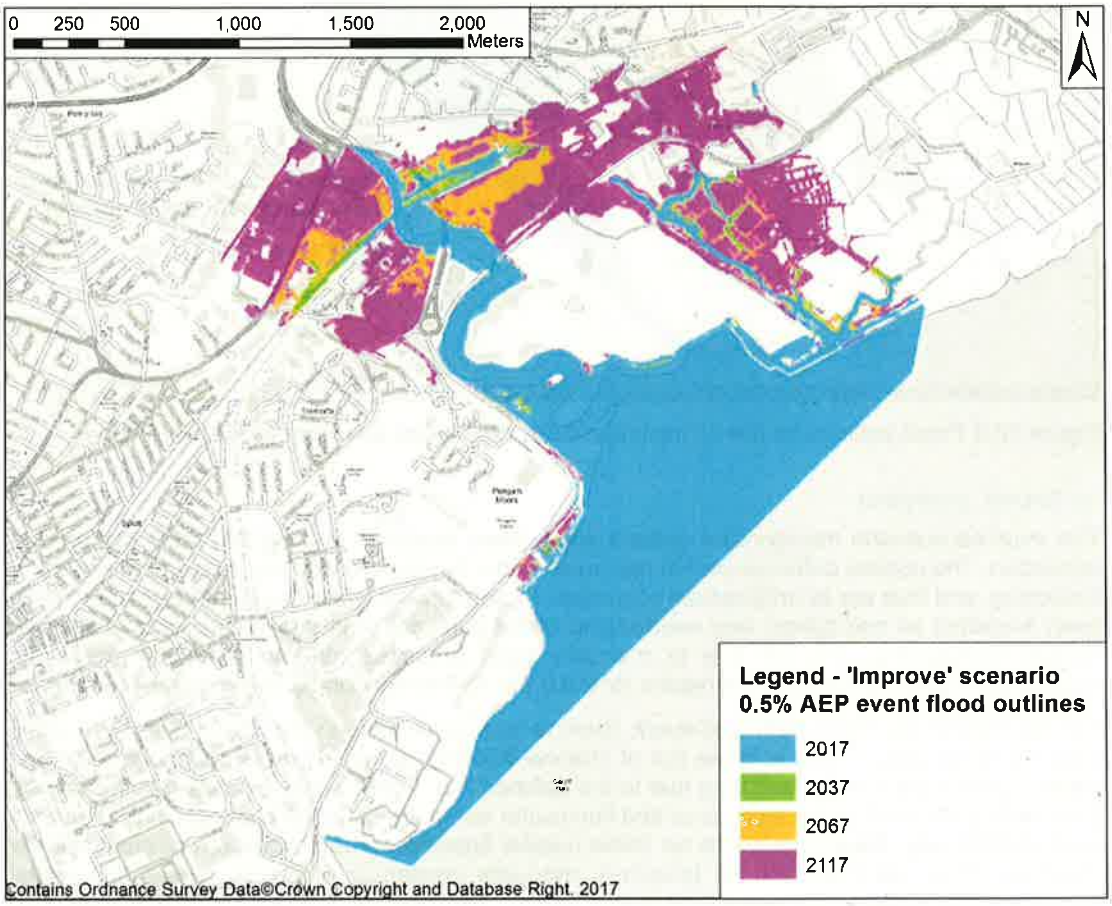


Figure 10-3 Flood outlines for the improve scenario 0.5% AEP event across all modelled epochs

10.4 Comparisons

Direct comparisons between each of the shortlisted scenarios is also key to evaluating the flood risk to the Rover Way and Lamby Way Tip study area. Figure 10-4 and Figure 10-5 provide comparisons of the 0.5% AEP flood event for 2017 and 2117 respectively.

For the present day 0.5% AEP event, there is a marked difference between the three scenarios. The do nothing and do minimum flood extents are identical with the exception of the do minimum resulting in a reduced flood extent at Tremorfa. This difference is due to the deactivation of the main breach and breaches 1 and 2 in the do minimum simulations as a result of the protection against coastal erosion for 20 years as part of the maintenance plan. The improve scenario flood risk does not extent into Tremorfa, nor into the area around Parc Tredelerch in Rumney.

With 100 years' climate change, the 0.5% AEP flood extents are much greater than for the present day due to the predicted sea level rise. The flood outlines for do nothing and do minimum are identical due to the same conditions and breaches activated. All breaches are activated for these runs, and are identical due to maintenance ceasing to maintain the current standard by 2067. The standard of protection for the improve scenario is 0.5% AEP with 100 years' climate change. The formal defences designed for section 1, 2 and 3 are evident with no flood risk to Tremorfa or the highways infrastructure around the Rover Way and Lamby Way roundabout. There is a reduced extent to the Beaufort Square housing estate, the Rover Way highway and Rumney also. Sections of the Rover Way highway and Rumney subject to flood risk are a result of the overtopping which was applied to the model. Again, it is important to note that given the inherent uncertainty in the calculation of wave overtopping, the flood risk may be overestimated, but also that the defences are permeable and that there is no drainage element incorporated into the model.

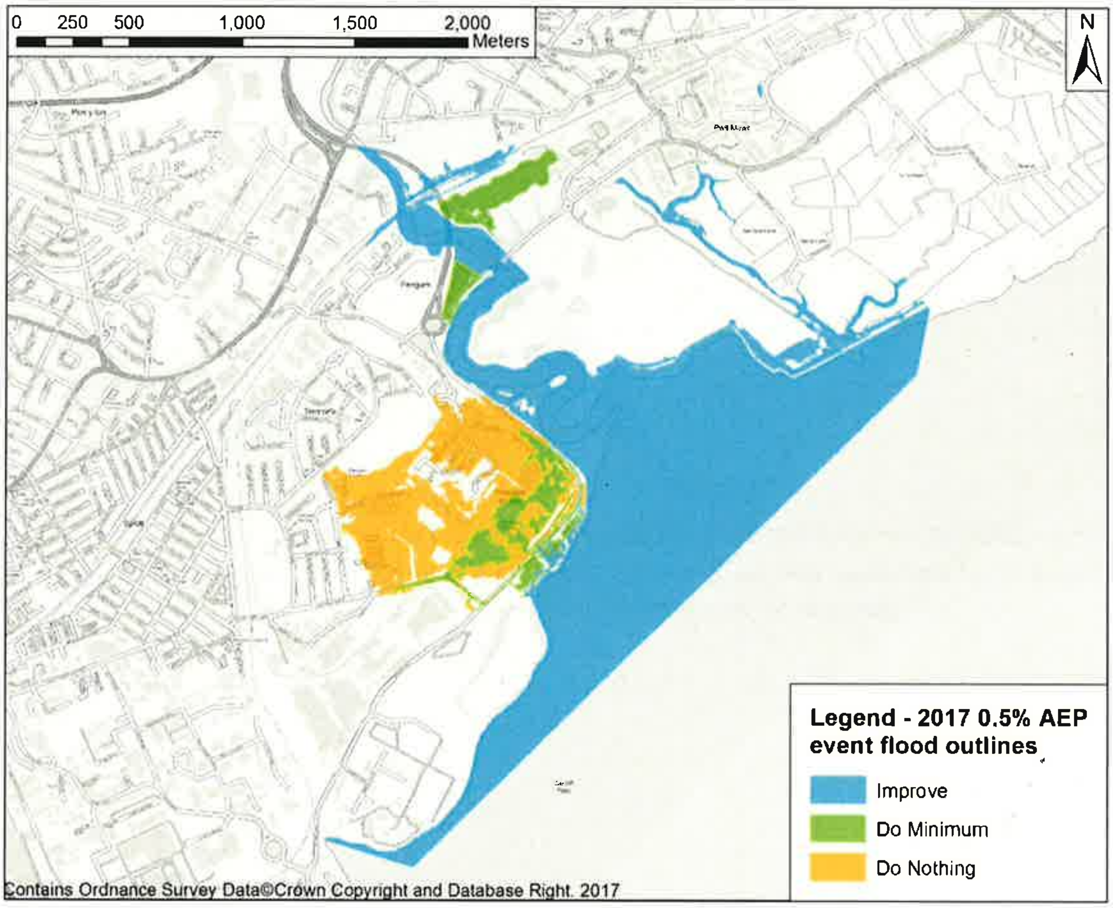


Figure 10-4 Flood extent outlines for the present day 0.5% AEP event for each of the shortlisted options

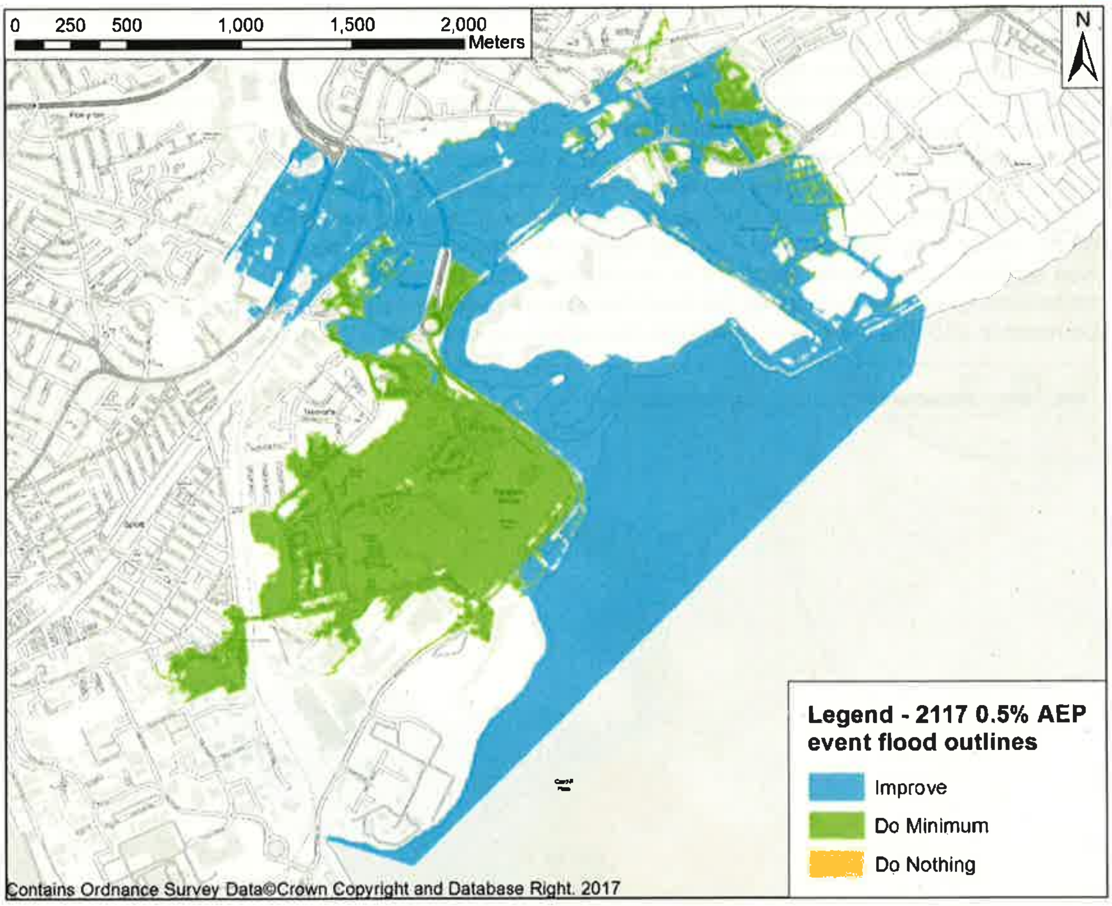


Figure 10-5 Flood extent outlines for the 0.5% AEP event with 100 years' climate change (ie, 2117) for each of the shortlisted options

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Cardiff Flood and Coastal Erosion Risk Management - Rover Way and Lamby Way Tip

Economic Appraisal

Draft Report

March 2017

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Contract

This report describes work commissioned by David Brain of Cardiff City Council, by a letter dated 21/10/2016. Amelia Wright of JBA Consulting carried out this work.

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Introduction

This report describes the economic appraisal undertaken for the Cardiff Coastal Risk Management Programme Outline Business Case. Although a standalone report, it complements the information in the main Outline Business Case.

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Abbreviations

AAD .... Annual Average Damages
AEP .... Annual Exceedance Probability
CCC .... City of Cardiff Council
CRMP .... Coastal Risk Management Programme
DSM .... Digital Surface Models
DTM .... Digital Terrain Models
EA .... Environment Agency
ECI .... Early Contractor Involvement
FCERM-AG .... Flood and Coastal Erosion Risk Management Appraisal Guidance
FRISM .... Flood Risk Metrics [JBA Consulting's impact analysis software]
LIDAR .... Light Detection and Ranging
mAOD .... Meters Above Ordnance Datum
MB .... Mass Balance
MCM .... Multi-Coloured Manual
NRW .... Natural Resources Wales
OBC .... Outline Business Case
PVd .... Present Value Damages

1 Introduction

1.1 Introduction

JBA Consulting was commissioned by the City of Cardiff Council (CCC) in 2016 to carry out an Outline Business Case (OBC) for Cardiff Coastal Defences, as part of the Coastal Risk Management Programme (CRMP). The study comprises the coastline along Rover Way and Lamby Way Tip, extending along both banks of the River Rhymney up to the railway bridge. This report focuses solely on the economic analysis, as an evaluation of the damages, economic benefits, and costs for the study area, without any influence of other factors. Other areas of consideration for the multi-criteria assessment are outlined in the main OBC and detailed within the OBC appendices.

This economic appraisal has been prepared in compliance with the Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG) (Environment Agency, 2010), Multi-Coloured Manual (MCM) (Flood Hazard Research Centre, 2013), MCM Handbook (Flood Hazard Research Centre, 2016), and HM Treasury's The Green Book (HM Treasury, 2011).

1.2 Problem

Cardiff is at risk of tidal flooding and coastal erosion. The two study areas considered as part of the OBC are Lamby Way Tip (immediately east of the Rhymney River) and Rover Way (immediately west of the Rhymney River). The northern extent of the appraised area is the railway bridge. At these locations, the topography is generally low-lying floodplain and the flows of the Rhymney River play no part in the flood risk, which is solely of tidal influence from the Severn Estuary. The contribution of climate change in the form of predicted sea level rise is escalating this risk. Taking climate change into account, the 0.5% AEP (1 in 200 year) flood event in 100 years (2117) is estimated to affect 1,169 additional properties in the study area compared to the present day. The study area is also at risk of coastal erosion.

Without flood and erosion protection works, there is the risk to people and property across the study area. Ongoing flooding and erosion would also have negative social implications and future development in the area would be blighted by flood risk.

1.3 Outline Business Case aims

The Cardiff OBC aims to provide a preferred option with a 200-year standard of protection in 100 years, accounting for rising sea levels and extreme tidal events. The scheme aims to be technically sound, economically viable and environmentally sustainable.

1.4 Principles of cost-benefit analysis for flood protection schemes

In accordance with FCERM-AG, benefits are defined as Annual Average Damages (AAD) avoided by scheme options. From this, Present Value Damages (PVd) have been calculated for the 100-year appraisal period using HM Treasury discount rates as presented in The Green Book (Annex 6, p99). The discount rates are as follows: 3.5% for years 0-30, 3.0% for years 31-71, and 2.5% for years 76-125. These are compared with the whole life cost, including capital and maintenance costs, of implementing the option expressed as a present value. If the benefits exceed the costs for the option, with the cost-benefit ratio exceeding unity, the scheme is deemed to be economically viable and worthwhile for promotion. This report will summarise the economic viability for each option, as part of the decision-making process. Other factors, including heritage, environmental, and future development, are considered and contained within the OBC and the other OBC appendices' reports.

1.5 Scope of this report

This report is an up-to-date assessment of the flood risk, tidal levels, damages, and economic benefits for potential flood and erosion protection measures for Lamby Way and Rover Way in Cardiff. This report can therefore be taken as a standalone report for the purpose of confirming the flood and erosion damages, option costings and cost-benefit viability of the scheme options.

The purpose of this report is to detail the methodology used to derive the benefit-cost ratios for the selected design options and to identify the most economically appropriate option. This report records the decision-making process and represents a transparent approach to the investment appraisal process. Specifically, this report includes:

- An economic assessment of the direct damages associated with baseline flood and erosion risk;

- An economic assessment of the direct damages associated with flood and erosion risk post design options work and implementation;
- A statement of the methodologies to determine the damages for both the baseline and options;
- A summary of sensitivity analysis to test the robustness of the economic assessment;
- A summary of the costs for each shortlisted option; and
- A statement of the cost-benefit ratios for each design option.

2 Selection of Options

2.1 Standard of protection

The probability of a flood occurring is typically expressed as the annual exceedance probability (AEP), as the probability of a flood greater than a specific flow occurring in any one year. Table 2-1 provides the range of flood events used within this project.

The coastal and fluvial defence options have been designed to a 0.5% AEP standard of protection with 100 years climate change (ie, 0.5% AEP in 2117), at 8.98mAOD.

Table 2-1: Flood annual probabilities and associated return period used within this project

Annual Exceedance Probability [AEP] (%)	Return Period
50	2 year
10	10 year
5	20 year
2	50 year
1.33	75 year
1	100 year
0.5	200 year
0.1	1000 year

2.2 Do Nothing scenario

A baseline scenario is required for the economic appraisal in order to assess the benefits of the flood protection options. This represents a 'Do Nothing' scenario based on the present-day conditions of Cardiff with no intervention in the natural processes. This has been modelled with the use of breaches to the areas which are most at risk. The current standard of protection of defences is compromised with the impact of climate change, under which the existing defence assets are not sufficient to prevent flooding to Cardiff in the future.

2.3 Do Minimum scenario

The first option scenario is the Do Minimum scenario. This will involve light rock armour along the coast to delay erosion for 20 years. Although no additional formal works will be undertaken, the current defence will be maintained through patch and repair along the fluvial sections of defence. This means that the standard of protection will remain as it is presently, and overtopping of the defences may occur in the future with rising sea levels.

2.4 Improve scenario

The second option considered is the improve scenario. This incorporates options which have been designed to the 0.5% AEP standard of protection. The coastal defences and at risk areas of the fluvial defences are raised to prevent any breaching, and thus the tidal overtopping rates have also been modified with the design development. Therefore, all of the improve options have the same benefits and damages, but with differing costs for each scheme. The details of each sub-option within the improved scenario are given below:

- Improve 1: Rock option along the coast and along Lamby Way roundabout;
- Improve 2: Sheet piling option along the coast and rock option along Lamby Way roundabout;
- Improve 3: Concrete wall option along the coast and rock option along Lamby Way roundabout;
- Improve 4: Rock option along the coast and sheet piling along Lamby Way roundabout;
- Improve 5: Sheet piling option along the coast and sheet piling along Lamby Way roundabout; and
- Improve 6: Concrete wall option along the coast and sheet piling along Lamby Way roundabout.

3 Flood Levels

3.1 Introduction

Flood levels for Cardiff have been obtained from TUFLOW modelling. The flood depths at each property were extracted based the depth grids generated by the TUFLOW modelling. Further details on this can be found in the Model User Report.

3.2 Incorporation of climate change

Climate change has been incorporated into the calculation of damages. Under climate change scenarios, the AAD will increase as a result of sea level rise exacerbating the flood risk. Therefore, to account for gradually changing impacts of climate on coastal and hydrological systems, the increasing AAD at specific epochs must be calculated. The results for each period are then summed using variable discount factors to obtain a PVd to determine the climate attributable benefits of flood protection over the appraisal period.

The flood scenarios were based on extreme tidal events. This methodology assumes that at the start of the project life, the damages avoided represent the existing baseline case without any allowance for climate change. Further into the 100-year project appraisal period, tidal levels will increase. Therefore, the damages will increase over time in the baseline scenario.

To account for these changes in sea levels, flood levels were modelled for the following epochs:

- 2017 (year 0; the base year);
- 2037 (year 20);
- 2067 (year 50); and
- 2117 (year 100).

For each epoch, a range of flood events were modelled using appropriate tidal levels at the downstream extent of the Rhymney River. Table 3-1 shows the peak level for each event. It also illustrates that a present day 0.5% AEP standard of protection (8.23mAOD) would not be sufficient with the impact of climate change as would overtop in the 0.5% AEP event in 2037 (8.35mAOD). Tide curves were obtained for each of the return periods, as determined by a matrix. Further details of this modelling approach can be found in the Model User Report.

Table 3-1 Peak tidal levels for each return period at each epoch modelled. All levels are given in meters

AEP (%)	50	10	5	2	1.33	1	0.5	0.1
2017	7.48	7.70	7.814	7.96	8.04	8.10	8.23	8.63
2037	7.60	7.82	7.93	8.07	8.15	8.22	8.35	8.75
2067	7.81	8.03	8.14	8.28	8.36	8.43	8.56	8.96
2117	8.23	8.45	8.56	8.71	8.79	8.85	8.98	9.38

4 Economic Damages Assessment

4.1 Introduction

Damages estimates have been derived for direct tangible flood damages, emergency costs, road disruption and erosion damages. No allowance at this time has been made for additional indirect or intangible damages such as increased stress and health effects as a result of flooding. The approach to assess the damages was undertaken in accordance with FCERM-AG (EA, 2010), the MCM (FHRC, 2013), the MCM Handbook (FHRC, 2016) and The Green Book (HM Treasury, 2011).

4.2 Method

This application of the MCM has been undertaken using JBA Consulting's in-house Flood Risk Metrics (FRISM) software.

FRISM is a GIS based impact analysis software that computes a range of metrics, including property damages, in accordance with the techniques outlined in the MCM. FRISM computes a variety of metrics by combining flood modelling results together with a range of receptor data as discussed below. The metrics that can be calculated depend on both the geometry type of the receptor data and the type of modelling results used. As depth grids were produced for this project, detailed property level analysis was computed and included minimum, maximum and mean depths and damages at each property. Property level analysis was then summed across the study area to determine the total impact e.g. total damages for a particular flood event. As multiple events were modelled, the long term AADs were also computed for each metric. AAD have been calculated by the software which are converted into Present Value Damages (PVd) by using the appropriate discount factors as outlined in the HM Treasury's The Green Book (Annex 6, p99). FRISM has also been used to provide property counts for each event with each of the three main scenarios. These figures can be used to quantify the benefits of design options for the flood protection of Lamby Way and Rover Way.

4.3 Available data

The following datasets were used to calculate the damage estimates and property counts:

- Hydraulic modelling results - depth grids generated by the TUFLOW modelling give the water depths across the study area for each flood event for each scenario;
- National Receptor Data (NRD; 2014) - provided by CCC, NRD property point dataset contains information such as building type, class description, floor area, floor level, and MCM code;
- Land Registry House Price Index (2017) - average market value for each type of residential property for the Cardiff area was extracted; and
- Ordnance Survey MasterMap (2016) - the building footprint polygon layer was extracted from the OS MasterMap and used to determine whether a property would be flooded. For this assessment, if any part of the building footprint is within the flood extent, then the building is considered flooded.

4.3.1 Property data

Property data is based upon the NRD dataset as provided by CCC. The NRD was processed to eliminate any property points which should be excluded from the assessment, in accordance with FCERM AG guidance. The full property exclusion list is taken from the NRD2014 guidance as non-reportable property points. These properties include, but are not limited to, street records, PO boxes, property shells and advertising hoarding. All of the remaining properties within the study area have been included within the analysis.

The following assumptions were made:

- Upper floor flats were removed from analysis as direct flood damages are unlikely to impact upon first floor flats and above;
- Property floor areas were verified using OS MasterMap data; and
- Capping of property damages has been applied to residential properties based on land registry market value per property type.

4.3.2 Property areas

Property areas were taken directly from the NRD. This was verified, with only properties with an associated OS MasterMap footprint being included within the calculations for a more accurate representation of properties.

4.3.3 Property types

In addition to the exclusion of property points as outlined in Section 4.3.1, the NRD was prepared by the addition of a category column. The MCM code and class description was used to categorise the NRD property points into:

- Residential [1] - all properties with an MCM code of 1 or a class description of residential;
- Critical infrastructure [3] - all properties which are defined as critical infrastructure, including education facilities, health facilities or telecommunications; and
- Non-residential [2] - all properties which are not deemed residential or critical infrastructure, therefore including retail and office spaces, leisure centres and places of worship.

A summary of the properties included within the appraised area is shown in Table 4-1. Table 4-1 Summary of properties categorised within the appraised area provides the breakdown of types of the residential property classification. Some residential properties are classified as 'Other'; these are properties which have been defined as residential but the property type has not been specified.

Table 4-1 Summary of properties categorised within the appraised area

Variable	Number / Percentage
Total number of properties included in damage calculations	13,296
Number of residential properties	11,646
% of residential properties included in damage calculations	87.6%
Number of non-residential properties	1604
% of non-residential properties included in damage calculations	12.1%
Number of properties defined as critical infrastructure	46
% of residential properties defined as critical infrastructure	0.3%

Table 4-2 Breakdown of residential property types within the appraised area

Residential Property Type	Number (Percentage, %)
Detached	449 (3.9)
Semi-Detached	1764 (15.1)
Terrace	5944 (51.0)
Flat	3465 (29.8)
Other	24 (0.2)
Total	11,646 (100)

4.3.4 Property values

Average property values were taken from the Land Registry on 10th March 2017. Table 4-3 presents the extracted data for the Cardiff local authority for December 2016, as the most recent dataset published at the time. These values were added to each residential property in the NRD according to house type. For those residential properties which have not been assigned a house type, the average for all house types was applied.

Table 4-3 Average residential property values for Cardiff. As taken from the Land Registry, 2017.

All House Types (£)	Detached (£)	Semi-detached (£)	Terraced (£)	Flat (£)
190,716	358,573	217,116	178,087	134,776

Non-residential and critical infrastructure properties use the rateable value together with an equivalent yield to estimate market value, in accordance with FCERM-AG, using the following relationship:

Estimate of property capital valuation = (100/Equivalent yield) x Rateable value

However, for this appraisal, not all of the non residential properties have been assigned property values. The final PVd values were reviewed to asssess whether capping of properties was required. The top five properties in terms of PVd value were then capped but below this capping would not have impacted upon the PVd as the damages for each property were below the asset value.

4.4 PVd Threshold Survey

A floor level threshold was applied to all properties within the study area, which must be exceeded by the flood depth for a property to be considered flooded. A value of 300mm has been applied. This is the standard threshold used, and was confirmed to be appropriate for the study area using Google Street View. This is deemed an appropriate tool for determining the property threshold level in the MCM Handbook (FHRC, 2016; p40).

4.5 Direct damage estimation methodology

This section outlines the damage calculations undertaken. In assessing the damages the following assumptions have been made:

- Damages for flood durations less than 12 hours; and
- The floodwater is salt water, due to this being tidal flooding. This will typically result in greater damages than those associated with fluvial waters.

4.5.1 Detailed property count

As both property point and property polygon data was available the detailed count method was used. This means that NRD property points were associated with OS MasterMap building footprints by their spatial relationship. Each NRD property point was then counted as flooded if any part of its associated building footprint intersected with the flood outline. The detailed count is an accurate counting method and enables properties on the edge of flood datasets to be included. The detailed property count has been undertaken for all return periods and for each epoch.

4.5.2 Property damage

Damages were calculated at the property level using the well-established methods set out in the MCM (FHRC, 2013). The data included in the MCM is updated annually and the 2013 release of the MCM resulted in a major change in depth damage curves including a complete revision of the non-residential flood damage data compared to those included in previous releases. The subsequent releases only alter the damage values to account for inflation. For this economic appraisal, the flooding scenario is taken to be for salt water with a short duration and the associated MCM 2013 depth damage curves were used. The damage curves, were uplifted to 2017 values using the consumer price index (CPI), as recommended in the MCM (FHRC 2013; p86).

The MCM damage estimates have been factored against the current CPI in order to align them with present day prices by adjusting the curves to account for inflation. A factor of 1.04 was applied. The 2013 and 2017 indices for the CPI are provided in Table 4-4.

Table 4-4 Consumer Price Index values

Indices	2013 CPI Rate	2017 CPI Rate	Factor
Consumer Price Index (CPI)	124.4	129.6	1.0418

The MCM code field within the NRD dataset was used to assign an appropriate MCM curve to each property. In the case of residential properties, the house type attribute was used to further classify the properties, and identify the appropriate damage curve. The mean property depth value was then used in conjunction with the depth damage curve to obtain a unit damage value per metre squared (£/m^2) for the property. This value was then multiplied by the floor area of the property, as defined in the NRD, to convert it to a property damage value. Damages were not calculated for upper floor properties.

4.5.3 Annual Average Damages (AAD)

Annual average damages (AAD) represent the long-term average or expectation of consequence in any given year. They are calculated by integrating the area under the curve describing the relationship between flood damage and event probability. It assumes that damages for rarer events do not increase beyond those incurred at the highest modelled return period. In this appraisal, this is the 0.1% AEP event.

4.5.4 Present Value Damages (PVd)

As part of an economic appraisal, the MCM (FHRC, 2016; p186) states that proprietary software should be used to calculate the property PVd. PVd have been calculated for a 100-year appraisal period and take into account the potential climate change impacts over that period. AAD have been generated at each property for the present day and for four future epochs, taking into account sea level rise as a result of climate change. The AAD have been linearly interpolated between the different climate change intervals and multiplied by the appropriate discount factor to calculate the PVd for each property (the discount factors applied are provided in Table 4-5). FRISM assumes the infinity value to be equal to the largest event inputted. However, it is noted that generally damages rarer than 0.5% AEP have minimal influence of the PVd due to more frequent events having a greater weighting.

Table 4-5 Long-term discount rates. As taken from HM Treasury The Green Book [Annex 6, p99]

Period of years	0-30	31-75	76-125
Discount rate	3.5%	3.0%	2.5%

4.5.5 Capping

The PVd of individual properties has been capped, in accordance with FCERM-AG (2010) to prevent damages from exceeding the market value of the property. Residential property values have been capped using the average value within Cardiff defined by house type (ie, detached, semi-detached, terrace, and flat) taken from the data published by the Land Registry (2017). Therefore, properties that would accrue damages greater than their assigned property value will be capped at the property value.

Capping of all other non-residential properties, including critical infrastructure underwent a different capping approach due to the complexity of these property data points. A preliminary economics assessment was undertaken to determine the properties accruing the most damage. Due to the property values in Cardiff, all property points with a damage of greater than £100k were extracted. Where appropriate, the current valuations were taken from the HMRC View My Valuation service on 24 January 2017. Table 4-6 presents the non-residential properties and their associated capping values.

Table 4-6 Additional capping values for non-residential properties

Address Line 1	Postcode	Capping Value (£k)
Tesco Extra Superstore	CF24 2HP	17,434
Tesco Extra Petrol Station	CF24 2HP	1,340
Baden Powell Junior and Infant School	CF24 2SJ	345
Four Elms Medical Centre	CF24 2HB	263

The capping of Willows High School, St Albans Baden Powell Infant and Primary School, and Tremorfa and Baden Powell nurseries was also considered using estimated costs provided by CCC to relocate these assets. The maximum damages achieved under the Do Nothing scenario for the 0.1% AEP event in 2117 did not exceed the relocation values provided, and thus capping of these assets was not required.

4.6 Indirect and intangible damages

In addition to the direct property damages calculated using depth damage curves, FRISM can also be used to quantify indirect and intangible damages as set out in the MCM. As part of this economic appraisal emergency costs have also been calculated within FRISM, whilst road traffic disruption has been calculated manually, in accordance with the MCM Handbook (FHRC, 2016) and FCERM-AG (EA, 2010) respectively.

Emergency costs have been calculated based upon the AAD with an uplift factor of 5.6%, as is the standard factor for concentrated urban areas such as Cardiff (FHRC, 2016).

5 Summary of Flood Damages

5.1 Direct property damages

Event damages have been calculated for flood events with a range of return periods and future climate change epochs. The output provides event damages based on MCM depth-damage curves, updated to the 2017 base date.

5.1.1 Annual Average Damages (AAD)

The AAD has been derived at years 0, 20, 50 and 100, representative of 2017, 2037, 2067 and 2117. For the 2017 Do Nothing baseline scenario, the number of properties inundated by flooding and subsequent damages begin to accrue during the 1.33% AEP flood event with 187 properties (184 residential and 3 non-residential) and a total flood damage of £7,320k.

The AAD for each of the three scenarios is presented in the following sections.

5.1.1.1 Do Nothing

In the Do Nothing scenario, property flood damages accrue during the present day 1.33% AEP flood event, with 187 properties incurring £7,320k of damages. The AAD incurred across the range of events and epochs investigated is presented in Table 5-1 and Table 5-2.

Table 5-1 Total number of properties flooded within the study area for the Do Nothing scenario

Year	Type	50% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP	0.1% AEP
2017	Res	-	-	-	-	184	217	249	586
	Non-Res	-	-	-	-	3	3	3	11
2037	Res	-	-	-	207	229	244	351	789
	Non-Res	-	-	-	3	3	3	10	69
2067	Res	-	180	226	261	358	448	561	1,165
	Non-Res	-	3	3	4	10	11	22	201
2117	Res	249	464	557	716	820	919	1,212	2,291
	Non-Res	3	14	22	36	78	147	209	388

Table 5-2 Total flood damages within the study area for the Do Nothing scenario

Year	50% AEP (£k)	10% AEP (£k)	5% AEP (£k)	2% AEP (£k)	1.33% AEP (£k)	1% AEP (£k)	0.5% AEP (£k)	0.1% AEP (£k)
2017	-	-	-	-	7,320	8,226	10,222	21,436
2037	-	-	-	7,801	9,028	9,991	13,180	29,264
2067	-	7,145	8,706	11,222	13,503	15,446	19,903	47,202
2117	10,220	16,057	19,748	25,675	30,532	34,643	49,229	116,189

5.1.1.2 Do Minimum

In the Do Minimum scenario, the number of properties inundated by flooding and subsequent damages begin to accrue during the 0.5% AEP flood event with two properties, both non-residential, incurring a total flood damage of £836k. The AAD incurred across the range of events and epochs investigated is presented in Table 5-3 and Table 5-4.

The maximum number of properties affected in the 0.1% AEP with 100 years climate change (2117) is 2,679, and is the same as for the Do Nothing scenario, with equivalent damages of £116,189.

Table 5-3 Total number of properties flooded within the study area for the Do Minimum scenario

Year	Type	50% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP	0.1% AEP
2017	Res	-	-	-	-	-	-	-	126
	Non-Res	-	-	-	-	-	-	2	6
2037	Res	-	-	-	-	-	-	22	318
	Non-Res	-	-	-	-	-	-	4	15
2067	Res	-	180	226	261	358	448	561	1,165
	Non-Res	-	3	3	4	10	11	22	201
2117	Res	249	464	557	716	820	919	1,212	2,291
	Non-Res	3	14	22	36	78	147	209	388

Table 5-4 Total flood damages within the study area for the Do Minimum scenario

Year	50% AEP (£k)	10% AEP (£k)	5% AEP (£k)	2% AEP (£k)	1.33% AEP (£k)	1% AEP (£k)	0.5% AEP (£k)	0.1% AEP (£k)
2017	-	-	-	-	-	-	836	2,123
2037	-	-	-	-	-	-	871	11,852
2067	-	7,145	8,706	11,222	13,503	15,446	19,903	47,202
2117	10,220	16,057	19,749	25,676	30,532	34,643	49,229	116,189

5.1.1.3 Improve scenario

In the present day, damages do not accrue for the Improve scenario until the 0.1% AEP flood event. During this event, 23 properties are flooded (20 residential and three non-residential) incurring £388k of damage.

In the 0.1% AEP event with an allowance for 100 years climate change, an estimated 1,084 properties are flooded, incurring damages of £59,210k. This is less than the £116,189k of damages resulting from 2,679 properties which are flooded in the same event for the Do Nothing and Do Minimum scenarios.

The AAD incurred across the range of events and epochs investigated is presented in Table 5-5 and Table 5-6.

Table 5-5 Total number of properties flooded within the study area for the improve scenario

Epoch	Type	50% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP	0.1% AEP
2017	Res	-	-	-	-	-	-	-	20
	Non-Res	-	-	-	-	-	-	-	3
2037	Res	-	-	-	-	-	-	-	35
	Non-Res	-	-	-	-	-	-	-	7
2067	Res	-	-	-	-	-	-	5	96
	Non-Res	-	-	-	-	-	1	1	120
2117	Res	-	-	5	27	35	38	96	805
	Non-Res	-	1	1	6	42	45	137	279

Table 5-6 Total number of properties flooded within the study area for the improve scenario

Epoch	50% AEP (£k)	10% AEP (£k)	5% AEP (£k)	2% AEP (£k)	1.33% AEP (£k)	1% AEP (£k)	0.5% AEP (£k)	0.1% AEP (£k)
2017	-	-	-	-	-	-	-	388
2037	-	-	-	-	-	-	-	1,559
2067	-	-	-	-	-	2	139	10,725
2117	-	4	132	1,209	2,011	3,796	11,678	59,210

5.1.2 Present Value Damages (PVd)

PVd have been calculated for the 100 year appraisal period and including an allowance for climate change. The calculated PVd flood damage value for the Do Nothing scenario is £42,603k. For the Do Minimum scenario, the PVd is £36,973k, whilst the improve scenario is significantly lower at £971k. A full breakdown is provided in Table 5-7.

Table 5-7 Calculated PVd for the study area for each scenario

Scenario	Property Type	PVd (£k)	PVd (% of Base PVd)	0.1% AEP [2117] Number of Properties	Emergency Costs PVd (£k)	Sub-total PVd (£k)
Do Nothing	Res	20,889	51.8	2,291	2,293	42,603
	Non Res	19,410	48.2	388		
	Total	40,310	100	2,679		
Do Minimum	Res	18,150	51.9	2,291	1,980	36,973
	Non Res	16,842	48.1	388		
	Total	34,992	100	2,679		
Improve	Res	252	27.4	805	52	971
	Non Res	668	72.6	279		
	Total	920	100	1,084		

6 Summary of Erosion Damages

6.1 New road costs

Lamby Way Roundabout and the surrounding sections of highway, are at risk of erosion as the river bank erodes along the outside of the river meander. The erosion of the banks of the Rhymney River will undermine the highway structures leading to failure of the road. Alternative routes may be appropriate if short term flooding were to take place, but there are no suitable alternative for use on a permanent basis should the road be lost to erosion. As such, the damages have been taken as the rebuild cost of the road at an appropriate nearby location, in which calculations have been derived from Spon's Civil Engineering and Highway Works Price Book (2010) and uplifted to the present day via CPI inflation values. The present value loss has been calculated as £5,350k.

It has been estimated that the most likely case will see the rebuilding of this section of road network in 20 years for the Do Nothing scenario and 50 years for the Do Minimum scenario. As a result, a discount factor derived from the HM Treasury The Green Book (2011; p99) has been applied. This is shown in Table 6-1. The resulting PVd values are combined with the previous sub-total damages of the property damages and emergency costs, with the breakdown provided in Table 6-2, totalling £45,294k and £38,026k for the Do Nothing and Do Minimum scenarios respectively. The improve scenario will protect this section of road, and thus does not accrue any damages of this nature.

Table 6-1 Present Value damages associated with rebuilding of Lamby Way Roundabout and surrounding highway

Scenario	Total Cost of Road Rebuild (£k)	Year of Damage Occurrence	Discount Factor	Discounted Cost of New Site (£k)
Do Nothing	5,350	20	0.503	2,691
Do Minimum	5,350	50	0.197	1,054
Improve	5,350	-	-	-

Table 6-2 Calculated road PVd for each scenario, and updated total flood PVd

Scenario	Flood PVd (£k)	Road Erosion PVd (£k)	Total PVd (£k)
Do Nothing	42,603	2,691	45,294
Do Minimum	36,973	1,054	38,026
Improve	971	-	971

6.2 Rover Way Travellers Site damages

6.2.1 Introduction

Rover Way Travellers Site, located on the coast to the south of Rover Way, is at risk of coastal erosion. CCC have a duty to provide a required number of Traveller Pitches, and it was identified in the :LDP that an additional 72 pithces are required in Cardiff. As a result, if this site is lost to erosion an alternative site must be provided. The erosion damages are therefore taken to be the cost of relocating the site.

6.2.2 Calculations

It has been estimated that £120k is required for construction of each new pitch in a comparable brownfield location to that of the study area. Land purchase has been estimated at £75k per acre. These costs do not account for remediation and clean-up costs associated with abandonment of the existing Travellers site or further risks associated with identifying and developing a new site. These figures have been verified by CCC. Table 6-3 provides a summary of the relocations costs for the Rover Way Travellers site.

Table 6-3 Breakdown of relocation costs for the Travellers site at Rover Way

Caravan Type	Number of Pitches	Construction of New Site Cost (£k)	Site Area (acres)	Purchase of New Land Cost (£k)	Total Relocation Cost (£k)
Rover Way	47 [29 static; 18 tourer]	5,640 [3,480 static; 2,160 tourer]	2.1	158	5,798

6.2.3 Summary of results

The present value loss of the Rover Way Travellers site due to total relocation costs is £5,798k. At present, the site is approximately 10m from the coast. With rapid erosion rates of 1.7m per year (Appendix 1 - Geomorphology Report), erosion will impact upon the travellers site in six years time. However, due to the erosion, the defence is likely to breach prior to this, and thus the Travellers site is at high risk of flooding as a result of erosion from base year, 2017. Therefore, the total PVd for the Do Nothing scenario will increase to £51,091k, as shown in **Error! Reference source not found.**. The addition of a rock armour toe as part of the Do Minimum scenario will result in the 20-year delayed onset of the accrued damages. This increases the total PVd for the Do Minimum scenario to £40,940k. The Improve scenario will prevent erosion of the coastline and so the Rover Way Traveller Site would no longer be at flood or erosion risk., accruing no damages. The full breakdown of factors contributing to these PVd values are presented in Figure 6-1.

Figure 6-1 Breakdown of all factors incorporated into the final PVd for each scenario

Table 6-4 Rover Way Caravan Site erosion damages with a discount factor applied for each scenario

Scenario	Total Relocation Cost (£k)	Year of Damage Occurrence	Discount Factor	Discounted Cost of New Site (£k)	Updated PVd (£k)
Do Nothing	5,798	0	0.842	5,798	51,091
Do Minimum	5,798	20	0.503	2,914	40,940
Improve	5,798	-	-	-	941

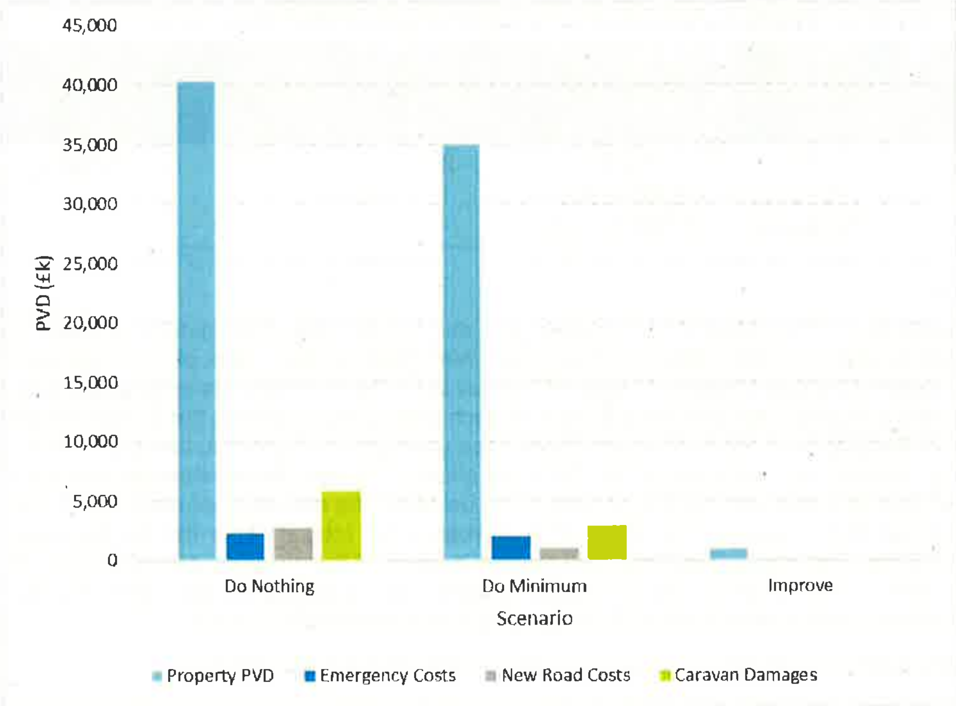

Figure 6-1 Breakdown of all factors incorporated into the final PVd for each scenario

7 Cost Estimates

7.1 Design options costs

Design costs have been developed for each of the options summarised in sections 2.3 and 2.4. Both capital and maintenance costs have been estimated by JBA Consulting and Raymond Brown Construction Ltd, using early contractor involvement (ECI). Raymond Brown Construction Ltd are a local civil engineering contractor with experience of working on many similar coastal construction works.

7.2 Price base date

The price base for cost estimates is March 2017, in line with the values applied in the flood and erosion damage assessment.

7.3 Scheme cost summary

Table 7-1 provides a summary of the present value scheme costs. A summary sheet is provided in Table 8-2, while the full 100 year cost stream can be found in Annex 4.

The project costs are high level cost estimates based on concept design information and would be refined during the detailed design phase once further detail on option design and construction is available. The current estimates include the following:

- Construction costs - estimated based on unit rates for key construction items, based on similar schemes undertaken recently by the ECI contractor;
- Existing staff costs - 2% of construction costs for CCC to provide project management and leadership for the duration of the project;
- Consultancy costs - 5% of construction costs;
- Contractors fees - 1.25% of construction costs;
- Site investigation, survey and testing - ground investigation, boreholes and testing assumed at 5% of construction costs;
- Environmental mitigation and enhancement - estimated at £192k for all improve options;
- Site supervision - 1.5% of construction costs;
- Project risks - estimated as 10% of construction costs;
- Maintenance costs - based in recent experience of similar maintenance works, as estimated by JBA Consulting; and
- Optimism bias - 40% of maintenance costs.

Table 7-1 Summary of Present Value costs for each shortlisted option

Option	Project Total PVd Costs (£k)
Do Nothing	0
Do Minimum	7,501
Improve 1	13,666
Improve 2	19,868
Improve 3	19,736
Improve 4	14,450
Improve 5	20,834
Improve 6	20,702

8 Benefit-Cost Ratio

8.1 Introduction

The benefit-cost analysis of the flood protection options has been carried out in accordance with FCERM-AG (EA, 2010). The principles are summarised as follows:

- Derive the damages associated with do-nothing baseline;
- Derive the damages associated with each proposed option;
- Derive the benefits (ie, damages avoided) associated with each proposed option;
- Derive the whole life cost for each option; and
- Derive the cost-benefit ratio for each option, based on present value costs and benefits.

All appraisal calculations have been undertaken using FCERM-AG (EA, 2010). The FCERM-AG summary sheet is provided in Table 8-2.

8.1.1 Assumptions

The following assumptions have been made:

- All shortlisted options have been designed with a standard of protection of 0.5% AEP with 100 years' climate change allowance;
- The life span of the scheme is assumed to be 100 years; and
- Discounting of the flood and erosion damages have been calculated using the revised HM Treasury The Green Book (2011; p99) discount rates.

8.2 Benefit-cost results

The BCR for each of the shortlisted options is presented in Table 8-2 and summarised in Table 8-1. The benefits for each option include the appropriate capped flood damages and erosion damages for each scenario. The ratio must be greater than one for a viable economic case. In this study, no options have a benefit cost ratio of less than one. The Improve 1 option is the most economically viable with a benefit-cost ratio of 3.7. The Improve 4 option has a BCR close to that of Improve 1, as the second most economically viable at 3.5. The rest of the Improve options have a BCR of 2.4-2.5. This highlights the need for sensitivity to establish which of Improve 1 or Improve 4 is the most robust option for the protection of the study area at Rover Way and Lamby Way Tip.

Table 8-1 100 year PVd benefit-cost ratio for each of the shortlisted design options

Option	Project Total PVd Costs (£k)	Project Total PVd Benefits (£k)	100 Year PVd Benefit-Cost Ratio
Do Nothing	0	0	-
Do Minimum	7,501	10,151	1.4
Improve 1	13,666	50,120	3.7
Improve 2	19,868	50,120	2.5
Improve 3	19,736	50,120	2.5
Improve 4	14,450	50,120	3.5
Improve 5	20,834	50,120	2.4
Improve 6	20,702	50,120	2.4

Table 8-2 Summary sheet for each shortlisted option, in accordance with FCERM-AG (EA, 2010) supporting spreadsheet

Project Summary Sheet

Client/Authority			Prepared (date)	29/03/2017
Cardiff City Council			Printed	31/03/2017
Project name			Prepared by	TW
Cardiff Flood and Erosion Risk Management - Rover Way and Lamby Way Tip			Checked by	AMM
Project reference	2016s5078		Checked date	
Base date for estimates (year 0)	Mar-2017			
Scaling factor (e.g. £m, £k, £)	£			
Year	0	30	75	(used for all costs, losses and benefits)
Discount Rate	3.5%	3.00%	2.50%	
Optimism bias adjustment factor	40%			
Costs and benefits of options				

	Costs and benefits £							
Option number	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**
Option name	Do Nothing	Do Minimum	Improve 1 - Rock option along coast and along Lamby Way roundabout	Improve 2 - Sheet piling option along coast and rock along Lamby Way roundabout	Improve 3 - Concrete wall option along coast and rock along Lamby Way roundabout	Improve 4 - Rock option along coast and sheet pilling along Lamby Way roundabout	Improve 5 - Sheet piling option along coast and along Lamby Way roundabout	Improve 6 - Concrete wall option along coast and sheet piling along Lamby Way roundabout
AEP or SoP (where relevant)			0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding
COSTS:								
PV capital costs	0	926,782	3,681,516	8,143,224	8,058,998	5,048,357	9,639,644	9,555,418
PV operation and maintenance costs	0	4,318,031	5,654,199	5,078,722	5,078,722	4,665,273	4,089,796	4,089,796
PV other	0	113,030	425,640	969,786	959,514	608,142	1,152,288	1,142,016
Optimism bias adjustment	0	2,143,137	3,904,542	5,676,693	5,638,894	4,128,709	5,952,691	5,914,892
PV negative costs (e.g. sales)								
PV contributions								
Total PV Costs £ excluding contributions	0	7,500,980	13,665,896	19,868,425	19,736,128	14,450,480	20,834,420	20,702,123
Total PV Costs £ taking contributions into account	0	7,500,980	13,665,896	19,868,425	19,736,128	14,450,480	20,834,420	20,702,123
BENEFITS:								
PV monetised flood damages	42,602,790	36,972,606	971,356	971,356	971,356	971,356	971,356	971,356
PV monetised flood damages avoided		5,630,183	41,631,434	41,631,434	41,631,434	41,631,434	41,631,434	41,631,434
PV monetised erosion damages	8,488,371	3,967,505	0	0	0	0	0	0
PV monetised erosion damages avoided (protected)		4,520,865	8,488,371	8,488,371	8,488,371	8,488,371	8,488,371	8,488,371
Total monetised PV damages £	51,091,160	40,940,112	971,356	971,356	971,356	971,356	971,356	971,356
Total monetised PV benefits £		10,151,049	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805
PV damages (from scoring and weighting)								
PV damages avoided/benefits (from scoring and weighting)								
PV benefits from ecosystem services								
Total PV damages £	51,091,160	40,940,112	971,356	971,356	971,356	971,356	971,356	971,356
Total PV benefits £		10,151,049	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805
DECISION-MAKING CRITERIA:								
excluding contributions								
Based on total PV benefits (includes benefits from scoring and weighting and ecosystem services)								
Net Present Value **NPV**		2,650,068	36,453,909	30,251,380	30,383,677	35,669,324	29,285,385	29,417,682
Average benefit/cost ratio **BCR**		1.4	3.7	2.5	2.5	3.5	2.4	2.4
Incremental benefit/cost ratio **IBCR**			6.5	3.2	3.3	5.8	3.0	3.0

8.3 Sensitivity testing

A number of sensitivity tests have been undertaken to determine whether the assumptions and parameters used in the analysis are sufficient to influence the BCR and identification of the economically preferred option. This helps to determine that the identification of the preferred option is robust to a variety of key assumptions.

Sensitivity tests have been undertaken for the following aspects which are thought to have the greatest impact:

- Delayed onset of erosion damages impacting the Rover Way Caravan Site with the Do Nothing and Do Minimum scenarios;
- Delayed onset and advanced onset of road loss and subsequent new road costs with the Do Nothing and Do Minimum scenarios; and
- An increase and a decrease in the cost of rock armour.

8.3.1 Delayed onset of erosion damages at Rover Way Travellers Site

The Rover Way Travellers Site is at risk of erosion. If the site is lost to erosion it will require relocation. The relocation of the site has been estimated as being required in year 0 for the Do Nothing scenario and year 20 for the Do Minimum scenario. The improve scenario will protect Rover Way Traveller Site.

Sensitivity analysis has been undertaken with a ten-year delay in the onset of damages to the Travellers site. A ten-year delay results in the decrease of damages from £5,798k to £4,110k for Do Nothing and £2,914k to £2,066k for the Do Minimum scenario. The impact of this on the BCR is provided in Table 8-3.

All BCR have decreased by between 0.09 and 0.12, although all options can still be considered economically viable. The decreased Rover Way Traveller Site erosion damages do not directly impact the Improve options, but the BCR alters as the damages avoided are reduced due to the change in baseline damages. Improve options 1 and 4 were impacted the most, but they remain the most economically viable options with BCR of 3.5 and 3.4 respectively.

Table 8-3 Sensitivity Test - Benefit-Cost Ratio with variation in timing of erosion to the Rover Way Travellers Site

Option	Benefit-Cost Ratio	Benefit Cost Ratio
Do Nothing	-	-
Do Minimum	1.4	1.2
Improve 1	3.7	3.5
Improve 2	2.5	2.4
Improve 3	2.5	2.5
Improve 4	3.5	3.4
Improve 5	2.4	2.3
Improve 6	2.4	2.3

8.3.2 Delayed and advanced onset of new road costs

The roundabout connecting Rover Way and Lamby Way, and the surrounding highways are at risk of erosion. The erosion of the banks of the Rhymney River will undermine the highways structures, leading to loss of the road. It has been estimated that the most likely case will see the rebuilding of this section of road network in 20 years for the Do Nothing scenario and 50 years for the Do Minimum scenario. The Improve scenarios will protect this section of road.

Sensitivity analysis of the timing of accrued damages have been undertaken with both a delayed onset and an advanced onset of damages. Delaying the erosion of highways infrastructure by ten-years (to year 30) for Do Nothing and 20-years (to year 70) for Do Minimum has decreased the BCR for all shortlisted options, whilst advancing damages to year five for Do Nothing and year 20 for Do Minimum increases the BCR. The results are provided in Table 8-4.

With both the delayed and advanced onset of damages incorporating the new road costs, all BCR remain above unity, and thus all options remain economically viable. The greatest impact for both sensitivity tests are on Improve option 1, with a BCR decreasing by 0.06 with the delay and increasing by 0.13 for the advancing scenario, but this option remains the most economically viable option. Improve option 4 remains the second most economically viable option with BCR of 3.4-3.6.

Table 8-4 Sensitivity Test - Benefit-Cost Ratio with variation in timing of erosion to the Lamby Way and Rover Way roundabout

Option	Benefit-Cost Ratio	Benefit-Cost Ratio	Benefit Cost Ratio
Do Nothing	-	-	-
Do Minimum	1.4	1.3	1.4
Improve 1	3.7	3.6	3.8
Improve 2	2.5	2.5	2.6
Improve 3	2.5	2.5	2.6
Improve 4	3.5	3.4	3.6
Improve 5	2.4	2.4	2.5
Improve 6	2.4	2.4	2.5

8.3.3 Impact of increased rock armour costing

The cost of rock has been estimated based on discussions during ECI with local rock suppliers. The cost of rock could however increase due to supply and demand impacts should a number of large schemes be requiring rock at the same time, such as a number of CRMP Projects and the potential Swansea Bay Tidal Lagoon. A sensitivity assessment has been undertaken with both a doubled cost and halved cost of rock armour.

Table 8-5 shows the impact of the rock armour cost on the total project costs for each shortlisted option. With the exception of the Do Nothing scenario, all options are impacted by the cost of rock armour. The Do Minimum option and Improve options 1-4 all incorporated significant volumes or rock armour, whilst improve options 5 and 6 only include small amounts at the toe of the proposed fluvial defences. Alterations in the total project costs impact upon the BCR, of which the results are provided in Table 8-6.

Decreasing the cost of rock armour results in an increased BCR for the Do Minimum scenario and Improve options 1-4. The greatest impact was on Improve options 1 and 4, by an increase of 0.63 and 0.47 respectively. The BCR does not alter for Improve options 5 and 6. Improve option 1 remains the most economically viable option with a BCR of 4.3, followed by Improve option 4 at 3.9.

If rock armour were to double in cost, the BCR for all shortlisted options would decrease. Improve options 1 and 4 incorporate the highest volumes of rock armour, and thus are influenced the most with BCR decreasing by 0.84 and 0.68 respectively. Improve options 5 and 6 were impacted the least at 0.12. Improve options 1 and 4 are considered the most economically viable options with a BCR of 2.8.

Table 8-5 Sensitivity Test - Present Value costs with variation in cost of Rock Armour

Option	Baseline Project Total PV Costs (£k)	Decreased Rock Armour Cost Project Total PV Costs (£k)	Increased Rock Armour Cost Project Total PV Costs (£k)
Do Nothing	0	0	0
Do Minimum	7,501	6,803	8,898
Improve 1	13,666	11,658	17,710
Improve 2	19,868	19,681	21,266
Improve 3	19,736	19,549	21,135
Improve 4	14,450	12,713	17,952
Improve 5	20,834	20,809	21,908
Improve 6	20,702	20,667	21,776

Table 8-6 Sensitivity Test - Benefit-Cost Ratio with variation in cost of Rock Armour

Option	Baseline PVd Benefit-cost Ratio	Decreased Rock Armour Cost Project PVd Benefit-cost Ratio	Increased Rock Armour Cost Project PVd Benefit-cost Ratio
Do Nothing	-	-	-
Do Minimum	1.4	1.5	1.1
Improve 1	3.7	4.3	2.8
Improve 2	2.5	2.5	2.4
Improve 3	2.5	2.6	2.4
Improve 4	3.5	3.9	2.8
Improve 5	2.4	2.4	2.3
Improve 6	2.4	2.4	2.3

8.3.4 Sensitivity assessment conclusions

Sensitivity tests were carried out to assess the impact of delayed onset of erosion damages and the subsequent relocation of the Rover Way Traveller Site, the delayed and advanced onset of erosion damages to the Lamby Way and Rover Way roundabout and subsequent new road building costs, and the increased and decreased cost of rock armour on the BCR. These assessments were undertaken on all of the shortlisted options. Improve option 1 proves to be the most economically viable option for protection measures across the Rover Way and Lamby Way Tip study area. This shortlisted option has a baseline BCR of 3.7, which fluctuates between 2.8-4.3 with sensitivity testing. Improve option 4 is a close second in the economic case with a baseline BCR of 3.5, with sensitivity analysis resulting in BCR of 2.8-3.9.

9 References

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Annex 1

Do Nothing with Emergency Costs [capping and 300 mm threshold applied]

Property Counts

Return Period		Total	Residential	Non-Residential	Critical Infrastructure
2017					
2		0	0	0	0
10		0	0	0	0
20		0	0	0	0
50		0	0	0	0
75		187	184	3	0
100		220	217	3	0
200		252	249	3	0
1000		597	586	7	4
2037					
2		0	0	0	0
10		0	0	0	0
20		0	0	0	0
50		210	207	3	0
75		232	229	3	0
100		247	244	3	0
200		361	351	6	4
1000		858	789	65	4
2067					
2		0	0	0	0
10		183	180	3	0
20		229	226	3	0
50		265	261	3	1
75		368	358	6	4
100		459	448	7	4
200		583	561	18	4
1000		1366	1165	194	7
2117					
2		252	249	3	0
10		478	464	10	4
20		579	557	18	4
50		752	716	32	4
75		898	820	74	4
100		1066	919	143	4
200		1421	1212	201	8
1000		2679	2291	375	13

Do Nothing with Emergency Costs [capping and 300 mm threshold applied]

Damages

Return Period		Total	Residential	Non-Residential	Critical Infrastructure	Emergency Costs	PVD
2017							
2		£ -	£ -	£ -	£ -	£ -	
10		£ -	£ -	£ -	£ -	£ -	
20		£ -	£ -	£ -	£ -	£ -	
50		£ -	£ -	£ -	£ -	£ -	
75		£ 7,730,412.29	£ 3,729,214.11	£ 3,591,252.07	£ -	£ 409,946.11	
100		£ 8,686,547.91	£ 4,278,721.19	£ 3,947,176.45	£ -	£ 460,650.27	
200		£ 10,794,365.35	£ 5,373,652.33	£ 4,848,284.55	£ -	£ 572,428.47	
1000		£ 22,636,785.94	£ 11,857,125.66	£ 7,495,307.75	£ 2,083,916.91	£ 1,200,435.62	
2037							
2		£ -	£ -	£ -	£ -	£ -	
10		£ -	£ -	£ -	£ -	£ -	
20		£ -	£ -	£ -	£ -	£ -	
50		£ 8,238,262.01	£ 4,018,225.65	£ 3,783,158.82	£ -	£ 436,877.53	
75		£ 9,533,823.72	£ 4,738,930.01	£ 4,289,312.16	£ -	£ 505,581.56	
100		£ 10,550,570.26	£ 5,273,032.92	£ 4,718,037.41	£ -	£ 559,499.94	
200		£ 13,917,617.62	£ 6,734,785.73	£ 5,696,224.97	£ 748,551.45	£ 738,055.48	
1000		£ 30,902,727.47	£ 16,202,526.09	£ 10,536,896.20	£ 2,524,524.18	£ 1,638,781.00	
							£ 42,602,789.64
2067							
2		£ -	£ -	£ -	£ -	£ -	
10		£ 7,523,721.05	£ 3,614,235.44	£ 3,510,500.40	£ -	£ 398,985.21	
20		£ 9,193,769.40	£ 4,551,641.41	£ 4,154,579.62	£ -	£ 487,548.38	
50		£ 11,850,587.34	£ 5,815,396.62	£ 5,161,600.14	£ 245,150.35	£ 628,440.24	
75		£ 14,259,051.00	£ 6,889,930.69	£ 5,769,732.42	£ 843,226.09	£ 756,161.80	
100		£ 16,310,489.26	£ 7,964,280.76	£ 6,177,743.36	£ 1,303,514.96	£ 864,950.19	
200		£ 21,017,193.34	£ 10,775,673.93	£ 7,302,682.73	£ 1,824,288.56	£ 1,114,548.13	
1000		£ 49,845,811.25	£ 23,538,398.26	£ 20,276,043.27	£ 3,388,031.24	£ 2,643,338.48	
2117							
2		£ 10,220,054.71	£ 5,389,384.03	£ 4,830,670.68	£ -	£ 10,792,377.77	
10		£ 16,956,672.40	£ 8,317,879.16	£ 6,335,660.95	£ 1,403,914.82	£ 899,217.48	
20		£ 20,854,493.59	£ 10,686,826.46	£ 7,253,199.34	£ 1,808,547.67	£ 1,105,920.11	
50		£ 27,113,438.15	£ 14,476,963.17	£ 8,883,038.22	£ 2,315,602.92	£ 1,437,833.84	
75		£ 32,241,537.05	£ 16,927,042.10	£ 11,002,637.42	£ 2,602,079.06	£ 1,709,778.48	
100		£ 36,582,770.82	£ 18,829,085.91	£ 13,007,785.55	£ 2,805,903.94	£ 1,939,995.42	
200		£ 51,986,211.36	£ 24,715,462.27	£ 20,982,306.46	£ 3,531,598.09	£ 2,756,844.54	
1000		£ 122,695,352.43	£ 53,075,145.59	£ 57,148,799.85	£ 5,964,835.26	£ 6,506,571.72	

Annex 2

Do Minimum with Emergency Costs [capping and 300 mm threshold applied]					
	Property Counts				
Return Period		Total	Residential	Non-Residential	Critical Infrastructure
2017					
2		0	0	0	0
10		0	0	0	0
20		0	0	0	0
50		0	0	0	0
75		0	0	0	0
100		0	0	0	0
200		2	0	2	0
1000		132	126	6	0
2037					
2		0	0	0	0
10		0	0	0	0
20		0	0	0	0
50		0	0	0	0
75		0	0	0	0
100		0	0	0	0
200		26	22	4	0
1000		333	318	12	3
2067					
2		0	0	0	0
10		183	180	3	0
20		229	226	3	0
50		265	261	3	1
75		368	358	6	4
100		459	448	7	4
200		583	561	18	4
1000		1366	1165	194	7
2117					
2		252	249	3	0
10		478	464	10	4
20		579	557	18	4
50		752	716	32	4
75		898	820	74	4
100		1066	919	143	4
200		1421	1212	201	8
1000		2679	2291	375	13

Do Minimum with Emergency Costs [capping and 300 mm threshold applied]							
	Damages						
Return Period		Total	Residential	Non-Residential	Critical Infrastructure	Emergency Costs	PVD
2017							
2		£ -	£ -	£ -	£ -	£ -	
10		£ -	£ -	£ -	£ -	£ -	
20		£ -	£ -	£ -	£ -	£ -	
50		£ -	£ -	£ -	£ -	£ -	
75		£ -	£ -	£ -	£ -	£ -	
100		£ -	£ -	£ -	£ -	£ -	
200		£ 882,624.68	£ -	£ 835,818.83	£ -	£ 46,805.85	
1000		£ 2,241,565.05	£ 2,032,297.92	£ 90,396.25	£ -	£ 118,870.87	
2037							
2		£ -	£ -	£ -	£ -	£ -	
10		£ -	£ -	£ -	£ -	£ -	
20		£ -	£ -	£ -	£ -	£ -	
50		£ -	£ -	£ -	£ -	£ -	
75		£ -	£ -	£ -	£ -	£ -	
100		£ -	£ -	£ -	£ -	£ -	
200		£ 813,779.84	£ 4,323.97	£ 766,300.88	£ -	£ 43,154.99	
1000		£ 12,515,271.53	£ 5,777,133.97	£ 5,623,054.16	£ 451,394.76	£ 663,688.64	
2067							£ 36,972,606.35
2		£ -	£ -	£ -	£ -	£ -	
10		£ 7,523,721.05	£ 3,614,235.44	£ 3,510,500.40	£ -	£ 398,985.21	
20		£ 9,193,769.40	£ 4,551,641.41	£ 4,154,579.62	£ -	£ 487,548.38	
50		£ 11,850,587.34	£ 5,815,396.62	£ 5,161,600.14	£ 245,150.35	£ 628,440.24	
75		£ 14,259,051.00	£ 6,889,930.69	£ 5,769,732.42	£ 843,226.09	£ 756,161.80	
100		£ 16,310,489.26	£ 7,964,280.76	£ 6,177,743.36	£ 1,303,514.96	£ 864,950.19	
200		£ 21,017,193.34	£ 10,775,673.93	£ 7,302,682.73	£ 1,824,288.56	£ 1,114,548.13	
1000		£ 49,845,811.25	£ 23,538,398.26	£ 20,276,043.27	£ 3,388,031.24	£ 2,643,338.48	
2117							
2		£ 10,220,054.71	£ 5,389,384.03	£ 4,830,670.68	£ -	£ 10,792,377.77	
10		£ 16,956,672.40	£ 8,317,879.16	£ 6,335,660.95	£ 1,403,914.82	£ 899,217.48	
20		£ 20,854,493.59	£ 10,686,826.46	£ 7,253,199.34	£ 1,808,547.67	£ 1,105,920.11	
50		£ 27,113,438.15	£ 14,476,963.17	£ 8,883,038.22	£ 2,315,602.92	£ 1,437,833.84	
75		£ 32,241,537.05	£ 16,927,042.10	£ 11,002,637.42	£ 2,602,079.06	£ 1,709,778.48	
100		£ 36,582,770.82	£ 18,829,085.91	£ 13,007,785.55	£ 2,805,903.94	£ 1,939,995.42	
200		£ 51,986,211.36	£ 24,715,462.27	£ 20,982,306.46	£ 3,531,598.09	£ 2,756,844.54	
1000		£ 122,695,352.43	£ 53,075,145.59	£ 57,148,799.85	£ 5,964,835.26	£ 6,506,571.72	

Annex 3

Improve with Emergency Costs [capping and 300 mm threshold applied]				
	Property Counts			
Return Period	Total	Residential	Non-Residential	Critical Infrastructure
2017				
2	0	0	0	0
10	0	0	0	0
20	0	0	0	0
50	0	0	0	0
75	0	0	0	0
100	0	0	0	0
200	0	0	0	0
1000	23	20	3	0
2037				
2	0	0	0	0
10	0	0	0	0
20	0	0	0	0
50	0	0	0	0
75	0	0	0	0
100	0	0	0	0
200	0	0	0	0
1000	42	35	7	0
2067				
2	0	0	0	0
10	0	0	0	0
20	0	0	0	0
50	0	0	0	0
75	0	0	0	0
100	1	0	1	0
200	6	5	1	0
1000	216	96	119	1
2117				
2	0	0	0	0
10	1	0	1	0
20	6	5	1	0
50	33	27	6	0
75	77	35	42	0
100	83	38	45	0
200	233	96	136	1
1000	1084	805	274	5

Improve with Emergency Costs [capping and 300 mm threshold applied]						
	Damages					
Return Period	Total	Residential	Non-Residential	Critical Infrastructure	Emergency Costs	PVD
2017						
2	£ -	£ -	£ -	£ -	£ -	
10	£ -	£ -	£ -	£ -	£ -	
20	£ -	£ -	£ -	£ -	£ -	
50	£ -	£ -	£ -	£ -	£ -	
75	£ -	£ -	£ -	£ -	£ -	
100	£ -	£ -	£ -	£ -	£ -	
200	£ -	£ -	£ -	£ -	£ -	
1000	£ 409,454.05	£ 338,488.69	£ 49,251.89	£ -	£ 21,713.47	
2037						
2	£ -	£ -	£ -	£ -	£ -	
10	£ -	£ -	£ -	£ -	£ -	
20	£ -	£ -	£ -	£ -	£ -	
50	£ -	£ -	£ -	£ -	£ -	
75	£ -	£ -	£ -	£ -	£ -	
100	£ -	£ -	£ -	£ -	£ -	
200	£ -	£ -	£ -	£ -	£ -	
1000	£ 1,646,075.24	£ 643,137.36	£ 915,646.01	£ -	£ 87,291.87	
						£ 971,355.64
2067						
2	£ -	£ -	£ -	£ -	£ -	
10	£ -	£ -	£ -	£ -	£ -	
20	£ -	£ -	£ -	£ -	£ -	
50	£ -	£ -	£ -	£ -	£ -	
75	£ -	£ -	£ -	£ -	£ -	
100	£ 3,138.86	£ -	£ 2,972.41	£ -	£ 166.45	
200	£ 146,758.83	£ 128,818.31	£ 10,157.86	£ -	£ 7,782.67	
1000	£ 11,325,751.29	£ 1,706,167.34	£ 8,986,657.47	£ 32,318.47	£ 600,608.02	
2117						
2	£ -	£ -	£ -	£ -	£ -	
10	£ 4,698.57	£ -	£ 4,449.40	£ -	£ 249.17	
20	£ 139,462.87	£ 121,697.54	£ 10,369.57	£ -	£ 7,395.76	
50	£ 1,277,145.96	£ 478,852.85	£ 730,565.68	£ -	£ 67,727.44	
75	£ 2,123,579.19	£ 681,395.32	£ 1,329,569.81	£ -	£ 112,614.05	
100	£ 4,008,846.61	£ 773,737.90	£ 3,022,518.36	£ -	£ 212,590.35	
200	£ 12,332,472.83	£ 1,856,511.86	£ 9,782,823.93	£ 39,142.27	£ 653,994.77	
1000	£ 62,525,513.57	£ 15,554,779.96	£ 42,437,115.98	£ 1,217,870.70	£ 3,315,746.93	

Annex 4

Present Value Costs for all options

Client/Authority
The City of Cardiff Council
Project name
Cardiff Flood and Coastal Risk Management Programme - Rover Way and Lamby Way Tip Outline Business Case
Project reference: 2016s5078
Base date for estimates (year 0): Mar-2017
Scaling factor (e.g. £m, £k, £): £
Initial discount rate: 3.5%

	Results (INCL OB) £							
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
PV total costs	£ -	£ 7,500,580	£ 13,665,896	£ 19,868,425	£ 19,736,124	£ 14,450,480	£ 20,834,420	£ 20,702,123

		Option 1	Do Nothing			TOTALS: PV	PV	PV	PV	PV	Option 2	Do Minimum			TOTALS: PV	PV	PV	PV	PV
		Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs	Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs
	Cash sum	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ 1,297,495	£ 21,423,402	£ 158,242	£ -	£ 22,879,139	£ 1,297,495	£ 6,045,244	£ 158,242	£ -
Year	Discount Factor																		
0.00	1.00		£ -	£ -		£ -	£ -	£ -	£ -	£ -	£ 1,297,495		£ 158,242		£ 1,455,737	£ 1,297,495	£ -	£ 158,242	£ -
1.00	0.97		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 208,824	£ -	£ -
2.00	0.93		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 201,515	£ -	£ -
3.00	0.90		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 194,462	£ -	£ -
4.00	0.87		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 187,656	£ -	£ -
5.00	0.84		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 181,088	£ -	£ -
6.00	0.81		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 174,750	£ -	£ -
7.00	0.78		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 168,634	£ -	£ -
8.00	0.75		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 162,732	£ -	£ -
9.00	0.73		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 157,036	£ -	£ -
10.00	0.70		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 151,540	£ -	£ -
11.00	0.68		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 146,236	£ -	£ -
12.00	0.65		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 141,118	£ -	£ -
13.00	0.63		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 136,178	£ -	£ -
14.00	0.61		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 131,412	£ -	£ -
15.00	0.59		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 126,813	£ -	£ -
16.00	0.57		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 122,374	£ -	£ -
17.00	0.55		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 118,091	£ -	£ -
18.00	0.53		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 113,958	£ -	£ -
19.00	0.51		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 109,969	£ -	£ -
20.00	0.49		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 106,121	£ -	£ -
21.00	0.47		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 102,406	£ -	£ -
22.00	0.46		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 98,822	£ -	£ -
23.00	0.44		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 95,363	£ -	£ -
24.00	0.43		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 92,026	£ -	£ -
25.00	0.41		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 88,805	£ -	£ -
26.00	0.40		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 85,697	£ -	£ -
27.00	0.38		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 82,697	£ -	£ -
28.00	0.37		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 79,803	£ -	£ -
29.00	0.36		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 77,010	£ -	£ -
30.00	0.34		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 74,314	£ -	£ -
31.00	0.33		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 72,085	£ -	£ -
32.00	0.32		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 69,922	£ -	£ -
33.00	0.31		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 67,825	£ -	£ -
34.00	0.30		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 65,790	£ -	£ -
35.00	0.29		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 63,816	£ -	£ -
36.00	0.29		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 61,902	£ -	£ -
37.00	0.28		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 60,045	£ -	£ -
38.00	0.27		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 58,243	£ -	£ -
39.00	0.26		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 56,496	£ -	£ -
40.00	0.25		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 54,801	£ -	£ -
41.00	0.25		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 53,157	£ -	£ -
42.00	0.24		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 51,562	£ -	£ -
43.00	0.23		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 50,016	£ -	£ -
44.00	0.22		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 48,515	£ -	£ -
45.00	0.22		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 47,060	£ -	£ -
46.00	0.21		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 45,648	£ -	£ -
47.00	0.20		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 44,278	£ -	£ -
48.00	0.20		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 42,950	£ -	£ -
49.00	0.19		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 41,662	£ -	£ -
50.00	0.19		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 40,412	£ -	£ -
51.00	0.18		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 39,199	£ -	£ -
52.00	0.18		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 38,023	£ -	£ -
53.00	0.17		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 36,883	£ -	£ -
54.00	0.17		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 35,776	£ -	£ -
55.00	0.16		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 34,703	£ -	£ -
56.00	0.16		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 33,662	£ -	£ -
57.00	0.15		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 32,652	£ -	£ -
58.00	0.15		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 31,672	£ -	£ -
59.00	0.14		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 30,722	£ -	£ -
60.00	0.14		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 29,801	£ -	£ -
61.00	0.13		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 28,907	£ -	£ -
62.00	0.13		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 28,039	£ -	£ -
63.00	0.13		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 27,198	£ -	£ -
64.00	0.12		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 26,382	£ -	£ -
65.00	0.12		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 25,591	£ -	£ -
66.00	0.11		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 24,823	£ -	£ -
67.00	0.11		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 24,078	£ -	£ -
68.00	0.11		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 23,358	£ -	£ -
69.00	0.10		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 22,655	£ -	£ -
70.00	0.10		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 21,976	£ -	£ -
71.00	0.10		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 21,316	£ -	£ -
72.00	0.10		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 20,677	£ -	£ -
73.00	0.09		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 20,057	£ -	£ -
74.00	0.09		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 19,455	£ -	£ -
75.00	0.09		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 18,871	£ -	£ -
76.00	0.09		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 18,399	£ -	£ -
77.00	0.08		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 17,939	£ -	£ -
78.00	0.08		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 17,491	£ -	£ -
79.00	0.08		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 17,054	£ -	£ -
80.00	0.08		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 16,627	£ -	£ -
81.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 16,212	£ -	£ -
82.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 15,806	£ -	£ -
83.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 15,411	£ -	£ -
84.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 15,026	£ -	£ -
85.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 14,650	£ -	£ -
86.00	0.07		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 14,284	£ -	£ -
87.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 13,827	£ -	£ -
88.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 13,579	£ -	£ -
89.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 13,239	£ -	£ -
90.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 12,908	£ -	£ -
91.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 12,586	£ -	£ -
92.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 12,271	£ -	£ -
93.00	0.06		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 11,964	£ -	£ -
94.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 11,665	£ -	£ -
95.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 11,373	£ -	£ -
96.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 11,089	£ -	£ -
97.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 10,812	£ -	£ -
98.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 10,542	£ -	£ -
99.00	0.05		£ -			£ -	£ -	£ -	£ -	£ -		£ 216,398			£ 216,398	£ -	£ 10,278	£ -	£ -
	0.05																		

Option 3	Improve 1			TOTALS:	PV	PV	PV	PV	Option 4	Improve 2			TOTALS:	PV	PV	PV	PV
Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs	Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs
£ 5,154,122	£ 28,052,640	£ 595,896	£ -	£ 33,802,658	£ 5,154,122	£ 7,915,878	£ 595,896	£ -	£ 11,400,513	£ 25,197,480	£ 1,357,701	£ -	£37,955,694	#########	£ 7,110,211	£ 1,357,701	£ -
£ 5,154,122		£ 595,896		£ 5,750,018	£ 5,154,122	£ -	£ 595,896	£ -	£ 11,400,513		£ 1,357,701		£12,758,214	#########	£ -	£ 1,357,701	£ -
	£ 283,360			£ 283,360	£ -	£ 273,442	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 245,612	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 263,872	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 237,015	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 254,636	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 228,720	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 245,724	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 220,716	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 237,124	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 212,990	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 228,824	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 205,535	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 220,816	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 198,341	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 213,087	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 191,399	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 205,629	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 184,700	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 198,432	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 178,236	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 191,487	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 171,998	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 184,785	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 165,978	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 178,317	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 160,168	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 172,076	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 154,563	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 166,054	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 149,153	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 160,242	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 143,933	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 154,633	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 138,895	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 149,221	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 134,034	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 143,998	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 129,342	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 138,958	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 124,815	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 134,095	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 120,447	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 129,402	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 116,231	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 124,872	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 112,163	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 120,502	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 108,237	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 116,284	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 104,449	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 112,214	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 100,793	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 108,287	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 97,266	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 104,497	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 93,861	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 100,839	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 90,576	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 97,310	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 87,406	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 94,391	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 84,784	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 91,559	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 82,240	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 88,812	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 79,773	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 86,148	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 77,380	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 83,563	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 75,059	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 81,057	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 72,807	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 78,625	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 70,623	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 76,266	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 68,504	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 73,978	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 66,449	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 71,759	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 64,455	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 69,606	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 62,522	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 67,518	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 60,646	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 65,492	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 58,827	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 63,528	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 57,062	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 61,622	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 55,350	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 59,773	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 53,689	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 57,980	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 52,079	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 56,240	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 50,516	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 54,553	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 49,001	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 52,917	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 47,531	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 51,329	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 46,105	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 49,789	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 44,722	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 48,296	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 43,380	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 46,847	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 42,079	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 45,441	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 40,816	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 44,078	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 39,592	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 42,756	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 38,404	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 41,473	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 37,252	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 40,229	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 36,134	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 39,022	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 35,050	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 37,851	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 33,999	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 36,716	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 32,979	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 35,614	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 31,990	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 34,546	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 31,030	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 33,510	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 30,099	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 32,504	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 29,196	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 31,529	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 28,320	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 30,583	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 27,471	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 29,666	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 26,646	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 28,776	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 25,847	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 27,913	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 25,072	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 27,075	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 24,319	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 26,263	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 23,590	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 25,475	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 22,882	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 24,711	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 22,196	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 24,093	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 21,641	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 23,491	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 21,100	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 22,903	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 20,572	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 22,331	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 20,058	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 21,773	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 19,557	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 21,228	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 19,068	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 20,698	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 18,591	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 20,180	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 18,126	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 19,676	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 17,673	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 19,184	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 17,231	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 18,704	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 16,800	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 18,236	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 16,380	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 17,781	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 15,971	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 17,336	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 15,572	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 16,903	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 15,182	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 16,480	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 14,803	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 16,068	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 14,433	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 15,666	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 14,072	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 15,275	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 13,720	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 14,893	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 13,377	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 14,521	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 13,043	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 14,158	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 12,717	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 13,804	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 12,399	£ -	£ -
	£ 283,360			£ 283,360	£ -	£ 13,459	£ -	£ -		£ 254,520			£ 254,520	£ -	£ 12,089	£ -	£ -

Option 5	**Improve 3**			TOTALS:	PV	PV	PV	PV
Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs
£ 11,282,597	£ 25,197,480	£ 1,343,320	£ -	£ 37,823,397	#########	£ 7,110,211	#######	£ -
£ 11,282,597		£ 1,343,320		£ 12,625,917	#########	£ -	#######	£ -
	£ 254,520			£ 254,520	£ -	£ 245,612	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 237,015	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 228,720	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 220,715	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 212,990	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 205,535	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 198,341	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 191,399	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 184,700	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 178,236	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 171,998	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 165,978	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 160,168	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 154,563	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 149,153	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 143,933	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 138,885	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 134,034	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 129,342	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 124,815	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 120,447	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 116,231	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 112,163	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 108,237	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 104,449	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 100,793	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 97,266	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 93,861	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 90,576	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 87,406	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 84,784	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 82,240	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 79,773	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 77,380	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 75,053	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 72,807	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 70,623	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 68,504	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 66,449	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 64,455	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 62,522	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 60,646	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 58,827	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 57,062	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 55,350	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 53,689	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 52,079	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 50,516	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 49,001	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 47,531	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 46,105	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 44,722	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 43,380	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 42,079	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 40,816	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 39,592	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 38,404	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 37,252	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 36,134	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 35,050	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 33,999	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 32,979	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 31,990	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 31,030	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 30,099	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 29,196	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 28,320	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 27,471	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 26,646	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 25,847	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 25,072	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 24,319	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 23,590	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 22,882	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 22,196	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 21,641	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 21,100	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 20,572	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 20,058	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 19,557	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 19,068	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 18,591	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 18,126	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 17,673	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 17,231	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 16,800	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 16,380	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 15,971	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 15,572	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 15,182	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 14,803	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 14,433	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 14,072	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 13,720	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 13,377	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 13,043	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 12,717	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 12,399	£ -	£ -
	£ 254,520			£ 254,520	£ -	£ 12,089	£ -	£ -

Option 6	**Improve 4**			TOTALS:	PV	PV	PV	PV
Capital	Maint.	To FBC	Negative costs	Cash	Capital	Maint	To FBC	Negative costs
£ 7,067,700	£ 23,145,200	£ 851,399	£ -	£ 31,065,299	£ 7,067,700	£ 6,531,382	#######	£ -
£ 7,067,700		£ 851,399		£ 7,919,099	£ 7,067,700	£ -	#######	£ -
	£ 233,800			£ 233,800	£ -	£ 225,617	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 217,720	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 210,100	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 202,747	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 195,651	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 188,803	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 182,195	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 175,818	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 169,664	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 163,726	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 157,996	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 152,466	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 147,129	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 141,980	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 137,011	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 132,215	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 127,588	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 123,122	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 118,813	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 114,654	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 110,642	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 106,769	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 103,032	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 99,426	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 95,946	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 92,585	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 89,347	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 86,220	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 83,203	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 80,290	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 77,882	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 75,545	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 73,279	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 71,081	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 68,948	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 66,880	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 64,873	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 62,927	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 61,039	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 59,208	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 57,432	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 55,709	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 54,038	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 52,417	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 50,844	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 49,319	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 47,839	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 46,404	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 45,012	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 43,661	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 42,352	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 41,081	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 39,849	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 38,653	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 37,494	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 36,369	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 35,278	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 34,219	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 33,193	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 32,197	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 31,231	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 30,294	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 29,385	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 28,504	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 27,649	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 26,819	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 26,015	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 25,234	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 24,477	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 23,743	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 23,031	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 22,340	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 21,669	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 21,019	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 20,389	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 19,879	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 19,382	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 18,898	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 18,425	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 17,964	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 17,515	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 17,077	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 16,651	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 16,234	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 15,828	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 15,433	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 15,047	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 14,671	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 14,304	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 13,946	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 13,598	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 13,258	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 12,926	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 12,603	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 12,288	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 11,981	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 11,681	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 11,389	£ -	£ -
	£ 233,800			£ 233,800	£ -	£ 11,105	£ -	£ -

Prepared (date)	31/03/2017
Printed	31/03/2017
Prepared by	TW
Checked by	AW

Option 7 Improve 5

Capital	Maint.	To FBC	Negative costs	TOTALS: Cash	PV Capital	PV Maint	PV To FBC	PV Negative costs
£ 13,495,502	£ 20,291,040	£ 1,613,204	£ -	£35,399,745	£13,495,502	£5,725,714	£1,613,204	£ -
£ 13,495,502		£ 1,613,204		£15,108,705	£13,495,502	£ -	£1,613,204	£ -
	£ 204,960			£ 204,960	£ -	£ 197,788	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 190,864	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 184,184	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 177,737	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 171,516	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 165,513	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 159,720	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 154,130	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 148,736	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 143,530	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 138,506	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 133,659	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 128,981	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 124,466	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 120,110	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 115,906	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 111,849	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 107,935	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 104,157	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 100,511	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 81,167	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 78,326	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 75,585	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 72,939	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 70,386	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 68,275	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 55,165	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 53,510	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 51,905	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 50,347	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 48,837	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 47,372	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 45,951	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 44,572	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 43,235	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 41,938	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 40,680	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 39,459	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 38,276	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 37,127	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 31,883	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 30,926	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 20,190	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 16,991	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 16,566	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 16,152	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 15,749	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 14,232	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 11,622	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 11,049	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 10,772	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 10,503	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 10,240	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 9,984	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 9,735	£ -	£ -

Option 8 Improve 6

Capital	Maint.	To FBC	Negative costs	TOTALS: Cash	PV Capital	PV Maint	PV To FBC	PV Negative costs
£13,377,586	########	£ 1,598,823	£ -	£35,267,449	£13,377,586	£5,725,714	########	£ -
£13,377,586		£ 1,598,823		£14,976,409	£13,377,586	£ -	########	£ -
	£ 204,960			£ 204,960	£ -	£ 197,788	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 190,864	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 184,184	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 177,737	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 171,516	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 165,513	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 159,720	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 154,130	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 148,736	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 143,530	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 138,506	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 133,659	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 128,981	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 124,466	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 120,110	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 111,849	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 107,935	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 72,939	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 55,165	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 18,996	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 16,566	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 14,971	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 14,597	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 14,232	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 13,876	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 12,226	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 11,920	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 11,622	£ -	£ -
	£ 204,960			£ 204,960	£ -	£ 11,332	£ -	£ -
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	£ 204,960			£ 204,960	£ -	£ 9,984	£ -	£ -
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Outline Business Case

Local Authority Name: Cardiff City Council

Project Name: Cardiff Flood and Coastal Erosion Risk Management
Outline Business Case
Rover Way and Lamby Way Tip

Project Manager Name:
David Brain

Email: david.brain2@cardiff.gov.uk
Contact Details: 02922 330693

Version: 0

Date: March 2016

Approvals Sheet

	Signature / Dates
Project Name	***Cardiff Coastal OBC: Rover Way and Lamby Way Tip***
Local Authority	**Cardiff City Council**
Project Manager	**David Brain**
Consultant	**JBA Consulting, March 31st 2017** A. Moon.
Local Authority approvals **Head of Service** **Head of Finance**	
Welsh Government Review	
Welsh Government Approval **Programme SRO**	

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Glossary of Abbreviations

CRMP	Coastal Risk Management Programme
FCERM	Flood and Coastal Erosion Risk Management
NHCP	National Habitats Compensation Programme
OBC	Outline Business Case
PV	Present Value
PWLB	Public Works Loan Board
SMP2	2nd Shoreline Management Plans
SOC	Strategic Outline Case

1 Executive Summary

1.1 Introduction

This Outline Business Case (OBC) is for a coastal erosion and flood risk management scheme for Cardiff Coastal Defences, between Rover Way in the west and Lamby Way in the east, extending up the River Rhymney as far as the railway bridge. The project aims to improve the existing coastal and fluvial defences to provide improved protection to people and property in parts of south east Cardiff from coastal erosion and flood risk, and prevent the erosion of two decommissioned landfill sites; The Frag Tip and Lamby Way Tip.

Much of the coastline across the project area is eroding and with predicted sea level rise due to climate change, the flood and erosion risk will increase into the future. The proposed scheme will manage flood risk to 1,116 residential and 72 non-residential properties over 100 years, as well as preventing erosion of landfill material, key road infrastructure and the Rover Way Travellers Site.

Approval is being sought for the project to proceed to Detailed Design as part of the Welsh Government Coastal Risk Management Programme.

1.2 Strategic case

1.2.1 Strategic context

The proposed Cardiff Coastal Defence Scheme has considered a range of local strategies including:

- Cardiff City Council Local Development Plan (2006-2026) (LDP)
- Cardiff Flood Risk Management Plan (Dec 2015)
- Cardiff Local Flood Risk Management Strategy (September 2014)
- Cardiff Strategic Flood Consequences Assessment (Atkins, 2011)
- Severn Estuary Shoreline Management Plan 2, Anchor Head to Lavernock Point (2010) (SMP2)

The proposed scheme is in accordance with the policies in the above studies.

1.2.2 The case for change

The coastal defences across the study area are in very poor condition and erosion is already taking place at a rapid rate. To the west of the River Rhymney, landfill material is eroding into the Severn Estuary from the disused Frag Tip, while the Rover Way Travellers site is at risk of being lost to erosion and flooding. The coastal defences here are already at risk of breach due to erosion, leading to flooding of the land behind.

Along the west bank of the river there are low sections of defence which will overtop as sea levels rise, increasing flood risk to people and property to the west of the river. The Lamby Way roundabout and Rover Way, key infrastructure supporting the economy of Cardiff, are situated immediately behind the embankment on the outside of the river meander and are at risk of being undermined and lost to erosion within 20 years.

The defences along the east bank of the river and the coastal defences to the east of the river mouth are also at risk of erosion. It is estimated that if no works are undertaken along the coast, erosion will continue to increase and will impact upon the disused Lamby Way Tip within 20 years, releasing landfill material into the Severn Estuary and having significant environmental impacts.

1.2.3 Objectives

The project set out to achieve seven key project objectives:

No	Objective
1	Reduce and manage coastal flood risk to people and assets within part of south east Cardiff for the next 100 years, taking into account predicted future climate change.
2	Manage erosion along the coast to reduce the risk of failing coastal flood defences and the release of contaminated landfill material into the Severn Estuary from Lamby Way Tip and the Rover Way Frag Tip, in the immediate future and over the next 100 years.
3	To achieve wider benefits alongside coastal erosion and flood risk management, aligned with WG's 7 Wellbeing Goals and with WG and CCC's vision for development and economic growth of the area.
5	Implement a coastal flood and erosion risk management option which is affordable over the next 100 years.
6	Protect existing features of nature conservation value and seek opportunities to improve biodiversity though the enhancements of existing habitats.
7	Produce technically feasible and buildable engineering options

1.3 Economic case

1.3.1 Options considered

The variation in existing defences and geomorphological process throughout the study area mean that different options are appropriate for different sections of defence within the study area.

Longlist options for the coastal frontages include;

- **Do Minimum** – addition of a rock toe to reduce erosion
- **Improve** - using rock armouring, concrete sea wall, sheet pile wall, concrete block work revetment or rock armour with sheet piling.
- **Managed Retreat** – allow the coastline to erode to a new set back location

Longlist options for the river defences include:

- **Do Minimum** – maintenance of existing defences
- **Improve** – by raising low sections of earth embankments, adding sheet pilling with a rock toe, providing rock armour scour protection to the bank or adding concrete embankment.
- **Managed retreat** – allow the coastline to erode to a new set back location

The longlist options removed in the shortlisting process were:

- **Concrete block work revetment** – this option would have greater environmental and landscape impacts.
- **Rock armour with sheet piling** –the project focus is management of erosion and flood risk, which would be managed by the rock armour alone. The addition of sheet pile to manage contaminated land issues will be picked up in a separate project.
- **Concrete embankment** - this option would have much greater environmental and landscape impacts than other solutions.

- **Managed retreat**– this option would have significant environmental impacts through the release of landfill material into the Severn Estuary and conflict with the SMP policy for the area.

The individual section options were combined into the following options for the whole study area to provide a shortlist of options. The study area was divided into 5 sections based on the appropriate options and the level of risk. The coastline formed one section, while the river banks were divided into 4 sections based on whether they required erosion protection, embankment raising or just maintenance works.

Option	Name	Description
1	Do Nothing	No works undertaken. Allow natural coastal and fluvial processes to continue.
2	Do Minimum	Maintenance works along existing earth embankments. Add small rock toe to the eroding coastal defences to slow erosion.
3	Improve 1	Rock revetment along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Scour protection added to Lamby Way Bridge.
4	Improve 2	Sheet piling along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
5	Improve 3	Concrete sea wall along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
6	Improve 4	Rock revetment along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
7	Improve 5	Sheet piling along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
8	Improve 6	Concrete wall along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankment elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.

1.3.2 Key findings

The options considered are listed below, with 100 year whole life PV costs,

- **Do minimum** – this would manage flood and erosion risk for 50 years including an allowance for climate change and would **cost £7,501k**.
- **Improve** would manage flood and erosion risk to a 0.5% Standard of Protection to 2117 including an allowance for climate change and would **cost between £13,666k and £20,834k**.

Damage estimates have been derived for flood and coastal erosion damages under these same options, with Improve being designed to a standard of 0.5% AEP plus climate change for the 100 year lifetime of the scheme. Damage estimates are:

- **Do Nothing - £50,175k**: *£42,603k flood damages, £8,488k attributed to erosion risk of key road infrastructure and Rover Way Travellers site.*
- **Do minimum – £40,940k:** *£36,973k flood damages, £3,968k attributed to erosion risk of key road infrastructure and Rover Way Travellers site.*
- **Improve – £971k:** *£971k flood damages, £0k erosion damages.*

Based on the economic assessment;

- The economically preferred option is to Improve with Option 3, Improve 1 with a benefit **cost ratio of 3.7**
- The next economically preferred option is to Improve with Option 6: Improve 4 with a benefit **cost ratio of 3.5**

A Multi Criteria Analysis identified a preferred option of Option 6: Improve 4. This option scored well in all aspects and had the least environmental, landscape and geomorphological impacts while also providing the required standard of protection. It is also the least intrusive due to the use of rock armour on the coast which would reduce the construction risks associated with working on or near the unknown material in The Frag Tip.

Do Minimum scored low in the well-being assessment as it would delay erosion and flood for 50 years, but would not be able to manage it into the future as sea levels rise and defences exceed their residual life.

1.3.3 Preferred way forward

Based on the Multi Criteria Assessment and Well-being assessment the preferred option is Option 6: Improve 4. The economically preferred option is Option 3: Improve 1.

The key difference between Option 6 and Option 3 is the technical approach to improving the defences along section 3, Lamby Way roundabout. Option 6 involves installation of a sheet pile wall, whereas Option 3 involves the addition of rock scour protection to the river bank. The addition of rock has a number of disadvantages which mean that the preferred option would be to install sheet piling along this stretch with just small amounts of rock at the toe for scour protection. The key disadvantages include:

- The negative environmental impact of adding a significant volume of rock to manage erosion as this would cover much of the intertidal area, which supports protected bird species;
- The risk of increased erosion downstream of the works, as the rock structure would narrow the channel, increasing the river flow velocities downstream. This could increase erosion to Rover Way located parallel to the defence in section 2.

The benefit cost ratio of Option 6 and Option 3 are very close, and are significantly higher than the other options assessed in the economic analysis.

The overall preferred option is Option 6: Improve 4, consisting of:

- Rock revetment along the coast to manage erosion and wave overtopping (Section 1)
- Sheet piling along Lamby Way Roundabout (Section 3)
- Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk (Sections 2, 4 and 5)
- Rock scour protection added to Lamby Way Bridge

1.4 Commercial case

The project has been undertaken by JBA Consulting on behalf of CCC, with Early Contractor Involvement (ECI) support from Raymond Brown Construction Ltd, all three of whom have knowledge of the area and have a considerable track record of delivering successful infrastructure and regeneration schemes of this nature.

Delivery of the project will require subsequent procurement exercises being undertaken for both the Design and Construction Stages, with the latter being substantially larger.

The consultancy services for the Outline Business Case were procured under the Construction Consultancy Framework (ref. NPS-PS-0027-15) managed by the National Project Service (NPS), using the relevant 'Water Management' Lot under the framework. It is envisaged that the detailed design stage of the project would be procured using a similar arrangement.

The construction procurement exercise will be completed following detailed design.

1.5 Financial case

The total value for Coastal Risk Management Plan Approval is; **£10,883,537**

The total value of the Welsh Government cost apportionment would be; **£8,162,652**

The total value of the CCC cost apportionment would be; **£2,720,884**

At this early development stage, CCC commit in principle to fund up to 25%. Formal consideration for the commitment to the scheme will be provided following the May 2017 elections. The funding will be subject to review as the design is developed as there is potential for assistance from private sources as a wider strategy for development in the area is considered.

Due to the geographical separation of key elements of this scheme, and potential for links with other projects, CCC may consider a phased approach to constructing this project if this offered efficiencies. Welsh Government Funding levels for the detailed design phase may also affect the development schedule for the scheme.

1.6 Management case

The project will be delivered and managed by officers of CCC with Governance from elected Members of the Council. The Senior Responsible Officers are the Operational Managers of City Operations, reporting to the Director of Environment, who reports to Council Members Cabinet.

The project will be delivered by a Project Core Team, with members to be agreed. It is proposed that the project will be managed by an externally sourced project manager.

Advice will be sort from CCC's internal departments for consideration of funds management and marketing.

Following approval of this OBC, it may be appropriate to undertake further studies and investigations in advance of the detailed design stage to better manage key project risks.

Changes are inevitable in construction projects and Change Management is a critical problem faced by the construction industry. CCC will implement an agreed process based on the selected contract.

2 The Strategic case

2.1 Introduction

This Outline Business Case (OBC) presents the business case and implementation plan for Cardiff Coastal Defences between Rover Way in the west and Lamby way in the east. The project aims to improve the existing coastal and fluvial defences to provide improved protection to people and property from coastal erosion and flood risk, and prevent the erosion of two decommissioned landfill sites; The Frag Tip and Lamby Way Tip.

The project includes the coastline along Rover Way, beginning at the eastern end of the privately owned Dwr Cyru Welsh Water (DCWW) defences, extending along the coast along Rover Way and up the west bank of the river as far as the railway line. The extent continues down the east bank of the river and along the coast around Lamby Way Tip to the location of the recently constructed Natural Resources Wales (NRW) defences. Figure 1 shows the extent of the study area and Figure 2 provides a contextual overview of the area.

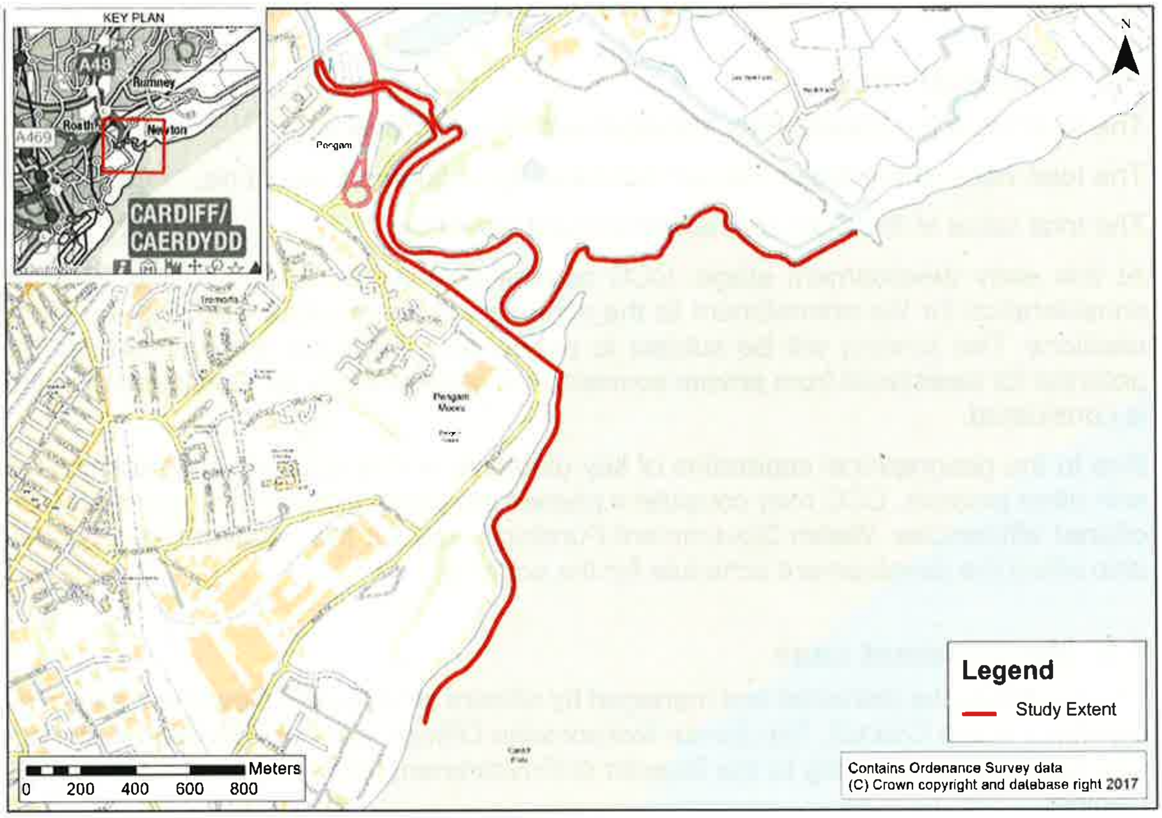

Figure 1: Study Area

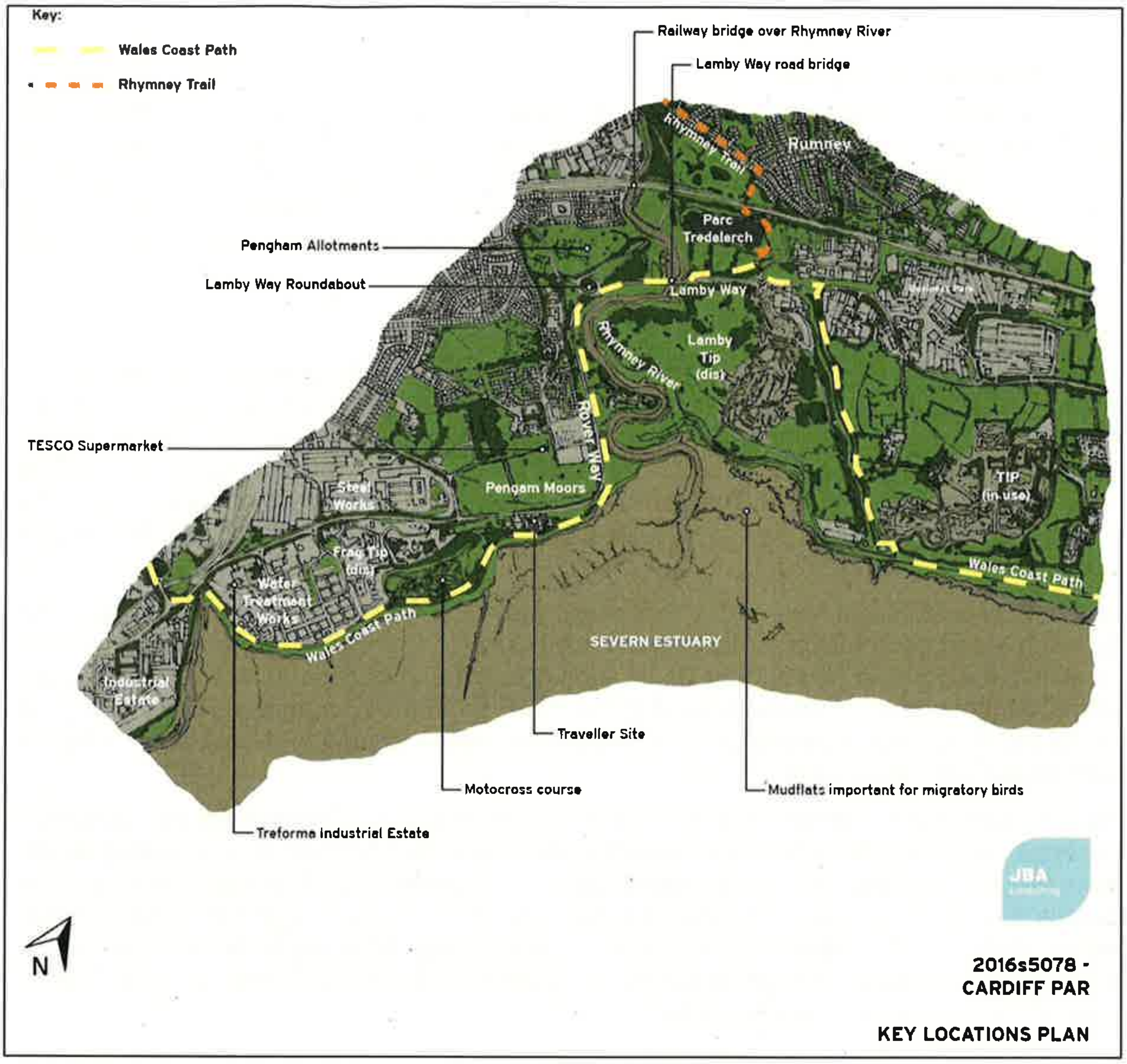

Figure 2: Study area overview

This scheme is comprised of two main areas:

- The flood cell to the west of the River Rhymney. Here people and property are at risk from coastal erosion and flooding from the sea. Additionally, fluvial erosion and tidal flooding can occur from the River Rhymney. In a 0.5% Annual Exceedance Probability (AEP) event 249 residential properties and 3 non-residential properties are at risk of flooding, increasing to 1212 residential and 209 non-residential properties by 2117. Along the coastal frontage of the flood cell the coastline is currently eroding and releasing landfill material into the estuary.
- A second cell to the east of the River Rhymney. Here the main risk is erosion of the coast and fluvial defences leading to the release of Lamby Way Tip material into the Severn Estuary and associated detrimental environmental impacts. Land elevations are higher on this side of the river leading to more limited flood risk but there is a risk of up to 50m of erosion along the coast within 20 years, and 270m by 2117.

The two flood cells have been combined into one scheme due to their geographic proximity and the similarities in the works required. Significant efficiencies can be realised in undertaking these works as one scheme, both during design and construction.

2.1.1 Baseline Conditions

The study area is currently defended from coastal erosion and flood risk by a combination of defence types, including rock gabions, earth embankments and sheet pile walls. Along the open coast most of the defences are in very poor/failing condition, and new or upgraded defences are urgently required. Along the banks of the River Rhymney there is a risk of erosion and tidal overtopping along isolated sections which will increase with climate change as sea level rises.

Land use and community

The coastline in the study area is heavily modified by urban development and industry along much of its extent. This includes the presence of extensive areas of Made Ground that are now used for a variety of industrial and recreation purposes, as well as significant transport and utilities infrastructure. To the west of the Rhymney River, the main industrial activities taking place include metal salvage and recycling yards and vehicle repairers in Tremorfa Industrial Estate and steelworks and waste disposal associated with the Celsa Steelworks north and south of Rover Way.

Lamby Way and Rover way cross the study area and form key road infrastructure for commuters and commercial traffic in south east Cardiff. Lamby Way road bridge crosses the river to the north of Lamby Way Tip, to join Lamby Way roundabout, located immediately behind the defences on the west bank of the river. From the roundabout Rover Way runs behind the flood embankments parallel to the river before turning to run parallel along the coast towards the steel works.

The land east of the Tremorfa Industrial Estate consists of a mix of green space, residential properties, and local amenities such as schools, leisure facilities and a large supermarket. There are also two allotment sites located close to the western bank of the Rhymney River towards the northern end of the project area. In addition, there is a Traveller site located directly off Rover Way between the road and the coastline. Adjacent to the travellers site is an electricity substation, thought to supply the DCWW Water Water Treatment Works which is located to the west of the study area.

The land east of the river is primarily comprised of made ground and includes the decommissioned Frag Tip which contains unknown landfill materials. The dirt bike track to the west of the Travellers site has been constructed upon the Frag Tip material.

To the east of the river is Lamby Way landfill site, which was until recently was the principal waste disposal facility in Cardiff. The western half of the site has been remediated and landscaped, whilst the eastern portion of the site is currently undergoing a capping process. The future use of the site once its restoration process is complete has yet to be finalised, although the Cardiff LDP identifies that the majority of land is likely to be used as public open space, whilst a new municipal recycling facility will also be developed at the site. Along the coastline fronting the Lamby Way Tip is a row of mains electricity pylons running parallel to the coast.

The Rhymney River supports a wide range of recreational activities. The Rhymney River Motor Boat Sail and Angling Club is located on the west bank of the river adjacent to Rover Way, whilst other river and coastal users include Glamorgan Angling Club, Cardiff Sea Cadets and Cardiff Canoe Club. The area is also a popular bird-watching location and is known to support a large number of overwintering and coastal bird species.

The Wales Coast Path follows the coastline for much of the project area west of the Rhymney River. To the east of the river, the path diverts away from the coastline along Lamby Way highway, before diverting southwards along the eastern boundary of the landfill site back to the coastline. The section of the path between the WTW and the roundabout connecting Rover Way to Lamby Way is also designated as a Public Right of Way. Sections of the path along Rover Way are in a poor state of repair and are at immediate risk from coastal erosion.

The Wales Coast Path is a nationally important recreation and amenity resource, and is used by both local residents and visitors. Proposals have been developed by NRW and CCC to realign the path east of the river so that it follows the western boundary of the landfill site before connecting back into the coastline.

Rover Way and Lamby Way are key transport routes for commuters and commercial traffic to and from the industrial estates in south east Cardiff.

Existing Defences

An asset condition assessment was undertaken to ascertain the condition of the existing coastal and fluvial defences in the study area (Appendix 1 – Asset Condition Report). The coastal defences are comprised principally of rock gabions and earth embankments. Along the majority of the coastal frontage the defences are in 'very poor' condition having being severely eroded and in many sections no defences remain in place. In the location of the decommissioned Frag Tip, landfill material can be seen on the beach where erosion has cut into the land releasing the tip material. Also, in front of the Rover Way Travellers site there are no defences remaining and the coast is rapidly eroding the Made Ground (Figure 3). Immediately east of the study area the defences are maintained by Natural Resources Wales and are in good condition.

Figure 3: Existing coastal defences to the west of the mouth of the River Rhymney

The fluvial defences along the Rhymney River are principally comprised of earth embankments and sheet pile walls. The condition grade varies throughout the estuary from 'good' to 'very poor'. A key area of concern is alongside Lamby Way roundabout where the earth embankment is at risk of failure. Here the bank is eroding along the outside of the river meander. Both the roundabout and Rover Way are located immediately behind the defence and are at high risk of erosion.

On the east bank, there are isolated areas of erosion where the banks are beginning to fail. In one location, just south of the Lamby Way bridge, works have recently been undertaken by the Lamby Way Tip management company to stabilise the bank following a significant slope failure due to erosion of the bank. However upstream of the bridge simlair issues are occurring and works are urgently required to prevent the foundations of the bridge from being fully exposed. In time this would lead to increasing more expensive repair costs and risk of failure of the bridge.

There are currently no ongoing plans in place by CCC to monitor the defences or undertake maintenance works.

Biodiversity and nature conservation

The project area is located within the Severn Estuary European Marine Site. This site is designated for a wide range of coastal habitats and species, including inter-tidal and sub-tidal mudflats, saltmarsh, fish species and overwintering bird species. In addition, the Severn Estuary is designated as a Site of Special Scientific Interest (SSSI) and the Rhymney River is designated as a Site of Importance for Nature Conservation (SINC). Several other SINC sites are located in the project area. The study area includes a range of sensitive habitat types encompassing both coastal/estuarine habitats and terrestrial habitats. These habitats are known to support protected and notable species.

Geology and land contamination

The outer and central Severn Estuary has formed within a geological basin of folded and faulted lower Jurassic mudstones and limestones, overlying Silurian bedrock. This basin is overlain with Quaternary sediments, which have been subject to extensive reworking due to glacial and inter-glacial sea level fluctuations. Relatively small sediment contributions occur from erosion of rock features and alluvial input from the Severn, Taff, Usk and Rye Rivers; however, the predominant input has estuarine origin, being silts and muds.

Much of the project area west of the Rhymney River comprises Made Ground, known locally as the 'frag tip', which may contain waste materials (frag) from metal working industry. To the east of the Rhymney River is Lamby Way Landfill Site, which is the principal landfill for Cardiff. Both sites are at risk of erosion.

The following potential sources of land contamination have been identified from regulatory data and historic and current land uses on the site and surrounding area:

- Areas of unknown fill materials - including landfills and waste management
- Waste water treatment and sewage works, and associated sewerage network
- Various historical and current industrial and commercial sites (including associated railway networks, airport and fuel sites)

Geomorphology

The estuary of the River Rhymney is entirely tidally dominated within the study area. There are two road bridges across the channel towards the north of the study area on the A4232 and Lamby Way. The river has a meandering planform and is constrained by both the Lamby Way and Rover Way.

The banks of the River Rhymney are composed of fine sediments and in-channel morphological diversity is low. The river banks are eroding in places, especially on the outside of meander bends, with slumping of material and bank slips. Small sections of rubble and rock armour are present along the river banks originally provided to protect infrastructure. The defence/embankment line is mainly set back from the channel edge: on the right river bank the defence is visible alongside the Rover Way in places and is constructed of sheet piles with a concrete capping.

The study area is located adjacent to the River Rhymney and Cardiff Flats, within the wider setting of the Severn Estuary. Key geomorphology processes along this coastline are related to mudbank dynamics and this must be considered in the design of a coastal defence scheme. Longshore movement of sediment is minimal along this coastline.

Available information to describe the Cardiff and Wentlooge foreshores has demonstrated that the area has experienced historic erosion pressure, consistent with substantial progressive retreat of the mudbank immediately in front of the coast. There is evidence of several factors contributing to the mudbank lowering, including sediment dynamics of the wider Severn Estuary, drainage management, saltmarsh restoration efforts and presence of substantial outfall structures along this section of coast. Erosion effects from mudbank lowering are expected to be enhanced in response to sea level rise, and may be locally exacerbated by the presence of tidal channels along parts of the foreshore.

Projection of active processes over time frames of up to 100 years suggests that there is higher potential for erosion than has previously been identified using linear projection of shoreline changes.

Water environment

The Water Framework Directive (WFD) (2000/60/EC) requires that environmental objectives are set for all surface and groundwaters in England and Wales, with the aim of achieving good status by a defined date.

There are two WFD waterbodies in the study area. These are the Severn Lower transitional surface water waterbody and the SE Valleys Southern Devonian Old Red Sandstone & Triassic Mercia Mudstone groundwater waterbody.

The Severn Lower waterbody (Waterbody ID: GB530905415401) is classified as a HMWB due to the presence of flood defence infrastructure. The waterbody has an overall target of achieving Good Potential by 2021. The current (Cycle 2 RBMP) ecological status is assessed as being Moderate, whilst its chemical status is assessed as being Fail. Reasons for this failure include elevated levels of mercury (and its compounds) and brominated diphenylether, impacts on saltmarsh habitat and flowering plant species, and failure to deliver identified mitigation measures.

The SE Valleys Southern Devonian Old Red Sandstone & Triassic Mercia Mudstone groundwater waterbody (Waterbody ID: GB40902G201500) encompasses a large area between Cowbridge in the west and Newport in the east, and extends northwards to Caerphilly. The waterbody has an overall target of Good status by 2015 and is currently meeting its status objectives.

Landscape

The study area is a predominantly flat landscape with a few small hills that have been created by landfill sites in the area. Views are available of industrial areas to the south and residential areas to the west, with the A4232 and B4239 flyovers as visually dominant features in the north of the study area. Around, the Rhymney River and the Severn Estuary, views open out to provide expansive views across the estuary.

The project area is not located within any nationally or locally designated landscapes although it is adjacent to the Wentlooge Levels Special Landscape Area. The study area has three distinct landscape character areas consisting of industrial development in the south, residential development in the west, and semi-natural/amenity greenspace around the Rhymney River. The study area is located within the semi-natural/amenity greenspace comprising Pengam Moors and Parc Tredelerch, community allotments, a landfill reclamation site, a motocross course, mature woodland, scrubland, lakes and the Rhymney River. The Wales Coast Path, a long distance recreational route, runs alongside the Rhymney River and the Severn Estuary. The banks of the River Rhymney and River Severn feature a mixture of embankments, mud flats, sand, stone, rock armour and old flood defence walls that are in a state of disrepair. Along sections of the estuary foreshore fly tipping is evident, erosion of the estuary banks has created vertical drops and exposed layers of rubble, waste and geotextile making it unattractive for users of the Wales Coast Path.

2.1.2 Do Nothing Scenario

If no works are undertaken to maintain or improve the existing coastal defences, there will be significant erosion and flood risk across the study area and this will increase over time as asset condition deteriorates and sea levels rise with predicted climate change. Figure 4 shows the predicted flood extents for the Do Nothing scenario for present day and up to 100 years into the future.

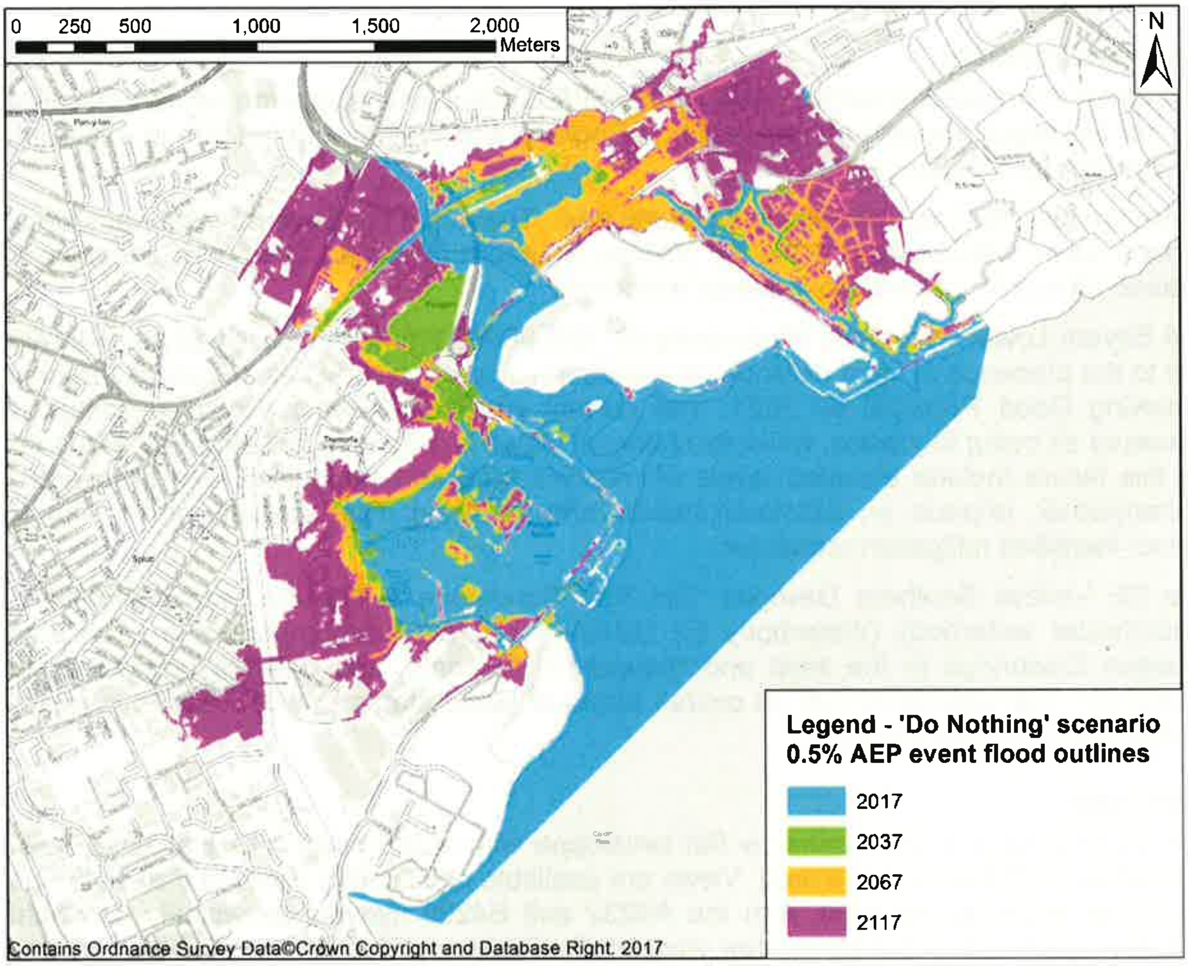

Figure 4: Predicted flood extents for a 0.5% AEP event in 2017, 2037, 2067 and 2117

To the west of the River Rhymney, the coast will continue to erode, with approximately 30m of retreat predicted by 2036, 50m by 2067 and 170m by 2117, based on predicted erosion rates and taking into account predicted sea level rise (Appendix 1 - Geomorphological Report). This will lead to loss of the Rover Way Travellers site and the adjacent electrical substation within 5 years and further release of large volumes of unknown tip material from the Frag tip into the Severn Estuary. Under present day conditions this erosion is quickly establishing a breach of the coastal defences to the east of the Rover Way Travellers site, resulting in flood risk to a significant areas of land behind, including Rover Way which runs parallel to the defence, Tremorfa industrial estate, areas of residential properties, local amenities and a large supermarket.

Along the west bank of the river there are number of sections of embankment with lower crest heights than the surrounding defence. These lower sections will start to overtop as sea levels rise, leading to potential breaches in the unmaintained defences and flooding of the land behind. One low section is in the earth embankment adjacent to the Rover Way. This section is at risk of breach under a 1.33% Annual Exceedance Probability (AEP) event under present day conditions increasing to a 10% AEP event in 2067 and 50% AEP event in 2117. This would lead to further flood risk to Tremorfa industrial estate, areas of residential properties, local amenities and a large supermarket.

Along the outside of the river meander close to Lamby Way roundabout, also along the west bank, is a lower section of the embankment. However, at this location the embankment is at greater risk of erosion than overtopping. It is estimated that should the bank continue to erode it would be likely to lead to undermining and loss of the Lamby Way Roundabout and sections of Rover Way. Breach would also lead to further flooding of land behind, by 2037.

The embankment adjacent to the Pengam allotments, north of the Lamby Way Roundabout also has a lower section. Here overtopping and breach of these defences would cause flooding of the allotment area behind, but would not lead to flooding of properties. This section is at risk of breach under a 0.5% Annual Exceedance Probability (AEP) event by 2037, increasing to a 5% AEP event by 2067 and 50% AEP event in 2117.

Under this Do Nothing Scenario 249 residential properties and 3 non-residential properties are at risk of flooding under a 0.5% AEP event, increasing to 1212 residential and 209 non-residential properties by 2117 with sea level rise.

At the Lamby Way road bridge, the bridge structure is constricting the river and high flow velocities are leading to exposure of the foundations. If no works are undertaken, this erosion will continue and the foundations could be undermined. In the longer term this would lead to the requirement of significant and costly improvement works to the bridge and potential failure of the bridge and loss of Lamby Way, which provides a key transport link.

Along the east bank of the river, the defences are adjacent to the freshwater area at Parc Tredelerch. A short section of defence to the southern edge of the lake is lower than the surrounding defence. As sea levels rise the unmaintained earth defences may overtop and breach, leading to salt water flooding of the land behind, impacting upon freshwater habitat which has the potential to support a variety of designated species, included great crested newts. Here the defence is at risk of failure under a 0.5% AEP event in 2067, increasing to a 5% AEP event in 2117.

The eastern river bank the soft river banks are eroding and a large slip has recently occurred. Work has begun to try to stabilise the bank in this location. However, without significant further improvement works erosion is likely to continue. Although there is no flood risk should the defence fail due to the topography of Lamby Way Tip, there is significant risk from erosion of Lamby Way Tip material into the river and Severn Estuary should erosion continue.

The coastal frontage of Lamby Way tip, to the immediate east of the River Rhymney, is predicted to continue to erode, with approximately 50m of retreat by 2036, and 270m by 2117, based on predicted erosion rates and taking into account sea level rise (Appendix 1 - Geomorphological Report). This will lead to erosion of the Lamby Way tip and release of contaminated tip material into the Severn Estuary within 20 years which would be likely to have significant environmental impacts on this designated estuary.

2.2 Business strategies

Local Strategy

The proposed Cardiff Coastal Defence Scheme has considered a range of local strategies including:

- Cardiff City Council Local Development Plan (2006-2026) (LDP)
- Cardiff Flood Risk Management Plan (Dec 2015)
- Cardiff Local Flood Risk Management Strategy (September 2014)
- National Strategy for Flood and Coastal Erosion Risk Management (FCERM) in Wales (2011)
- Cardiff Strategic Flood Consequences Assessment (Atkins, 2011)
- Severn Estuary Shoreline Management Plan 2, Anchor Head to Lavernock Point (2010) (SMP2)

The proposed scheme is in accordance with the policies in the above studies.

The SMP2 policy for the Cardiff coastline is to Hold The Line for the next 100 years.

The LDP[1] provides land use policies and proposals that will shape the future growth of Cardiff up until 2026. The proposed scheme will help protect existing employment areas identified within the LDP, whilst also protecting key existing infrastructure, in particular Rover Way and the Lamby Way roundabout. One of the four objectives of the LDP is to respond to evidenced economic needs and provide the necessary infrastructure to deliver development.

The LDP identifies that 72 additional pitches are required, to meet the identified needs of the Cardiff Traveller community, reinforcing the requirement to maintain the existing sites where practical and economically viable. The proposed coastal defence scheme aims to reduce flood and erosion risk to the existing Rover Way Travellers site. The site will require urgent relocation if coastal protection works are not implemented as the site is already at risk of flooding and erosion.

Phase 1 of the Eastern Bay Link Road is currently under construction, due to be completed in March 2017. This initial phase of the Eastern Bay Link connects the A4232 at the Queensgate roundabout with the A48 at the Ocean Way roundabout in Tremorfa, providing a more direct route between the A4232 Butetown tunnel and Rover Way. The new road will increase accessibility from east Cardiff to major employment sites. A second phase of the Eastern Bay Link Road is in the planning phase and will involve an extension of the improved link from Ocean Way roundabout across the study area of this OBC to further improve links across east Cardiff. The proposed defences will provide improved protection to the area in which the Eastern Bay Link is planned, this supporting these planned infrastructure improvements.

Welsh Government Strategy

This project has been identified as a candidate for further consideration as part of the Welsh Government's Coastal Risk Management Programme (CRMP). Plans for CRMP were announced by the Welsh Government in 2014 and are based around the use of long term borrowing and low interest rates by Welsh Government to support a programme of capital investment in coastal risk management infrastructure. Key details of the programme include:

- £150 million capital value investment;

[1] Cardiff City Council Local Development Plan (2006-2026) Adopted January 2016
https://www.cardiff.gov.uk/ENG/resident/Planning/Local-Development-Plan/Examination/Pages/default.aspx

- co-funded between Welsh Government and local authorities with Welsh Government contributing 75% of capital costs of construction;
- with construction scheduled 2018-2021;
- focussed on managing coastal flood and erosion risk to properties, people and infrastructure;
- enabling adaptation to climate change and implementation of 2nd Shoreline Management Plan recommendations;
- achieving wider additional and community benefits alongside reduced flood and erosion risk;
- contributing across the breadth of Welsh Government Well-Being Objectives but with particular emphasis on Objectives 6,7 and 8, looking for wider benefits also in support of the other objectives :
    - Objective 6. Support the change to a low carbon and climate resilient economy
    - Objective 7. Connect communities through sustainable and resilient infrastructure
    - Objective 8. Support safe, cohesive and resilient communities

2.3 Sustainability and Well-Being Strategic Fit and Context

The Wellbeing of Future Generations (Wales) Act is about improving the social, economic, environmental and cultural well-being of Wales. Table 1 summarises how the proposed scheme works towards achieving the seven objectives set out in the Wellbeing of Future Generations (Wales) Act.

Table 1: Wellbeing objectives and opportunities

Wellbeing objective	Project opportunities
A prosperous Wales	Reduces flood and erosion risk to key economic areas in Cardiff and key road infrastructure. Provides protection to area identified for the proposed Eastern Bay Link Phase 2. The scheme will aim to use local labour and materials where possible, including the use of local rock sources.
A resilient Wales	Manages flood and erosion risk into the future, including capacity for predicted climate change. The scheme has been designed with consideration of the habitat and biodiversity of the area.
A healthier Wales	Prevention of release of landfill material into the Severn Estuary from Lamby Way Tip and the Frag Tip. Reduction in stress to communities currently at flood and erosion risk (reduced flood risk to 1116 residential properties).
A more equal Wales	Provision of benefits to Gypsy & Traveller community; a marginalised social group.
A Wales of cohesive communities	Provides increased flood protection to 1116 residential and 65 non-residential properties over 100 years.

	Improve erosion protection prevents the release of landfill material into the Severn Estuary.
A Wales of vibrant culture and thriving Welsh language	Improvements to the Wales Coastal Footpath, encouraging people into sports and recreation such as walking, running and cycling. Flood protection to Parc Tredelerch which provides a recreation amenity as a fishing lake.
A globally responsible Wales	Responsible use of sustainable materials. Prevent erosion of landfill material into the Severn Estuary from Lamby Way Tip and The Frag Tip.

2.4 Investment objectives

The project objectives for the Cardiff Coastal Defences Scheme are outlined in Table 2. These aim to provide clear aims against which potential options can be appraised.

Table 2: Project Objectives

No	Investment Objective
1	Reduce and manage coastal flood risk to people and assets within part of south east Cardiff for the next 100 years, taking into account predicted future climate change.
2	Manage erosion along the coast to reduce the risk of failing coastal flood defences and the release of contaminated landfill material into the Severn Estuary from Lamby Way Tip and the Rover Way Frag Tip, in the immediate future and over the next 100 years.
3	To achieve wider benefits alongside coastal erosion and flood risk management, aligned with WG's 7 Wellbeing Goals and with WG and CCC's vision for development and economic growth of the area.
5	Implement a coastal flood and erosion risk management option which is affordable over the next 100 years.
6	Protect existing features of nature conservation value and seek opportunities to improve biodiversity though the enhancements of existing habitats.
7	Produce technically feasible and buildable engineering options

2.5 Current arrangements

The coastal defences in the study area are owned and maintained by Cardiff City Council but there is no current maintenance plan in place and no regular condition surveys or maintenance works are undertaken. As such there are no current investment or revenue costs to report.

2.6 Main benefits

The overall benefits of the scheme are:

- reduction in flood risk to 1116 residential and 72 non-residential properties in south east Cardiff
- reduction in erosion risk of the coastline, preventing the release of land fill material from the decommissioned Frag Tip and Lamby Way Tip
- reduction in flooding and erosion risk to Rover Way Travellers Site.

- reduction in flood and erosion risk to key road infrastructure including Rover Way, Lamby Way and the proposed Eastern Bay Link.

The scheme will manage the flood risk to 1116 residential properties and 72 commercial properties for a 0.5% AEP event over the next 100 years.

The scheme will manage erosion to key road infrastructure, namely Rover Way and Lamby Way, which provide access to south east Cardiff for both commercial traffic and commuters. This infrastructure is key to sustaining the Cardiff Economy.

The scheme will also prevent loss of the Rover Way Travellers site, which is already at risk of erosion. CCC has a legal requirement to provide Traveller pitches and as such this site would require relocation should erosion continue, which would incur a significant cost to the council. Managing erosion risk to the site maintains the 47 traveller pitches currently present.

Adjacent to the traveller site is an electricity sub-station thought to be owned by the National Grid which supplies St Mellons to the east and which would also be protected by the proposed scheme. This has not been included in the economic analysis as CCC have been unable to obtain the required information from the asset owner, but this will be further investigated at detailed design stage. In addition, there are 3 mains pylons currently at risk of erosion to the east of the river, which will be protected by the scheme. Further information is required from the asset owner to include these in the economic analysis.

Improved erosion protection to the Frag Tip to the east will prevent unknown tip material from being eroded and released into the Severn Estuary. This material is currently being eroded and deposited along the coastline causing unsightly and potentially dangerous, polluting debris to build up along the coast.

Erosion protection along the coastline to the east of the River Rhymney and maintenance of the eastern river bank will manage erosion of the Lamby Way Tip, preventing landfill material from this decommissioned tip from being released into the estuary.

Raising of the embankments to the north of Lamby Way will reduce the risk of flooding to the Pengam allotments, providing recreational benefits.

Raising of the embankments to reduce flood risk to Parc Tredelerch will prevent salt water ingress into the freshwater and terrestrial habitat, which currently provides the suitable habitat for a number of protected species, including Great Crested Newts, and has a key recreational use as a fishing lake.

In addition to coastal flood and erosion benefits, the new defences will be able to incorporate an improved footpath along the coastal frontage to enhance the Wales Coast Path. Currently the Rover Way section of the Wales Coastal Path is not attractive to visitors due to its poor condition.

Areas of undeveloped land, such as the green area between Rover Way and Tremorfa will have a reduced flood risk, potentially enabling potential future development in these locations.

2.7 Main risks

Key risks to the achievement of a robust strategic case for a flood risk and coastal erosion project are shown in Table 3 below:

Table 3: Key strategic risks

Risk	Outcome	Mitigation
Requirement for additional works to manage potential contaminated land issues related to erosion of Frag Tip	Preferred option not accepted as it does not sufficiently address potential contaminated land issues.	Early consultation with key stakeholders including NRW and CCC. Option designed so that it can be adapted in the future should contaminated land be found to require additional management.
Delayed delivery places the project outside the CRMP window	Lack of secure funding from Welsh Government and abortive design work Flood and erosion damages	Advance the detailed design stage to allow program buffer for construction completion.
Impact on Severn Estuary European /Marine Site leads to greater or earlier requirement for compensatory habitat.	Increased costs or delay to programme whilst compensatory habitat requirements are put in place.	Early engagement with NRW over habitat loss calculation methods. Programme level agreement on compensatory habitat needs.
Construction of Cardiff Tidal Lagoon	Reduced economic justification for the scheme as wave conditions and erosion risk are reduced through construction of the lagoon breakwaters	Monitor progress and likely timeframes of Cardiff Tidal Lagoon.
Erosion damages occur to the Travellers Site in advance of project delivery	Risk to life and property Reputational harm to CCC Reduced economic case for intervention	Erosion monitored by CCC. Localised emergency repairs if needed.

2.8 Constraints

The following constraints have been identified by Welsh Government at CRMP level for consideration at project level:

- Welsh Government Constraints:
  - Welsh Government construction finance not available until FY 2018-19
  - Welsh Government project contribution of no higher than 75% of detailed design and construction costs
  - Welsh Government current construction timeframe is over three years starting FY 2018-19

CCC have identified that the project is dependent on Cardiff City Council cabinet approval for 25% contribution funding.

2.9 Dependencies

The following dependencies have been identified at national and local levels:

- The project is dependent on Welsh Government approval for further Welsh Government funding.
- The project is dependent on Cardiff City Council approval for 25% contribution funding.

2.10 Stakeholder Engagement

A Stakeholder Engagement Plan (SEP) was developed to guide and record stakeholder engagement during the design process. The SEP followed the "Building Trust with Communities" guidance developed by the Environment Agency, which encourages the project team to engage with stakeholders early on to understand their concerns, interests, and priorities.

Each stakeholder has different levels of influence on the direction and outcomes of the scheme. Considerable focus was applied identifying and evaluating an appropriate approach to be adopted for engagement level.

Stakeholders were grouped and a range of engagement methods and approaches were assigned for each group to gain their input effectively. A variety of engagement methods were used including statutory consultation meetings, site visits, and meetings.

An environmental scoping letter was also produced including a brief overview of the flood risk and coastal erosion alleviation project and the environmental and socio-economic context. This was delivered to provide information to stakeholders that may be interested in the project and facilitate a means of communication. A communications record for the consultations has been kept throughout the project, which includes records of meetings and other communications.

Consultation undertaken with key stakeholders within this project helped inform the scope of environmental issues and assessment, and to inform the option selection and development.

3 The Economic Case

3.1 Introduction

The economic case has been prepared to determine value for money for the proposed scheme. The economic assessment has been undertaken in accordance with the Flood and Coastal Risk Management – Appraisal Guidance (FCERM-AG)[2]

Costs have been developed from 'concept-level' scheme designs developed to a level of detail equivalent to RIBA work stage 2. Early Contractor Involvement (ECI) has been procured to assist in developing the scheme costs

Development process and timeline for the OBC

A process compatible with the 5 Case Model has been used in the development, evaluation and final selection of options for this project. The following records this process and gives key programme items and project milestone dates achieved in the preparation of the Outline Business Case for Cardiff Coastal Defences.

1. Develop project objectives and critical success factors (October 2016)
2. Develop longlist options and initial benefits assessment (December 2016)
3. Shortlisting workshop (January 2017)
4. Develop shortlist options including concept designs, costs and benefits assessment (January 2017 - February 2017)
5. Preferred options workshop (February 2017)
6. Develop preferred option concept design and verify costs and benefits (Feb-March 2017)
7. Submit Strategic Outline Case (SOC) and Outline Business Case (OBC) document (March 2017)

3.2 Investment Objectives and Critical success factors

The investment objectives for the proposed scheme are presented in Table 4.

Table 4: Investment Objectives

No	Investment Objective
1	Reduce and manage coastal flood risk to people and assets within part of south east Cardiff for the next 100 years, taking into account predicted future climate change.
2	Manage erosion along the coast to reduce the risk of failing coastal flood defences and the release of contaminated landfill material into the Severn Estuary from Lamby Way Tip and the Rover Way Frag Tip, in the immediate future and over the next 100 years.
3	To achieve wider benefits alongside coastal erosion and flood risk management, aligned with WG's 7 Wellbeing Goals and with WG and CCC's vision for development and economic growth of the area.
5	Implement a coastal flood and erosion risk management option which is affordable over the next 100 years.
6	Protect existing features of nature conservation value and seek opportunities to improve biodiversity though the enhancements of existing habitats.
7	Produce technically feasible and buildable engineering options

2 Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG), Environment Agency, 2010 (http://webarchive.nationalarchives.gov.uk/20131108051347/http:/a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0310bsdb-e-e.pdf)

Table 5 presents the critical success factors for the scheme. The generic CRMP critical success factors provided by Welsh Government must be met by any proposed option for it to be taken forward under the CFRMP. To represent the aspirations of the local authority, stakeholders and project partners, additional project specific critical success factors have been produced. These are shown in red italics.

Table 5: Critical Success Factors

No	Critical Success Factor	Further Definition (*project specific CSFs in italics*)
1	Strategic Fit and Business Needs	• Adapting to climate change • Delivery of National Strategy and Shoreline Management Plan objectives • Local Authority support • Alignment with local Well-being plans • *Meets investment objectives*
2	Value for Money	• Protect and enhance the Welsh economy by avoiding flood damage to residential and commercial properties and economic assets and infrastructure. • *Protect and enhance the Welsh economy by avoiding erosion damage to residential and commercial properties and economic assets and infrastructure, including key roads: Rover Way and Lamby Way* • Positive Net Present Value
3	Potential Achievability	• Local Authority capacity to produce and manage projects
4	Supply side capacity	• Supply side capability to deliver affordable solution within time-frame
5	Potential Affordability	• Achievable within current or anticipated Welsh Government and Local Authority funding settlements and borrowing powers • *Identify and secure the interest of external project funding partners.*
6	Additional project specific CSFs	• *Protect existing features of nature conservation value and seek opportunities to improve biodiversity though the enhancements of existing habitats.* • *Identify opportunities to improve the amenity value of the site; providing benefits to local residents and attracting outside visitors.*

3.3 Longlist Options development

A long list of potential flood and coastal erosion risk management options was developed based on discussions with stakeholders and the project team. These were evaluated against the Project Objectives and Critical Success Factors and reviewed at an options shortlisting workshop.

Figure 5 provides a summary of the long list options. Due to the size of the study area the defences were divided into sections based upon the type and condition of the defence and the geomorphological processes. A full description and evaluation of the long list options is provided in Appendix 1 - Cardiff Coastal Defences Engineering Report.

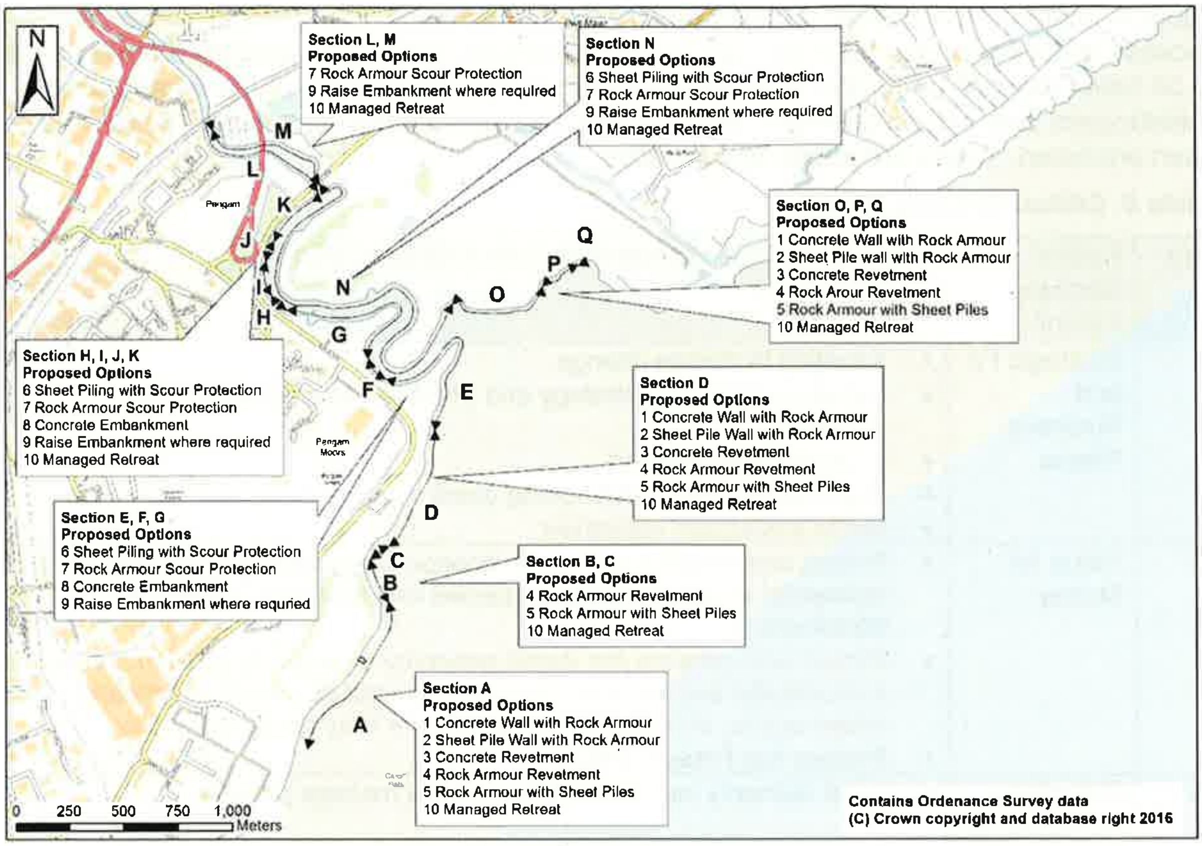

Figure 5: Long List of Option for each Asset Section

The long list options removed in the shortlisting process were:

- Option 3 - Concrete block work revetment
- Option 5 - Rock armour with sheet piling
- Option 8 - Concrete embankment
- Option 10 – Managed retreat

Option 3: The concrete block work revetment proposed for the coastal frontages was not taken forwards as the larger footprint required for this option would have environmental implications, the structure would have limited tolerance of scour, and the large formal structure would have a significant impact on the landscape character and visual amenity of the area as there are no other similar structures in the nearby area.

Option 5: Rock armour with sheet piling was proposed as the rock would best manage erosion, while the sheet piling would provide a barrier to potential contaminated land within the Frag Tip. Discussion with CCC concluded that the sheet pile would be not required as this study would focus on coastal erosion and flood risk only. The material within the Frag Tip will be subject to a separate contaminated land study. The rock option (without sheet pile) is taken forwards, and if it is identified in the contaminated land study that sheet pile is required it will be possible to adapt this option in the future to add the sheet pile.

Option 8: The concrete embankment option was discounted for the fluvial sections as there is insufficient space available for this option to be successful in managing erosion. It would also have greater environmental implications than other options due to the large footprint required and it would have a significant impact on the landscape character and visual amenity of the area.

Option 10: Managed retreat was discounted as the resulting release of landfill material from the Lamby Way Tip or the Frag Top could lead to significant environmental detriment to the Severn Estuary.

Whilst assessing the options it was found that several of the asset sections could be merged into five sections to enable simpler assessment of the shortlisted options. Figure 6 presents the merged shortlist sections and lists the shortlisted options for each section.

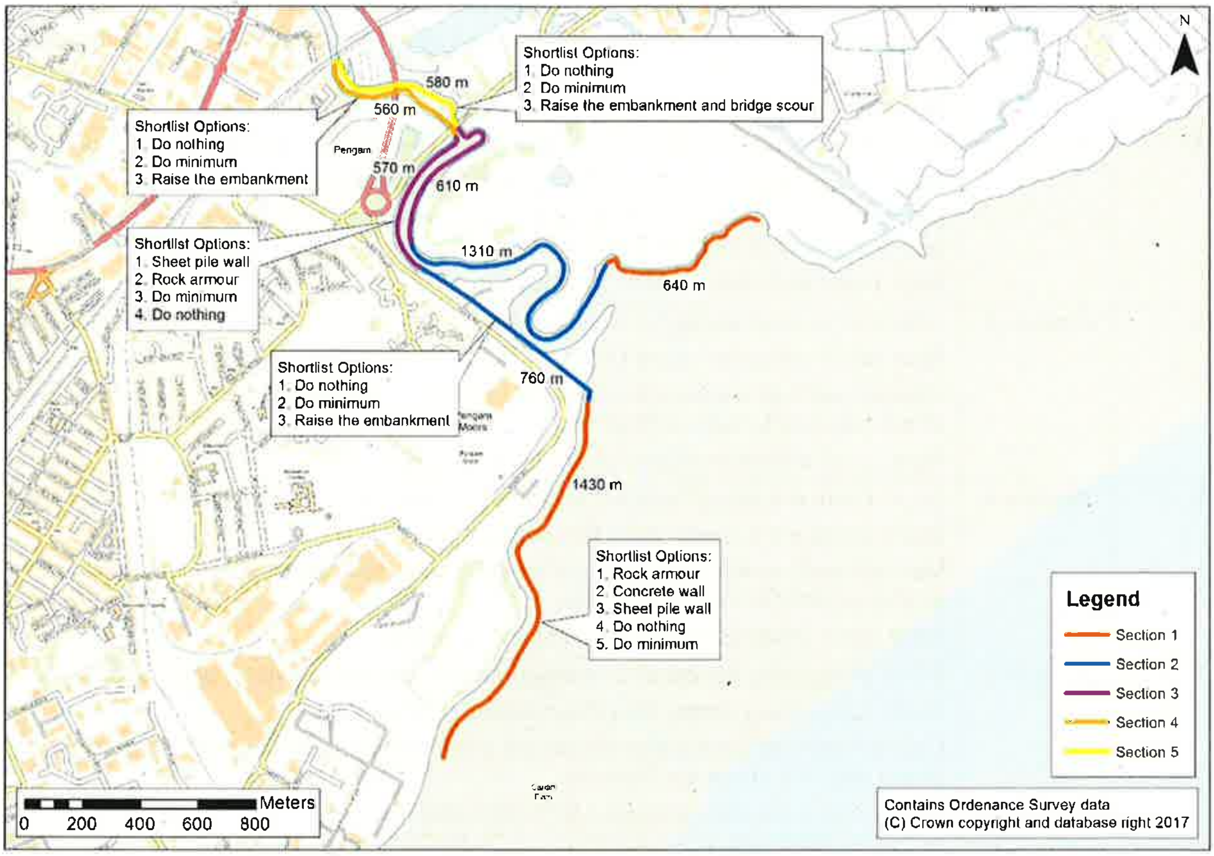

Figure 6: Short List Options for each Section in the study area

3.4 Short list assessment

3.4.1 Overview

To assess the most appropriate holistic option across the whole study frontage the options were combined to form six scheme options, which are presented in Table 6. The economic analysis and preferred option assessment are based on these six options.

Table 6: Short List Options for Study Area

Option	Name	Description
1	Do Nothing	No works undertaken. Allow natural coastal and fluvial processes to continue.
2	Do Minimum	Maintenance works along existing earth embankments. Add small rock toe to the eroding coastal defences to slow erosion.
3	Improve 1	Rock revetment along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Scour protection added to Lamby Way Bridge.
4	Improve 2	Sheet piling along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
5	Improve 3	Concrete sea wall along the coast to manage erosion and wave overtopping (Section 1) Rock scour protection along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
6	Improve 4	Rock revetment along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
7	Improve 5	Sheet piling along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.
8	Improve 6	Concrete wall along the coast to manage erosion and wave overtopping (Section 1) Sheet piling along Lamby Way Roundabout (Section 3) Maintain earth embankment elsewhere and raise low points in earth embankments where required to reduce flood risk. Rock scour protection added to Lamby Way Bridge.

3.4.2 Technical assessment

A brief description of the shortlisted options is provided in Table 6.

The Improve options (Options 3 to 8) would be designed to provide a 0.5% AEP standard of protection including an allowance for climate change to 2117 Flood resilience measures, such as emergency plans, will need to be in place for events exceeding this.

The Do Minimum option (Option 2) will maintain the defences in the short to medium term. However, it is not possible to manage erosion and flood risk across the study area in the longer term without improvement works to the defences. As such, the Do Minimum option is considered to delay erosion to year 20 (2037) along the coast, while the fluvial breaching would be delayed to year 50 (2067) and after this time the grassed embankments would be likely to fail from overwashed. At this time erosion along Lamby Way Roundabout would also impact the road infrastructure. This has been based on the condition survey of the defences, geomorphological assessment, predicted climate change and specialist engineering judgement.

Concept engineering design has been undertaken for the key components of the shortlisted flood and erosion risk management options considered. The level of detail required has been considered in sufficient detail to provide key quantities to allow construction cost estimation and to provide an understanding of the effectiveness and impacts of each option.

All the proposed options comprise of standard civil engineering structures. None of the proposed works are exceptional in terms of complexity or scale.

The construction methods have been considered when designing and costing options, including access for piling, potential road closures required and access points along the coastal sections. In addition, the information available on the ground conditions has been considered. The risk of ground condition issues is greater with the sheet pile wall and concrete wall options along the coast than the rock armour options.

For additional details regarding the concept engineering design, refer to Appendix 1 - Cardiff Coastal Defences Engineering Report.

The following considerations and assumptions were made regarding the concept design of the flood defences:

- The standard of protection provided by proposed flood defences would be a 200 year return period event (0.5% annual chance) for 100 years into the future (Year 2117).
- Sea level rise has been calculated using the document 'Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities' (Environment Agency, 2016)
- Wave overtopping was calculated using the EurOtop[3] Neural Network Methodology.
- Flood inundation modelling has been undertaken using TUFLOW (2D Model version 2016-03-AD). For full detail of the modelling undertaken see Appendix 1 – Model User Report.

3.4.3 Sustainability and wellbeing assessment

Key outcomes with respect to the achievement of wellbeing and sustainability objectives for each of the options are summarised in Table 7.

Option 2, Do Minimum provides a reduced flood risk over 50 years (2017-2067), but it is not possible to manage flood and erosion risk further into the future without implementing capital works to improve the defences. As such, this option only works to achieve the well-being objectives in the shorter term, delaying the risk but leaving it for future generations to manage. The maintenance works undertaken in this option will not include improvements to the amenity of the area, such as enhancements to the Wales Coastal Footpath which would be undertaken as part of the improve options.

Although the "Improve" option can be undertaken through a variety of technical combinations (Options 3 to 8), these options all work to manage flood and erosion risk to the same standard of protection providing sustainability and wellbeing outcomes.

3 Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from www.overtopping-manual.com

Table 7: Shortlisted options sustainability and wellbeing assessment

Wellbeing objective	Flood and Coastal Erosion Risk Management Options	
	Do Minimum Option 2	**Improve Options 3- 8**
A prosperous Wales	Provides reduced flood and erosion protection to economic areas and key road infrastructure in the short term (50 years)	Provides flood and erosion protection to economic areas and key road infrastructure in the longer term (100 years)
A resilient Wales	Flood risk management Erosion risk management	Flood risk management Erosion risk management
A healthier Wales	Reduction of potential social and health related harms caused by erosion of landfill material into the estuary over 20 years. Reduction in stress to communities currently at flood and erosion risk (reduced flood risk to 471 residential properties).	Reduction of potential social and health related harms caused by erosion of landfill material into the estuary over 100 years. Reduction in stress to communities currently at flood and erosion risk (reduced flood risk to 1116 residential properties).
A more equal Wales	Reduced impact on Gypsy & Traveller community; a marginalised social group, as relocation is delayed giving time to prepare.	Provision of benefits to Gypsy & Traveller community; a marginalised social group.
A Wales of cohesive communities	Provides increased flood protection to 471 residential and 53 non-residential properties over 20-50 years.	Provides increased flood protection to 1,116 residential and 72 non-residential properties over 100 years.
A Wales of vibrant culture and thriving Welsh language.	Reduction of erosion along the coast will retain the Wales Coastal Path in place in the short term. Pengam allotments are maintained.	Improvements to the Wales coastal path encourages people to walk, run and cycle along the welsh coast and river. Parc Tredelerch is retained as a fishing lake providing recreational amenity. Pengam allotments are maintained.
A globally responsible Wales.	Erosion of landfill material from the Frag Tip and Lamby Way tip into the Severn Estuary and the associated detrimental impact on the environment is reduced.	Erosion of landfill material from the Frag Tip and Lamby Way tip into the Severn Estuary and the associated detrimental impact on the environment is prevented.

3.5 Economic appraisal

3.5.1 Benefits

As required by the MCM and Green Book, the assessment of project benefits has been based on an estimated 100-year present value discounted damages avoided by project implementation. The estimation of average damages has incorporated four main components:

1. A hydraulic flood modelling study of the area based on the Coastal Flood Boundary Conditions dataset, current sea level rise estimates and EurOtop neural network wave overtopping calculations. The flood damages were assessed using the modelled flood depths and National Receptor Dataset (2014) in accordance with FCERM AG and the MCM/Green Book economic analysis methods, using a JBA proprietary software package called FRISM, thereby assessing average 100 year damages with rising sea levels as part of the economic analysis.
2. Based on the Geomorphological Appraisal, it is estimated that the erosion of the river bank along the outside of the meander will lead to undermining of Lamby Way roundabout and part of Rover Way in 20 years. At this point, with no active intervention, the road would require rebuilding along a similar route further landward. The damages have been taken as the cost to rebuild the road inland of the erosion zone along the shortest appropriate route. Rebuild of the road in present value costs with construction in year 20 was calculated as £2,690k.
3. Based on the Geomorphological Appraisal, it is estimated that the coastal defences in the vicinity of the Rover Way Traveller site are likely to breach due to erosion within a year. At this point, with no active intervention, the residents living at the Rover Way Traveller Site will require relocation away from this erosion prone location at a substantial cost to CCC. This cost avoided, discounted to present value, is presented as a potential benefit to this scheme within the economic analysis. Relocation of the Rover Way Traveller Site was based on per unit relocation costs of a similar site in South Wales and was estimated as £5,798. No discounting is applied as the site requires immediate relocation.

Damage estimates have been derived for direct tangible flood and coastal erosion damages under Do Nothing, Do Minimum and Improve to a standard of 0.5% AEP plus climate change for the 100 year lifetime of the scheme.

Additional detail regarding the economic analysis, is provided in Appendix 1 - Economic Appraisal Report. Table 8 and Table 9 provide a summary of the benefits of the shortlisted options. These show that the improve options, which all provide the same standard of protection, provide a significant reduction in the damages and numbers of properties flooded. Do Minimum reduces the damages by a smaller amount, and is only able to provide improved protection for the first 50 years of the scheme.

Table 8: Summary of short list option damages and benefits

Option		Present Value damages (£k)		Present Value benefits (£k)	Net Present Value
		Flood	Erosion		
Option 1	Do Nothing	42,603	8,488	-	-
Option 2	Do Minimum	36,973	3,968	10,151	2,650
Option 3	Improve 1	971	-	50,119	36,453
Option 4	Improve 2	971	-	50,119	30,251
Option 5	Improve 3	971	-	50,119	30,383
Option 6	Improve 4	971	-	50,119	33,669
Option 7	Improve 5	971	-	50,119	29,285
Option 8	Improve 6	971	-	50,119	29,418

Table 9: Properties at risk of flooding under 0.5% AEP Event

Option		No Properties Flooded in 0.5% AEP event (2037)		No Properties Flooded in 0.5% AEP event (2117)		Reduction in No. Properties Flooded in 0.5% AEP event (2037)		Reduction in No. Properties Flooded in 0.5% AEP event (2117)	
		Res	Non Res	Res	Non Res	Res	Non Res	Res	Non Res
1	Do Nothing	351	10	1,212	209	-	-	-	-
2	Do Minimum	22	4	1,212	209	329	6	-	-
3-6	Improve	-	-	96	137	351	10	1,116	72

There are additional benefits which have been identified in the study area but have not been valued and included within the economic appraisal. These are listed below:

- Adjacent to the Rover Way Traveller Site is an electricity substation thought to be a DCWW asset. This site will be at risk of flooding and erosion within 20 years. We have been unable to obtain a likely value for this asset from the owner and as such it has not been included in the economic assessment. This asset is thought to supply electricity to the DCWW Waste Water Treatment Works.
- There are 3 Main Electricity Pylons located along the Lamby Way Tip coastline which link to the substation near Rover Way. Under Do Nothing these will be at risk of erosion with 20 years. We have also been unable to obtain asset values for these pylons from the asset owner, so have been unable to include them in the economic assessment.
- Lamby Way Road Bridge is at risk of erosion due to scour of the foundations. Works are included in the option to protect the bridge to prevent extensive and expensive works being required in the future and to manage the risk of failure of the bridge. The cost for loss of the bridge has not been included in the benefits assessment as it is not a direct flood risk benefit. The cost for rebuild of the bridge would be high compared to the existing benefits.
- Based on the hydraulic modelling, it is estimated that flooding along Rover Way is likely to lead to a diversion being required during extreme events as sea levels rise. Economic damages resulting from an appropriate diversion can be calculated

based upon traffic count data in accordance with the methodology in the MCM. This was investigated but damages were found to be low in proportion to the overall scheme damages and so this was taken further and these damages were not included in the benefit assessment.

- Finally, should no works be undertaken, Lamby Way Tip itself will be at risk of erosion, leading to the release of landfill material into the sea. A value has not been allocated to this within the economic assessment, however this has been taken into account in the multi criteria analysis.

The benefits of undertaking a scheme to protect south east Cardiff are significant and as such these additional benefits were not progressed at this concept design stage as they were not required to provide an economically viable scheme. However, should a preferred option be taken forwards to detailed design for the study, then these benefits could be further investigated if necessary.

3.5.2 Costs

Project costs have been developed for each of the shortlisted options.

Capital cost and maintenance cost estimation has been undertaken by Raymond Brown Construction Ltd and JBA Consulting using Early Contractor Involvement (ECI). Raymond Brown are a local civil engineering contractor with experience of the local area and of coastal construction works.

These project costs include the following items for each option. These are high level cost estimates based on concept design information and would be refined during detailed design once further detail on option design and construction is available.

- Construction costs have been estimated based on unit rates for key construction items. The unit rates have been based on similar schemes undertaken recently by the ECI Contractor.
- Consultancy costs have been estimated at 5% of the construction cost.
- Site investigation, survey and testing costs have been estimated at 5% of the construction cost.
- Early Contractor Involvement (ECI) costs have been estimated as 1.25% of construction costs.
- Environmental mitigation costs have been estimated based on the high level design information available.
- Site supervision costs have been estimated at 1.5% of the construction cost.
- Existing CCC staff costs to provide project management and leadership for the duration of this project have been estimated at 2% of construction costs.
- Project risks have been estimated as 10% of construction costs for the shortlisted options
- An Optimism Bias of 40% has been applied to the shortlisted options.

All these costs are proposed to be attributable to Flood and Erosion Risk management.

Table 10 presents the costs breakdown for each of the shortlisted options.

Table 10: Shortlisted options' costs

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
	Do Nothing	Do minimum	Improve 1	Improve 2	Improve 3	Improve 4	Improve 5	Improve 6
Existing staff costs (2%)	£ -	£ 17,061	£ 64,247	£ 146,383	£ 144,832	£ 91,795	£ 173,930	£ 172,380
Consultants' fees (5%)	£ -	£ 42,653	£ 160,619	£ 365,957	£ 362,081	£ 229,488	£ 434,826	£ 430,950
Contractors' (ECI) fees (1.25%)	£ -	£ 10,663	£ 40,155	£ 91,489	£ 90,520	£ 57,372	£ 108,706	£ 107,737
Site investigation and survey (5%)	£ -	£ 42,653	£ 160,619	£ 365,957	£ 362,081	£ 229,488	£ 434,826	£ 430,950
Optimism Bias	£ -	£ 45,212	£ 170,256	£ 387,914	£ 383,806	£ 243,257	£ 460,915	£ 456,807
SUBTOTAL (Cash Costs to FBC)	**£ -**	**£ 158,242**	**£ 595,896**	**£ 1,357,701**	**£ 1,343,320**	**£ 851,399**	**£ 1,613,204**	**£ 1,598,823**
Construction		£ 853,054	£ 3,212,375	£ 7,319,141	£ 7,241,616	£ 4,589,750	£ 8,696,517	£ 8,618,991
Environmental mitigation			£ 191,500	£ 191,500	£ 191,500	£ 191,500	£ 191,500	£ 191,500
Site supervision (1.5%)	£ -	£ 12,796	£ 48,186	£ 109,787	£ 108,624	£ 68,846	£ 130,448	£ 129,285
Optimism bias (40%)	£ -	£ 346,339.97	£ 1,380,824.18	£ 3,048,171.21	£ 3,016,695.97	£ 1,940,038.67	£ 3,607,385.70	£ 3,575,910.46
Prioject Risk Budget (10%)	£ -	£ 85,305	£ 321,237	£ 731,914	£ 724,162	£ 277,564.71	£ 869,651.65	£ 861,899
SUBTOTAL (Construction Phase Cash Costs)	**£ -**	**£ 1,297,495**	**£ 5,154,122**	**£ 11,400,513**	**£ 11,282,597**	**£ 7,067,700**	**£ 13,495,502**	**£ 13,377,586**
Future costs (maintenance) per annum		£ 154,570	£ 202,400	£ 181,800	£ 181,800	£ 167,000	£ 146,400	£ 146,400
Future costs (maintenance) per annum (incl 40% OB)	£ -	£ 216,398	£ 283,360	£ 254,520	£ 254,520	£ 233,800	£ 204,960	£ 204,960
Future costs 100 year cash	£ -	£ 21,423,402	£ 28,052,640	£ 25,197,480	£ 25,197,480	£ 23,146,200	£ 20,291,040	£ 20,291,040
Future costs 100 year PV Discounted	£ -	£ 6,045,244	£ 7,915,878	£ 7,110,211	£ 7,110,211	£ 6,531,382	£ 5,725,714	£ 5,725,714
Project total (present-value) costs	£ -	**£ 7,500,980**	**£ 13,665,896**	**£ 19,868,425**	**£ 19,736,128**	**£ 14,450,480**	**£ 20,834,420**	**£ 20,702,123**
Project total (cash) costs	£ -	£ 22,879,139	£ 33,802,658	£ 37,955,694	£ 37,823,397	£ 31,065,299	£ 35,399,745	£ 35,267,449

3.5.3 Present Values

The present value discounted costs and benefits for the shortlisted options are presented in Table 11 using the FCERM AG standard methods. The costs and damages have been calculated for the 100 year design life of the scheme and long-term discount rates have been applied in accordance with HM Treasury's Green Book.

Table 11: Summary of shortlisted option present values and benefit cost ratio

Option	Present Value costs (£k)	Present Value damages (£k)	Present Value benefits (£k)	Average benefit:cost ratio (BCR)
Option 1: Do nothing	-	50,175	-	-
Option 2: Do min	7,501	40,940	9,235	1.4
Option 3: Improve 1	13,666	971	49,204	3.7
Option 4: Improve 2	19,868	971	49,204	2.5
Option 5: Improve 3	19,736	971	49,204	2.5
Option 6: Improve 4	14,450	971	49,204	3.5
Option 7: Improve 5	20,834	971	49,204	2.4
Option 8: Improve 6	20,702	971	49,204	2.4

3.5.4 Benefit Cost Ratio

Table 12 presents a summary of the benefit cost ratio assessment of the shortlisted options. Based on the benefit cost ratio assessment Option 3, Improve 1, rock on the coast and rock along Lamby Way roundabout, is the economically preferred option with a BCR of 3.7.

The next best economically preferred option is Option 6: Improve 4, rock on the coast and sheet piling along Lamby Way roundabout. This has a very close BCR to the economically preferred option at 3.5.

The remaining Improve options have lower BCRs of 2.4-2.5, while Do Minimum is also economically viable at 1.4.

The overall **economically preferred option** is therefore **Option 3, Improve 1**. However, it is recommended that sensitivity testing is undertaken on the option costs as the BCR of the next best option Option 6: Improve is very close with a BCR difference of just 0.2. Both of these options would be considered economically viable for this study.

Table 12: Benefit Cost Ratio Summary Table

Discount Rate		3.5%	3.00%	2.50%				
Optimism bias adjustment factor		40%						
Costs and benefits of options								
	Costs and benefits £							
Option number	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
Option name	Do Nothing	Do Minimum	Improve 1 - Rock option along coast and along Lamby Way roundabout	Improve 2 - Sheet piling option along coast and rock along Lamby Way roundabout	Improve 3 - Concrete wall option along coast and rock along Lamby Way roundabout	Improve 4 - Rock option along coast and sheet piliing along Lamby Way roundabout	Improve 5 - Sheet piling option along coast and along Lamby Way roundabout	Improve 6 - Concrete wall option along coast and sheet piling along Lamby Way roundabout
AEP or SoP (where relevant)			0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding	0.5% AEP flooding
COSTS:								
PV capital costs	0	926,782	3,681,516	8,143,224	8,058,998	5,048,357	9,639,644	9,555,418
PV operation and maintenance costs	0	4,318,031	5,654,199	5,078,722	5,078,722	4,665,273	4,089,796	4,089,796
PV other	0	113,030	425,640	969,786	959,514	608,142	1,152,288	1,142,016
Optimism bias adjustment	0	2,143,137	3,904,542	5,676,693	5,638,894	4,128,709	5,952,691	5,914,892
PV negative costs (e.g. sales)								
PV contributions								
Total PV Costs £ excluding contributions	0	7,500,980	13,665,896	19,868,425	19,736,128	14,450,480	20,834,420	20,702,123
Total PV Costs £ taking contributions into account	0	7,500,980	13,665,896	19,868,425	19,736,128	14,450,480	20,834,420	20,702,123
BENEFITS:								
PV monetised flood damages	42,602,790	36,972,606	971,356	971,356	971,356	971,356	971,356	971,356
PV monetised flood damages avoided		5,630,183	41,631,434	41,631,434	41,631,434	41,631,434	41,631,434	41,631,434
PV monetised erosion damages	8,488,371	3,967,505	0	0	0	0	0	0
PV monetised erosion damages avoided (protected)		4,520,865	8,488,371	8,488,371	8,488,371	8,488,371	8,488,371	8,488,371
Total monetised PV damages £	51,091,160	40,940,112	971,356	971,356	971,356	971,356	971,356	971,356
Total monetised PV benefits £		10,151,049	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805
PV damages (from scoring and weighting)								
PV damages avoided/benefits (from scoring and weighting)								
PV benefits from ecosystem services								
Total PV damages £	51,091,160	40,940,112	971,356	971,356	971,356	971,356	971,356	971,356
Total PV benefits £		10,151,049	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805	50,119,805
DECISION-MAKING CRITERIA:								
excluding contributions								
***Based on total PV benefits** (**in**cludes benefits from scoring and weighting and ecosystem services)*								
Net Present Value **NPV**		2,650,068	36,453,909	30,251,380	30,383,677	35,669,324	29,285,385	29,417,682
Average benefit/cost ratio **BCR**		1.4	3.7	2.5	2.5	3.5	2.4	2.4
Incremental benefit/cost ratio **IBCR**			6.5	3.2	3.3	5.8	3.0	3.0
			IBCR>1	IBCR>1	IBCR>1	IBCR>1	IBCR>1	IBCR>1
***Based on monetised PV benefits** (**ex**cludes benefits from scoring and weighting and ecosystem services)*								

3.6 Non financial benefits appraisal

3.6.1 Introduction

A wide ranging non-financial benefits appraisal was undertaken using Multi Criteria Analysis to identify a non-financial preferred option. The Shortlisted options were rated against a range of categories designed to assess the relative merits of the proposed options against the project objectives and critical success factors.

3.6.2 Multi Criteria Analysis

The Multi Criteria Analysis approach was used to score the Shortlisted Options according to their achievement of the various objectives and sub categories set out to help identify which options best meet the project objectives and critical success factors. The categories and scoring systems were prepared in collaboration with stakeholders at the shortlisting workshop in January.

The multi criteria analysis approach was undertaken for each of the sections presented in Figure 5, so that the relevant short listed options were assessed for each individual section.

Table 13 presents the categories and weighting used in the assessment, while Table 14 presents a summary of the results. For each category, the option was given a score on a range of 1 to 5, with 5 being advantageous, 3 no change compared to existing case and 1 detrimental. The weighting was designed to ensure that each category was fairly represented and the more important sub categories were having a greater contribution to the overall score.

The full results of the Multi Criteria Analysis can be found in Appendix 1 – Engineering Report. A summary of the final results for each section are presented in Table 14.

Table 13: Multi Criteria Analysis Categories and Weighting

Category	Considerations	Weighting
Technical	Still water level flood protection	2
	Overtopping protection	2
	Design Life	1
	Erosion Protection	2
	Ease of construction	1
	Capital Cost	2
	Maintenance Cost	2
	Public Health and Safety	2
Environmental and Social	Impact on the coast path use	2
	Impact on biodiversity	2
	Impact on landscape character	1
	Impact on heritage	1
	Ability to be modified in the future	1
	Carbon footprint	2
	Impact on coastal processes	1
	Contaminated land protection	2
Financial	Partnership Funding	2
Strategic	Strategic Policy (SMPs)	2
	Consents and Licences	1

Table 14: Multi Criteria Analysis Scoring

a) Coastal Defences

	Total Score				
	Option A Rock Armour	**Option B Concrete Wall**	**Option C Sheet Pile Wall**	**Option D Do Minimum**	**Option E Do Nothing**
Section 1	123	110	109	88	57

b) Fluvial Defences

	Total Score				
	Option A Sheet Piling	**Option B Rock Armour**	**Option C Raise Embankment**	**Option D Do Minimum**	**Option E Do Nothing**
Section 2			114	95	74
Section 3	111	98		81	63
Section 4			114	95	74
Section 5			118	95	78

Based on the Multi Criteria Assessment the overall preferred option across the study area is as follows:

Section 1 – Rock Armour Revetment along the coastline to manage erosion and wave overtopping. The rock armour will provide an adaptive approach to climate change and would be the most fitting with the existing landscape. This option requires no piling and less excavation than other Improve options and so would provide less disturbance of the Frag Tip material. Should additional work be required to manage potential contaminated land issues once the contaminated land assessment has been undertaken by CCC then sheet piling could be installed behind the revetment to provide a cut-off.

Section 2 – Raise the earth embankment where low sections are present and maintain the remaining defence at the current height elsewhere to provide protection up to a 0.5% AEP event, including an allowance for climate change.

Section 3 – Sheet piling with rock armour scour protection to manage erosion and raise the flood defence level to provide protection up to a 0.5% AEP event, including an allowance for climate change. This will manage both flood and erosion risk as the sheet pile wall would increase the height of the defence. The sheet pile wall would be lower maintenance than just rock scour protection alone, as rock is likely to move in this high velocity location, requiring replacement and relocation at regular intervals. The foot print of rock scour protection as a primary defence would have significant environmental impacts on the inter tidal area which supports a variety of designated species, whereas sheet piling with rock toe protection will require only a small rock toe, minimising environmental impacts. The rock toe scores low on Geomorphological impacts, as it would constrict the river channel, which could lead to increased erosion locally. Currently the Lamby Way Bridge is causing a constriction in the river which is leading to the higher velocities and erosion in Section 3. Narrowing the channel may move the issue further downstream into Section 2.

Section 4 – Raise the earth embankment where low sections are present and maintain the remaining defence at the current height elsewhere to provide protection up to a 0.5% AEP event, including an allowance for climate change. Only a short section of embankment would require raising. This would protect the allotments at Pengam thus maintaining the public amenity of the area and helping contribute to Well-being goals.

Section 5 – Raise the earth embankment where low sections are present and maintain the remaining defence at the current height elsewhere to provide protection up to a 0.5% AEP event, including an allowance for climate change. This would manage flood risk to Parc Tredelerch, protecting habitat which is able to support a variety of designated species such as Great Crested Newt. Raising works would be along the currently set back defences and would be small scale in nature. Scour protection works are also required to manage the erosion risk to the foundations of the Lamby Way bridge. This is included in all Improve options.

This combination of options comprises **Option 6 – Improve 4.**

Do Minimum is not the preferred option for any section as although it will maintain the existing defences along the river bank, flood and erosion risks would increase into the future. Flood risk would increase as sea levels rise into the future and there would be significant flood risk to people and property across south east Cardiff in 50 to 100 years. Do Minimum would only be able to manage erosion for 20-50 years, after which the coastline would continue to erode at a rapid rate, releasing unknown landfill material into the estuary from the Frag Tip and land fill material from Lamby Way Tip into the Severn Estuary, resulting in serious potential environmental detriment to the Severn Estuary. Under Do Minimum the Travellers site would require relocation within 20 years as it becomes at risk of flooding and erosion. With minimum works to the fluvial defences there would be significant risk of undermining and erosion of Lamby Way and Rover Way which are key infrastructure for both commuters and commercial traffic, supporting the economy of Cardiff City.

3.6.3 Sustainability and wellbeing assessment

As a result of the economic analysis undertaken for this project, CCC have become increasingly aware of the large costs associated with providing alternative accommodation for the Gypsy and Traveller Community, should maintaining the Rover Way Traveller Site become non-viable due to increased flood and erosion risks. This aspect has become a key consideration regarding the selection of a preferred option, with reference to the Well-being of Future Generations (Wales) Act 2015.

Relocation of the caravan sites would likely lead to disruption to and/or fragmentation of the long-established community of Rover Way Traveller site. In addition to the substantial capital costs of establishing replacements for 47 pitches, which we estimate as £5.8m (cash costs 2017, see the Economics Report in Appendix 1 for details), other non-financial costs may arise from a relocation of these sites. These would include a wide range of social malaise, health and education costs, that would likely accrue as a result of the increased hardships and stresses placed on the Gypsy and Traveller community by relocation.

If the relocation of Rover Way Traveller Site is avoided by way of a flood and erosion risk management project, then a wide range of future costs can reasonably be attributed to that project as non-financial benefits.

Of the options under consideration, only the Improve options offer flood and coastal erosion risk management to the Traveller site. This would contribute to several of the goals from the Well-being of Future Generations (Wales) Act 2015, such as;

1. A prosperous Wales; by avoiding wide ranging and long term economic damages to the Gypsy and Traveller community
2. A resilient Wales; by improving the resilience of the Gypsy and Traveller community against climate change
3. A healthier Wales; by avoiding future harm to a marginalised group identified as having some of the poorest health outcomes of any group in society[4], and facilitate future capitalisation of the numerous heritage features and the dockside setting by incorporating improved connections of the coastal path and cycle routes
4. A more equal Wales; by delivering positive outcomes to the marginalised Gypsy and Traveller community
5. A Wales of cohesive communities; by sustaining a well-established community, known for its strong intergenerational, family and community bonds

Therefore, with respect to the wellbeing and sustainability of both the Gypsy and Traveller community, and the wider benefits to the community, 'Improve' is the preferred option. All of the six improve options would fulfil this goal.

3.7 Selection of the Preferred Option

Based on the Multi Criteria Assessment and Well-being assessment the preferred option is **Option 6: Improve 4**. This option is summarised in Figure 7 and comprises:

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[4] Impact of insecure accommodation and the living environment on Gypsies' and Travellers' health (2016) Margaret Greenfields and Matthew Brindley https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/490846/NIHB_-_Gypsy_and_Traveller_health_accs.pdf

- Rock revetment along the coast to manage erosion and wave overtopping (Section 1)
- Sheet piling along Lamby Way Roundabout (Section 3)
- Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk.
- Rock scour protection added to Lamby Way Bridge

The economically preferred option is **Option 3: Improve 1** and comprises:

- Rock revetment along the coast to manage erosion and wave overtopping (Section 1)
- Rock scour protection along Lamby Way Roundabout (Section 3)
- Maintain earth embankments elsewhere and raise low points in earth embankments where required to reduce flood risk.
- Rock scour protection added to Lamby Way Bridge

Although Option 3: Improve 1 has a slightly higher BCR (3.7 compared to 3.5) both options are economically viable and provide good value for money.

The key difference between Option 6 and Option 3 is the technical approach to improving the defences along section 3, Lamby Way roundabout. Option 6 involves installation of a sheet pile wall, whereas Option 3 involves the addition of rock scour protection to the river bank. The addition of rock has a number of disadvantages which mean that the preferred option would be to install sheet piling along this stretch with just small amounts of rock at the toe for scour protection. The key disadvantages include:

- The negative environmental impact of adding a significant volume of rock to manage erosion as this would cover much of the intertidal area, which supports protected bird species;
- and the risk of increased erosion downstream of the works, as the rock structure would narrow the channel, increasing the river flow velocities downstream. This could increase erosion to Rover Way located parallel to the defence in section 2.

Based on the assessments undertaken the overall preferred option is Option 6: Improve 4.

3.8 Sensitivity analysis

Introduction

A number of sensitivity tests have been undertaken to ensure that the preferred option choice is robust and that the option selection is not sensitive to key assumptions.

Sensitivity tests have been undertaken for the following factors which have inherent uncertainty and could have the greatest impact on preferred option identification. These have been selected as:

- Delayed onset of erosion damages impacting the Rover Way Travellers Site
- Variation in onset of erosion impacting on Lamby Way Roundabout and Rover Way
- Variation in the cost of rock armour

Sensitivity 1 – Erosion damages to Rover Way Travellers Site

Delaying the erosion of Rover Way travellers site by 10 years under Do Nothing and Do Minimum reduced the Benefit Cost Ratio of all Improve options by between 0.08 and 0.12

due to a reduction in benefits. The Benefit Cost Ratio of Do Minimum reduced by 0.2. This has no impact on the choice of economically preferred option.

Sensitivity 2 – Erosion damages to Road Infrastructure

Delaying the erosion of Rover Way and Lamby Way Roundabout by 10 years under Do Nothing and 20 years under Do Minimum reduces the Benefit Cost Ratio of all Improve Options by between 0.04 and 0.06. This has no impact on the choice of economically preferred option.

Increasing the erosion of Rover Way and Lamby Way Roundabout so that they are lost in Year 5 under Do Nothing and year 20 under Do Minimum increases the Benefit Cost Ratio of all Options by between 0.02 and 0.13. This has no impact on the choice of economically preferred option.

Sensitivity 3 – Variation in Rock Cost

The cost of rock has been estimated based on discussions during ECI with local rock suppliers. The cost of rock could however increase due to supply and demand impacts should a number of large schemes be requiring rock at the same time, such as a number of CRMP Projects and the potential Swansea Bay Tidal Lagoon. To assess the impact of increased rock costs on the option choice, the rock component of the scheme costings was doubled and the BCR reassessed.

Doubling the cost of the rock leads to a decrease in the BCR of all options although all options remain economically viable (Table 15). However, the BCR falls by a greater proportion on the options involving rock armour along the coast (Options 3 and 6), which are the two options which previously had been identified as having the highest BCR. These options have a reduction in BCR of 0.9 and 0.7 respectively, with option 3 falling by a greater amount as it uses rock along the Lamby Way Roundabout and along the coast while option 3 uses sheet pile along the Lamby Way Roundabout and rock along the coast. As a result, the economically preferred option becomes Option 6, Improve 4 or Option 3, Improve 1 as these now have the same Benefit Cost Ratio at 2.8. Option 6, Improve 4 is the overall preferred option for the project showing that the cost of rock does not impact upon the overall choice of preferred option.

Table 15: Change in Benefit Cost Ratio as a result of doubling cost of rock

	Option 2	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**
	Do Minimum	Improve 1	Improve 2	Improve 3	Improve 4	Improve 5	Improve 6
Original BCR	1.4	3.7	2.5	2.5	3.5	2.4	2.4
Sensitivity BCR	1.1	2.8	2.4	2.4	2.8	2.3	2.3
Change in BCR	0.3	0.9	0.1	0.1	0.7	0.1	0.1

Halving the cost of the rock leads to an increase in the BCR of Options 2, 3, 5 and 6 (Table 16). The BCR increases by a greater proportion on the options involving rock armour along the coast (Options 3 and 6), which are the two options which previously had been identified as having the highest BCR. These options have an increase in BCR of 0.6 and 0.4 respectively, with option 3 increasing by a greater amount as it uses rock along the Lamby Way Roundabout and along the coast while option 3 uses sheet pile along the Lamby Way Roundabout and rock along the coast. As a result, the economically preferred option remains as Option 3, Improve 1 and the gap between the two BCRs increases from 0.2 to

0.4. The options are still very close however and the BCRs for these options remain notably higher than the BCRs for other Improve options and the overall choice of preferred option would not change.

Table 16: Change in Benefit Cost Ratio as a result of halving cost of rock

	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
	Do Minimum	Improve 1	Improve 2	Improve 3	Improve 4	Improve 5	Improve 6
Original BCR	1.4	3.7	2.5	2.5	3.5	2.4	2.4
Sensitivity BCR	1.5	4.3	2.5	2.6	3.9	2.4	2.4
Change in BCR	0.1	0.6	0	0.1	0.4	0	0

3.9 Development of the Preferred Option

The costs for the preferred option were developed using the same methods as the costs for the Shortlisted options, with a final verification by the ECI contractor.

In addition to the costs, a risk register was developed in collaboration with the ECI contractor, to develop a risk budget for the preferred option. This has been developed using The Environment Agency's National Capital Programme Management Service Risk register template. This has been analysed using @Risk Monte Carlo Analysis, to give 50%ile and 95%ile project risk allowances.

3.9.1 Consultation responses

A number of consultation responses have been received as part of the stakeholder engagement programme (Table 17). These responses have been used to guide the direction of the preferred option, specifically through the selection of the preferred option through the Multi Criteria Assessment.

Table 17: Stakeholder engagement input

Organisation	Interest	Consultation response	Actions taken
RSPB	Wildlife conservation	The recommendations of the Living Levels Partnership should be considered so CCC can help meet its objectives.	These recommendations have been considered within the landscape appraisal to inform the preferred option.
NRW	Flood risk management / wildlife conservation / ground contamination	Further analysis of ground contamination should be undertaken for the Frag Tip site (off Rover Way) to inform risk of contamination mobilisation and to inform design requirements. Severn Estuary designated as a SAC, SPA and Ramsar. Habitat Regulations Assessment required to assess effects on designations and requirement for habitat compensation.	Ground contamination investigation to be undertaken by CCC as a separate project. Results to inform flood defence scheme at detailed design stage. Habitat Regulations Screening Assessment undertaken at OBC stage. Further assessment required at detailed design stage. Consultation with NRW regarding compensation requirements is ongoing.

Cadw	Archaeology and cultural heritage	Particular attention should be given to the impacts of the project on the Rumney Great Wharf Relict Seawall (GM474).	This issue has been addressed in the archaeological desk based assessment (DBA), concluding only a low risk of an impact to the setting of the scheduled monument.
Dwr Cymru/ Welsh Water	Owner of adjacent defences to the west	Undertaking separate assessment of DCWW defences. Would be interested in sharing information and potentially combining schemes to gain efficiencies.	Discussion with DCWW have continued and meetings are underway to discuss potential to combine scheme design and construction.

3.9.2 Preferred Option Description

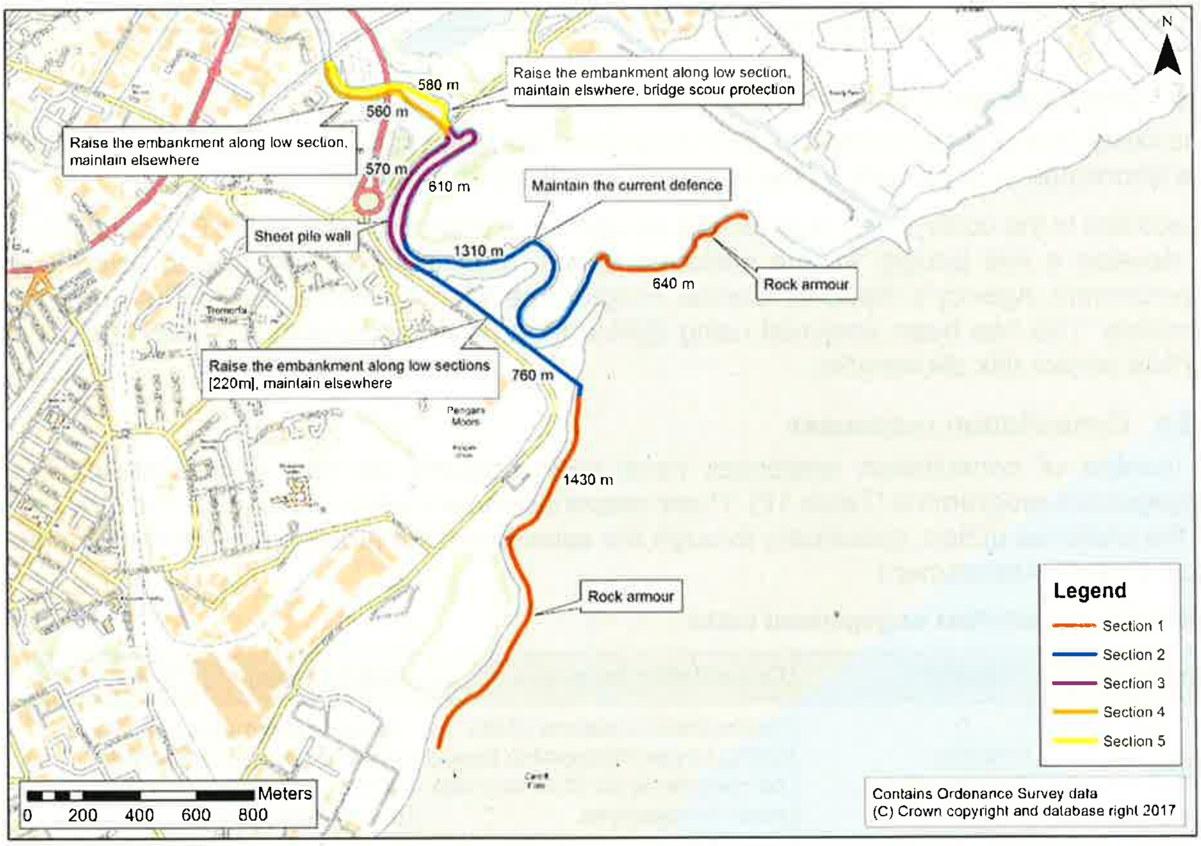


Figure 7: Summary of Preferred Option: Option 6, Improve 4

Section 1

Section 1 extends along the entire coastal reach with the rock armour revetment being the preferred option. The volume of overtopping discharge varies along the coast dependent on the flood risk and level of ground in land from the defence which is detailed in the shortlist design section. The design wave height along the coast is 1.36m with a period of 5 seconds which requires a rock grading of 1 to 3 tonnes with scour protection at the toe embedded to 0.5 metres. A geotextile membrane will also be applied under the rock armour to stop sediment wash out, as shown in Figure 8.

The defence design will be able to incorporate a coastal footpath behind the crest which may be raised to the crest level or just below. This will result in enhancements to the existing Wales Coast Footpath which can be detailed in the detailed design phase in combination with CCC Rights of Way and NRW.

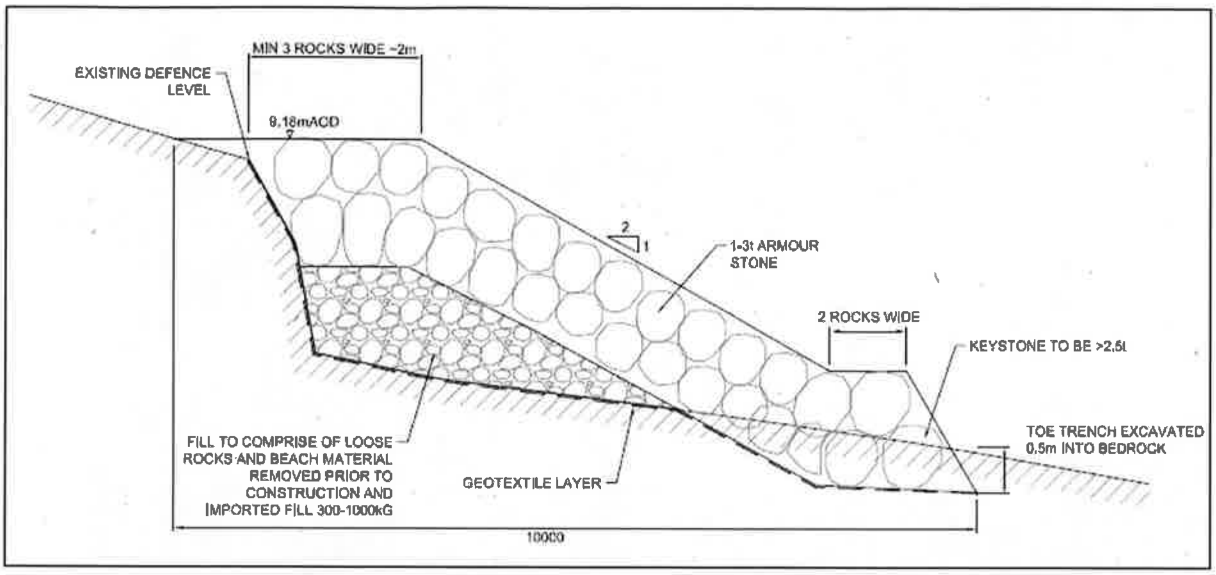


Figure 8: Section 1 – Preferred Option – Rock Armour

Section 2

Section 2 extends away from the coast on the east and west bank of the River Rhymney. The preferred option for this section involves a do minimum and maintenance approach with minor raising to a 220m section of the embankment to raise this lower section to the required level for a 0.5% AEP event, as shown in Figure 9. Consideration is required at the private access to the boat yard due to the level being below the design SOP. Raising of the road could involve a 1 in 20 graded entry or a flood gate although regrading of the road would be preferred so that human intervention in shutting the flood gate is not required.

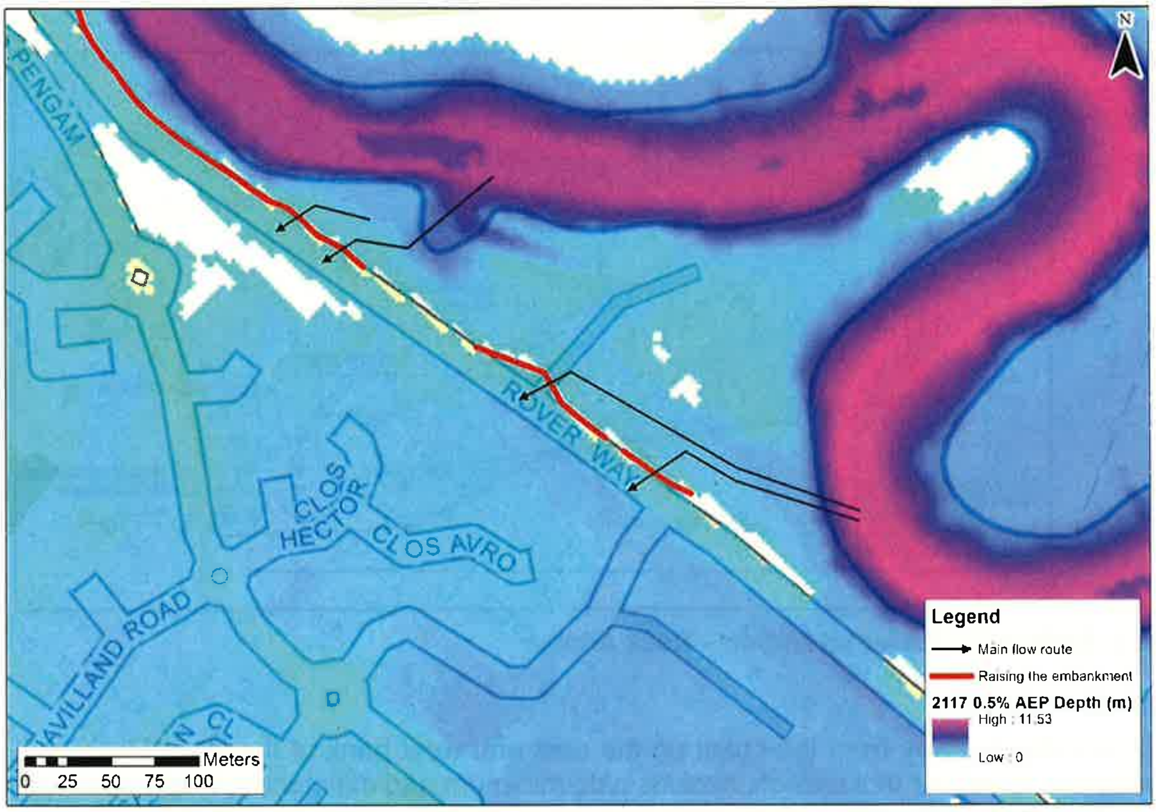


Figure 9: Section 2 – Required raising

This will improve the standard of protection on the Rover Way section of the river to a 0.5% AEP in the year 2117. Where the embankments are already at a sufficient height, the do minimum approach to the section should address the following general maintenance issues associated with grass embankments:

- Vegetation management with removal of trees and shrubs – all grass should be maintained to a short length.
- Patch repair works due to unforeseen events such as pedestrian damage.
- Bi-annual condition assessments to monitor the condition of the defence.

Section 3

Section 3 includes a meander section of the river close to Rover Way and Lamby Way roads. To the north of the section is a bridge in which the abutments narrow the natural width of the river. In most sections along the river the embankment is set back from the river bank but this is not the case for Section 3 and significant assets are at risk due to the risk of erosion to the embankment. In order to prevent further erosion to the embankment and the loss of significant transport infrastructure the preferred option is a sheet pile wall on the full stretch of the west bank and a 100 metre section in front of the bridge on the east bank where the flows are accelerated due to the bridge abutments.

During the concept design stage several assumptions were made in the design of the sheet piles, including assumptions on ground conditions and drivability of the piles. A conservative approach was adopted. It has also been assumed that the piles will have paint protection with a 25 year design life and a sectional loss of 7.5mm over 75 years. The design of the sheet piles will have to be reviewed at detailed design taking into account the results of a full ground investigation campaign. This is particularly the case in relation to the pile embedment. The outline design is shown in Figure 10 below.

The public footpath could be located along the concrete cap of the sheet pile as is currently in place along much of Section 2.

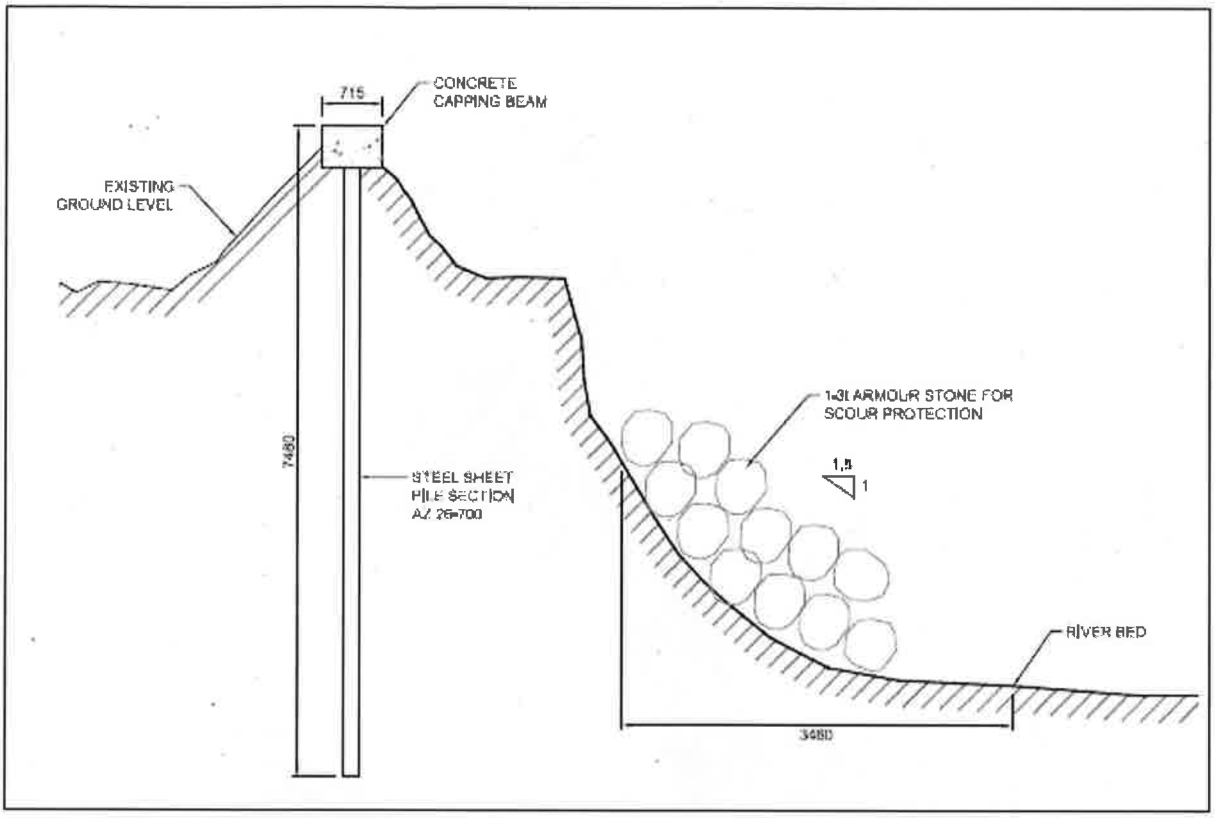


Figure 10: Section 3 – Sheet pile – Preferred option

Section 4

Section 4 runs along the west bank of the Rhymney between Lamby Way Bridge and the railway line. The defence currently consists of a grass embankment set back from the river bank and in places is below the 2117 200 year still water level. This requires 155m of raising to bring the embankment in line with the desired standard of protection as shown by the flow routes on Figure 11.

This will improve the standard of protection on the Pengam section of the river to a 200-year water level to the year 2117. In keeping with the do minimum approach the preferred option should also address the following general maintenance issues associated with grass embankments:

- Vegetation management with removal of trees and shrubs – access provision needed for all grass to be maintained to a short length.
- Patch repair works due to unforeseen events such as pedestrian damage.
- Bi-annual condition assessments to monitor the condition of the defence.

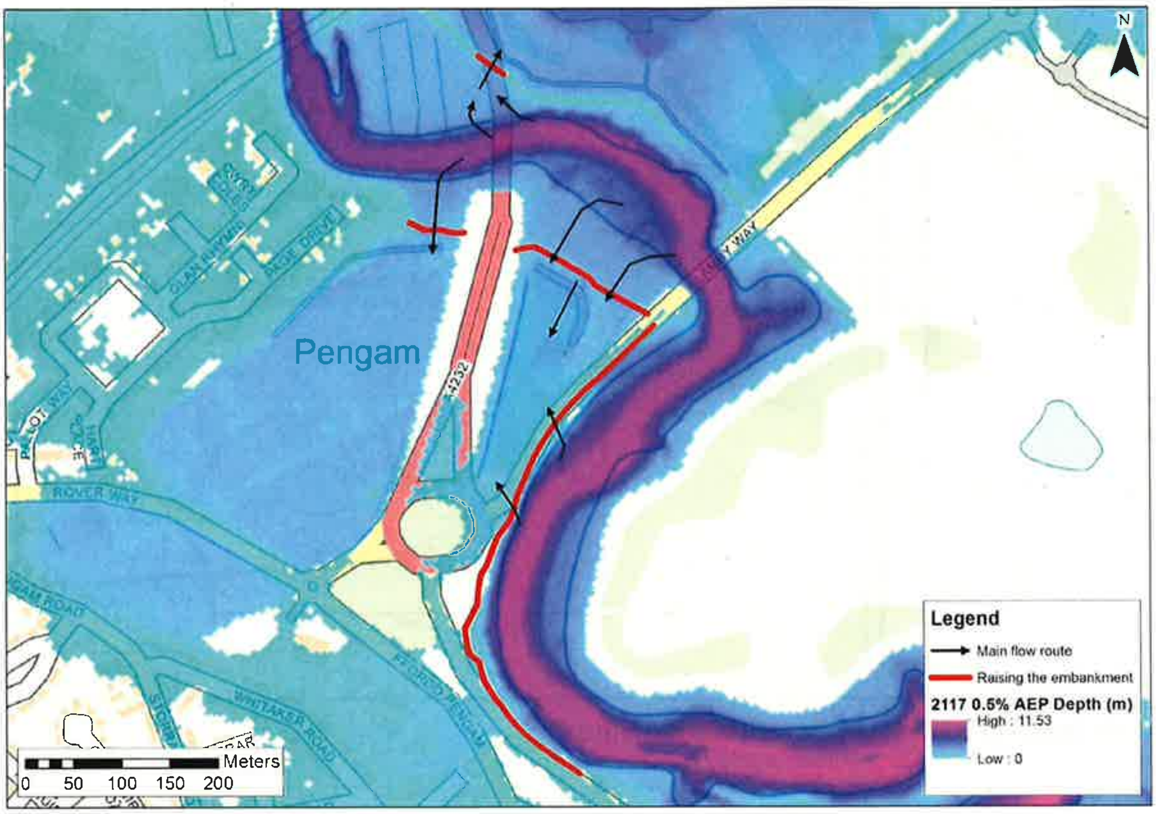


Figure 11: Section 4 & 5 – Required raising

Section 5

Section 5 runs along the east bank of the Rhymney between Lamby Way Bridge and the railway line. The defence currently consists of a grass embankment set back from the river bank and in places is below the 2117 200 year still water level. The preferred option for this section involves a combination of options, firstly tying in a 35m section of the embankment into the existing defence levels at 8.4 mAOD.

In keeping with the do minimum approach the preferred option should also address the following general maintenance issues associated with grass embankments:

- Vegetation management with removal of trees and shrubs – all grass should be maintained to a short length.
- Patch repair works due to unforeseen events such as pedestrian damage.
- Bi-annual condition assessments to monitor the condition of the defence.

Finally, the bridge abutment at Lamby Way is experiencing scour erosion which should be addressed through rock armour protection. This study was to look at erosion and flood risk so the structural stability of the bridge has not been assessed and it is recommended that this is done so through a separate study. However, the bridge does form part of the flood defence and therefore protecting the foundations of the bridge with rock armour is part of the preferred option. It is noted that the bridge abutment restricts the river flow and replacing the bridge would resolve this but at this stage the option is not discussed any further.

Environmental Enhancements

Allowances have been made for the provision of Environmental Enhancements, including interpretation boards (£1,500), Wales Coast Footpath Improvements (£104,000), bat & bird boxes (£500), and incorporation of bioblocks into the rock armouring (£10,000).

Compensatory Habitat Requirements

In accordance with the Habitat Regulations, compensatory habitat may be required to mitigate the potential for a significant impact on the Severn Estuary European Marine Site due to the implementation of a HTL policy and the future impacts of coastal squeeze as sea levels rise.

An initial assessment has been undertaken to identify potential habitat compensation requirements for the preferred option. There are ongoing discussions on the methodology and requirements for compensatory habitat with NRW and therefore this assessment may be subject to change.

The initial assessment indicates that the following compensatory habitat areas may be required, to allow for the impacts of coastal squeeze over the 100 year lifetime of the proposed scheme:

- Mudflat = 85 hectares
- Saltmarsh = 7 hectares

These habitat areas are to be refined and agreed through further discussion with NRW. Costs have not been calculated for these areas as they have not yet been agreed by NRW.

There are no immediate habitat requirements resulting from the footprint of the preferred option.

The requirements for compensatory habitat arise from any measure that implements the 'hold the line' SPM2 policy for the area.

3.10 Preferred Option Cost Breakdown

The costs for the preferred option are presented in Table 18.

Table 18: Summary costs for the preferred option

Costs		Cost for economic appraisal (PV)	Whole-life cash cost	Total project cost (approval)
Costs to OBC:	N/A -sunk costs		£ 100,000	Exc previous app
Existing staff costs				
Further staff costs				
Site investigation and survey				
Consultants' fees				
Contractors' fees				
Cost consultants' fees				
Subtotal			£ 100,000	£ -
OBC to FBC (in yr 0):				£ -
Existing CCC staff costs		£ 91,795	£ 91,795	£ 91,795
Further staff costs				
Site investigation and survey		£ 229,488	£ 229,488	£ 229,488
Consultants' fees		£ 229,488	£ 229,488	£ 229,488
Contractors' fees		£ 57,372	£ 57,372	£ 57,372
Cost consultants' fees				
Optimism Bias to FBC		£ 243,257	£ 243,257	£ 243,257
Subtotal		£ 851,399	£ 851,399	£ 851,399
Construction (in yr 4):				
Construction costs		£ 4,589,750	£ 4,589,750.41	£ 4,589,750.41
Environmental enhancement		£ -	£ -	£ -
Environmental mitigation		£ 191,500	£ 191,500.00	£ 191,500.00
Site supervision		£ 68,846	£ 68,846.26	£ 68,846.26
Cost consultants' fees		£ -	£ -	£ -
Land purchase & compensation		£ -	£ -	£ -
Other costs (specify – see note (1))		£ -		
Optimism Bias Construction		£ 1,940,039	£ 1,940,039	£ 1,940,039
Subtotal		£ 6,790,135	£ 6,790,135	£ 6,790,135
Risk contingency:				
Optimism Bias TOTAL		£ 2,183,295	£ 2,183,295	£ 2,183,295
Risk - Monte Carlo 95%				£ 773,230
Risk - Monte Carlo 50%		£ 277,565	£ 277,565	
Future costs (yr 3-100):				
Maintenance		£ 4,665,273	£ 16,533,000	
Future construction		£ -		
Optimism Bias (on future costs)		£ 1,866,109.06	£ 6,613,200	
Project total costs		£ 14,450,480	£ 31,065,299	£ 8,414,764

Inflation allowance for costs in 2017-2021	£ 804,179
VAT payable @ 20% (excl. CCC Staff costs)	£ 1,664,593.80

Total for CRMP Approval	**£ 10,883,537**

4 The Commercial case

4.1 Introduction

The concept level design for the Cardiff Coastal Flood and Erosion Risk Management project has been undertaken by JBA Consulting on behalf of CCC, with Early Contractor Involvement (ECI) support from Raymond Brown Construction Ltd, all three of whom have knowledge of the area and have a considerable track record of delivering successful infrastructure and regeneration schemes of this nature.

4.2 Key contractual terms & risk allocation

The Design Stages (including ECI) will be carried out under the terms and conditions of the ECC3 Professional Services Contract (June 2005) (with amendments 2006 & 2011), or similar

The Construction works will be carried out under terms and conditions of the Engineering and Construction Contract (June 2005) (with amendments 2006 & 2011) Option C Target Contract.

The NEC Suite of contracts is designed to promote a collaborative team working approach and is well suited to this kind of project. Several 'main options' are available within the NEC contract suite, with selection largely driven by the allocation of out-turn financial risk ownership between the project team. Option C is a target cost contract with an activity schedule. In this contract, the out-turn financial risks are shared between the client and the contractor in an agreed proportion, leading to its colloquial name of the 'pain-gain share' option.

This approach has proven to be commercially attractive to Civil Engineering Contractors, as this it encourages proactive engagement with project risks by the whole project team. It sits well with general partnership approach of the NEC Suite, and the application of the NEC Suite to this project, where key project risk ownership would be anticipated to be shared.

4.3 Procurement route and timescales

Delivery of the project will require subsequent procurement exercises being undertaken for both the Design and Construction Stages, with the latter being substantially larger.

The consultancy services for the Outline Business Case were procured under the Construction Consultancy Framework (ref. NPS-PS-0027-15) managed by the National Project Service (NPS), using the relevant 'Water Management' Lot under the framework. It is envisaged that the detailed design stage of the project would be procured using a similar arrangement.

The construction procurement exercise will be completed following detailed design.

5 The Financial Case

5.1 Costs

The costs associated with the design, ECI and construction phases have been estimated in the previous sections.

The total value for Coastal Risk Management Plan Approval is; **£10,883,537**

The total value of the Welsh Government cost apportionment would be; **£8,162,652**

The total value of the CCC cost apportionment would be; **£2,720,884**

The initial anticipated spend profile is presented in Table 19.

Table 19: Annualised funding needs and programme summary, VAT inclusive

Annualised funding needs (£)	Yr 0 2017	Yr 1 2018	Yr 2 2019	Yr 3 2020	Total
Summary Program	Design phase (£)		Construction phase (£)		
Detailed Design					
Welsh Government (75%)	376,245	376,245			752,490
Local Authority (25%)	125,415	125,415			250,830
Construction					-
Welsh Government (75%)			3,403,514	3,403,514	6,807,029
Local Authority (25%)			1,134,505	1,134,505	2,269,010
Inflation from 2016 rates	2.4%	4.8%	7.3%	9.7%	
Inflation allowance £	12,125	24,251	329,058	438,744	804,179
Project total costs	513,785	525,910	4,867,077	4,976,764	10,883,537

5.2 Funding / Assessment of Affordability

5.2.1 Welsh Government Funding

This financial case assumes that Welsh Government will fund onward capital costs for detailed design and construction of at least 75% of the total costs.

5.2.2 Local Funding

At this early development stage, CCC commit in principle to fund up to 25%. Formal consideration for the commitment to the scheme will be provided following the May 2017 elections. The funding will be subject to review as the design is developed as there is potential for assistance from private sources as a wider strategy for development in the area is considered.

Due to the geographical separation of key elements of this scheme, and potential for links with other projects, CCC may consider a phased approach to constructing this project if this offered efficiencies. Welsh Government Funding levels for the detailed design phase may also affect the development schedule for the scheme.

It is noted that this approach requires that some burden of risk be carried regarding the potential realisation of early erosion damages to Rover Way. Should this risk be realised, having an approved OBC and detailed design being progressed would allow an erosion event to be managed in a different way to that described in a do-nothing scenario. Temporary emergency repairs to protect property and people can be effected in a manner that allows cost effective incorporation in the permanent works, reducing the out-turn construction cost and the detailed design and delivery of this low complexity coastal revetment scheme could be accelerated.

It is also noted that advancing the detailed design stage offers the opportunity to ameliorate project risks relating to delays resulting in project completion outside of CRMP funding window.

5.3 Assumptions

A Value Added Tax (VAT) Rate of 20% has been reflected in the capital costs. Rates for CCC staff are not VAT chargeable.

6 The Management case

6.1 Project management

The key success factors for the scheme are:

- Coordination of Third Party Interfaces
- Timely Delivery with Effective Traffic and Pedestrian Management Systems
- Delivery of a Quality Product
- Zero Health and Safety Incident
- Maximum Community Benefits
- Delivering within programme and to budget

The scheme presents a number of logistical and buildability challenges that requires a phased approach to development whereby interfaces with Third Parties and Traffic Management can be fully considered.

6.1.1 Project structure and governance

The project will be delivered and managed by officers of CCC with Governance from elected Members of the Council. The Senior Responsible Officers are the Operational Managers of City Operations, reporting to the Director of Environment, who reports to Council Members Cabinet.

The project will be delivered by a Project Core Team with members to be agreed. It is proposed that the project will be managed by an externally sourced project manager.

The Project Team will be considered during the procurement exercise for the design element and construction works; however, there will be consideration for continuity for the transition between design to construction.

Advice will be sort from CCC's internal departments for consideration of funds management and marketing.

6.2 Communications and Stakeholder engagement

Following approval of this OBC, I may be appropriate to undertake further studies and investigations in advance of the detailed design stage to better manage key project risks.

Further stakeholder engagement with the following key stakeholders is recommended:

NRW

- As the regulatory authority in Wales, consultation is imperative to efficiently adhere to environmental legislation. This is particularly important to agree the requirements for compensatory habitat in line with the Habitat Regulations.

Gypsy and Traveller community

- As the key land occupier on site, sensitive communication with this community will help to alleviate concerns they may have, and reassure.

Local businesses

- Businesses using Rover Way and Lamby Way for access should be consulted.

Local residents and public

- Before the construction phase of the project begins, the public need to be informed, most likely via written notices.

Service providers

- Consultation should be sought from Dwr Cymru and Wales and West Utilities to confirm exact locations of buried services.

Other interested parties

- Advice from organisation such as Sustrans, local wildlife groups and Cadw and Glamorgan-Gwent Archaeological Trust.

The consenting process follows the detailed design stage, and the need for an Environmental Impact Assessment (EIA) will be confirmed via an EIA screening opinion from CCC. Should an EIA not be required, a range of environmental assessments, based on the topics covered in this report, are likely to be required to support the consenting of the project. The preparation of an EAP will be required to capture the mitigation and enhancement measures. Other statutory consents relating to footpath or road closures/diversions or protected species, will also be sought if required, subject to consultation with relevant authorities. Stakeholder engagement is imperative at each of these stages.

6.3 Risk management

Changes are inevitable in construction projects and Change Management is a critical problem faced by the construction industry. The effort of managing change orders imposes a huge burden on project management. Changes are identified as the major cause of project delay, cost overruns, defects, or even project failure.

The prescriptive processes detailed within the NEC3 are essential in the effective control of change. CCC are advocates of using Contract Change Management Software that improves communications and facilitates a documented proactive approach based around a Risk Register.

The Project Manager will be responsible for the maintenance of the Risk Register and will engage all members of the delivery team to develop a register that is robust and considers all aspects of potential cost, programme, 3rd party or technical risk. It is essential that the risk registers are discussed in workshops by team members will differing views and that solutions are owned by members of the entire team.

A Risk Register has been developed with ECI input and will be maintained through the Design Development and Construction Stages. The Risk Register can be found in Appendix 1 and should be regularly reviewed and updated by the project team.

6.4 Contract management

The scheme will be delivered by Cardiff City Council and an external contractor. The Council have in-house knowledge of the area and have a considerable track record of delivering successful infrastructure and regeneration schemes of this nature.

6.4.1 Procurement & Development Process

Delivery for the scheme will result in procurement exercises being undertaken for both the Design and Construction Stages.

6.4.2 Design Procurement

Detailed design services will be procured using the NPS Construction Consultancy Frameworks and the NEC Professional Services Contracts. It is envisaged that CCC will manage the design process and assist in developing the design and managing stakeholders.

6.4.3 Construction Stage Procurement

Procurement for the Construction Stage will be undertaken following detailed design with advise sort from CCC's procurement services.

6.5 Assurance

6.5.1 Welsh Government

Welsh Government reviews of the project will be conducted at key decision points for approval of further funding. These will be:

- Progress to Detailed Design
- Progress from Detailed Design to Construction

6.5.2 Local Authority

CCC is fully aware of the importance of collecting and reporting accurate data relating to its operations and has a proven track record of doing so successfully.

A Monitoring and Evaluation Plan will be developed which will outline the system that will be used to effectively collect all data relating to the Operation. The Monitoring & Evaluation Plan will consider:

- Evaluation Objectives
- Lessons learned from previous projects
- Operational Context
- Activities to be undertaken
- Management Responsibility
- Delivery Plan
- Indicators
- Targets
- Data Quality
- Reporting Arrangements
- Evaluation
- Potential use of Evaluation
- Indicative Timetable
- Dissemination

The Monitoring and Evaluation Plan will be reviewed on a regular basis by the Project Manager with results and progress reported to the Welsh Government within the quarterly progress report. An independent Evaluation Consultant will be appointed to carry out a full evaluation of the progress and impact of the operation.

6.5.3 Post project evaluation

The Evaluation will report on the impact and effectiveness of the operation and will include feedback on indicators, aims and objectives, effectiveness of project management and will make recommendations or suggestions or improvement or ideas for future operations.

The evaluation final report will be distributed upon completion of the project and will be made available to the Welsh Government, stakeholders and will be reported to the relevant senior management and cabinet boards as appropriate.

The longer-term benefits will be monitored including long term community benefits, business growth, tourism and jobs created on the site following construction.

6.6 Contingency plans

Contingency plans will be fully considered and drawn up at the procurement stages for detailed design and construction.

Appendix 1 - List of reports produced

1. Preliminary Ecological Appraisal
2. Water Framework Directive Screening and Scoping Assessment
3. Preliminary Environmental Information Report
4. Engineering Report
5. Landscape Appraisal
6. Geoenvironmental and Geotechnical Desk Study Report
7. UXO Desk Study & Risk Assessment
8. Archaeological Desk-based Assessment
9. Preliminary Ground Investigation Scope Economic Appraisal
10. Economic Appraisal
11. Geomorphology Assessment
12. Asset Condition Report
13. Habitats Regulation Assessment (HRA)
14. Risk Register
15. Model User Report

Fig 1 – Thornhill Park (Oct 2014)

This is a small piece of land surrounded by houses and currently used by the community, the park itself is flat with good access and already incorporates a small building and carpark. The size of the site and it's close proximity to houses would mean little burial space left after a buffer zone is planted to screen from houses, after discussions with OM of parks it is agreed that this is a well-used piece of park land that is currently utilised by the community, due to its size close proximity to houses and current utilisation by the community it is deemed unsuitable.

Fig 2 – Hill Snook Park Rhiwbina (Oct 2014)

This is a small piece of land surrounded by houses and currently used by the community, the park itself is flat with good access. The size of the site and it's close proximity to houses would mean little burial space left after a buffer zone is planted to screen from houses, ground also appears to be very wet in places with rushes growing this would possibly lead to the loss of more burial spaces. At present it is used frequently by dog walkers etc. Due to its overall size its proximity to houses and current community use it is deemed unsuitable

Fig 3 – Land adjoining Radyr Cricket club (Dec2014)

This is a large site that could offer burial space for decades to come, it has the Taff River acting as a buffer zone on one side and a railway on the other, its close proximity to the river however raises concerns over possible flooding in future and the possible contamination of the water way from burials, it also has major access issues as no high vehicles including possibly hearses being able to fit through the low narrow tunnel under the railway, due to this it is deemed as unsuitable

Fig 4 – Land at Llwynypia Farm, Lisvane (Nov2014)

This is a medium sized site that could offer good burial space, it is reasonably flat and has reasonable access. The access however is through a housing estate that may increase traffic to an unacceptable level, also advised by estates that this will form part of the LDP in future and set aside for housing so unavailable.

Fig 5 – Land at Maerdy Farm, Lisvane (Oct 2014)

This a large site that offer huge potential for burial space, it has reasonable access although through already very busy lanes, the site is also reasonably flat, I have been informed by estates that this land is no longer available as it will form part of the LDP and is set aside for housing.

Fig 6 – Land at Briwnant, Lisvane to West of Caerphilly road (Jan 2015)

Huge site on gradual slope could offer potential for decades of burials, woodland sections and meadow sections, advised that area currently held in trust which would make development difficult without a compulsory purchase order, large amounts of the site has groups of protected trees and concerns raised that development may affect a Sheduled Ancient Monument (castell Morgraig)

Fig 7 – Land At Church House Farm, Lisvane (Nov 2014)

Medium site that is reasonably level, consists of narrow access that may be expensive to widen, would have the potential for long life cemetery. Advised through estates that this area will form part of the LDP and is earmarked for houses.

Fig 8- Land at Briwnant, Lisvane to East of Caerphilly road (Jan 2015)

Council owned land consisting of gently sloping fields that will have the potential for decades of burials, good access of main road, potential through proximity to existing Thornhill to be run from there to save on offices and welfare facilities etc. not over looked by many houses etc. but does have sitting tenant currently using site for grazing livestock.

Fig 9 – Land to North of ty Mawr public house Lisvane

Large site but very steep with steep narrow access where vehicles are unable to pass, site impractical for access and burials.

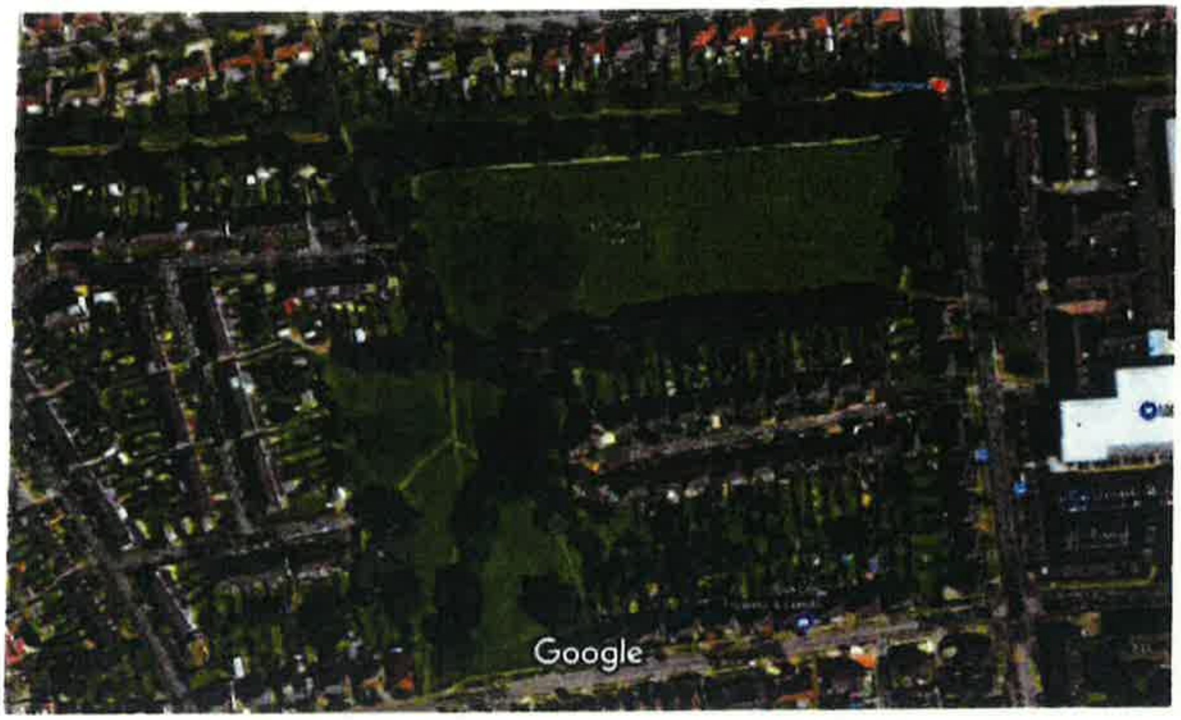
Fig 1

Google Maps

Imagery ©2017 Google, Map data ©2017 Google 50 m

Fig 2

Google Maps



Imagery ©2017 Google, Map data ©2017 Google 20 m

Fig 3

Google Maps

 50 m

FIG 4

Land at Llwynypia Farm, Lisvane

Reference number :	**68**
Area :	**7.34 ha** 18
Existing use :	**Agriculture/woodland**
Proposed use:	**Mixed use - residential, local centre, education, public open space (4,500 dwellings total for wider proposal)**

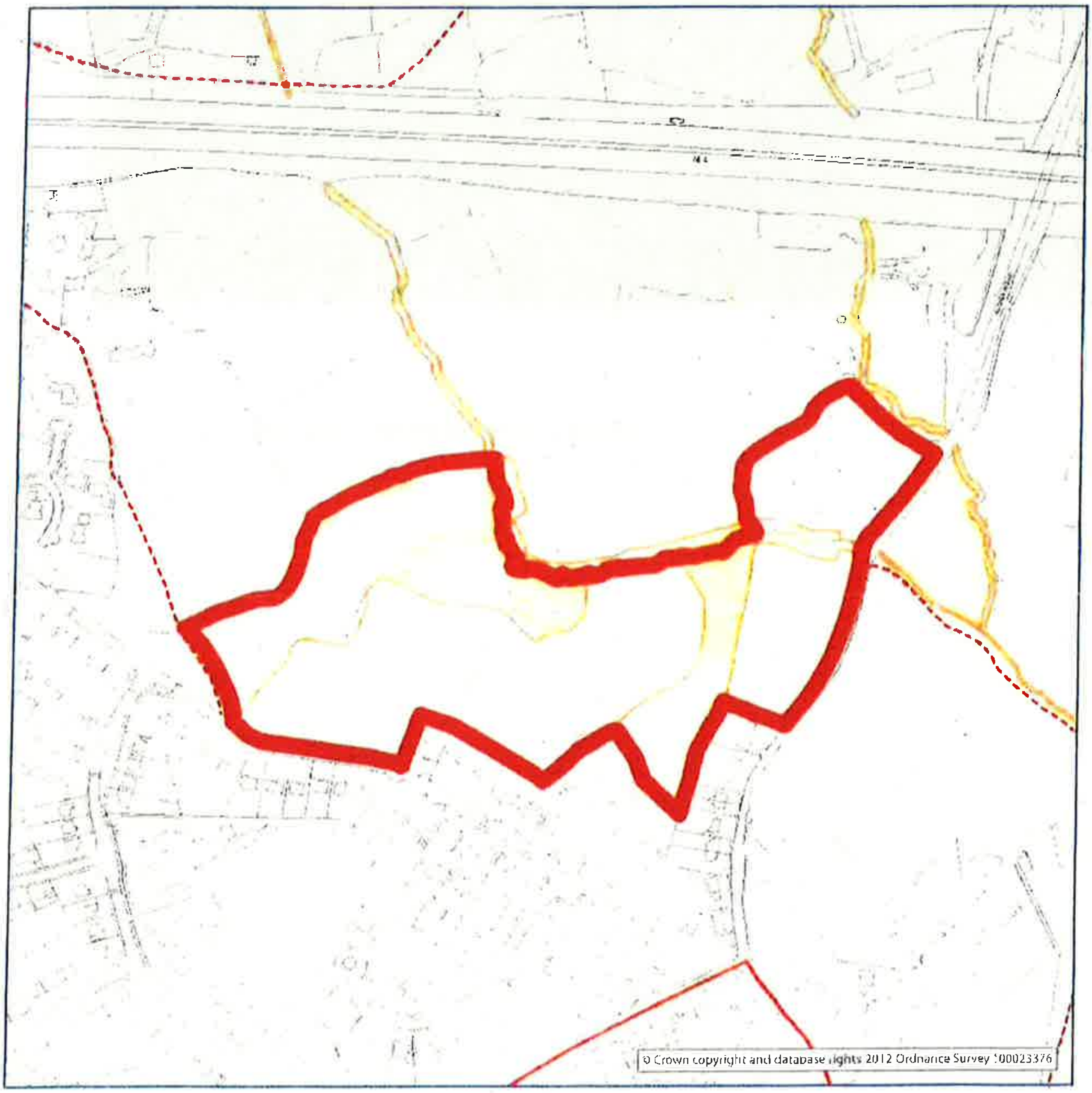


FIG 5

Land at Maerdy Farm, Lisvane

Reference number :	**67**
Area :	**32.03 ha** 29.
Existing use :	**Agriculture/woodland**
Proposed use:	**Mixed use - residential, local centre, education, public open space (4,500 dwellings total for wider proposal)**

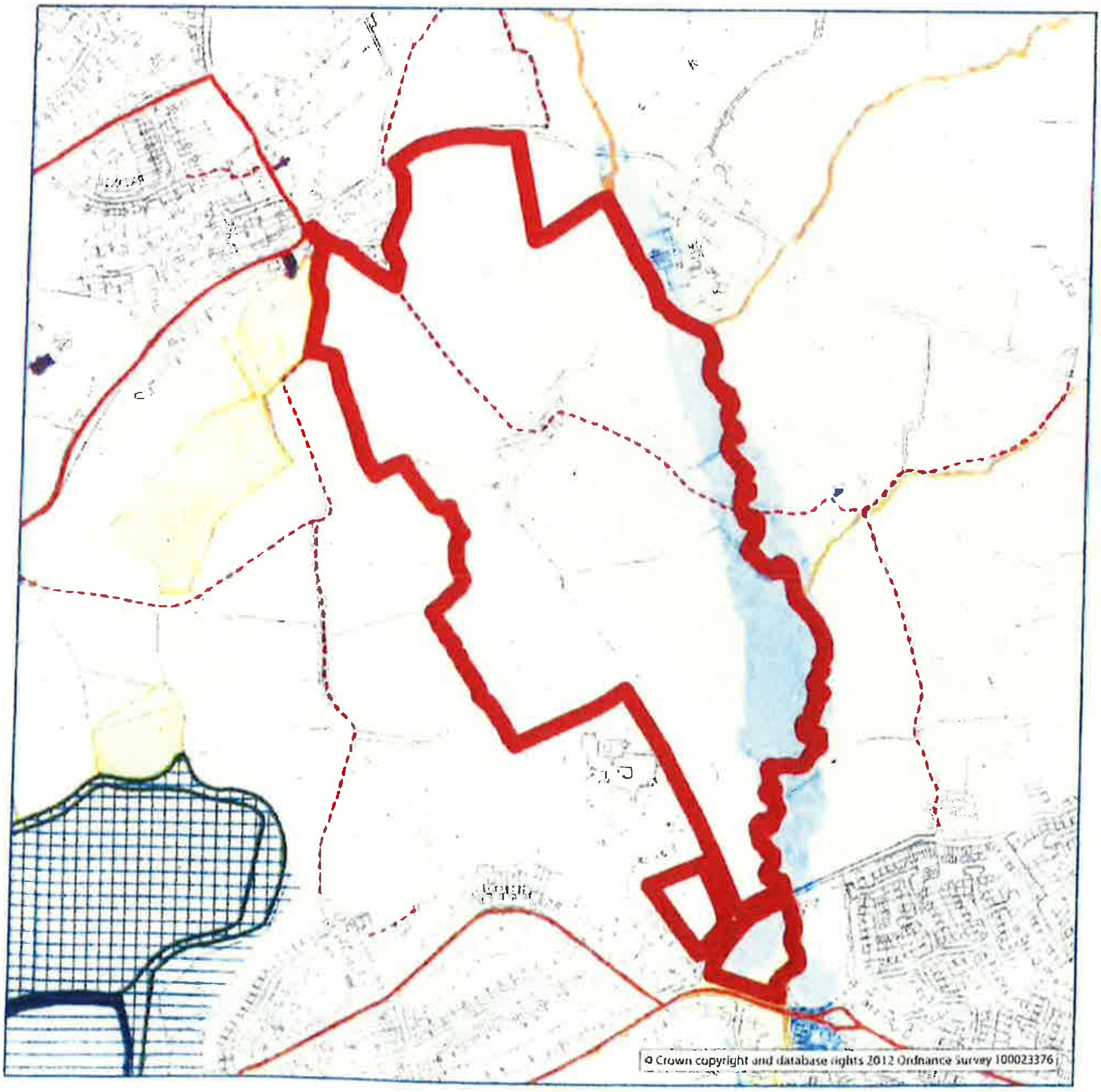


FIG 6

Land at Briwnant

Reference number :	50
Area :	157.00 ha
Existing use :	Grazing land
Proposed use:	Residential, village centre, primary school, local shopping & community facilities, business park, park & ride facility. Country park. (1,200 dwellings)

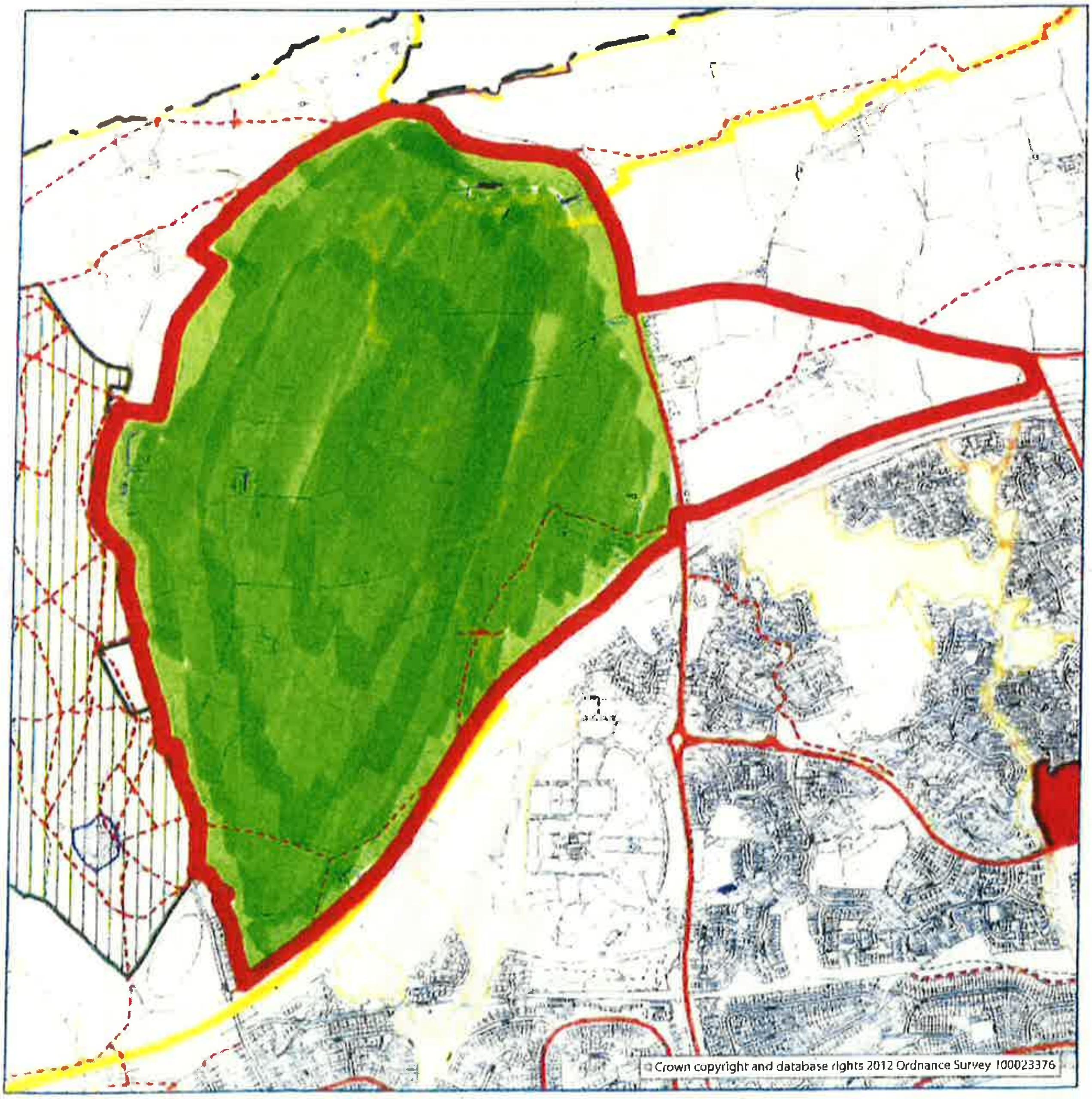


FIG 7

Land at Church House Farm, Lisvane

Reference number :	**66**
Area :	**9.70 ha** 23.9
Existing use :	**Agriculture/woodland**
Proposed use:	**Mixed use - residential, local centre, education, public open space (4,500 dwellings total for wider proposal)**

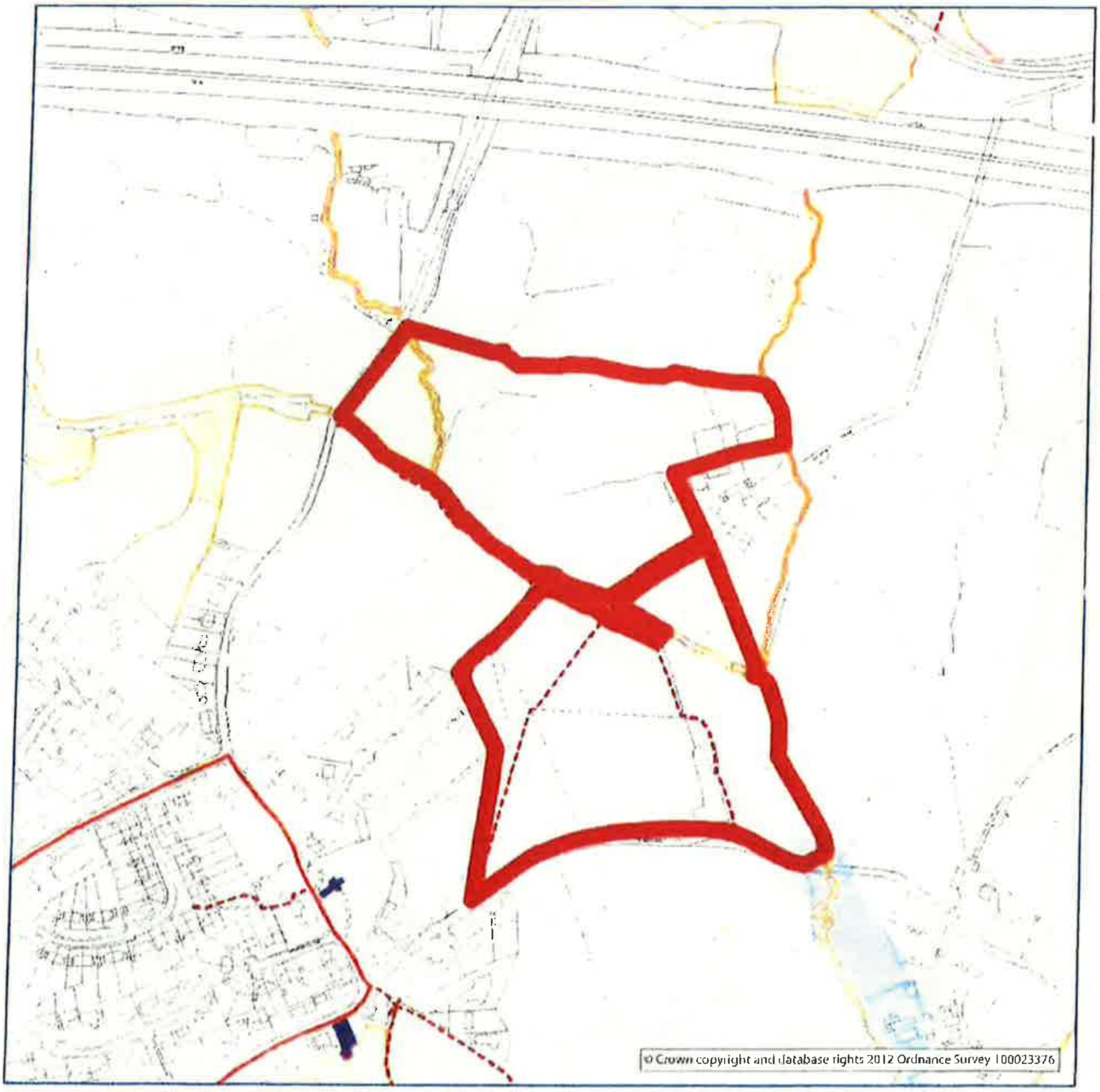


FIG 8

Land at Briwnant

Reference number :	50
Area :	157.00 ha
Existing use :	Grazing land
Proposed use:	Residential, village centre, primary school, local shopping & community facilities, business park, park & ride facility. Country park. (1,200 dwellings)

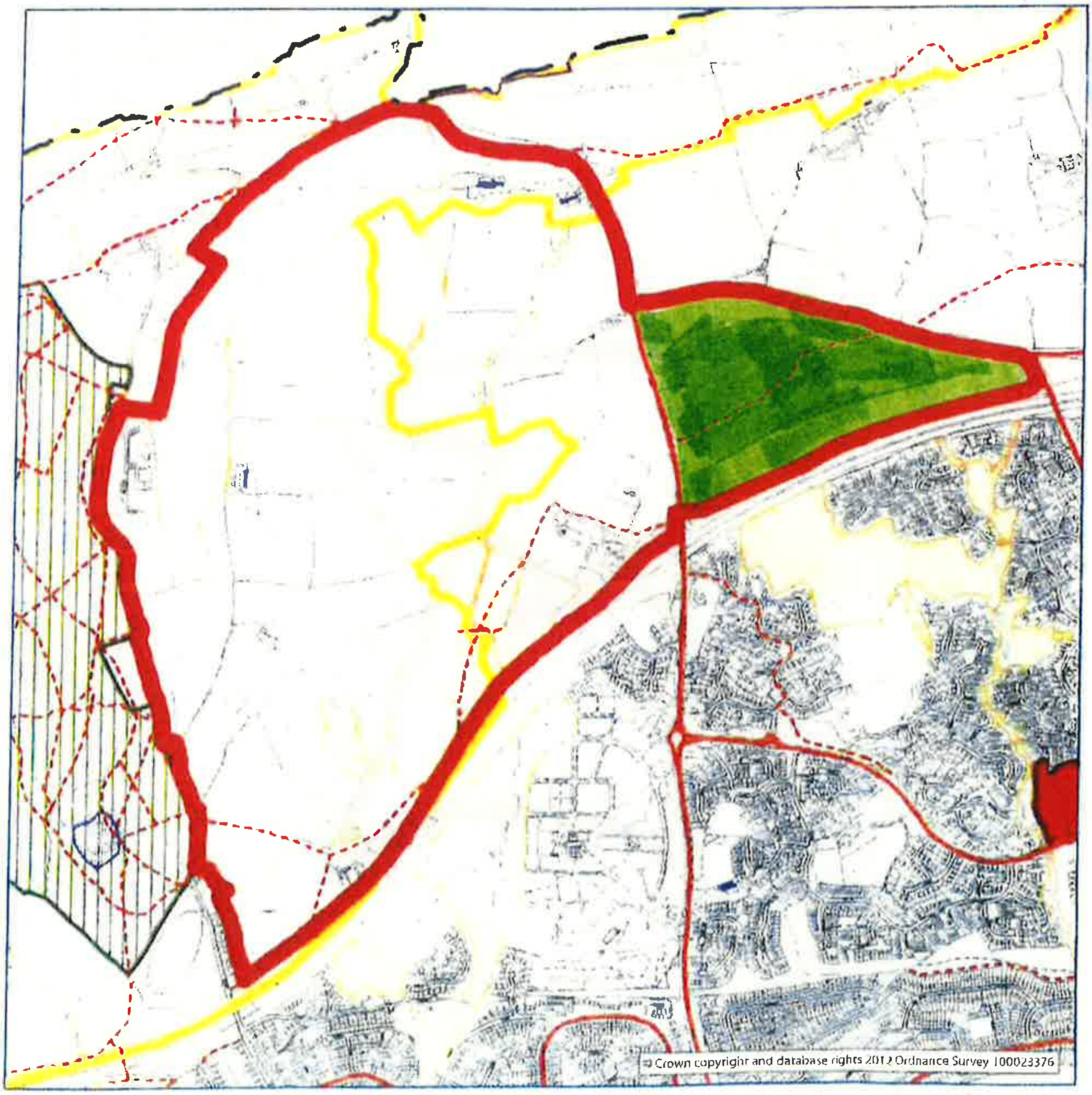


FIG 9

Google Maps

Imagery ©2017 Google, Map data ©2017 Google 50 m