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Musselburgh Flood Protection Scheme

Preferred Scheme Report

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November 2019

East Lothian Council

Musselburgh Flood Protection Scheme

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Contents

Executive Summary

The purpose of this report is to summarise the appraisal process and the recommended preferred options which could be implemented to form the Musselburgh Flood Protection Scheme (the Scheme).

An option appraisal strategy was developed for the Scheme which involved a series of workshops attended by key project team members as well as wider stakeholders, where appropriate, to develop the long and shortlists of options, using Scottish Government and Scottish Environment Protection Agency (SEPA) guidance.

The options were developed in accordance with the aspiration to achieve a 0.5% AEP + CC standard of protection against fluvial, coastal and surface water flooding. A sophisticated fluvial and coastal hydraulic model was developed which enabled combinations of river and sea levels to be modelled and corresponding flood risk to be determined and mapped. This approach has been generally accepted by SEPA.

The options were assessed against a range of factors, including technical feasibility, economics, impact on environment, health and safety risks, impacts on social and stakeholders. A range of workshops and technical meetings were held throughout the option appraisal process, to ensure all interested parties had an opportunity to comment on the proposals and input to the relevant decision making. A spreadsheet based tool was developed which applied a RAG (Red, Amber, Green) analysis to these factors, allowing the long list of options to be readily appraised and unsuitable or unfeasible options rejected in an auditable and easy to understand manner.

All options which were shortlisted were then subject to a greater degree of assessment, including a full economic analysis using industry standard methodologies. The outputs from this assessment, combined with testing combinations of options in the hydraulic model (to develop a range of Scenarios), determined the preferred Scheme components.

The preferred Scheme consists of a combination of direct defences, pumping stations and bridge removal and replacement in Musselburgh town centre, combined with an upper catchment debris trap and adaption of two Scottish Water reservoirs to store greater volumes of water during a flood event, all to provide protection against the fluvial, coastal and surface water 0.5% AEP + CC events.

This is known as Scenario D and is the only economically viable scenario which, subject to more detailed hydraulic modelling and option testing during Stage 4, offers the potential to neutralise the increase in flood levels at structures through the town centre caused by the presence of direct defences. This scenario ensures that there is negligible impact on the Roman and Rennie Bridges and reduces flood levels through the town centre to visually acceptable levels.

The cost of Scenario D is estimated at £36.5 million and generates a Benefit Cost Ratio of 1.08.

Should Scenarios C or D prove to be undeliverable from a technical, economic, hydraulic or stakeholder issue, the minimum combination of components would be those represented by Scenario B. Careful analysis of the impacts on the Roman Bridge will require to be discussed with key stakeholders and a solution to incorporate the Rennie Bridge into the scheme will be required, along with consideration of the need to protect Cell 9 Inveresk Estate. The risk of objection due to unacceptably high direct defences is elevated compared to Scenario D, but Scenario B offers a more cost effective and economically beneficial solution, with a delivery cost estimate of £33.0 million and BCR of 1.18.

Further hydraulic modelling, ground investigation, topographic, ecological and structural surveys are required in advance of or during Stage 4 to fully determine the preferred Scheme Scenario.

1. Introduction

1.1 Purpose

The purpose of this report is to summarise the appraisal process and the recommended preferred options which could be implemented to form the Musselburgh Flood Protection Scheme (the Scheme). A number of reports, technical documents and drawings were prepared during this process; generally referred to in this report and included in appendices. This report represents the preferred scheme proposal which will form the basis of the submission under the Flood Risk Management (Scotland) Act 2009 (the FRM) and will also document the transition to the outline design stage.

1.2 Background and Sources of Flooding

Musselburgh, in East Lothian, has a history of fluvial flooding from the River Esk, coastal flooding from the Forth Estuary and groundwater flooding from the Pinkie Burn. A number of significant flood events have been recorded (refer to Table 1.1), most recently in July 2010 and January 2014.

Date	Description of flood event
24th July 1888	Pluvial flooding, several shops in the High Street flooded
Sept 1891	River Esk flooded the Paper Mills and other factories, as well as nearby houses
12th Feb 1894	Buccleuch House in Fisherrow flooded to 0.45m, rail track submerged
July 1897	High Street and Shorthope Streets flooded
11th August 1901	Pluvial flooding of shops in High Street, New Street and Millhill
October 1907	Pluvial flooding on High Street and Newbigging to 0.6m. Streets and railway flooded near Newhailes Station
17th August 1920	River Esk flooded fields; one tier of iron bridge knocked down by a tree
Sept 1927	River Esk flooded Shirehaugh and other areas upstream. Footbridge at Shirehaugh swept away.
13th August 1948	Worst event on record. River Esk flooded Shorthope Street, Millhill, James Street, Eskside East & Eskside West. Many houses flooded to two feet
14th August 1966	Major flooding of Eskside West, Eskside East, Shorthope Street & Millhill
6th October 1990	Flooding from River Esk after debris retained water at structures
30th March 2010	Coastal flooding affecting properties along Fisherrow and the harbour
7th July 2012	Fields along River Esk flooded to depth of 2-3m
4th January 2014	Cycle path and Eskside West flooded

Table 1.1: Summary of recorded flood events

The Scheme is being promoted by East Lothian Council (ELC) under the Flood Risk Management (Scotland) Act 2009. Jacobs was appointed by ELC in December 2017 to develop a scheme for Musselburgh to reduce flood risk from all sources of flooding.

In Musselburgh, approximately 2,500 properties are at risk from the impacts of flooding from the 0.5% AEP (1 in 200 year) plus climate change design flood event from a number of sources, presented in Figure 1.1:

- **River Esk / Pinkie Burn fluvial flooding** – occurs when the flow volume within the watercourse exceeds the flow capacity of the channel, resulting in out of bank flow (mitigated by constructing direct defences along the riverbanks)

- **North Sea / Forth Estuary coastal (tidal) flooding** – flooding that results from high sea levels or a combination of high sea levels and storm conditions causing overtopping of existing coastal defences or the natural shoreline (mitigated by constructing new/higher direct defences along the coastline and/or a series of pumping station to deal with wave overtopping)

- **Pinkie groundwater flooding** – caused by water rising up from underlying impermeable ground, often coincident with adjacent high river levels and generally a contributing factor to flooding rather than the primary source (potential to be mitigated by installation of groundwater pumping stations)

- **Surface water (pluvial) flooding** – occurs when the volume of rainwater during a high rainfall event does not drain away through the existing drainage network (due to being overwhelmed) or soak into the ground, but lies on or flows over the ground instead

- **Secondary (post-scheme) flooding** – potential to occur when surface water becomes 'trapped' behind newly constructed flood defences and can no longer flow into the watercourse (mitigated through installation of surface water pumping stations)

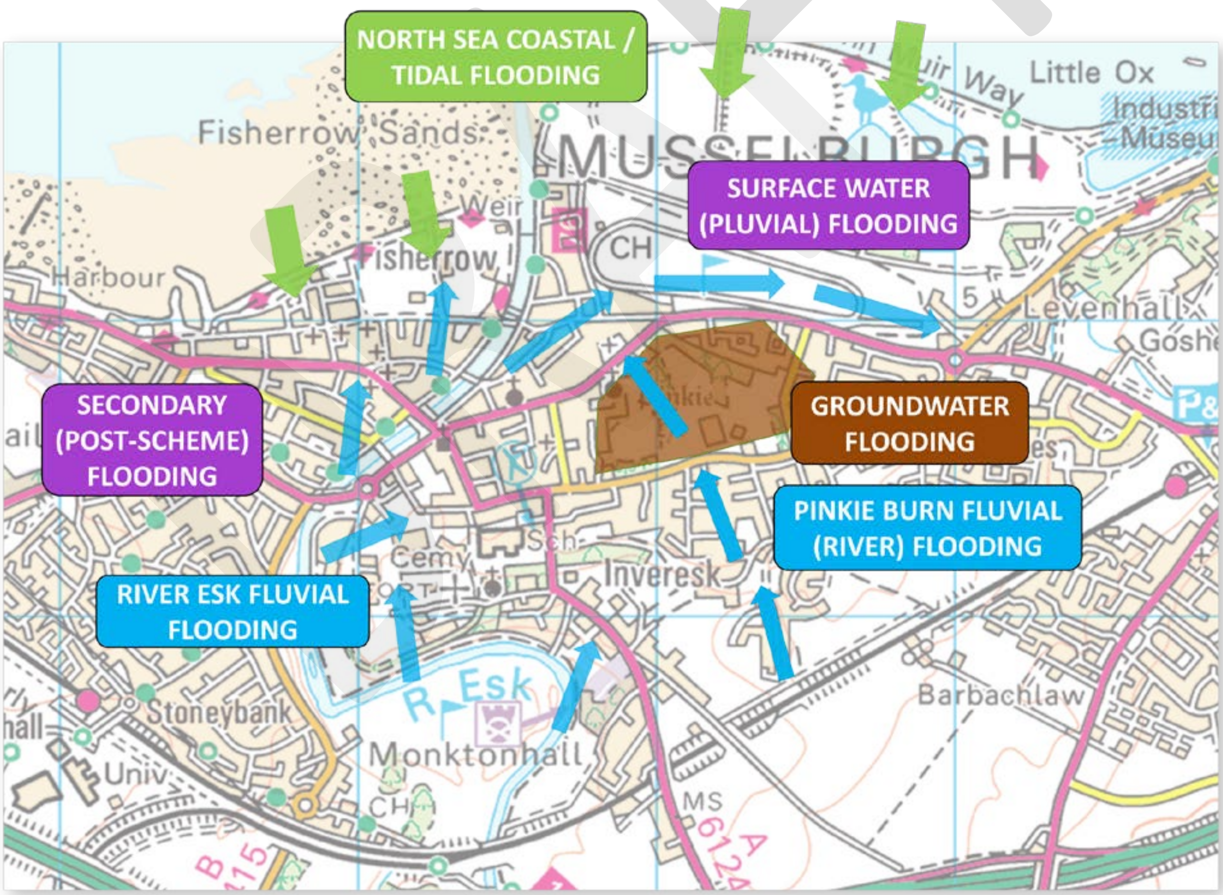

Figure 1.1: Sources of flood risk to Musselburgh

1.3 Scheme objectives

A total of 33 scheme objectives were established by ELC and clearly defined in the original tender documents.

1.3.1 General Objectives

1. To deliver the Scheme in accordance with the agreed Local Flood Risk Management Plan
2. To advance as many of the 'selected actions' identified within the Local Flood Risk Management Plan as possible and to a level that is reasonable through the project during the life-cycle of the project
3. To investigate and develop design solutions for the Scheme that are technically sound and the most fit for purpose
4. To advance the Scheme under the FRM, its 2010 Regulations and the appropriate guidelines for designing a formal flood protection scheme
5. To ensure that the Scheme complies with all legislative requirements
6. The Scheme will strive to consider all possible options for reducing the flood risk within the Option Appraisal Process
7. That where possible, the Scheme will strive to achieve multiple benefits
8. To advance a Scheme that tries to interpret the ethos of the FRM and which is developed in a consultative framework with other internal Council Officers, statutory stakeholders and those that have a real interest in the project

1.3.2 Economic Objectives

9. To ensure that the Scheme, as a minimum, achieves a Benefit Cost Ratio (BCR) equal to one for each flood cell within the economic analysis (and thereby for the Scheme as a whole). It is assumed that individual flood cells cannot cross-fund each other to achieve a basic 1.0 ratio
10. To ensure that a full analysis of BCR is undertaken during the Option Appraisal Process (during Stage 3 – the Option Appraisal Process) such that a full understanding of economic benefit and cost is achieved. The Scheme does not require to have the optimum BCR however economic benefit is to remain a key consideration
11. To reduce the exposure to economic damages from flooding to both residential and non-residential properties in Musselburgh
12. To choose a Scheme that is considered to be best value for money for the Council and the town of Musselburgh within consideration of both the short and long term

1.3.3 Hydraulic Objectives

13. To ensure that the Scheme delivers the maximum level of protection that is achievable within the context of the existing flood risk and all of these objectives. It is noted that the Scheme will be broken into stand-alone flood cells for design and economic appraisal purposes and it is assumed that the level of protection at each flood cell should be determined within the context of that flood cell, the impact of that cell's flood protection on other flood cells, and the town as a whole

14. That the Scheme will aspire to meet a level of protection to protect against the 0.5% AEP (1 in 200 year) flood event including an allowance for climate change

15. To ensure that the Scheme addresses all sources of flood risk

16. To ensure that any residual flood risks are fully documented and identified to the Council

17. That the Scheme will not materially increase the flood risk to another property through the delivery of flood protection to Musselburgh

1.3.4 Technical Objectives

18. To ensure that the Scheme is technically sound

19. That the Scheme will be designed (if determined necessary) with the flexibility to have its level of protection increased in the future (future flexibility)

20. To ensure that the Scheme is sustainable

21. To ensure that the Scheme addresses all appropriate Health & Safety during its design and delivery, including considerations for future operation and maintenance of the Scheme

22. To ensure that the Scheme complies with the obligations of BIM

1.3.5 Environmental Objectives

23. That the Scheme will achieve as a minimum a neutral impact on the environment

24. To ensure that the Scheme includes appropriate catchment and natural flood management (NFM) measures

25. To ensure that the Scheme considers the impact of climate change and includes appropriate provisions to mitigate any impact

26. To ensure that the Scheme considers in full, and includes for any appropriate measures to protect, the Firth of Forth and its protected statuses

27. To ensure that the Scheme consults with all appropriate environmental stakeholders

1.3.6 Social and Cultural Objectives

28. To ensure that the Scheme does not sever the town from its rivers (through the height / size of flood protection walls and / or embankments) in either the physical or visual sense

29. To ensure that the Scheme respects the cultural heritage of the town

30. To ensure that the Scheme takes account of people most vulnerable to flooding

31. To consult with stakeholders, businesses and the local population

32. To remove the real and perceived danger of a flooding event from the communities, individuals and businesses that lie in the floodplain

1.3.7 Regeneration Objectives

33. That where possible, and where not detrimental to the core objectives of the Scheme, the Scheme seeks to allow for the future regeneration of the town of Musselburgh through: (i) the flood protection provided by the Scheme; (ii) the confidence in investment it restores; and (iii) the engaged consultative process that also seeks to locate appropriate multiple benefits. It is noted that the Scheme will not be paying directly for regeneration but it is assumed that this can be achieved through intelligent use of existing flood protection money and the concept of multiple benefits.

1.4 Flood Protection Scheme Process

A simplified illustration of the flood protection scheme process is shown in Figure 1.2 below. This report is intended to summarise the findings, results and recommendations resulting from stages 2 and 3, leading to the outline design of the preferred scheme.

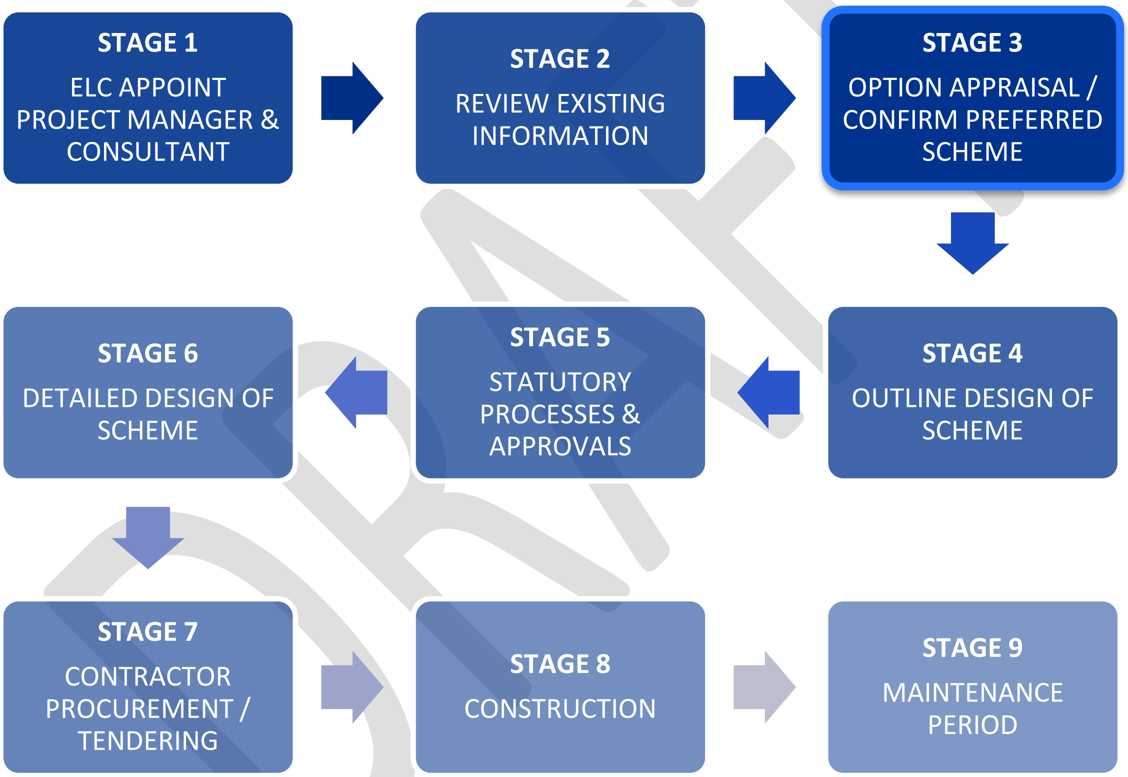

Figure 1.2: Summary of flood protection scheme process

1.5 Outline programme

The outline programme for the Scheme is presented in Figure 1.3 below. The option appraisal stage included a series of focussed meetings and workshops involving the project team as well as wider stakeholders and consultees, where appropriate. A key milestone in the option appraisal stage was the public exhibition held at the end of July (refer to section 2.3.4 for details).

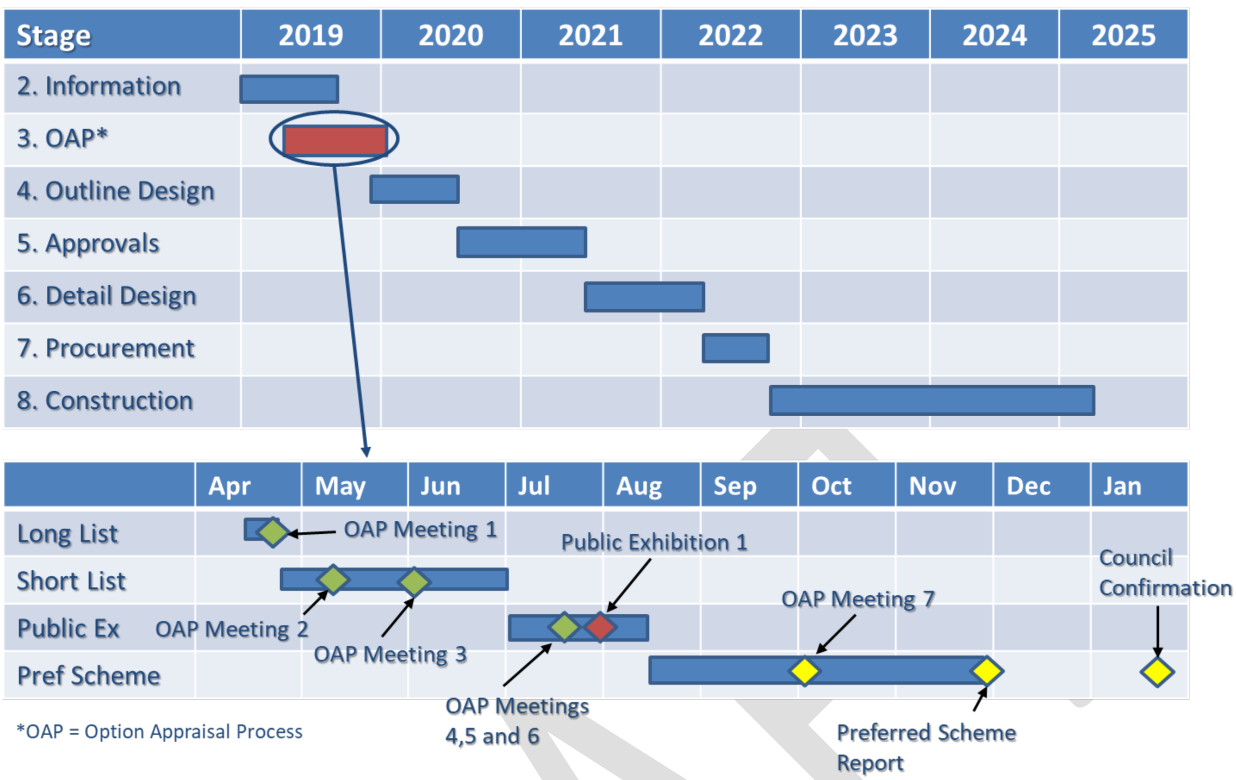

Figure 1.3: Outline programme

1.6 Existing information

An initial review of existing studies and available information was carried out during 2018 and early 2019 to determine the potential scope and programme for implementing additional studies, investigations and surveys required to inform the appraisal process. Information which was available and provided by ELC at tender stage included:

- records and photographs of historic flood events
- a series of historic flood studies and reports, the most recent of which was a flood study by Kaya Consulting Ltd in 2015 including an option appraisal and economic assessment to identify a preliminary preferred flood protection scheme for Musselburgh
- topographical and LiDAR survey data
- various environmental reports
- details of existing structures and related inspections
- public utility information

1.7 Additional information requirements

A review of the available data highlighted several gaps in information that were required to progress a robust option appraisal. It was noted at this early stage in the scheme development that some additional survey works may be abortive as particular options are discounted throughout the process, therefore the scope for any additional surveys was developed with this in mind. Table 1.2 summarises the data gathering activities/surveys that were carried out within stages 2 and 3 of the project, or are still ongoing at the time of writing this report:

Activity	Purpose	Status
Topographic survey	To augment the existing LiDAR data in accurately mapping floodplain flows in strategic areas and to provide the upgraded hydraulic model with accurate cross section information	Complete
Threshold survey	To provide accurate property threshold levels to inform the damage assessment and economic assessment	Complete
Ground investigation survey	To determine ground conditions in areas of likely flood protection works, potential technical feasibility of various construction methods and develop the outline design of the scheme	Complete
Phase 1 habitat and invasive plant survey	To establish the ecological baseline and identify prevailing habitat types, invasive plants, and suitable habitat and/or field signs of protected/notable species, which then informs requirements for more detailed surveys for specific habitat and protected/notable species	Ongoing
Review of potential service interactions	To determine potential clashes between preliminary scheme alignments and existing buried or overhead services	Ongoing
Land ownership	To understand parties that own land that may be affected by the implementation of any flood protection works and consult where necessary	Ongoing
SEPA Data Requests	To gather relevant data such as flood hazard and risk maps, mapping layers, supplementary hydraulic modelling data, hydrological data, River Basin Management Plan and morphology pressures data. Work with SEPA hydrology to determine updated gauge data	Ongoing

Table 1.2: Summary of additional data gathering

2. Option appraisal

2.1 Guidance and tools

In 2016, the Scottish Government published the document "*Flood protection appraisals: guidance for SEPA and responsible authorities"* which provides guidance on the economic, social and environmental aspects of options appraisal for actions promoted under the Flood Risk Management (Scotland) Act 2009. It provides methods for identifying and assessing positive and negative impacts and recommends a decision framework, based on the principles of sustainable flood risk management and consistent with the "*HM Treasury Green Book (2011)"*.

The guidance describes the process of option development, refinement and selection which should be carried out within a logical appraisal framework (refer to Figure 2.1).

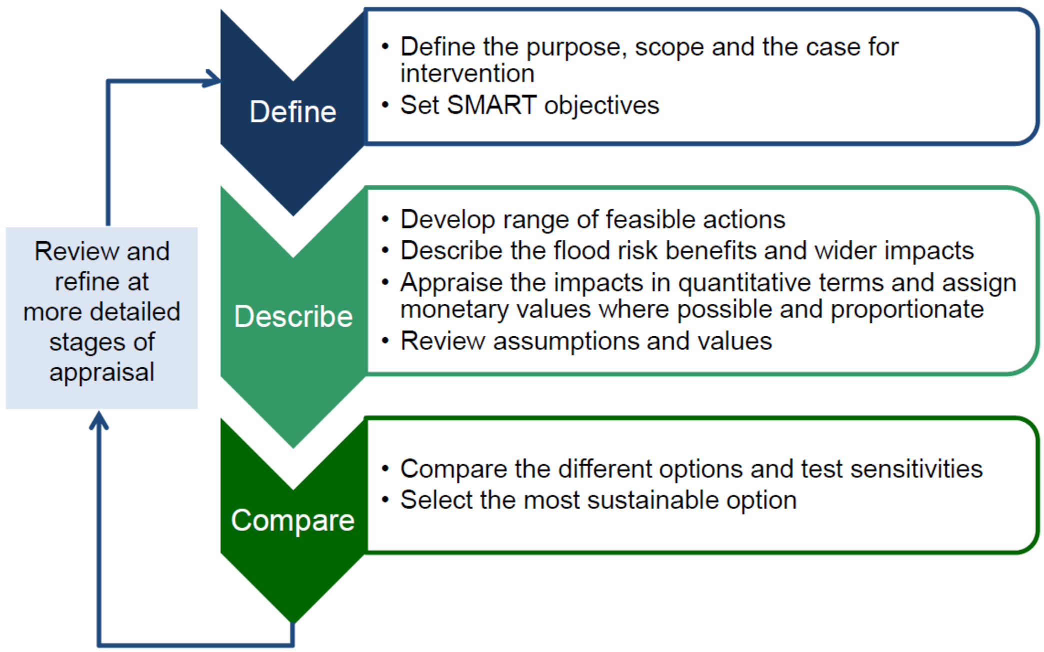

Figure 2.1: Summary of main stages in appraisal (reproduced from *Option Appraisal for flood risk management: Guidance to support SEPA and the responsible authorities)*

A wide range of factors should be considered in the decision-making process, some of which can be defined in monetary terms. The aim of an option appraisal is to identify and assess options that achieve flood risk management objectives whilst delivering other economic, social and environmental benefits. This informs the decision-making process and ultimately allows a preferred flood protection scheme to be determined.

2.2 Summary of approach to Musselburgh FPS

In line with the above guidance, an option appraisal strategy was developed for the Scheme which involved a series of workshops attended by key project team members as well as wider stakeholders, where appropriate. Figure 2.2 summarises the key stages in the option appraisal strategy for the Scheme.

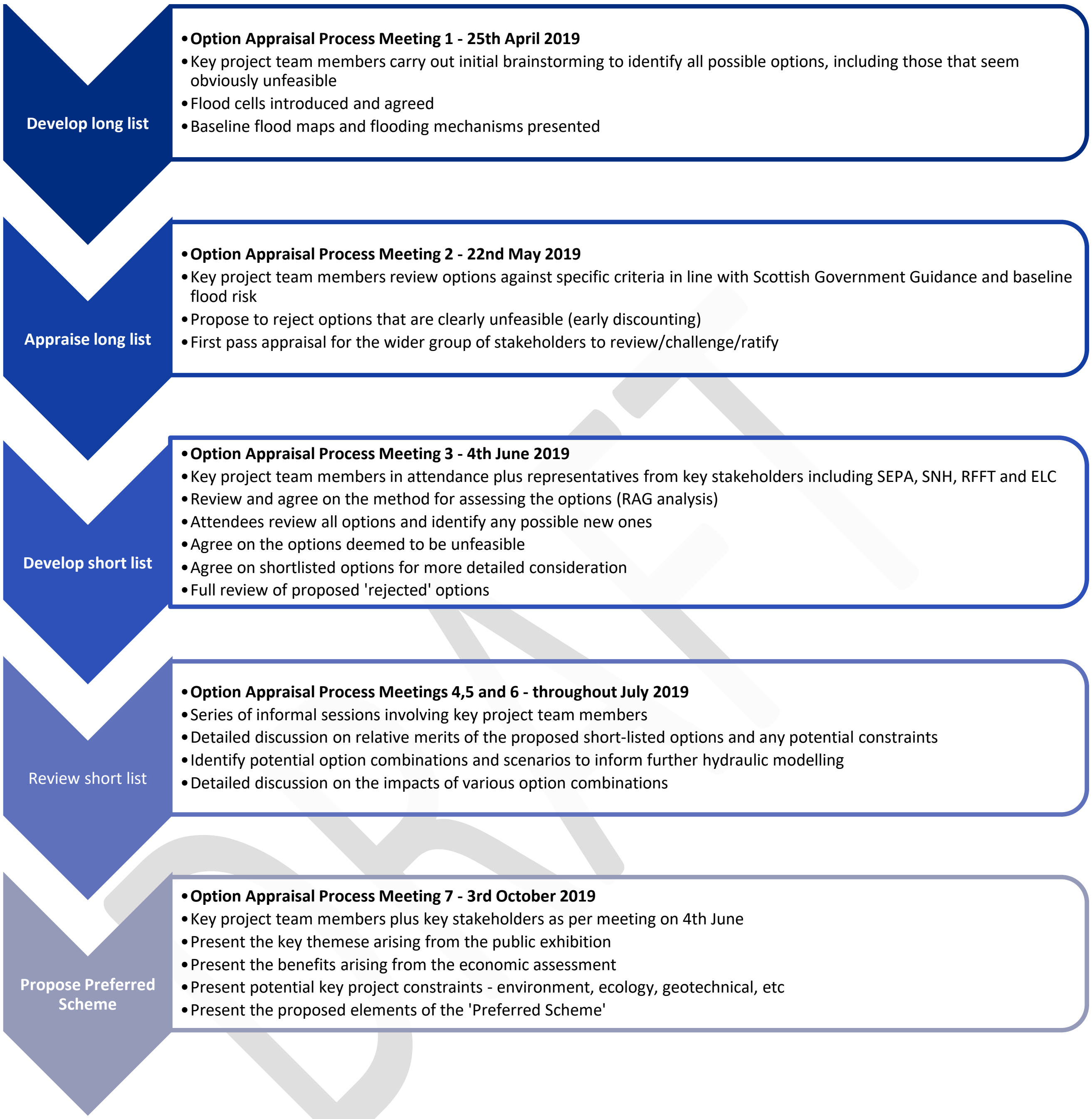

Figure 2.2: Overview of option appraisal strategy

2.3 Factors influencing the option appraisal

2.3.1 Economics

In order to determine an economically viable scheme for Musselburgh that demonstrates best use of public money, the results of an economic assessment will be a key driver behind the selection of preferred options. The benefit-cost analysis provides a transparent approach to decision-making involving comparison of options in terms of economic efficiency. In doing so, ensuring the total value of flood risk management interventions is maximised whilst also achieving the objectives set out for the Scheme.

Economic appraisal involves deriving an estimate of costs associated with the Scheme in conjunction with an assessment of flood damages to calculate a benefit-cost ratio (BCR). In some cases, it can be beneficial to calculate a range of BCRs for the Scheme as a whole, as well as a number of separate entities or flood cells as appropriate.

A key project objective (refer section 1.3) is to ensure that the Scheme, as a minimum, achieves a BCR equal to one for each flood cell within the economic analysis (and thereby for the Scheme as a whole). It is assumed that individual flood cells cannot cross-fund each other to achieve positive BCR.

2.3.2 Hydrology and hydraulic modelling

2.3.2.1 Standard of Protection

Flood protection structures are designed to be effective up to a specified flood likelihood or Standard of Protection (SoP). During flood events in excess of the design SoP, the defences will be overtopped, and flooding will occur. The chosen design SoP for a Scheme therefore determines the required defence height and / or capacity.

The magnitude of a flood event and SoP are generally referred to in terms of return period or annual exceedance probability (AEP). Return period is a measure of the rarity of a particular flood event i.e. the statistical average length of time between flood events of a similar size. It is important to note that this does not mean a particular flood event will only happen once every X number of years. Similarly, AEP is the statistical probability that a particular flood event will occur in any given year. For example, the 100-year return period flood can be expressed as the 1% AEP flood, which has a 1% chance of being exceeded in any year.

A key objective of the Scheme is that it will aspire to protect the town against the 0.5% AEP (1 in 200 year) flood event including an allowance for climate change. As such, the option appraisal (including option modelling and economic appraisal) has been progressed on this basis i.e. assuming that all areas at risk of flooding within Musselburgh shall be afforded protection up to the 0.5% AEP (plus climate change) flood event.

2.3.2.2 Hydrological assessment

The hydrological assessment includes the River Esk catchment with its two main water courses, the River South Esk and the River North Esk, and other minor tributaries, as presented in Figure 2.3. A combination of the FEH statistical method and the ReFH method is considered appropriate for flows estimation within this catchment, due to the presence of highly urbanised catchments. The Interim Report provided to SEPA in May 2019 presents the details of the hydrological analysis summarised herein and it is attached to the present Report in Appendix A.

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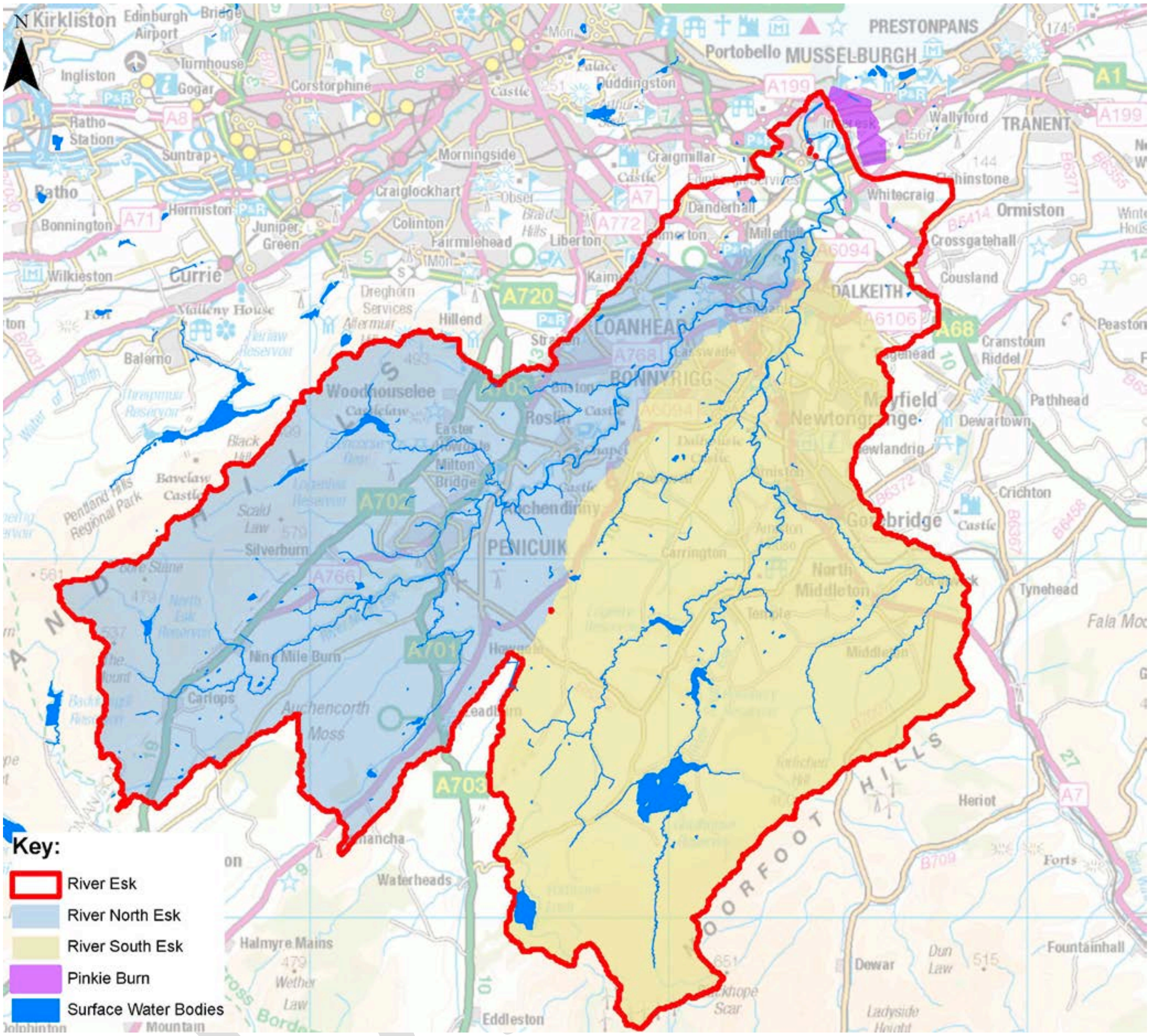

Figure 2.3: Catchment overview

The stage and flow data records were obtained from SEPA for the Dalmore (19004) and Dalkeith (19011) gauge stations (GS) along the River North Esk, the Prestonholm (19008) and Cowbridge (19021) gauge stations on the River South Esk and, finally, the Musselburgh (19007) gauge station on the River Esk.

The length of record for the gauge stations along the River North Esk are 14 years for Dalmore GS and 7 years for Dalkeith. Along the River South Esk, Prestonholm GS presents a record length of 26 years while Cowbridge GS has 27 years of gauge records. The Musselburgh GS presents the longest gauge record with 51 years of data. It is noted that SEPA continues to review the rating curve for the Musselburgh GS and there is a risk that that this review may impact on the design flows presented on this report.

A high-level assessment of the possible effects the cessation of mine water pumping has on flows pre- and post-1990 indicates that there is a significant increase in flows along the River South Esk and the lower River North

Esk, with resulting impacts on flows through Musselburgh. Therefore, for the purposes of this study, only AMAX data post-1990 was used for flow calculations for the affected stations.

The flow estimates for sub-catchments in the River North Esk and the River South Esk along with all the tributaries were routed through a 1D flow routing model. The aim of the hydrological routing model is to provide the upstream inflows to the Musselburgh hydraulic model and to provide an assessment tool for potential catchment management measures for reducing flows reaching Musselburgh, including NFM. The focus of the hydrological routing model was the timing of peak flows, as well as the peak flows themselves, which were later used as inflows of the hydraulic model for Musselburgh.

Climate change (CC) was considered for the fluvial sources, following the recommendations of SEPA guidance[1]. A High Emissions scenario projected for 2080 was assumed, with a 67% exceedance likelihood (unlikely to be exceeded), for the Forth area of Scotland, which resulted in a climate change allowance of 40% for peak flows.

Table 2.1 below summarizes the peak flows for different return periods for the River Esk, with and without the Climate Change Allowance of 40%.

[1] Flood Modelling Guidance for Responsibilities, Version 1.1, SEPA

Annual Exceedance Probability (AEP) [%]	Return Period	With no Climate Change [m^3/s]	With Climate Change Allowance (40%) [m^3/s]
50	1 in 2 year	72.27	101.18
25	1 in 5 year	96.20	134.68
10	1 in 10 year	116.37	162.92
5	1 in 30 year	147.48	206.47
2	1 in 50 year	165.45	231.63
1.33	1 in 75 year	179.92	251.89
1	1 in 100 year	191.23	267.72
0.5	1 in 200 year	222.43	311.40
0.2	1 in 500 year	270.49	378.69
0.1	1 in 1000 year	310.35	434.49

Table 2-1: Peak Flows at River Esk

2.3.2.3 Coastal Flood Risk

The tide conditions on the Firth of Forth influence the discharge conditions of the River Esk and present a flood risk to Musselburgh through the tide surge at its outflow and also through overtopping flows along its coastline during high wind events. A joint probability analysis of marginal extremes to determine pairs of water levels (which feed the downstream boundary condition of the Hydraulic Model) and wave heights (which lead to overtopping flows along the coastline) has been undertaken.

For the tide surge analysis, a baseline tidal curve has been created using the UKHO Admiralty Table harmonics for Leith. These harmonics have been analysed in SANDS (Jacobs' tool for Shoreline and Nearshore Data Analysis) to extract a predicted curve to coincide with measured data from July 2018 within the River Esk.

This baseline curve was then elevated using the surge profile for Leith (EA, 2011[2]) to produce tidal curves for each return period. Two sets of tide curves were produced:

[2] Environment Agency (2011). Coastal Flood Boundary Dataset – Surge Curves

1. The first using the marginal extreme water levels which is applied as the downstream boundary to the River Esk and applied where no wave overtopping occurs; and

2. The second applying the water level from the worst-case joint probability combination for each return period and creating a complementary time series of overtopping discharge across the tide. To develop the latter, a goal-seek exercise was undertaken using the overtopping equations to determine at what water level the overtopping discharge exceeded 0.1 l/s/m

Extreme water levels for point 3430 of the Coastal Flood Boundary Dataset (EA/SEPA, 2018[3]) were selected for the marginal extreme water levels while wind data record for Edinburgh Airport (from 01/01/1973 to 01/09/2018) has been analysed and hindcast to produce marginal extreme wave heights.

For Climate Change projections, UKCP18 RCP4.5 data was used, in line with SEPA Guidance. The 2080 Epoch was selected, under a 95th percentile emissions scenario which lead to a mean sea level rise of 0.455m. It is noted that at the time of writing, SEPA have yet to issue formal guidance on coastal climate change data. It is proposed that if the data is issued in advance of the Stage 4 hydraulic model development, the data will be incorporated into that updated model. If the data is not issued in accordance with the project programme, it is assumed that the figures and data used for the current fluvial and coastal hydrology will continue to be used. This approach requires discussion and agreement with ELC and SEPA.

Figure 2.4 and Figure 2.5 below present the resulting tide surge curves for the return periods analysed, considering present day scenario and for the 2080 epoch. These curves were adopted as the downstream boundary condition in the 1D hydraulic model as the River Esk discharges into the North Sea.

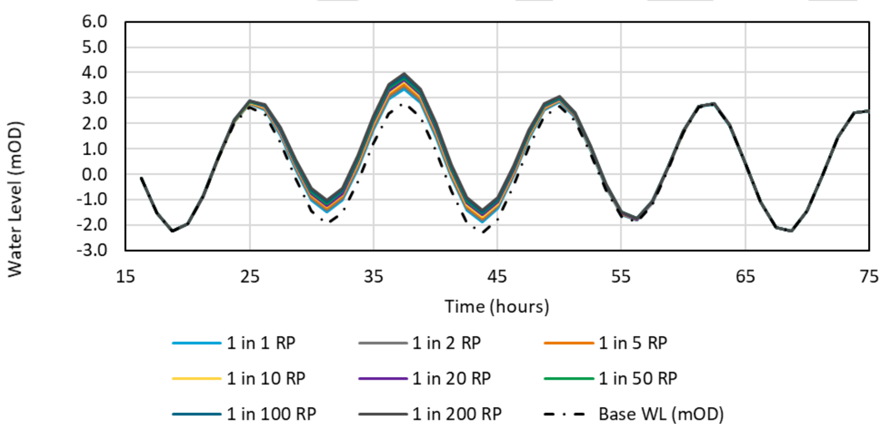

Figure 2.4: Tide surge curve for present day

[3] Environment Agency/SEPA (2018). Coastal Flood Boundary Dataset – Extreme Water Levels

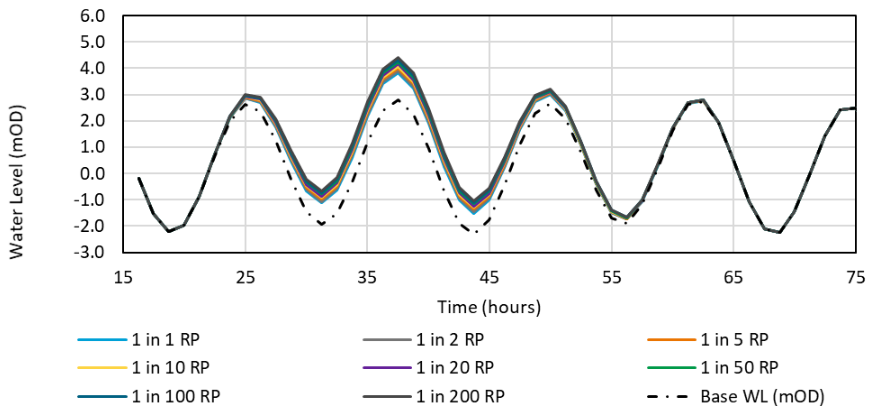

Figure 2.5: Tide surge curve for 2080

The design approach for coastal dikes and embankment sea walls described in Chapter 5 of EurOtop[4] (2018) was selected for the wave overtopping calculations.

The wave hindcasting for the Scheme follows the approach detailed in the CEM Part II Chapters 2 and 4. Wave heights are calculated using a Hindcasting tool developed by Jacobs. This tool uses four models to estimate the wave height resulting from a wind blowing across a fetch length. The four models are given below:

1. CEM: Part II, Chapter 4, page II-2-44;
2. Based on the JONSWAP spectrum, as reported in CIRIA C683: The Rock Manual, Eq. 4.67;
3. Based on the Sverdrup -Munk-Bretschneider model, as reported in CIRIA C683: Eq. 4.78 to 4.80 (variation of method 2);
4. Based on Wilson (1965) and Goda (2003), as reported in CIRIA C683: Eq. 4.84 to 4.85

Values based on the JONSWAP spectrum have been assumed the most suitable due to the proximity to the North Sea (Method 2 and 3). Method 3 gives the largest wave heights and thus this has been used for the joint probability analysis.

To determine the effect of wave breaking and shallow water on waves approaching the toe of the defence, the waves are transformed from the nearshore point to the toe of each structure. The method selected is described in Goda (2000)[5]. The toe level and foreshore slope at each location are estimated from the 50 cm resolution Lidar (Fugro, 2018) and topographic survey (Aird, 2018). The coastline was divided in four cross sections for the overtopping analysis, as shown on Figure 2.6, to represent observed changes in the top of beach / dune level.

[4] EurOtop (2018). Manual on wave overtopping of sea defences and related structures (2nd edition)
[5] Goda Y (2000). Random seas and design of maritime structures.

Figure 2.6: Cross sections along coastline of Musselburgh

Wave overtopping discharges in the present day and 2080 were calculated for eight return periods, ranging from 1 in 1 to 1 in 200 (100% AEP to 0.5% AEP), in line with recommendations from SEPA.

Under present day scenarios, wave overtopping is less than 0.1 l/s/m across all return periods for cross-sections 1 and 2 (west of Fisherrow Harbour and immediately east of Fisherrow); this is considered negligible and is not reported below. Discharge remains relatively low under all return periods as reported in Table 2.2.

Return Period	1 in 1	1 in 2	1 in 5	1 in 10	1 in 20	1 in 50	1 in 100	1 in 200
Cross-section 3	0.16 l/s/m	0.30 l/s/m	0.60 l/s/m	1.10 l/s/m	1.80 l/s/m	3.33 l/s/m	4.82 l/s/m	7.28 l/s/m
Cross-section 4	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	0.15 l/s/m	0.31 l/s/m	0.67 l/s/m	1.07 l/s/m	1.66 l/s/m

Table 2.2: Overtopping discharge – present day

Under 2080 wave and water level conditions, the predicted overtopping is greater across all cross-sections with a significant amount of overtopping occurring at cross-section 3.

Return Period	1 in 1	1 in 2	1 in 5	1 in 10	1 in 20	1 in 50	1 in 100	1 in 200
Cross-section 1	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	0.12 l/s/m	0.61 l/s/m	1.72 l/s/m	5.12 l/s/m
Cross-section 2	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	<0.1 l/s/m	0.54 l/s/m	2.02 l/s/m	7.69 l/s/m
Cross-section 3	2.28 l/s/m	4.01 l/s/m	7.49 l/s/m	11.39 l/s/m	15.99 l/s/m	27.89 l/s/m	41.35 l/s/m	61.82 l/s/m
Cross-section 4	<0.1 l/s/m	<0.1 l/s/m	0.24 l/s/m	0.50 l/s/m	0.93 l/s/m	1.83 l/s/m	2.76 l/s/m	4.07 l/s/m

Table 2.3: Overtopping discharge - 2080

2.3.2.4 Hydraulic modelling

A 1D-2D hydraulic model was constructed, using Flood Modeller software, to aid understanding of flood mechanisms and flood extents in Musselburgh for a Baseline Scenario. This hydraulic model, referred to as "Model A", extends from the A1 bridge across the River Esk to its outflow into the North Sea. Flood Modeller version 4.5 was used, with a 2m grid size in the 2D domain.

This hydraulic model was developed from a new bathymetric survey carried out by Aird in 2018. Physical data defining the river channels in the model have been derived from river cross section surveys and other site inspections conducted during model development. The 2D representation of floodplain in the model has been derived from a detailed LiDAR survey with a precision of 0.5m, flown in 2018 by Fugro. The aerial data was corroborated and supplemented with topographic survey data.

The channel roughness is represented through Manning's roughness coefficient, with a proposed value of 0.035 for the river bed. The floodplain roughness is a function of the type of coverage and structures across the model. To represent the variable roughness across the model area, the codes from the MasterMap® were used to assign Manning's coefficients to the floodplain.

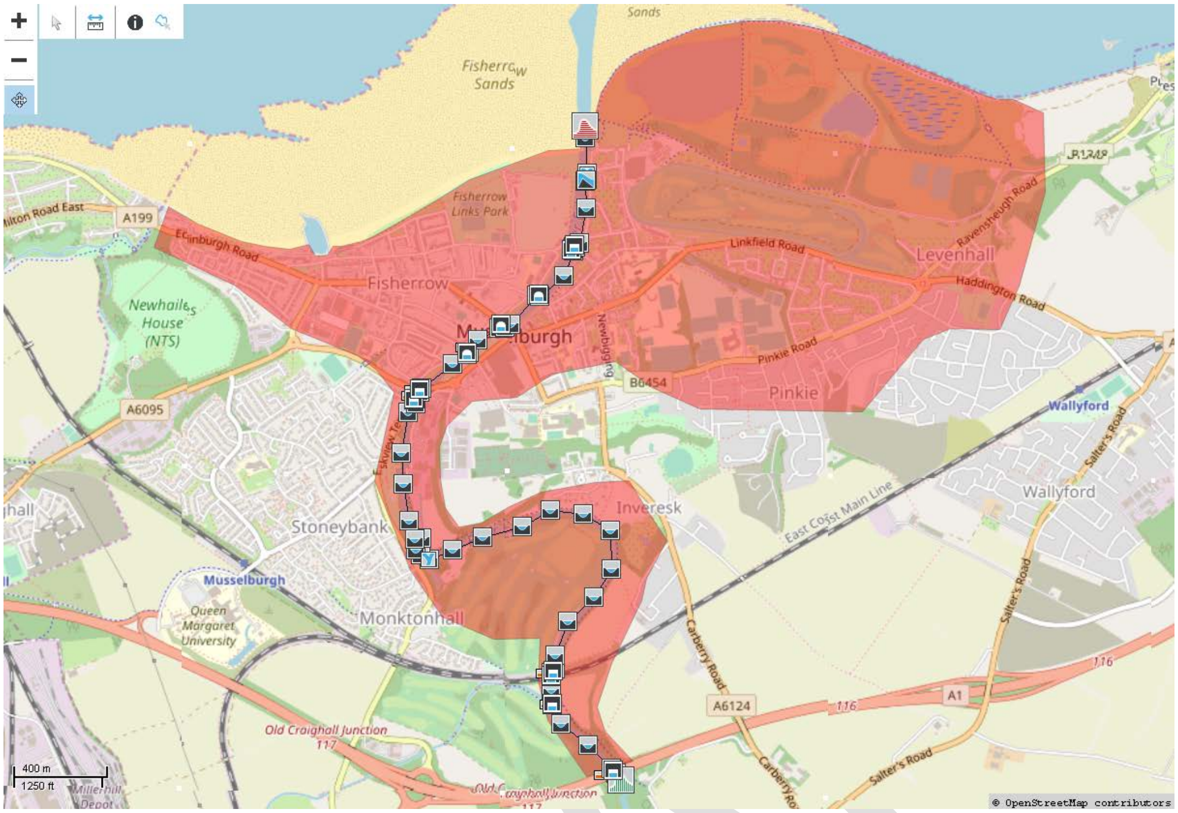

Figure 2.7: Hydraulic model schematization for River Esk at Musselburgh and active area of the 2D model

From the topographic survey carried out in 2018 the following structures across the River Esk were represented in the 1D model:

- A1 Road Bridge
- Footbridge upstream of the Railway
- Railway Bridge
- Footbridge downstream of the Railway
- Esk Weir (Inveresk)
- Ivanhoe (Cotton Mills) Footbridge
- Station (OliveBank) Road Bridge
- Old Roman Bridge
- New (Rennie) Stone Bridge,
- Shorthope Street (Millhill) Footbridge
- SSEB (Electric) Bridge
- Goose Green (New Street) Footbridge
- Goose Green weir

The main boundary conditions into the hydraulic model were represented through the River Esk inflows, estimated through a comprehensive hydrological assessment of the catchment on the upstream end, and through tidal curves and overtopping flows along the coastline on the downstream end.

The baseline scenario represents the existing conditions in the catchments. This scenario was tested under several return period and considering climate change effects as described above. The full set of results for the Baseline Scenario can be found on Appendix B.1.

Since Musselburgh is affected both by fluvial and tidal flood risk, the combined effects of these two flooding sources are presented by means of blending the flood grids for the same return period. As an example, the 0.5% AEP (1 in 200 year) plus CC blended map is presented on Figure 2.8. This map overlaps the effects of a 0.5% AEP plus CC event from the River Esk (i.e. fluvial flooding, under low tide conditions) with the 0.5% AEP plus CC event from the North Sea (i.e. tidal flooding with low flow conditions in the Esk), but not considering the joint effect of these two extreme events.

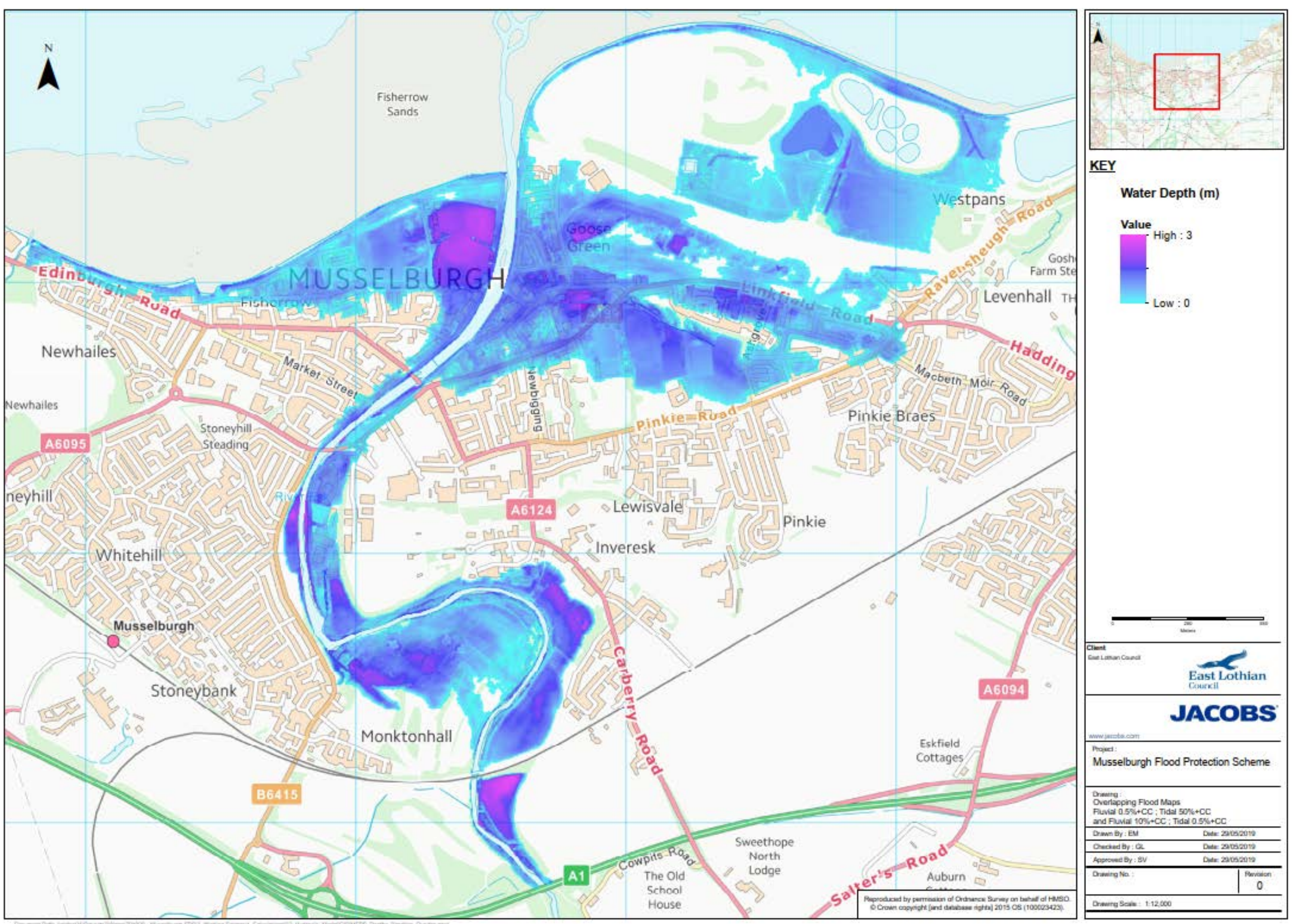

Figure 2.8: Overlap map for 0.5% AEP plus Climate Change for Fluvial and Tidal flood risk at Musselburgh

Animations from the 1D/2D model were also analysed to identify the flooding mechanisms across Musselburgh from the River Esk and the North Sea.

The baseline results from the hydraulic model formed the basis of the economic assessment of impacts from fluvial and tidal flooding in Musselburgh.

The bridges were also tested under blockage scenario, given there is evidence that debris and other floating logs can be trapped on these structures during a flooding event. Figure 2.9 below is an example of debris trapped on Rennie Bridge during the 1948 flood event.

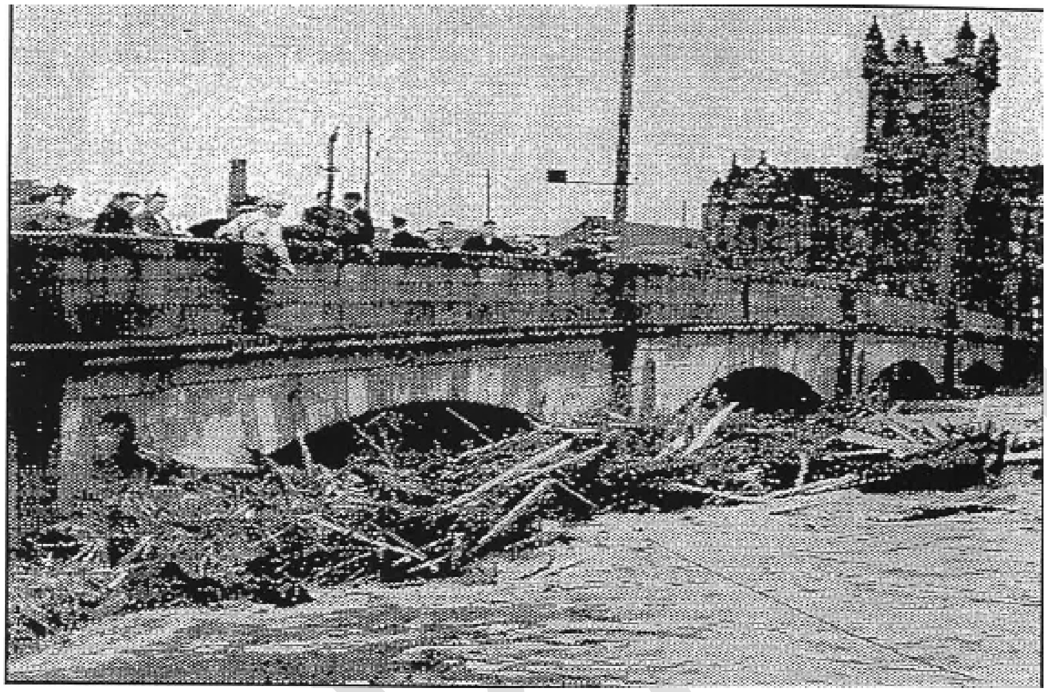

Figure 2.9: Flood water at the Rennie Bridge on the River Esk in Musselburgh on the 12th August 1948

Two sets of blockage were tested, the first one (SET 1) concentrated the higher blockage ratios on the New and Shorthope bridges, while the SET 2, assumed a 20% of blockage ratio at New Bridge (as per the observed blockage during 1948 flood event) and the ratios for the other structures were calculated as a function of the relative open area in comparison with the New Bridge.

Bridge	Blockage Ratio Set 1	Blockage Ratio Set 2
Ivanhoe	5%	25%
Olive Bank	10%	18%
Old Roman	20%	15%
New (Rennie)	30%	20%
Shorthope	30%	25%
Electric	10%	21%
Goose Green	5%	13%

Table 2-4: Blockage sets tested in the hydraulic model

Through hydraulic simulations it was found that Blockage SET 2 produced the highest water levels along the River Esk, therefore was selected for future blockage scenario tests in order to adopt a conservative approach.

2.3.2.5 Freeboard / residual uncertainty allowance

In February 2017, the Environment Agency (EA) published '*Report SC120014 - Accounting for residual uncertainty: updating the freeboard guide*' which aims to supersede the Environment Agency's *Fluvial Freeboard Guidance Note published* in 2000 (W187). The new guidance presents two methods for calculating 'residual uncertainty allowance' (previously called freeboard).

The current advice on using the new guidance from the EA is:

- Projects underway should not revise their cases to account for this new guide
- New projects can either continue using W187, or can trial the new approaches in the research report as part of the pilot study programme
- Developers should continue flood risk assessments in accordance with local advice

A review of the new guidance was undertaken and a theoretical fluvial freeboard value was determined using the 'development planning stage' method outlined in the report (refer to Appendix B.2). This is the more concise method of the two presented in the report and was considered appropriate for high-level analysis.

As the new guidance is still being refined and subject to updates following an ongoing pilot study by the EA, a traditional freeboard analysis was also carried out using the original W187 guidance for comparison. Refer to Appendix B.2 for details.

The results of the traditional and new analysis methods yielded fluvial freeboard allowances of 587mm and 600mm respectively. Therefore, a standard freeboard allowance of 600mm was added to all fluvial flood defence heights.

The determination of an appropriate freeboard allowance for coastal defences is not covered in the traditional EA guidance. A value was established using the simplified method contained within the new guidance, which involves crudely scoring the quality of the input data, coastal hydrology and modelling. This yielded a minimum freeboard of 450mm for coastal defences. However, recent SEPA guidance stipulates that a minimum of 600mm freeboard should be adopted for coastal defences, hence the higher of the two recommended values was adopted.

2.3.3 Engineering

A high-level review of technical information and potential engineering constraints was undertaken to determine whether any of the potential flood risk management options might impact on or be affected by:

- Ground conditions such as permeable ground or high/variable bedrock levels
- Existing structures such as walls, weirs, bridges and culverts
- Potential clashes with existing services and utilities

2.3.3.1 Ground conditions and geotechnical risks

In late 2018, a ground investigation survey was undertaken to inform the development of a preferred scheme for Musselburgh and ascertain ground and groundwater conditions along the River Esk, the Musselburgh foreshore and the Pinkie Burn. The key aims of the investigation were to:

- Provide information on the nature of the drift deposits, particularly the extent and thickness of any loose / low strength deposits and the presence of made ground;
- Provide information on the depth to and nature of the bedrock;
- Provide geotechnical parameters for future flood alleviation design;
- Investigate the presence of possible underground shallow mine workings within the underlying bedrock;
- Investigate the condition of existing training walls adjacent to the River Esk;
- Provide information on the ground gas and groundwater regime; and
- Provide chemical analysis data for soils (including made ground) and/or groundwater encountered at the site.

The investigation comprised the following works:

- 15 no. cable percussion boreholes to a maximum depth of 35m below ground level;
- 13 no. rotary cored follow-on drillholes within cable percussive boreholes to a maximum depth of 65m below ground level;
- 2 no. hand excavated observation pits adjacent to the existing training walls of the River Esk to a depth of 1.2m below ground level to identify the nature of the material behind the walls, the condition of the walls and the footing if exposed in the pit;
- 3 no. machine excavated trial pits to a maximum depth of 3.0m below ground level;
- 15 no. 50mm standpipes installed within boreholes;
- 7 no. electronic data loggers installed within the proposed exploratory holes and 3 no. electronic data loggers installed within existing wells;
- In-situ testing, groundwater monitoring, groundwater sampling and permeability testing within exploratory holes;
- Laboratory testing of soil samples to determine geotechnical parameters;
- Environmental testing and chemical testing to determine levels of contamination in soil, soil leachate and groundwater samples; and
- Preparation of a Ground Investigation Report

The results of the ground investigation works were reviewed in the context of the anticipated flood protection scheme options. From this, a geotechnical risk register, associated plan and cross-sections were prepared to identify significant geotechnical and geo-environmental hazards that may influence the selection of preferred scheme components.

Table 2.5 contains a summary of the geotechnical hazards identified and key locations where these are present. Appendix C.1 contains the full geotechnical risk register (GRR), associated plan and cross-sections which includes details of the potential impacts and recommended control measures.

Potential Geotechnical Hazard	Summary of key locations present
High or variable rockhead	Estuary right and left hand banks - Goose Green residential area and Loretto playing fields Eskmills Industrial Estate Upstream of Esk Weir at Golf Course
Potential for shallow coal seams	Inveresk area – south of the Inveresk Estate Loretto sports grounds – River Esk left hand bank
Artesian groundwater	Pinkie St. Peter's School sports grounds
Soft ground	River Esk Estuary mouth, both left and right hand banks
Potential contaminated soil, groundwater and asbestos	Goose Green residential areas Loretto sports grounds Pinkie area – upstream of Linkfield Road culvert inlet Eskmills Industrial Estate
Ground gas	River Esk Estuary mouth – both left and right hand banks

Table 2.5: Summary of geotechnical hazards and key locations

The presence of the above geotechnical hazards will require further review and analysis at the outline and detailed design stages with a view to recommending further investigations and analyses. However, in the context of the scheme it is not considered likely that these risks are potential 'show-stoppers' and as such can be adequately mitigated through additional surveys and use of appropriate forms of construction.

2.3.3.2 Existing structures

A review of available information on existing structures within the study area was undertaken to identify those that could be impacted by the Scheme. A table and associated plan details the owner and how those structures might be affected. The results are summarised in Table 2.6 and the associated plan is contained in Appendix C.2.

Structure/Asset Name	Owner	Potential Scheme Impacts
Eskmills Weir (incl. fish ladder and sluice gate)	East Lothian Council	Requirement to carry out improvement and maintenance works as part of the Scheme
Goose Green Weir	East Lothian Council	Requirement to carry out improvement and maintenance works as part of the Scheme
Mill Lade outlet 1	East Lothian Council	Protect during construction, formalise outfall headwall structure, pass through flood defence and fit with non-return flap valve

Structure/Asset Name	Owner	Potential Scheme Impacts
Mill Lade outlet 2	East Lothian Council	Protect during construction, formalise outfall headwall structure, pass through flood defence and fit with non-return flap valve
Mill Lade / Pinkie Burn outlet	East Lothian Council	Protect during construction, formalise outfall headwall structure, pass through flood defence and fit with non-return flap valve
Ivanhoe (Cotton Mills) Footbridge	East Lothian Council	Additional structural survey and site investigation. Flood defences to be tied into existing eastern bridge abutment
Station Road (Olive Bank) Road Bridge	East Lothian Council	Additional structural survey and site investigation. Flood defences to be tied into existing bridge abutments / wing walls (both upstream and downstream on right bank, downstream only on left bank)
Roman Bridge	East Lothian Council	Additional structural survey and site investigation, major reconfiguration of bridge approaches to accommodate flood defences, potential stairs/ramps and flood gates (dependent on preferred option) Possible bridge strengthening works required
New (Rennie) Stone Bridge	East Lothian Council	Additional structural survey and site investigation, major reconfiguration of bridge approaches to accommodate flood defences, potential stairs/ramps and flood gates (dependent on preferred option) Possible bridge strengthening works required
Shorthope Street Footbridge	East Lothian Council	Additional structural survey \and site investigation if bridge to be retained, possible flood gate and strengthening works Potential removal and replacement of entire bridge structure to above flood defence level Flood defences to tie in with bridge both upstream and downstream on both banks
SSEB (Electric) Bridge	Scottish Power	Additional structural survey and site investigation if bridge to be retained, possible flood gate and strengthening works Potential removal and replacement of entire bridge structure to above flood defence level Flood defences to tie in with bridge both upstream and downstream on both banks
Goose Green (New Street) Footbridge	East Lothian Council	Additional structural survey and site investigation if bridge to be retained, possible flood gate and strengthening works Potential removal and replacement of entire bridge structure to above flood defence level Flood defences to tie in with bridge both upstream and downstream on both banks
Murdoch's Green Sea Wall	East Lothian Council	Scheme may rely on continued operation of this structure for the design life of the Scheme Additional structural survey and site investigation if structure to be modified and incorporated in the Scheme
Lagoons Sea Wall	Scottish Power	Scheme may rely on continued operation of this structure for the design life of the Scheme Additional structural survey and site investigation if structure to be modified and incorporated in the Scheme
River Esk Training Walls	East Lothian Council	Potential removal and replacement of entire structure

Structure/Asset Name	Owner	Potential Scheme Impacts
		Additional structural survey and site investigation if structure to be retained and incorporated in the Scheme
Fisherrow Promenade Ad-Hoc Existing Walls & Embankment	East Lothian Council	Potential removal and replacement of entire structure Additional structural survey and site investigation if structure to be retained and incorporated in the Scheme
Golf Course/Monktonhall Embankment	Musselburgh Golf Club	Potential removal and replacement of entire structure Additional structural survey and site investigation if structure to be retained and incorporated in the Scheme
Mill Lade Grates	East Lothian Council	Potential removal and replacement of entire structure Additional structural survey and site investigation if structure to be retained and incorporated in the Scheme
Mill Lade Sluice Gate	East Lothian Council	Potential removal and replacement of entire structure Additional structural survey and site investigation if structure to be retained and incorporated in the Scheme
Common Riding Gabions	East Lothian Council	Requirement to carry out improvement and maintenance works as part of the Scheme
Demountable Barriers	East Lothian Council	Replaced by permanent flood defences incorporating flood gates (dependent on preferred option for bridges)
Fisherrow Harbour	Fisherrow Harbour Seafront Association	Scheme may rely on continued operation of this structure for the design life of the Scheme Additional structural survey and site investigation if structures to be modified and incorporated in the Scheme

Table 2.6: Summary of potential scheme impacts on existing structures

2.3.3.3 Services and utilities

A high-level review of public utility drawings provided by ELC was undertaken to determine those potentially affected by flood protection measures. The following data was available:

- BT Openreach – plans dated April 2016
- Scottish Power Energy Networks (SPEN) – plans dated April 2016
- Scotia Gas Networks (SGN) – plans dated April 2017
- Scottish Water (water supply) – plans dated April 2016
- Scottish Water (foul water) – plans dated March 2015

This review was carried out to determine whether costs may be incurred through the need to protect or divert existing services to facilitate construction of the Scheme. A five metre offset either side of the anticipated flood defence alignment was overlain with a digitised version of the utility plans to identify potential clashes. Refer to Appendix C.3 for details. The results by flood cell are summarised in Table 2.7.

Flood Cell	Scottish Water (mains supply)		Scottish Water (foul)		SGN		SPEN		BT	
	Diversion (length, m)	Protection / crossing (no.)	Diversion (length, m)	Protection / crossing (no.)	Diversion (length, m)	Protection / crossing (no.)	Diversion (length, m)	Protection / crossing (no.)	Diversion (length, m)	Protection / crossing (no.)
1	-	-	-	-	-	-	-	-	-	-
2	118	-	671	2	-	3	114 (HV) 76 (LV)	-	-	1
3	61	1	806	1	-	10	206 (HV) 58 (LV)	2	1290 (UG)	5
4	108	1	873	6	1226	7	194 (LV)	6	675 (UG)	4
5	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-
Total	287		2350		1226		648		1965	

Key:
MP medium pressure blue
LP low pressure red
HV high voltage red
LV low voltage brown
UG underground
OH overhead

Table 2.7: Summary of potential service diversions

As the scheme progresses, there may be scope to align the flood defences so as to reduce the need for service diversions. This will depend on other factors such as the presence of roads, footpaths, trees and other structures. The accuracy and precision of utility drawings can vary considerably, therefore there will likely be a need to carry out ground-truthing or ground penetrating radar exercises during the design phase to confirm the location and depth of existing services.

2.3.4 Consultation

Consultation and community engagement are a vital part of the FPS process, allowing those potentially affected by the Scheme and within the local community an opportunity to:

- Understand the process and what is being proposed;
- Help explore ways in which the Scheme can bring value to the town as well as identify opportunities for multiple benefits for other stakeholders;
- Identify which potential options would work best within a local context;
- Help shape potential solutions and have a say on the final preferred scheme

In a local context, the success of the Scheme can only be judged on the reaction of those who are directly or indirectly affected by the proposals, such that the Scheme is taken forward through formal approval with as few objections as possible, with the ultimate aim of avoiding the call-in of the Scottish Ministers.

To date, a number of key consultation exercises have been carried out, with many other planned as the project progresses. Refer to Table 2.8 for details.

Consultation exercise	Date	Purpose	Key outcomes / considerations
Environmental Working Group	3rd October 2018	Provide an initial briefing on the Scheme, discuss the environmental constraints and consider the consents, approvals and licences that will apply	To set up additional focussed working groups and to acknowledge that the scheme could have a significant adverse environmental impact
Public engagement event No1	26th February 2019	To introduce the community the Scheme and the project team, provide an update on progress to date and receive information from the public in relation to flooding	The event was well attended with a reasonable amount of very useful data obtained
Option Appraisal Process Meeting 3	4th June 2019	Key stakeholder meeting to review and agree on the method for assessing the options	Agreement on the options deemed to be unfeasible and the shortlisted options for more detailed consideration.
Coastal and Watercourse Working Group Mtg No1	16th July 2019	To develop a greater understanding of the specific coastal and watercourse environmental risks and opportunities which may impact the Scheme	Incorporation of green spaces with direct defences, Consideration of the impact of weir removal, maintenance of river banks
Roads, Access & Structures Working Group Mtg No1	17th July 2019	To develop a greater understanding of how the current feasible options will integrate with the roads, footpaths, bridges and other structures	Consideration of what impact flood defence walls would have on existing bridges - undermining / scouring of bridges.
Planning, Landscape and Heritage Working Group Mtg No1	18th July 2019	To develop a greater understanding of the specific planning, heritage and landscape risks and opportunities which may impact the Scheme	The key consideration from this meeting was related to the impact of the Scheme on the Roman and Rennie Bridges. The impact of weir removal was also considered.
Public Exhibition No1	30th and 31st July 2019	Provide information on flood risk to Musselburgh, outline the FPS process, present the option appraisal process and outcomes	The event was well attended with a significant amount of positive feedback. From the feedback provided, 85 (94.4%) indicated their support to the scheme. Most people that responded to the questionnaire would prefer to see set-back defences on the river and lower wall heights at the coast. The main themes of the feedback relate to the visual impacts of the defences, access to the river and beach and consideration being given to the use of upstream storage.
Option Appraisal Process Meeting 7	3rd October 2019	Stakeholder meeting to present the key themes arising from Public Exhibition No1, the results of the economics assessment, key project constraints and the proposed elements of the Preferred Scheme.	Agreement on the process followed to develop the preferred combination of options and the various scenarios modelled Identifying multiple benefit opportunities for the Scheme

Table 2.8: Summary of consultation exerciseA copy of Public Exhibition No 1 Report is included in Appendix D.

2.3.5 Environment

2.3.5.1 Preliminary Environmental Appraisal

The Preliminary Environmental Appraisal Report (PEAR) was produced 2018/2019 to inform the options appraisal process. Given the sensitivity of Musselburgh's natural and built environment (including nature conservation and heritage designations of international and national importance) and the proximity of residents to the anticipated scheme alignment, there is a potential for the construction and operation of the scheme to generate significant environmental impacts.

Table 2.9 below is a summary of the preliminary environmental constraints and opportunities exercise undertaken for the scheme and includes some outline recommendations which were used to inform the options appraisal process.

A copy of the PEAR is included in Appendix E.

Topic	Main constraints and opportunities	Recommendations
Population, Recreation and Amenity	Disturbance to important greenspaces and footpaths during construction. Opportunity to improve riverside setting, amenity and recreation opportunities.	1. Set-back embankments where possible. 2. Integrate sensitively into historic townscape and shorefront (engage with urban landscape architects at early stage). 3. Incorporate recreation / amenity features (e.g. decorative landscaping, raised walkways, lateral DDA compliant ramps, glass balustrade, include street furniture, consider outdoor exercise facilities, consolidate heritage interpretation). 4. Support sustainable transport strategy: ensure design incorporates outline plans for sustainable transport network (4 m wide shared-use cycle/footpath).
Biodiversity	INNS widespread throughout. Some protected species features. Firth of Forth SPA/SSSI.	1. Avoid areas of ancient woodland along the riverside. 2. Appraise opportunities to effectively manage INNS in long-term. 3. Improve biodiversity and wildlife connectivity (e.g. plant native trees, improve river banks, improve ecology at shorefront).
Noise & Vibration	Some constraints associated with listed features and potential impacts during construction.	1. Avoid aligning defences close to historic features (listed buildings and old bridge) where possible.
Landscape and Visual Amenity	Important historical designations (scheduled areas and Listed features) and riverside environment (amenity).	1. Engage urban landscape architect at design to develop sensitive design / alignment in relation to LVIA. 2. Explore opportunities to improve riverside setting and functionality and to improve views.

Topic	Main constraints and opportunities	Recommendations
Cultural Heritage	Several constraints associated with multiple cultural heritage designations including likely archaeological remains. Some opportunity exists to reveal archaeology through implementation of archaeological investigations and to potentially improve the setting of features through sensitive design.	1. Engage early with HES on scheduled monument / Cat. A Listed features. 2. Engage early with Council heritage and stakeholders on Cat. B/C Listed features, Conservation Area impacts and archaeology). 3. Assess results of archaeological investigations for GI to inform constraints / opportunities.
Water Environment	In-river working risks contamination and adverse effect on WfD status of Esk. The scheme has a potential to improve fish migration conditions through removal of fish barriers (i.e. weirs) and improve morphology of the local watercourses and increase the extent of natural floodplain, by setting back flood walls and/or embankments.	1. Set-back defences where possible to minimise contamination risk of watercourse and disturbance to aquatic habitats and species during construction. 2. Appraise opportunities to improve WfD status of River Esk, e.g. by removing fish barriers.
Coastal Processes	Restoring the dune system along Fisherrow to provide flood risk protection is not considered feasible. There are no particular constraints associated with developing more traditional defences toward the rear of the beach / dune system (i.e. sea wall or embankments).	1. Set-back embankments or walls. 2. Consider identifying where partial improvements to the existing beach / dune system may be achieved (e.g. add boardwalk, improve interpretation).
Land-use, Geology and Contamination	Sites of potential land contamination present both constraints (where high risk of contamination of watercourses during works) and opportunities (where land can be remediated, or pathways blocked)	1. Consider GI results at early stage to avoid contamination risk. 2. Avoid Grade 1 agricultural land to south of study area.
Air Quality and Climate	There is some potential for the scheme to design-out excessive concrete use (and associated CO2 equivalent emissions) by employing natural flood management, flood storage or embankments over flood walls.	1. Use embankments and S / NFM over walls where possible.
Traffic and Transport	Opportunity to coincide design / works with proposed Active Travel Masterplan.	1. Support sustainable transport strategy: ensure design incorporates outline plans for sustainable transport network (4 m wide shared-use cycle/footpath).

Table 2.9: Summary of Appraisal Outcomes

2.3.5.2 Ecology Surveys

Following the recommendations of the Preliminary Ecological Appraisal (refer to Appendix E), a suite of ecology surveys, including terrestrial and aquatic surveys, was proposed to inform the ecological baseline. All surveys follow current standard survey methods and guidance. The study area for ecological surveys focussed on the River Esk from the A1 crossing to the Firth of Forth, along the promenade to Fisherrow Harbour, and Pinkie Burn, with appropriate survey buffers. The study area was chosen to cover areas of likely scheme defences as identified at the early options appraisal stage. For the aquatic walkover, the study area was extended upstream to Dalkeith Country Park, and the wetland bird surveys covered the estuary out to 500m from the shore and the lagoons. Marine mammal surveys have not been undertaken, however it is considered that marine mammals are likely present within the Firth of Forth. Therefore, any works within the Firth of Forth would also be required to consider impacts on marine fauna.

A summary of the surveys undertaken to date, and those which are ongoing, are detailed in Table 2.10. Where available, survey results have been presented and the potential impacts and constraints have been considered.

Survey Type	Dates	Survey Details and Results Summary	Potential for Impacts and Constraints
Birds – Through the Tide Counts (TTTC)	October 2018 to March 2020	TTTC surveys are ongoing until March 2020 to capture two winters of bird activity. The study area principally covers the estuary from Fisherrow Harbour to the sea wall and Musselburgh Lagoons (at high tide). Wetland birds that were surveyed for included gulls, terns, divers, grebes, cormorants, herons, swans, geese, ducks, rails, waders and kingfisher. Many of the birds recorded during these surveys are qualifying species of the Firth of Forth Special Protection Area (SPA) and Ramsar site. Interim results indicate a winter peak count of wetland birds of 5586 individuals (January 2019), with oystercatcher (2700), bar-tailed godwit (540) (both SPA qualifying species) and black-headed gull (390) the most recorded species in this month. A total of 51 species of water birds were recorded during the TTTC surveys between October 2018 and March 2019 inclusive, of which 25 species were qualifying interests of the Firth of Forth SPA and Ramsar. Peak counts were generally recorded on the lagoons which represents an important high tide roost for waders. During low and mid tides, the results indicate that the intertidal sediments are generally used by water birds for feeding and loafing.	There is the potential for birds within the Firth of Forth to be disturbed during any works at the downstream extent of the River Esk and along the seafront and sea wall. A Habitats Regulations Appraisal (HRA) will be required to assess the potential for the proposed scheme to have likely significant effects (LSE) on the Firth of Forth SPA and Ramsar site. If LSE cannot be ruled out, an Appropriate Assessment (AA) would be required for which it may be necessary to identify mitigation to avoid LSE. If the potential for an adverse effect still remains after mitigation, compensation may be required. If an adverse effect cannot be ruled out, and no alternative solutions can be identified, the scheme would need to progress through Imperative Reasons of Overriding Public Importance (IROPI) to determine whether the proposals for the scheme can proceed. Consultation with Scottish Natural Heritage (SNH) is required at all stages.
Birds – Breeding Bird Surveys (BBS)	April to July 2019	Breeding bird surveys were carried out along the River Esk from upstream of Musselburgh Golf Course to Fisherrow Harbour, and the woodland adjacent to Pinkie Burn. Breeding bird habitat, including woodland, is present within the study area. Sixty three species were recorded during the breeding bird surveys, of which 32 species (including one Schedule 1 species – kingfisher) showed breeding evidence within the study area. Of the 63 species recorded, nine are red listed and 19	All wild birds are protected under the Wildlife and Countryside Act 1981 (as amended) which makes it an offence to intentionally or recklessly: • kill, injure or take a bird; • take, damage, destroy or interfere with a nest of any bird while it is in use or being built; • obstruct or prevent any bird from using its nest; and/or

Survey Type	Dates	Survey Details and Results Summary	Potential for Impacts and Constraints
		are amber listed species on the Birds of Conservation Concern (BoCC) Red List (Eaton et al. 2015).	• take or destroy an egg of any bird. Additionally species on Schedule 1 are afforded additional protection making it an offence to: • disturb any such bird while it is building a nest and/or while it is in, on, or near a nest containing eggs or young; and/or • disturb the dependent young of any such bird. There is the potential for breeding birds to be present during the works if undertaken during the bird breeding season (March to August inclusive). Furthermore, there is the potential for the proposed scheme specifically to cause disturbance to kingfisher and their nests. Once the design is finalised the disturbance impacts can be assessed. The results of the assessment would inform any mitigation necessary or licencing requirements.
Bats - Ground based assessment and activity surveys	January 2019	A ground-based visual assessment of the buildings, structures and trees within 50m of the study area was undertaken to assess their potential to support bat roosts. One hundred and twenty-one buildings, 12 structures and 132 trees were identified as having potential for roosting bats.	Bats are European Protected Species (EPS) and are protected, along with their roosts, under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended in Scotland). Any works which could disturb or harm a bat; or obstruct, damage or destroy its roost would require an EPS derogation licence to be obtained in advance of works from SNH. There is the potential for construction works to cause light, vibration and noise disturbance to commuting, foraging and roosting bats. There is also the potential for destruction of bat roosts, depending on the final scheme design. Once the design is finalised the impacts relating to disturbance and roost destruction can be assessed. The results of the assessment would inform any mitigation necessary or licencing requirements. Further surveys would likely be required.
	April - September 2019 (active season)	Transect surveys, emergence/re-entry surveys and deployment of static detectors have been undertaken to identify activity levels and species richness within the area and any roosts likely to be impacted by the proposed scheme. The data analysis is ongoing.	
Great crested newt (GCN) – environmental DNA (eDNA)	April 2019	Two ponds located at Inveresk Lodge Gardens were surveyed for GCN using eDNA techniques. Results of eDNA assessment indicate GCN absence from both ponds.	GCN are EPS which affords the species special protection against intentional or reckless killing, injury and disturbance. However, this species is considered absent from the study area.
Reptiles	April 2019	A walkover survey was undertaken along the River Esk to 50m from the bank to assess all areas for suitable reptile habitat within the study area. Suitable reptile habitat was identified in the dry stone walls and grassland located to the east of the River Esk adjacent to Inveresk Lodge	All reptile species found naturally in Scotland are given protection against intentional or reckless killing or injury under the Wildlife and Countryside Act 1981 (as amended). Based on information to date, it is unlikely reptiles would be impacted by the proposed

Survey Type	Dates	Survey Details and Results Summary	Potential for Impacts and Constraints
		Gardens. The habitat downstream of Inveresk Lodge Garden was considered generally unsuitable for reptiles.	scheme if appropriate mitigation is designed and followed during works.
Badger and otter survey	November 2018	Walkovers for otter and badger were undertaken and incidental signs have been recorded during other surveys. A potential otter holt has been identified in the study area. No badger setts have been found, however badger signs (prints) have been recorded.	Otter are EPS and are protected, along with their resting sites, under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended in Scotland). There is the potential for construction works to cause disturbance to otter and disturbance/destruction of an otter resting site. Once the design is finalised further surveys (to include holt monitoring) would likely be required to identify appropriate mitigation and ascertain any licencing requirements. Badgers and their setts are protected under the Protection of Badgers Act 1992 (as amended). As no setts were identified within the study area it is unlikely that badger would be impacted by the proposed scheme if standard best practice mitigation is followed during works.
Woodland survey	May 2020	A woodland survey to characterise the ecological interest of woodland likely to be impacted by the proposed scheme is to be undertaken, focussing along the Esk Walkway, a Local Wildlife Site.	The results of the woodland survey will inform the impact assessment and any mitigation or compensatory planting required.
River Habitat Assessment and Fish Surveys	March 2019	Walkover surveys have been undertaken to identify fish habitat within the River Esk from Dalkeith Country Park to the estuary. The results of the surveys informed additional survey effort.	The results of the aquatic surveys and analysis will inform the impact assessment and any mitigation necessary or licencing requirements.
	September 2019	Targeted electrofishing surveys have been undertaken to determine fish species present within the study area. Six species of fish were recorded during the surveys.	
Invasive Non-Native Species (INNS)	November 2018	A survey for INNS has been undertaken. Focus of the surveys was specifically on invasive non-native plant species. Giant hogweed, Japanese knotweed and Himalayan balsam are prevalent along the River Esk. Other INNS recorded were Japanese rose, cotoneaster sp. and butterfly bush.	For non-native plant species, under the Wildlife and Countryside Act 1981 (as amended), it is an offence in Scotland to: • plant, or otherwise cause to grow, a plant in the wild at a location outside its native range. Strict biosecurity, and management/control as appropriate, would be required for working within areas of INNS.

Table 2.10: Ecology surveys and potential constraints

2.3.5.3 Potential Scheme Impacts

Potential scheme ecological impacts and constraints were considered for each flood cell. In doing so, the probable scheme alignments were reviewed for the potential for / presence of protected and notable species or habitats. The potential impacts and constraints identified in Table 2.11 relate specifically to the interim results of the ecological surveys and are a high-level assessment only at this stage.

Note that for all possible options, a Habitats Regulations Appraisal (HRA) Screening would be required to assess whether the proposed works have potential for 'Likely Significant Impact' (LSE) on any European (i.e. Special Protection Area (SPA) or Special Area of Conservation (SAC)) or Ramsar site. Based on the anticipated scope of works, it is considered that the Firth of Forth SPA and Ramsar sites would be included within the assessment.

Flood Cell	Potential Impacts/Constraints
1: Stoneybank and Musselburgh Golf Course	No defences are anticipated within this Cell. If works, including site access and egress, are required in the Cell the following ecological considerations would apply based on the baseline to date: • Extensive INNS along the river bank, including infestations of Japanese knotweed, giant hogweed and Himalayan balsam. Potential for spread of INNS during works. • Potential for otter holts/couches within the river banks/riparian habitat and for otter foraging in the river. Potential for disturbance to an EPS and/or loss of a resting place as a result of the works. • Potential for breeding birds within trees/scrub adjacent to the river and within the golf course. Furthermore there is the potential for Schedule 1 bird species to be present. Potential for loss/disturbance of breeding bird habitats and of a Schedule 1 species as a result of the works. • Potential for bat roosts within trees and buildings, and commuting/foraging bats along the river. Potential for disturbance to an EPS and/or loss of roosts as a result of the works. • Any in-channel works have the potential to impact fish habitat. Removal of bankside vegetation would also have the potential to impact fish habitat.
2: Eskmills and Inveresk	A flood defence wall is anticipated within the Cell following the River Esk from Eskmills Industrial Estate to Olive Bank Bridge. The construction of this wall would likely require tree/vegetation removal and access is likely to be taken from Station Road and Eskmills Industrial Estate. The following ecological constraints and potential impacts are identified for any works within the Cell based on the baseline to date: • Removal of trees and scrub to construct the wall would result in loss of breeding bird habitat and potentially disturbance/destruction of nests if works scheduled in the breeding season (March to August inclusive). Potential for Schedule 1 bird species to be present. • Extensive INNS along the river bank, including infestations of Japanese knotweed, giant hogweed and Himalayan balsam. The field south of the Eskmills Industrial Estate has an infestation of giant hogweed, and although treated, would remain a constraint due to the seed bank present within the soils. • Potential for otter holts/couches within the river banks/riparian habitat, and potential for disturbance to foraging otter. • Potential for loss/disturbance of bat roosts within trees, structures and buildings, and disturbance of commuting/foraging bats along the river. • Any in-channel works have the potential to impact fish habitat. Removal of bankside vegetation would also have the potential to impact fish habitat.
3: Town Centre West and Fisherrow	A flood defence wall / embankment is anticipated within the Cell following the River Esk from Olive Bank Bridge to the mouth of the River Esk and along the sea front to the west of Fisherrow Harbour. The construction of the wall and embankment may require tree removal, and access and egress would likely be taken from the Promenade and Eskside West. The following ecological constraints and potential impacts are identified for the Cell based on the baseline to date: • Potential for disturbance to wintering birds using the Fisherrow Sands, especially during low and mid tide.

	• Removal of trees to construct the wall would result in loss of breeding bird habitat and potentially disturbance/destruction of nests if works scheduled in the breeding season (March to August inclusive). • Potential for INNS along the river bank, including Japanese knotweed, giant hogweed and Himalayan balsam. Most of the significant infestations are located upstream, however there is the potential for INNS to spread as a result of the works in the Cell. • Suitable fish habitat within the river within the Cell. Removal of bankside vegetation and in-channel working has the potential to impact fish habitat within the Cell. • Potential for disturbance to foraging otter; habitats in the downstream extent of the River Esk are less favourable for otter rest sites due to the bankside habitats and disturbance within the town centre. • Potential for loss/disturbance of bat roosts within trees, structures and buildings, and disturbance of commuting/foraging bats along the river.
4: Town Centre East	A flood defence wall is anticipated within the Cell as well as works adjacent to the open channel of Pinkie Burn. The alignment of the wall follows the River Esk from Olive Bank Bridge to the mouth of the River Esk; the alignment of the defences at Pinkie Burn are expected to follow the open channel. These works would likely require tree removal and access and egress would likely be made from Eskside East and Linkfield Road. The following ecological constraints and potential impacts are identified for the Cell based on the baseline to date: • Potential for disturbance to wintering birds using the Fisherrow Sands around the mouth of the River Esk. • Removal of trees to construct the wall and defences near Pinkie Burn would result in loss of breeding bird habitat and potentially disturbance/destruction of nests if works scheduled in the breeding season (March to August inclusive). • Potential for INNS along the river bank, including Japanese knotweed, giant hogweed and Himalayan balsam. Most of the significant infestations are located upstream on the River Esk, however there is the potential for INNS to be spread as a result of the works. • Suitable fish habitat within the river within the Cell. Removal of bankside vegetation and in-channel working within the River Esk has the potential to impact fish habitat within the Cell. • Potential for disturbance to foraging otter; habitats in the downstream extent are less favourable for otter rest sites due to the bankside habitats and disturbance within the town centre. • Potential for loss/disturbance of bat roosts within trees and buildings, and disturbance of commuting/foraging bats along the river and Pinkie Burn.
5: Pinkie Burn	This Cell overlaps with Cell 4 and would likely include works along the open channel of Pinkie Burn. These works would likely require tree removal and access and egress would likely be made from Linkfield Road. The following ecological constraints and potential impacts are identified for the Cell based on the baseline to date: • Removal of trees to construct the defences near Pinkie Burn would result in loss of breeding bird habitat and potentially disturbance/destruction of nests if works scheduled in the breeding season (March to August inclusive). • Potential for loss/disturbance of bat roosts within trees and buildings, and disturbance of commuting/foraging bats along the river and Pinkie Burn.
6: Old Sea Walls and Lagoons	No defences are proposed within the Cell, however any works would likely be limited to the sea wall only. If works on the sea wall, including site access and egress, are required in the Cell the following ecological considerations would apply based on the baseline to date: • Potential for disturbance to wintering birds using the Fisherrow Sands and open water, especially during low and mid tide. Dependent on the nature of the works, there would also be potential for disturbance to birds on the lagoons which are an important high tide roost. • No marine surveys have been undertaken, however there is potential for disturbance to marine fauna within the Firth of Forth.
7: Upper Catchment (upstream of A1 Bridge)	Further survey and assessment required as the study area does not cover the Cell. Similar constraints applicable to the other Cells are likely to apply, with the potential for additional protected species and habitats to be present depending on the works.

8: Fisherrow Sands and Coastal Management	Coastal management within the Cell, if included within the preferred scheme, has the potential for disturbance to wintering birds using the Fisherrow Sands and the open water of the estuary, especially during low and mid tide. Changes to the coastal regime could also impact functionally important coastal SPA habitat, potentially altering how the birds use the sands and may result in localised displacement. Furthermore, there would be potential for disturbance to marine fauna dependent on the nature of the proposals. This would require further assessment and survey.

Table 2.11: Potential scheme ecological impacts/constraints

2.3.5.4 EIA screening and scoping

Environmental Impact Assessment (EIA) is a means of drawing together, in a systematic way, an assessment of the likely significant environmental effects arising from a proposed development or project. It is a matter for planning authorities to consider whether a proposed development requires EIA and as such a formal screening opinion is normally requested from the local planning authority (in this case, ELC Planning).

As part of the next phase of the project, an EIA Scoping Report shall be prepared and submitted to relevant consultees through ELC planning department to inform the scope and method of assessment to be employed in the EIA. The information contained within this report will inform the EIA Scoping Report.

2.3.6 Health and safety

Health and safety risks associated with options were considered during the appraisal process, with the aim of ruling out any options with potential to pose unacceptable or unmitigable risks during construction, maintenance or operation of the scheme. Examples of health and safety risks identified include:

- Injury to operatives or members of the public during construction
- Injury to operatives during routine maintenance
- Damage to existing infrastructure such as roads and bridges
- Increase in flood risk to other areas as a result of scheme infrastructure
- Increased risk of secondary flooding (on dry side of flood defences)
- Risk to life due to measures requiring human intervention e.g. demountable defences
- Risk to life due to areas becoming cut off or inaccessible during flood events
- Proximity to existing services and utilities
- Potential to destabilise riverbanks
- Significant disruption to pedestrian and vehicular traffic

Conversely, those options which presented opportunities to improve health and safety associated with routine use and maintenance of structures were favoured, specific examples include:

- New (Rennie) Bridge clearing of secondary arches to improve head room beneath the bridge along the public footpath

- Reduced risk of vulnerable areas being cut-off during flood events

As the scheme progresses to outline design, a detailed and specific designer's risk assessment will be produced to ensure that foreseeable health and safety risks associated with the preferred scheme are, where possible, eliminated, reduced or controlled.

2.3.7 Interface with other projects

Development of the scheme options took cognisance of a number of other projects and initiatives, all of which are at varying stages of development. These include:

- Potential residential and commercial developments at Monktonhall on the Stoneybank Burn and on the field to the south of Eskmills Industrial Estate;
- A separate study into sustainable active travel corridors through Musselburgh, and;
- Traffic Studies and masterplanning initiatives for the town

Further interface with these projects and initiatives is critical to ensure that all development within Musselburgh have the opportunity integrate with the Scheme, where appropriate.

2.4 Developing the long list of options

Determining the most appropriate measures for flood risk reduction in Musselburgh is a complex task due to the interaction between tidal and fluvial influences, as well as considering stakeholder, landowner, economic, environmental and legislative constraints.

As per Figure 2.2 above, a strategic approach was defined to ensure that the option appraisal process could be managed efficiently, and the results of the decision-making process could be presented to the relevant stakeholders and authorities in a clear and concise manner.

2.4.1 Defining flood cells

A flood cell is a specifically defined and isolated geographical area which is separately considered (as a block of land and property) for economic appraisal purposes. This is to ensure that the economic benefits from one flood cell are not used to subsidise those from anther, ultimately demonstrating the economic viability of protecting specific areas.

Areas within Musselburgh at risk of flooding from the design event have been split into eight separate flood cells (refer to Appendix F for plan showing cell boundaries):

- Cell 1 – Stoneybank and Shire Haugh
- Cell 2 – Eskmills and Inveresk
- Cell 3 – Town Centre West and Fisherrow
- Cell 4 – Town Centre East
- Cell 5 – Pinkie Burn
- Cell 6 – Musselburgh Sea Wall and Lagoons

- Cell 7 – Upper catchment (upstream of A1 road bridge)
- Cell 8 – Fisherrow Sands coastline

The following should be noted with reference to the above flood cells:

- Cell 1 covers the area upstream of Station Road (Olive Bank) Bridge on the left hand bank (looking downstream). There are no residential properties at risk of flooding within this flood cell, but the Golf Course and Gas Governor are included.
- Cell 2 comprises residential and business properties within Eskmills and the Inveresk area. Following a review of baseline flood risk and depths it became apparent that upstream of the Eskmills Weir, only minor property flooding occurs to three high-value properties in the Inveresk Estate. As such, the Inveresk Estate was considered separately within the analysis to ensure the economic assessment was not skewed.
- Cell 5 covering the Pinkie Burn catchment has significant overlap with Cell 4 which covers the Town Centre East. With reference to baseline flood risk from both the River Esk and Pinkie Burn, an extreme fluvial event on the River Esk causes far greater flood depths and extents than would be experienced during an extreme event on the Pinkie Burn. As such, any property and land that floods within Cell 5 during the extreme event is covered within Cell 4. Therefore, to avoid double-counting in the economic appraisal, Cell 5 has not been considered in isolation and has been removed from the analysis.
- Cell 6 covers the Musselburgh old sea wall and lagoons. There are no residential properties at risk of flooding in this cell, flood damages are limited to sport and leisure grounds only.
- Cell 7 incorporates the entire River Esk catchment upstream of the A1 road bridge and as such is outwith the scope of the scheme in terms of determining flood risk and economic analysis. However, measures within the upper catchment which reduce downstream flood risk in the town will be considered.
- Cell 8 covers the Fisherrrow Sands coastline and includes coastal management measures to reduce flood risk, but again is not a viable cell in the context of economic appraisal.

2.4.2 Initial brainstorming

An initial option appraisal meeting was held in April 2019, involving key project team members from East Lothian Council, Turner and Townsend including CPE Consultancy (project management consultant) and Jacobs (design consultant) to present flood risk, define flood cells and carry out initial brainstorming of flood risk management options in line with Scottish Government guidance. The long list development process aspires to:

- Consider all sources of flooding
- Consider interventions as well as hard engineering
- Consider measures in the upper catchment as well as the town
- Consider ‘do-nothing’ as an option where appropriate
- Encourage open-mindedness and consider different combinations and variations of options

A focussed brainstorming session for each of the eight flood cells identified a total of 96 options, specific details of which are contained within Appendix G and Appendix H. Consideration was given to the following potential options, many of which are applicable to multiple flood cells:

- Do nothing – potentially appropriate, some areas with either low flood risk or no residential properties at risk
- Property abandonment or relocations – potentially appropriate where the cost of providing flood protection exceeds the value of the at risk properties
- Bank lowering to reconnect flood plain
- Improved drainage measures
- Bypass culverts/channels and improvements to increase capacity
- Weir modifications or removal
- Direct defences throughout urban areas - including permanent, demountable, embankments and floodwalls
- Bridge removal / raising / modifying to reduce risk of flooding upstream of structures
- Improved property flood resilience – where formal flood defences are not appropriate
- Pumping stations – new or modifying existing assets to cater for both surface and groundwater
- Road raising or modifying
- Flood storage in the upper catchment – both using existing reservoirs and new engineered storage areas
- Debris management in the upper catchment – to reduce the risk of blockage at downstream structures
- Harbour wall modifications
- Sea wall modifications and improved drainage
- Natural flood management
- Coastal flood risk management options including tidal barrier, beach replenishment, wave attenuation, breakwaters and managed realignment

2.4.3 'Do nothing' and 'do minimum' options

'Do nothing' on a catchment-wide basis is the baseline scenario from which flood damages were calculated in the economic appraisal. This option could be thought of as abandonment, following which, maintenance would cease to all existing assets which influence flood risk within the catchment. These may include riverbanks, retaining walls, weirs, culverts and bridges. They would therefore be allowed to deteriorate and, over time, fail. 'Do nothing' would also mean ending the provision of flood warning systems, temporary measures such as sand bags, and any other form of intervention which might reduce flood damages.

By contrast, “do minimum” on a catchment-wide basis would mean maintaining assets in their current condition and maintaining the current forms of intervention. Doing so would not reduce flood risk within the catchment but neither would it increase it. Maintenance activities might include repointing, concrete repairs, removal of debris from beneath bridges, and removal of sediment from within culverts. In some cases where assets are already in poor condition, maintaining the current level of flood risk in the long term might require significant maintenance, reconstruction or even replacement of an asset.

A number of different entities own and/or operate assets which may influence flood risk within the catchment. In each case, the current maintenance regime is equivalent to either ‘do nothing’ or ‘do minimum’ and was likely influenced by a combination of social, environmental and economic factors. This is because, while the assets may influence flood risk, there are not explicitly operated for the purpose of flood risk management.

While this section has considered ‘do nothing’ and ‘do minimum’ on a catchment-wide basis, in some cases it is also appropriate to consider ‘do nothing’ and ‘do minimum’ for individual assets. In such cases these have been considered later in the report as separate options within the relevant flood cell.

2.4.4 Catchment-wide flood mitigation measures

There are a number of general flood mitigation measures which could be implemented on their own or as part of an approved Flood Protection Scheme to reduce flood risk or more effectively respond to the effects of flooding.

2.4.4.1 Flood warnings and awareness

SEPA’s Floodline (http://www.floodlinescotland.org.uk/) provides flood warnings, live flooding information, and advice to help prepare for and respond to the risk of flooding. Individuals can sign up to receive advance warning of where and when flooding might occur. Resources available include:

- How to prepare a flood plan and flood kit
- What to do when flooding is expected
- What to do during a flood

The Scottish Flood Forum (https://scottishfloodforum.org) similarly provides support about how to prepare for and recover from the effects of flooding.

2.4.4.2 Property Level Protection (PLP)

PLP refers to measures which can be taken by property owners to keep floodwater out of individual properties. These could include:

- Installing bespoke flood doors and windows
- Installing flood boards on doors and windows
- Installing air brick covers
- Installing non-return valves on plumbing
- Sealing ductwork
- Repointing masonry

2.4.4.3 *Property Level Resilience (PLR)*

PLR refers to measures which can be taken by property owners to more easily restore individual properties after flooding. These could include:

- Installing solid floors
- Installing resilient plaster
- Installing pump sumps within floors
- Raising electrical installations above likely flood level
- Relocating furniture in during to flood warnings

2.4.4.4 *Flap valves to outfalls*

Flap valves are mechanical devices which can be fitted to pipes that discharge into watercourses. They are used to reduce the risk of backflow when river levels are high. Flap valves are a low-cost measure which can be implemented on their own or in combination with other flood protection measures.

2.5 Appraising the long-list

2.5.1 Early discounted options

Having established a long list of possible options, a baseline proforma for formal appraisal of those options was developed. Potential flood risk management options were appraised against a specific set of criteria using a simple **R**ed, **A**mber, **G**reen (RAG) analysis. Refer to Appendix G for details.

Each option was assessed at a high-level on the basis of five key appraisal categories:

- Economics
- Technical
- Environment
- Social and stakeholder
- Health and safety

Each appraisal category above (for each option) was assigned a colour coding at this stage:

(Red)	**Generally significant/unacceptable/insurmountable risks/impacts/constraints**
(Amber)	**Moderate impacts/risks/constraints**
(Green)	**Generally feasible with minor/mitigable impacts/risks/constraints**

General rejection guidelines were established amongst the project team and ratified by ELC and key stakeholders, these are summarised in Figure 2.10. On this basis, an 'early discounting' exercise could be carried out to narrow down the list of potential options to those that were generally deemed feasible and likely to provide a quantifiable flood risk reduction benefit.

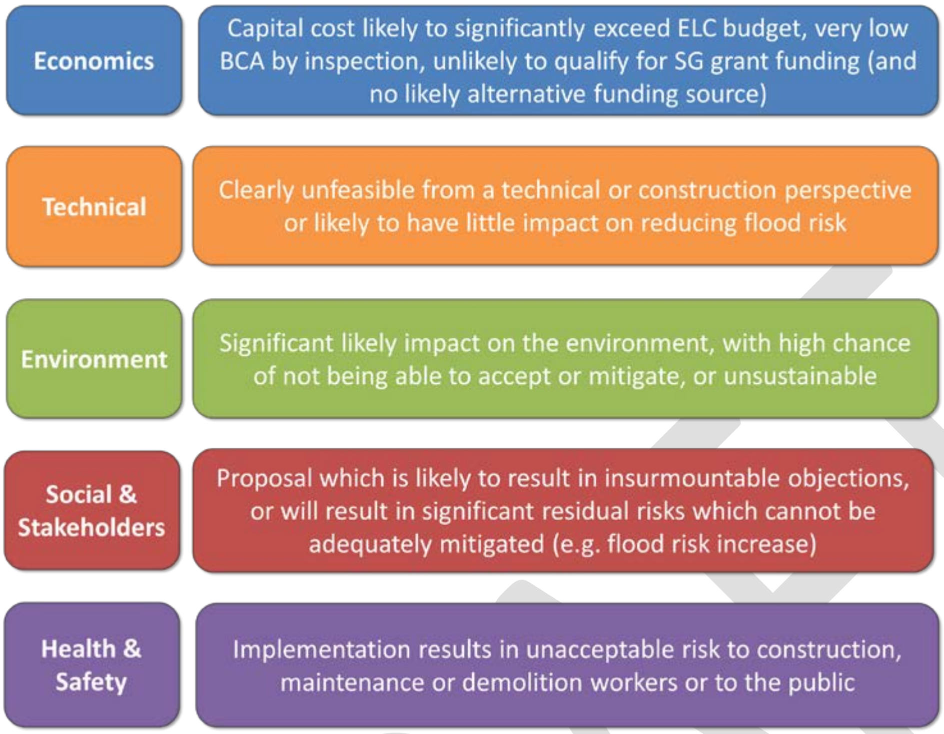

Figure 2.10: General rejection guidelines used in option appraisal for early discounting

Having assigned a colour coding under each individual appraisal category, a 'first pass' proposal was put forward at an option appraisal meeting involving key project team members on 22nd May 2019:

- **REJECT** – generally where one or more appraisal category flagged red (refer to Figure 2-3 above)
- **UNDECIDED** – generally requiring further information or consultation to make a clear informed decision e.g. further hydraulic modelling or stakeholder discussion
- **CONSIDER** – generally deemed a feasible option with mitigable constraints, where no categories were flagged red and few amber

At this stage, a total of 41 options were proposed to be discounted and therefore not considered further in the appraisal. Refer to Appendix G for details. A summary of early discounted options is contained in Table 2.12.

Ref	Option	Principal reason(s) for rejection
0.00, 0.10	Do nothing / Do minimum (in all cells/locations)	Not aligned with FRM Strategy, major public objection, existing infrastructure falls in to disrepair – risk to life
0.50, 2.14	Property abandonment in at risk areas	Major social impact, not economically viable
0.60	Fluvial dredging to increase channel capacity	Devastating environmental impact, unsustainable
1.04	Bypass channel/culvert through Musselburgh Golf Course	Not economically viable, increased flood risk downstream throughout the town

Ref	Option	Principal reason(s) for rejection
1.09	Flood storage within Haugh Park recreation ground / playpark	Insufficient storage capacity, public health and safety issues
2.01	Modify railway embankment to provide flood storage	Huge costs, unacceptable impact on Network Rail assets, only deals with fluvial flood risk
2.08	Eskmills Weir raising to attenuate flow upstream	Increased flood risk upstream, fish pass impacts, economically not viable
2.09	Mill Lade – culverting or increasing channel capacity	Major disruption to High Street and Racecourse / Golf Course, huge costs for no significant benefit
2.14 – 2.16	Modify/replace Ivanhoe (Cotton Mills) Footbridge	Negligible benefit (bridge not a major flood risk issue due to high soffit levels)
2.17	Station Road (Olive Bank) Bridge removal	Huge impact on town traffic links, major traffic disruption
3.01 – 3.02	Old Roman Bridge removal / replacement	Unacceptable impact on Grade A Listed structure
3.06	Loretto Playing Field as flood storage	Existing topography unsuitable – no storage capacity and would be overwhelmed by coastal flooding instantly
3.07	SW Esk sewage pumping station remedial works	SW assets outwith scope of Scheme funding
3.08	Raise New Street	Huge costs, potential to trap water in flooded areas
3.10 – 3.11	Fisherrow Harbour – infill/relocation	Socially unacceptable, loss of business and heritage
3.13	Raise Edinburgh Road (A199)	Huge costs, potential to trap water in flooded areas
4.01 – 4.02	New (Rennie) Bridge removal / replacement	Vital traffic link through town, huge construction and service diversion costs, alternative crossing would be required
4.11, 4.13, 4.14, 4.15	Modify / demolish Goose Green Weir	No flood risk benefit, potential increase in coastal flood risk, unacceptable impact on SPA
5.06	Pinkie Burn bypass channel/culvert through Musselburgh Links Golf Course	Unacceptable increase in flood risk to Old Golf Course, major impacts both during and post-construction, loss of business
6.06	New sea wall along entire coastline	Not economically viable, unacceptable impact on SPA, major social impacts and severance of beach front
6.07	Musselburgh Lagoons – ash stabilisation	Major environmental impacts (Lagoons protected), no guaranteed flood risk benefit or scheme design life
7.01	A1 Bridge embankment as flood storage area	Major reconstruction of road infrastructure, not economically viable, only reduces fluvial flood risk, unacceptable impacts on Transport Scotland assets
7.05, 7.06	Catchment transfer	Lack of suitable transfer sites, only deals with fluvial flooding, devastating ecological impacts, flood risk increase elsewhere
7.07	Flood relief channel / culvert	Not economically viable, only deals with fluvial flood risk, devastating environmental impacts
7.08	Pumping excess flows (upstream of town)	Huge costs and technical challenges, only deals with fluvial flooding
7.09	Weir removal in upper catchment	Negligible benefit in town, huge costs, devastating environmental and morphological impacts

Ref	Option	Principal reason(s) for rejection
8.01	Tidal flood barrier	Only deals with coastal flooding and potential increase in fluvial flood risk, huge costs and technical challenges
8.02	Managed realignment	Unquantifiable flood risk benefit, environmental and social impacts associated with loss of lagoon areas
8.03, 8.04	Beach recharge / replenishment / reduction	Only deals with coastal flooding, unquantifiable benefits, huge costs, limited availability of experienced large contractors, huge environmental impact on SPA
8.05	Breakwaters	Only deals with coastal flooding, unquantifiable benefits, huge costs, limited availability of experienced large contractors, visual impact on shoreline, huge environmental impact on SPA

Table 2.12: Summary of early discounted options

2.5.1.1 Fluvial dredging

To further assess the potential benefit or otherwise of dredging the River Esk, hydraulic modelling tests were run assuming a lowering of the bed level by 500mm along the entire study area from the A1 bridge down to its outfall into the North Sea.

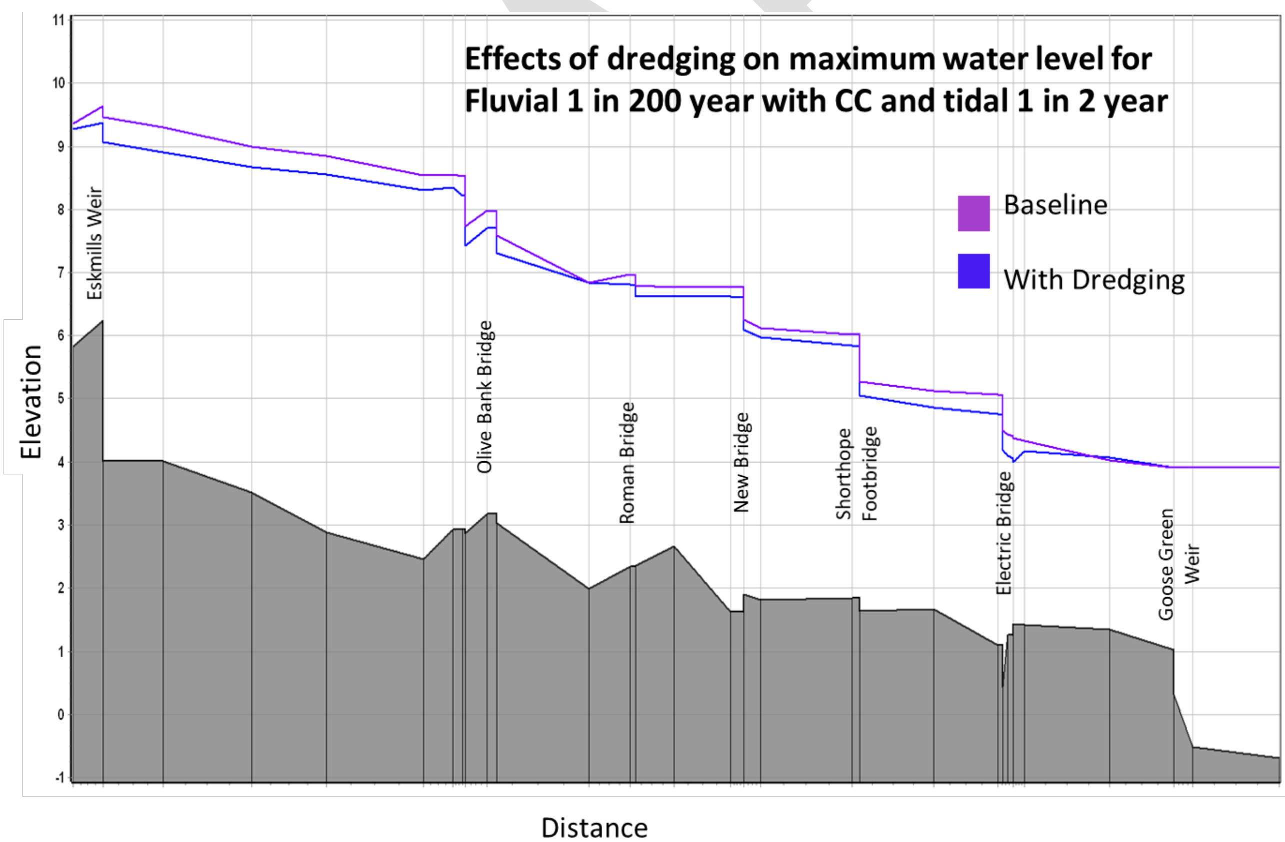

Figure 2.11: Long section of the River Esk showing maximum water levels for a 0.5% AEP event, under baseline scenario and with dredging along the water course

The long profile shows a minimal reduction of water levels for the dredged scenario. Furthermore, this solution would not only comprise the structural integrity of the existing bridges and weirs, but also generate a detrimental impact on the environmental status of the water course.

2.6 Proposed short-list

During a focussed one-day workshop on 4th June 2019, attended by relevant ELC and external stakeholders, recommendations for each option were discussed in more detail and proposed 'rejected' options were agreed by those present. Refer to Appendix G for full details and comments from stakeholders. Those options that were assigned '**CONSIDER**' or '**UNDECIDED**' at this stage of the appraisal process were taken forward for further consideration, as summarised in Table 2.13. Section 3 contains a detailed review of all short-listed options.

Option Ref.	Flood Cell	Option Description	Proposal (post option meeting 04/06/19)
1.00	1	Musselburgh Golf Course - do nothing	CONSIDER
1.01	1	Musselburgh Golf Course - direct defences	UNDECIDED
1.02	1	Musselburgh Golf Course - bank lowering at upstream end to reduce flood risk to Inveresk area	UNDECIDED
1.03	1	Musselburgh Golf Course - improved drainage (link to 1.2 as mitigation measure)	UNDECIDED
1.05	1	Gas Governor - do nothing	UNDECIDED
1.06	1	Gas Governor - abandonment and relocation outwith flood plain	UNDECIDED
1.07	1	Gas Governor - direct defences / demountables	UNDECIDED
1.08	1	Gas Governor - improvement of current flood resilience measures	UNDECIDED
2.02	2	Reconnection of flood plain by lowering riverside path level	UNDECIDED
2.03	2	Direct defences (with or without seepage) - along river edge, set-back, hybrid or demountables	CONSIDER
2.04	2	Abandonment of properties at risk - Inveresk residential	UNDECIDED
2.05	2	Eskmills Weir - do minimum (continue current maintenance)	UNDECIDED
2.06	2	Eskmills Weir - full demolition	UNDECIDED
2.07	2	Eskmills Weir - Partial demolition	UNDECIDED
2.10	2	Mill Lade - abandon / block up	CONSIDER
2.11	2	Eskmills Park (residential) - flood resilience measures	CONSIDER
2.12	2	Eskmills Park (residential) - abandonment	UNDECIDED
2.13	2	Inveresk Industrial Estate - flood resilience measures	CONSIDER
2.18	2	Station Road (Olive Bank) Bridge - raising / replacing	UNDECIDED
2.19	2	Station Road (Olive Bank) Bridge - block up / decrease conveyance to reduce downstream flood risk	UNDECIDED
2.20	2	Debris trap upstream of Olive Bank / Ivanhoe bridges to reduce potential downstream blockage risk	CONSIDER

Option Ref.	Flood Cell	Option Description	Proposal (post option meeting 04/06/19)
3.03	3	Old Roman Bridge - increase conveyance (by clearing out blocked arches)	UNDECIDED
3.04	3	Direct Defences - Eskside West + Loretto Playing Field (with or without seepage) - along river edge, set-back, hybrid or demountables	CONSIDER
3.05	3	Direct Defences - Loretto Playing Field + Fisherrow Promenade (with or without seepage and wave overtopping) - along river edge, set-back, hybrid or demountables	CONSIDER
3.08	3	Raise New Street	UNDECIDED
3.09	3	Fisherrow Harbour - walls to Brunstane Burn	CONSIDER
3.12	3	Fisherrow Promenade pumping stations (wave overtopping)	CONSIDER
3.13	3	Raise Edinburgh Road (A199)	UNDECIDED
4.03	4	New (Rennie) Bridge - increase conveyance (by clearing out blocked arches)	UNDECIDED
4.04	4	Shorthope Street Footbridge - remove	UNDECIDED
4.05	4	Shorthope Street Footbridge - raise / replace	UNDECIDED
4.06	4	SSEB (Electric) Bridge - remove	UNDECIDED
4.07	4	SSEB (Electric) Bridge - raise / replace	UNDECIDED
4.08	4	Goose Green (New Street) Footbridge - remove	UNDECIDED
4.09	4	Goose Green (New Street) Footbridge - raise / replace	UNDECIDED
4.10	4	Direct Defences - Eskside East + Goose Green (with or without seepage) - along river edge, set-back, hybrid or demountables	CONSIDER
4.12	4	Goose Green Weir - strengthen	UNDECIDED
4.15	4	Goose Green Weir - tidal barrier	UNDECIDED
5.01	5	Groundwater pumping station - Pinkie St. Peter's Primary School sports grounds	UNDECIDED
5.02	5	Culvert existing open channel section of Pinke Burn	UNDECIDED
5.03	5	Direct defences to open channel section	UNDECIDED
5.04	5	Increase capacity of existing culvert (overflow/replacement culvert)	UNDECIDED
5.05	5	Daylight existing culverted section of Pinkie Burn	UNDECIDED
5.06	5	Pinkie Burn bypass culvert/channel through Musselburgh Links Golf Course	UNDECIDED
5.07	5	Surface water pumping station at Pinkie Burn outlet	CONSIDER
5.08	5	Non-return flap valve on Pinkie Burn outlet	CONSIDER
6.01	6	Sea Wall - modify (wave deflection)	CONSIDER
6.02	6	Sea Wall - concrete encasement	UNDECIDED

Option Ref.	Flood Cell	Option Description	Proposal (post option meeting 04/06/19)
6.03	6	Sea Wall - back of wall drains + pumps	CONSIDER
6.04	6	Sea Wall - demolish and replace (along same alignment)	UNDECIDED
6.05	6	Secondary line of defence along old coastline alignment (new set-back wall)	UNDECIDED
7.02	7	NFM - afforestation, flood plain connectivity, leaky barriers, etc	UNDECIDED
7.03	7	Sustainable FRM using existing assets (SW/private) - e.g. St. Mary's Loch attenuation	UNDECIDED
7.04	7	Formal flood storage areas	CONSIDER
7.09	7	Weir removal - upper catchment	UNDECIDED
8.00	8	Fisherrow Sands - do nothing	CONSIDER
8.06	8	Wave energy attenuation	UNDECIDED

Table 2.13: Summary of short-listed options

3. Review of short-listed options

3.1 General

The following sections provide a detailed description of the shortlisted options available to protect each flood cell. Dedicated sections are provided for the hydraulic structures which have the potential to impact flood defence levels, as the proposals for these structures will have a direct impact on the preferred Scheme defence heights for each flood cell.

The hydraulic model developed to identify the baseline flood risk ("Model A") has been used to test the impact of the various flood protection options. The height of direct defences stated in the following sections is inclusive of 600mm freeboard and measured from the dry side of the defences. Unless otherwise noted, the options are designed to provide, either in isolation or in combination with other options as appropriate, a 0.5% AEP + climate change standard of protection. Option ID numbers are referenced to the RAG analysis spreadsheet.

Two options for direct defences were tested in the hydraulic model, in order to assess the impact of the flood defence location alignment on defence height. 'In-channel' assumes flood defences located along the River Esk are positioned next to the river channel. This effectively 'contains' the water over a smaller width and limits flood plain capacity. 'Set-back' defences are located as far from the channel's edge as is reasonably practicable, given the existing configuration of roads, footpaths and riverbanks at specific locations. Figure 3.1 shows the comparison between in-channel and set-back defence heights.

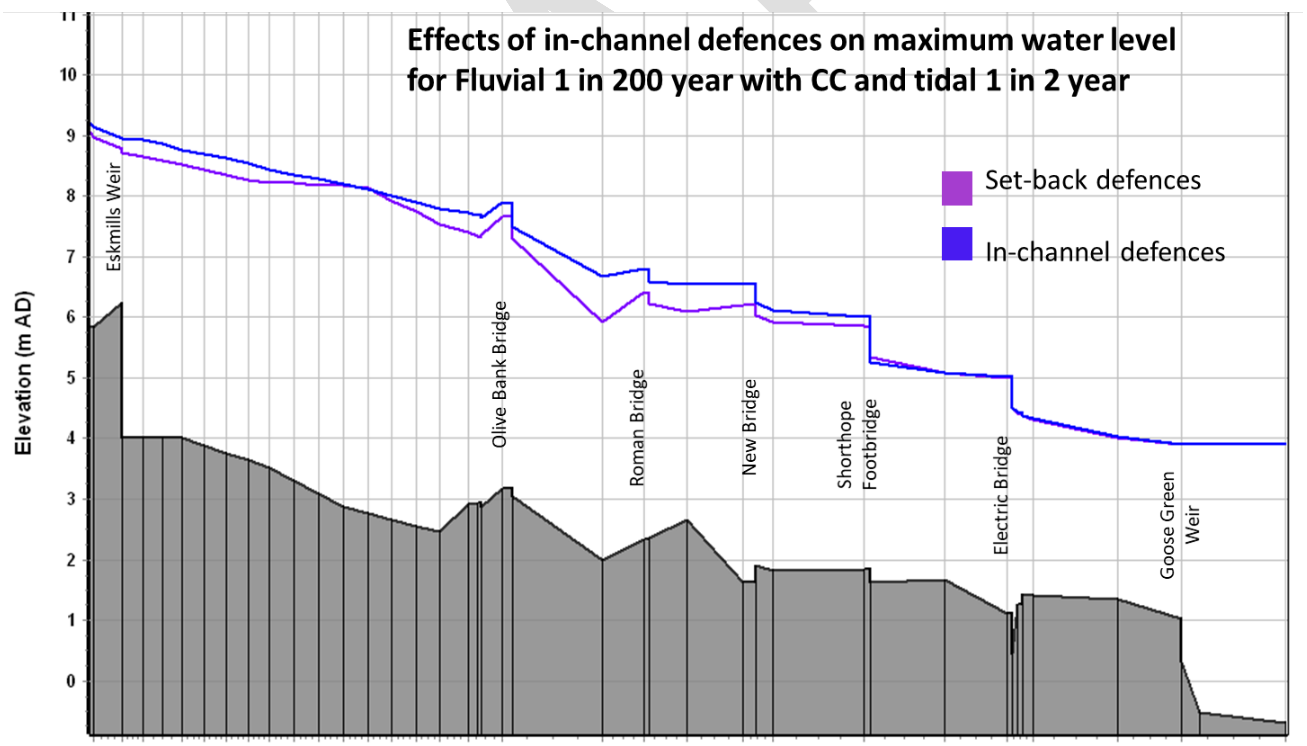

Figure 3.1: Comparison of flood levels with in-channel and set-back defence alignments

It can be observed that the in-channel defences option, although presenting some benefits for the construction stage, will require defences up to 600mm higher than the set-back option and will also cut the connection between the floodplain and the river channel. Furthermore, public feedback opinion was in favour of set-back defences to maintain public access to the green corridor along the River Esk. For these reasons, for the purposes of discussion in this section of the report, all components involving direct defences have been set back as far as possible from the river channel.

3.2 Cell 1 and 2 Structures: Eskmills Weir and A1, ECML, Ivanhoe and Olive Bank Road bridges.

Cells 1 and 2 are linked by a number of existing structures which cross the River Esk, the presence of which have potentially significant impact on river levels. The consideration of adapting the existing A1 road bridge and East Coast Main Line (ECML) bridges for the purposes of throttling or attenuating flow were discounted at a relatively early stage in the appraisal process due to the relatively limited amount of flood storage that could be achieved without flooding the railway, trunk road or private property and the uncertain costs associated with the structural and accommodation works required. The structures considered for further analysis were:

- Eskmills Weir (raise, remove, partially remove, do-nothing)
- Ivanhoe footbridge (raise, replace, do-nothing)
- Olive Bank Road bridge (raise, replace, do-nothing, reduce conveyance)

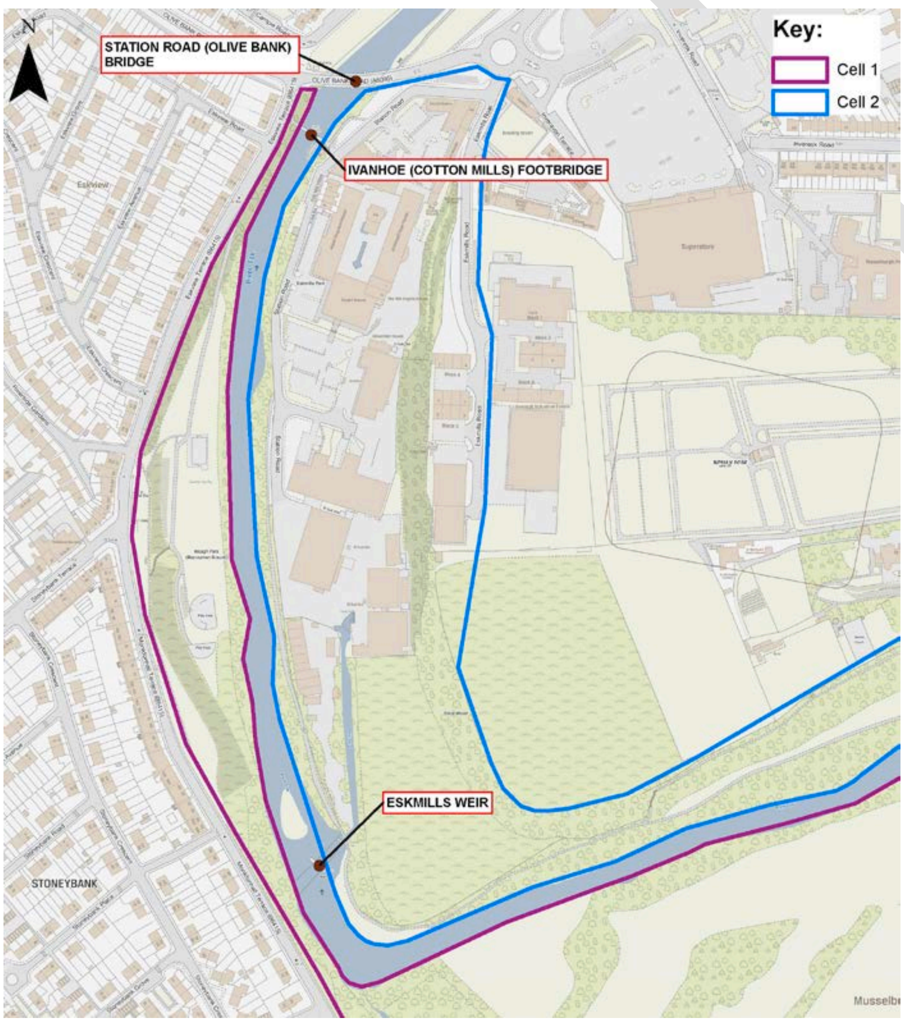

Figure 3.2: Location of structures that link Cell 1 and Cell 2.

3.2.1 Eskmills Weir

Refer to Figure 3.3. The Eskmills Weir is an historic ogee type weir which spans the full width of the River Esk at a slight angle to the orthogonal. Evidence of a weir at this location dates back to at least 1854, with anecdotal evidence suggesting there was a weir at this location earlier than this date. It is assumed that the primary reason behind construction of the weir was to supply water to the Mill Lade, a function which is still in operation today. Review of the baseline model demonstrates that the weir exerts a significant hydraulic control on levels upstream, courtesy of the 2.9m drop between crest level and average downstream bed level. The crest level is broadly uniform with a slightly lower west side compared to east side, and the weir is equipped with a central concrete fish ladder and sluice gate at the east end. The offtake to the Mill Lade at the eastern end of the weir is achieved by a simple series of manually operated penstocks.

Figure 3.3: Eskmills Weir

Option 2.05: Do nothing / Do minimum

Given the age of the existing weir and lack of evidence of maintenance over the many decades since it was constructed, if the weir is to remain as an integral part of the Scheme, then doing nothing to the structure over the 100 year design life of the scheme would appear not be an option. However, the degree of intervention (do something) to the weir structure may well be dependent on whether any future failure of the weir would have detrimental impacts on the performance of other scheme elements. Modelling of removal or partial removal of the weir was deemed essential to fully understand the impacts.

Option 2.06: Full Demolition

Removal of the weir in its entirety was considered as a standalone option, to check the impacts of such a measure on the baseline and with defences scenarios. Modelling of this scenario also serves as a check on the impacts of a future total weir collapse on the preferred Scheme. The results of the modelling exercise show that a negligible change occurs to flood levels upstream of the weir during the 0.5% AEP + CC event, but an increase of up to 100mm occurs downstream of the Olive Bank Road Bridge. Other issues associated with the demolition include unpredictable impacts on river morphology (potential erosion upstream and deposition downstream), potential increased scour to the large concrete retaining wall on the left hand bank, immediately downstream of the weir and a possible impact on established river ecology.

This modelling exercise shows that, for the 0.5% AEP + CC fluvial event, intended demolition of the weir has an adverse impact on flood levels downstream, resulting in defences approximately 100mm higher. In the event of total weir collapse, the effects would be to reduce the freeboard by 100mm. It would not be proposed to increase the height of defences to cover this very low risk scenario.

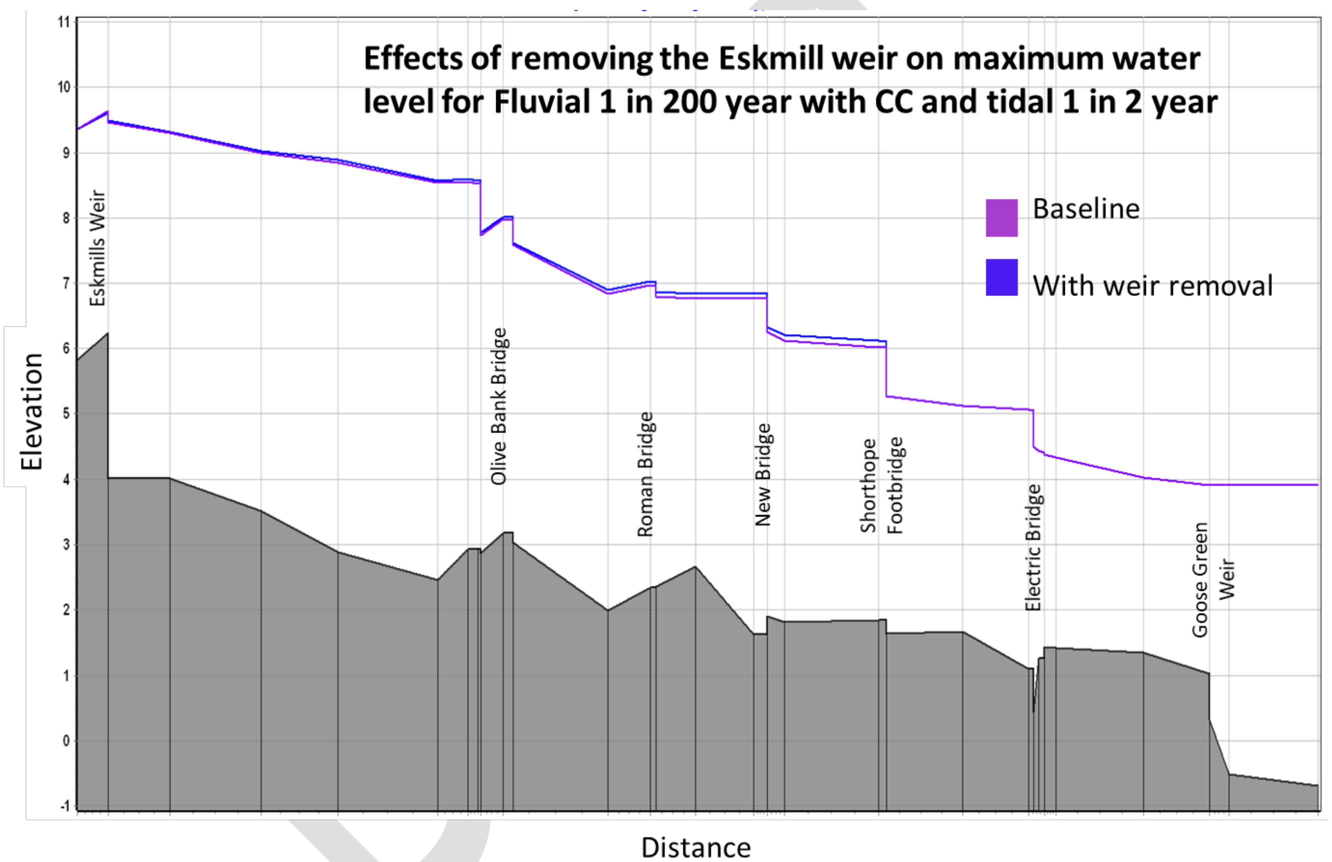

Figure 3.4: River Esk long section showing impact of Eskmills Weir removal

Based on the foregoing discussion, full demolition of the weir should not be considered as a component of the preferred scheme.

Option 2.07: Partial Demolition

Based on the determination that full demolition of the weir should not be considered as a component of the preferred scheme, partial removal of the weir was considered only in the context of the improvement to fish passage. As it cannot offer flood risk benefits, any modification to the weir solely for the purposes of fish passage is almost certain to be transferred from the scope of the scheme to the multiple benefits register, where it could be delivered as part of the scheme construction, but probably funded by other initiatives.

Option 2.08: Raise the weir

This option was rejected during short listing process – refer to RAG analysis.

Eskmills Weir – Conclusion

Based on the foregoing analysis, maintenance of the current status of the weir will improve the long-term security of the standard of protection and freeboard provided by the downstream defences. In addition, given the length of time that the weir has been influencing the river flow regime, any sudden future collapse may have significant adverse geomorphological impacts on the direct defences or undefended land and property.

It is recommended that a full structural investigation of the weir is undertaken during Stage 4 Outline Design to determine the extent of remedial work which may be required to the weir as part of the Scheme. Should any remedial work be required, then an opportunity exists to work with the relevant stakeholders to determine if fish passage improvements could be simultaneously delivered.

3.2.2 Ivanhoe Bridge

Refer to Figure 3.5. The Ivanhoe Bridge is a single span Ekki timber truss pedestrian bridge which is accessed from footpath level on the west side and via a ramp from Station Road on the east side. The river bank is approximately 2.2m lower on the east side compared to the west side. Analysis of the baseline hydraulic modelling output shows that, when the waterway beneath the bridge is partially blocked with debris, there is an impact on the upstream flood levels. Including for the effects of debris, the 0.5% AEP + CC flood levels are likely to be above the soffit of the bridge deck.

Figure 3.5: Ivanhoe bridge

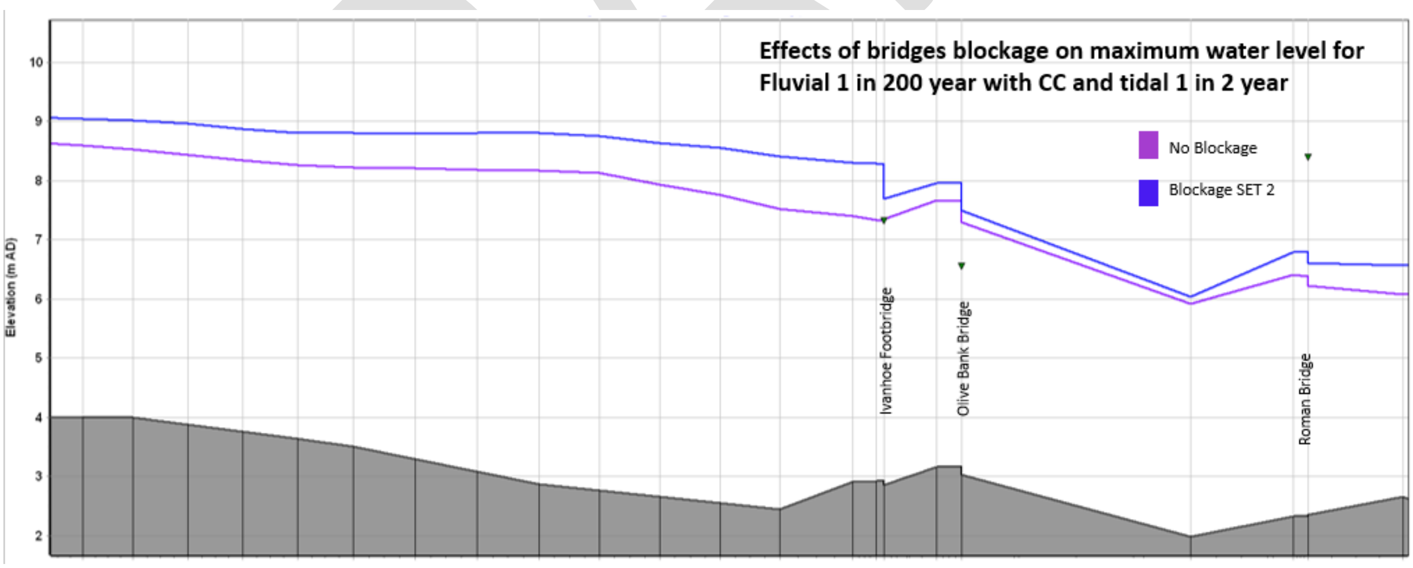

Figure 3.6: effects of blockage at Ivanhoe and Olive Bank Road bridge

Options to raise or replace the bridge (Option 2.15 / 2.16) were rejected at an early stage in the appraisal process because the nearby Olive Bank Road bridge provides a greater degree of hydraulic influence through this stretch of the River Esk, therefore the impact of change at this bridge would be negated by the presence of Olive Bank Road bridge.

It is recommended that raising the Ivanhoe footbridge is not a component of the preferred scheme. It is recommended that investigation into any change to the lateral and / or uplift forces acting on the structure, as a result of other preferred scheme components, is undertaken during Stage 4 Outline Design.

3.2.3 Olive Bank Road Bridge

Refer to Figure 3.7. The Olive Bank Road bridge used to convey part of the railway network across the River Esk up until the 1960s when many local branch lines were replaced with new road networks. This two span structure (utilising the ancient central stone pier) has an influence on upstream baseline river levels even when the effects of debris are not considered. The initial hydraulic modelling showed that whilst raising or replacement of the bridge would reduce flood levels (and thus defence heights) upstream, there would be an approximate 200mm water level increase downstream, including impacts on the Roman Bridge. Works to the bridge would result in significant traffic disruption as all cross river traffic would be forced to use the Rennie Bridge.

Figure 3.7: Olive Bank Road Bridge

Refer to figure 3-6 for details of the effects of debris blockage at Olive Bank Road bridge.

Higher defence heights would be required upstream of the bridge in a principally industrial area, compared to lower heights downstream of the bridge in a mix of commercial and residential areas.

It is therefore recommended that raising or replacement of the Olive Bank Bridge is not a component of the preferred scheme. It is recommended that investigation into any change to the lateral and / or uplift forces acting on the structure, as a result of other preferred scheme components, is undertaken during Stage 4 Outline Design.

3.3 Cell 1: Stoneybank and Musselburgh Golf Course

A range of options were investigated for Cell 1, which principally involved modification of how the River Esk interacts with the Musselburgh Golf Course.

Option 1.00 relates to the Do-Nothing or Do-Minimum option, where the current regime implemented by East Lothian Council is maintained.

Option 1.01 related to increasing the level of the left hand bank of the River Esk through a wall or bund. By inspection, the lack of property affected by flooding at the Musselburgh Golf Course combined with the very long length of defence required would result in a BCR significantly lower than 1.0, and ultimately failing one of the key objectives. In addition, there is an increased flood risk to the opposite bank and an increase in flood levels downstream of the Musselburgh Golf Course.

Option 1.02 related to lowering the left hand bank of the River Esk, thus flooding the Musselburgh Golf Course more frequently and to a greater depth. This resulted in minor reductions in flood levels to the Inveresk area, but with significant adverse impact on the Musselburgh Golf Course and no impact on flood levels at Eskmills.

Option 1.03 related to improving drainage within the Musselburgh Golf Course to provide resilience when recovering from a flood event. Closer review of this option showed that the existing Musselburgh Golf Course drainage is relatively robust and any new drainage may well be affected by silt and debris following a major flood, therefore the investment would have little benefit in return.

Options 1.05 to 1.08 related to options for protection to the Stoneybank Gas Governor (refer Figure 3.8), including Do-Nothing (Option 1.05), abandonment and relocation (option 1.06), direct or demountable defences (option 1.07) or flood resilience measures. Discussion with Scottish Gas Networks (SGN) has identified that there is the potential for relocation of the gas governor in its entirety as part of SGN's own flood resilience programme. In addition, the impact of flooding on the gas governor is relatively minor, given the lack of mechanical parts and the fact that SGN undertook their own flood resilience works for the more sensitive electrical features in the relatively recent past. It therefore follows that, unless other scheme components increase flood risk to the gas governor, there is no obligation to provide flood protection.

Figure 3.8: Location of the Stoneybank Gas Governor.

Based on the lack of positive impact on flood defence levels to other parts of Musselburgh, it is recommended that increasing the flood risk to Musselburgh Golf Course is not a component of the preferred scheme. Similarly, protecting the Musselburgh Golf Course has a number of significant negative impacts (increased flood risk to other parts of the town, probable lack of economic feasibility) and should not be a component of the preferred scheme, unless other scheme components cause an increase in flood risk to the Musselburgh Golf Course. This same principle applies to the Stoneybank Gas Governor.

It is therefore recommended that the Do-Nothing / Do-Minimum current approach to managing flood risk throughout Cell 1 is maintained.

3.4 Cell 2: Eskmills and Inveresk

Cell 2 represents the areas at risk of flooding on the right hand bank of the River Esk, from the A1 road bridge to the Olive Bank Road bridge. In this cell, the flooding sources are limited to:

- Fluvial flooding from the River Esk, and
- Depending on the necessity for direct defences, secondary flooding deriving from a pluvial event, surcharging sewer or burst water main.

The upstream part of this cell is semi-rural, with open flood plain and public footpaths backed by stone walls which delineate the boundary to private properties with large gardens at Inveresk. Note that some properties within the Inveresk Estate are at flood risk from the 0.5% AEP + CC Event and form part of a new flood cell (Cell 9). Downstream of the Eskmills weir, the landscape adjacent to the river is dominated by industrial and commercial land use, with some private residential properties near the Olive Bank Road bridge.

Refer to Figure 3.9. In addition to the potential to carry out remedial works to the Eskmills Weir, shortlisted options for consideration within this flood cell were focused on direct defences and the Mill Lade.

3.4.1 Flood plain recoupling

Option 2.02 considers the potential to recouple the flood plain upstream of the Inveresk Estate, where the existing public footpath runs on top of an existing low height embankment. Lowering the height of the embankment has the potential to provide a greater volume of flood storage by reducing the threshold of inundation of the flood plain. Preliminary hydraulic modelling has shown that because the flood plain inundates at a relatively low level, the volume of storage which could be made available is very quickly used up in the first hours of the flood event, well before the peak passes through. This means that the impact on peak flood level is negligible.

It is therefore recommended that flood plain recoupling upstream of the Inveresk Estate is not a component of the preferred scheme.

3.4.2 Direct Defences

Refer to Figure 3.9. Option 2.03 considers the provision of continuous direct defences from tying in to high ground around 100m upstream of the Eskmills weir to tie in with the upstream face of the Olive Bank Road bridge. The defences are likely to take the form of a combination of walls and embankments, depending on available space. Given the fact that the defences will cross or tie into existing accesses and structures (e.g. riverside path, Ivanhoe Bridge, SEPA gauging station), the provision of flood gates, steps or ramps will be required at various locations. The height of the defences is a function of the inclusion of other scheme components, but for the purposes of discussion in this section of the report, it is assumed the defences are provided as a standalone component.

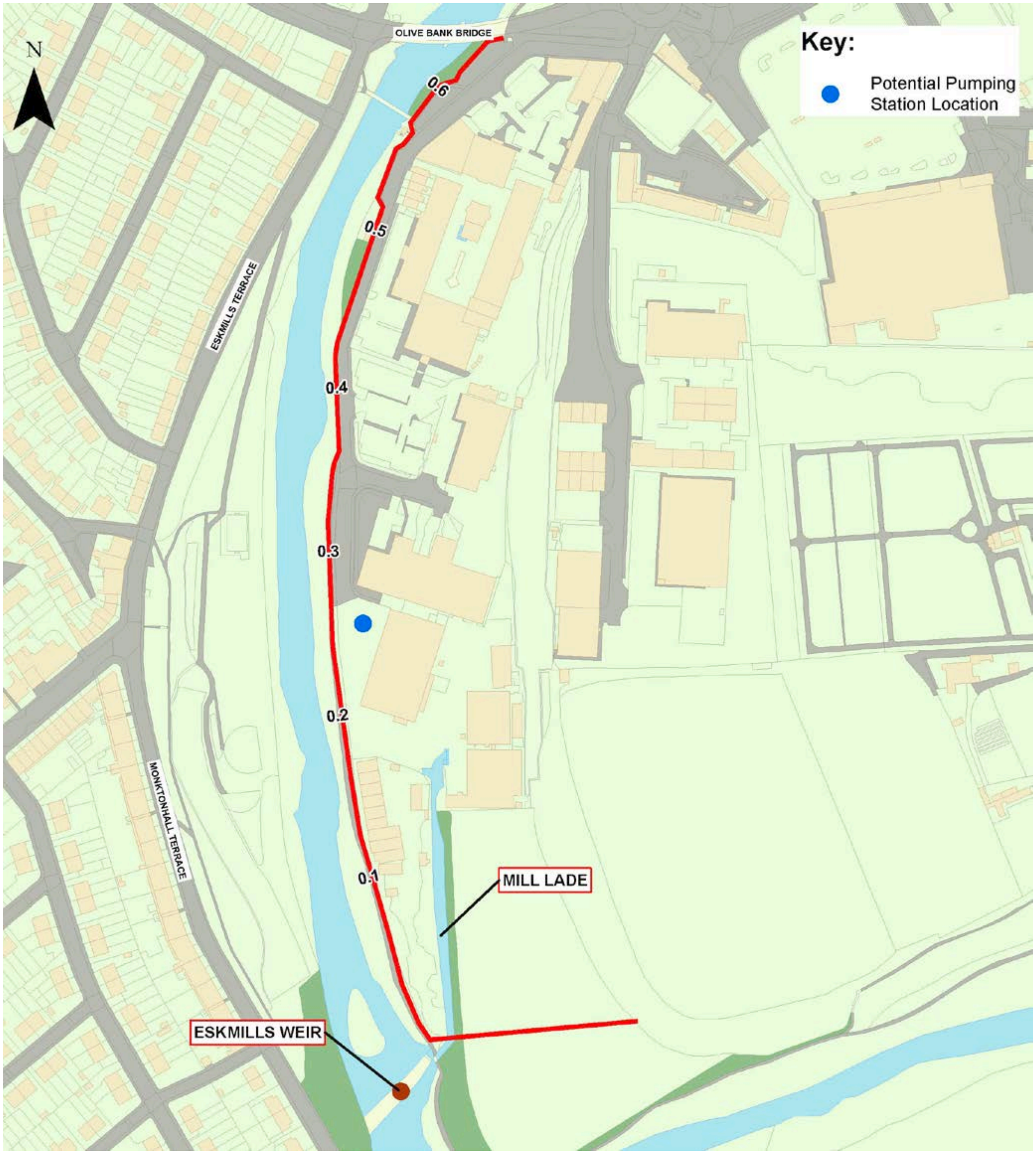

Figure 3.9: Potential alignment of direct defences at Cell 2.

Initial review of the 0.5% AEP + CC flood event shows that, in the worst case scenario with all existing bridges blocked with debris, the impact on baseline flood levels along the assumed defence alignment shown in Figure 3.9 is summarised in Table 3.1. The corresponding defence heights above adjacent dry side ground level are also shown, based on a 600mm freeboard allowance.

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
100	8.705	9.106	+0.401	2.379
200	8.342	8.919	+0.577	2.796
300	8.119	8.862	+0.743	3.219
400	8.208	8.877	+0.669	3.198
500	7.748	8.688	+0.94	2.724
600	7.230	8.372	+1.142	2.652
700	7.497	7.949	+0.452	2.526

Table 3.1: Impacts of Cell 2 direct defences on baseline flood levels and corresponding defence heights for the 0.5% AEP + CC flood event, with bridges blocked with debris in accordance with blockage set 2.

Table 3.1 highlights a number of potential issues with the provision of direct defences in Cell 2, with significant defence heights. Figure 3.10 demonstrates the change in visual impact associated with increasing defence height above adjacent footpath level. It is generally considered that defences above 1.6m high may require additional mitigation measures such as glazing panels or raised footpaths. It should be noted that the influence of debris on required defence height is significant and Table 3.2 highlights the change in flood levels at each chainage if no debris were present at any of the bridges which span the River Esk from Ivanhoe to Goose Green.

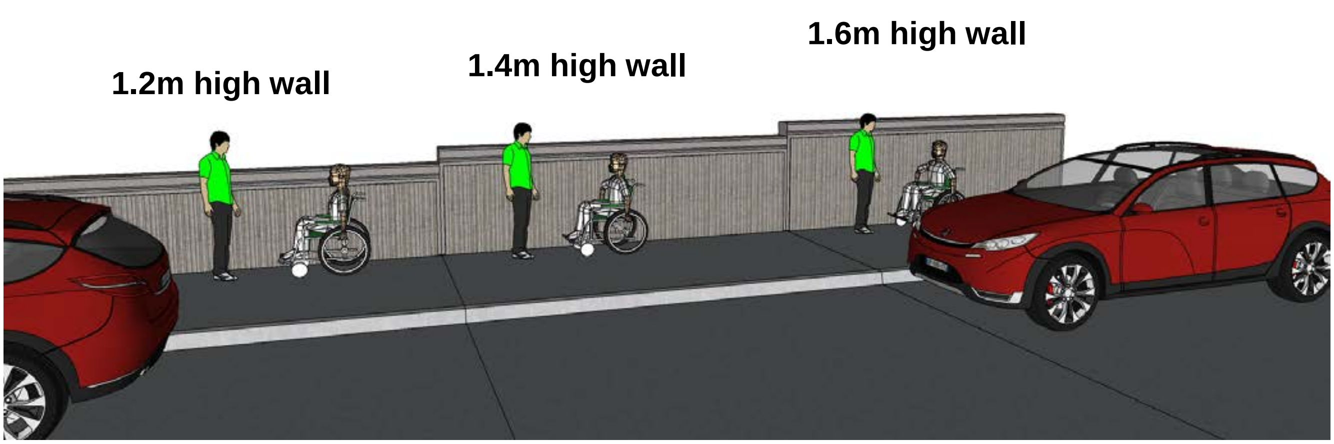

Figure 3.10: Graphic showing change in visual impact with increased defence height

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
100	8.705	8.613	-0.092	1.827
200	8.342	8.367	+0.025	2.217
300	8.119	8.359	+0.24	2.576
400	8.208	8.224	+0.016	2.554
500	7.748	7.998	+0.25	1.988
600	7.230	7.636	+0.406	2.341
700	7.497	7.642	+0.145	2.225

Table 3.2: Reduction in Cell 2 direct defence heights and impacts on baseline levels as a result of assuming no blockage at any of the River Esk bridges

3.4.3 Pumping Stations

The secondary and surface water flood risk to Cell 2 has still to be accurately modelled, and the severity of such flooding correspondingly ascertained. Musselburgh has recently experienced episodes of surface water flooding during torrential summer convective storms (August 2019), and there is a risk the scheme may exacerbate this flood risk by trapping surface water on the dry side of direct defences. Areas where surface water may accumulate have been derived by reviewing the low points from the LiDAR data and these areas have been identified as potential locations for pumping stations.

The impacts of surface water / secondary flooding in Cell 2 remain to be fully defined, but it is assumed that at least one automatic underground pumping station will be a component of the preferred scheme. Full modelling of the surface water flood risk will be required as part of Stage 4 Outline Design to ascertain the requirements, including location, flow rates, etc.

3.5 Cell 3 and 4 Bridges: Roman, Rennie, Shorthope St, Electric, Goose Green

Cells 3 and 4 are connected by a series of bridges, each with a variety of factors which could influence the preferred scheme. Consultation with key stakeholders during the Option Appraisal shortlisting process determined that if the scheme resulted in any negative influence on the Category A listed Roman Bridge, believed to have been constructed in its current form in 1597 (refer to Figure 3.12), then the risk of objection would be very high. One of the key objectives of reviewing the preferred combination of scheme components must be to consider this requirement.

Figure 3.11: Roman Bridge

3.5.1 Rennie Bridge

Refer to Figure 3.14. The Rennie or New Bridge was constructed in 1808 and significantly widened in 1925 to accommodate increased traffic flows. The five arch masonry bridge used to carry the main Edinburgh to London A1 road before the current A1 dual carriageway was introduced to bypass Musselburgh in the 1980s. The bridge is a significant feature within the town centre and provides a key vehicle and pedestrian crossing of the River Esk. The option appraisal process identified that the bridge presents a significant hydraulic influence on the river, with an afflux of 164mm during the 0.5% AEP + CC event with no debris blockage present. The relatively low arch soffits and large proportion of occupation of the waterway means the bridge is prone to blockage by floating debris. Figure 2.9, taken during the 1948 flood, highlights the blockage risk.

The Option Appraisal shortlisting process identified that, similar to the Roman Bridge, any change to this structure as a result of the proposed preferred scheme would result in a high risk of objection, and options to replace or modify the structure were rejected at a relatively early stage.

One option to improve the conveyance through the structure by reducing the level of the river bank within the dry arches was considered, but ultimately rejected as a standalone option due to its lack of impact during the 0.5% AEP + CC event. However, should further mitigation be required to reduce the impacts of the preferred scheme on the bridge, this relatively low cost, low impact option could be implemented in combination with other components.

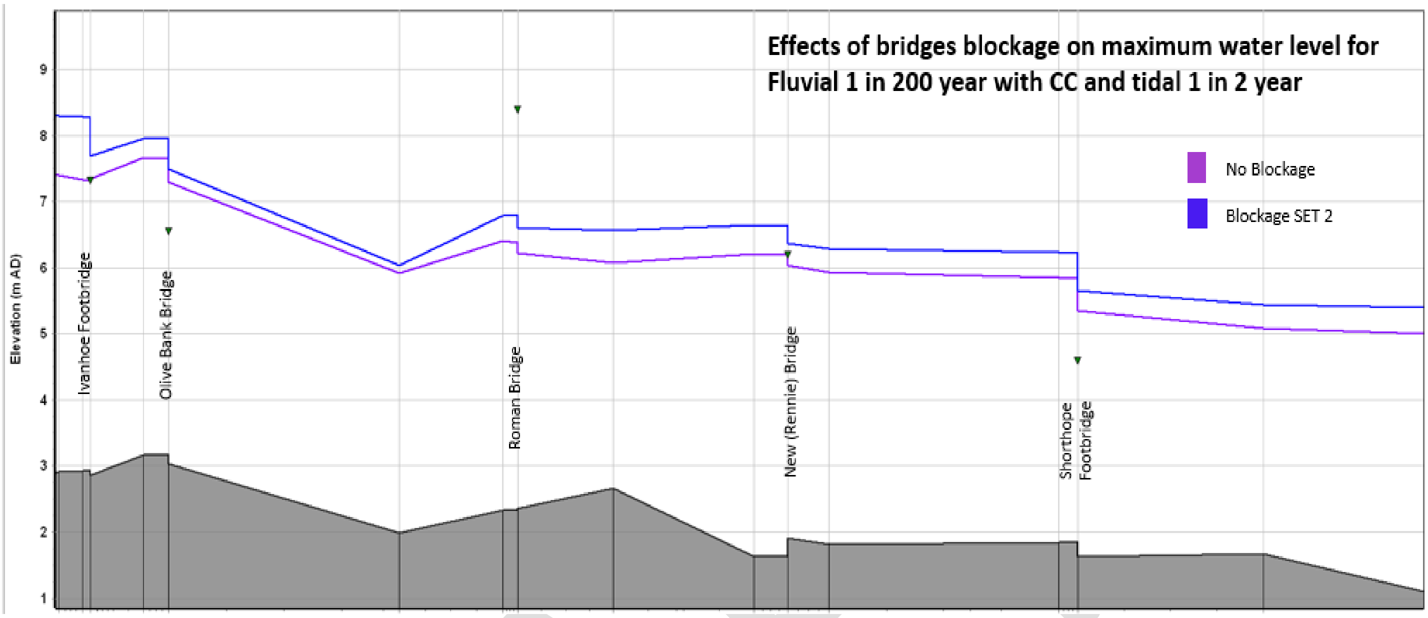

Figure 3.12: Effects of debris blockage between Ivanhoe and Shorthope Street footbridge

It is therefore recommended that the preferred scheme components are selected such that the hydraulic, structural and aesthetic impacts on the bridge are minimised to reduce the likelihood of objection risk and structurally complex and costly solutions. The option to improve the conveyance through the structure by reducing the levels of the river banks within the dry arches should only be considered in combination with other components, where there is a requirement to minimise said hydraulic, structural or aesthetic impacts.

Figure 3.13: Rennie Bridge

3.5.2 Shorthope Street footbridge

The Shorthope Street bridge is a pedestrian only two span reinforced concrete structure which spans the River Esk between North High Street and Shorthope Street. The structure has a relatively low soffit and is on a skew to the main river flow, which, anecdotally has led to a belief that the flood risk to the right hand is correspondingly increased. The shortlisting process determined that removal of the structure (option 4.04) or raising or replacement (option 4.05) of the bridge were worthy of consideration, depending on whether the structures have an influence on the fluvial flood risk.

More detailed analysis of the hydraulic modelling shows that the bridge exerts a significant influence on fluvial flood levels in both the blocked and unblocked scenarios over a notable distance upstream (refer to figures 3.13 and 3.16) and would be unavailable for use at relatively modest flood events (e.g. from the 2% AEP + CC event). In the worst case debris blockage scenario, the flood levels upstream of the structure are around 400mm higher than the unblocked scenario.

As a standalone option, removal and potential replacement of the bridge would offer flood level reductions of up to 300mm for the 0.5% AEP + CC flood event. When analysed in combination with direct defences, the reduction in flood levels offered by removal of the structure were even greater, up to 900mm in the blocked scenario (refer to Section 3.14 for more detail), with notable reduction in flood levels up to the Rennie Bridge.

Initial review of the height of direct defences upstream of Shorthope St bridge with the structure in place show that the cope of wall or top of embankment crest would be significantly higher than the general socially acceptable maximum height of 1.4m for both cells 3 and 4. Removing the bridge would provide a reduction in levels to cope or crest levels nearer the acceptable threshold. Including removal of the bridge in the preferred scheme would therefore significantly reduce the risk of objection against unacceptably high direct defences.

Raising the bridge was not considered further due to the composite form of construction (raising may be more expensive than replacement) and continued presence of a central pier which continues to impact on conveyance.

It is therefore recommended that removal of the Shorthope Street footbridge is a component of the preferred scheme. The decision relating to whether or not the bridge should be replaced at or near its current location with a higher, single span structure providing much improved conveyance is discussed in Section 3.14.

Figure 3.14: Shorthope Street Footbridge

3.5.3 Electric and Goose Green bridges

Refer to figures 3.17 and 3.18. The Electric Bridge is a three span steel composite bridge deck supported by in channel reinforced concrete piers, constructed in 1963 to facilitate delivery of plant and materials to the Cockenzie coal power station, 5 miles to the east. The bridge is currently owned by Scottish Power and is open to traffic only on race days at Musselburgh Racecourse. The Goose Green footbridge is immediately downstream of the Electric Bridge and is a three span steel truss structure supported by in-channel reinforced concrete piers. This is the furthest downstream crossing of the River Esk and carries pedestrians, cyclists (the John Muir Way) and a Scottish Gas Networks gas main across the watercourse. The undersides of the Electric Bridge beams are around 900mm lower than the bottom chord of the Goose Green footbridge and therefore exert the greatest influence on conveyance of the river.

The shortlisting process determined that removal (Options 4.06 and 4.08) or raising / replacement (4.07 and 4.09) of the structures should be investigated further, depending on whether the bridges had an influence on fluvial flood risk. For the purposes of the remaining sections of this report, the bridges are considered as a single structure, where removal / raising / replacement options would involve both bridges.

Having determined from the hydraulic model that the bridges have an influence on fluvial flood levels during the 0.5% AEP + CC event, the effects of removing both bridges as a standalone option and in combination with direct defences were analysed. Relatively insignificant effects were observed when considered as a standalone option, but when considered in combination with direct defences, the effects were much greater, demonstrating a reduction in flood levels of approximately 800mm. The effects of debris on flood levels at the structure were similar to other structures where the flood levels upstream of a worst case blockage scenario at the structure are around 400mm higher than the unblocked scenario.

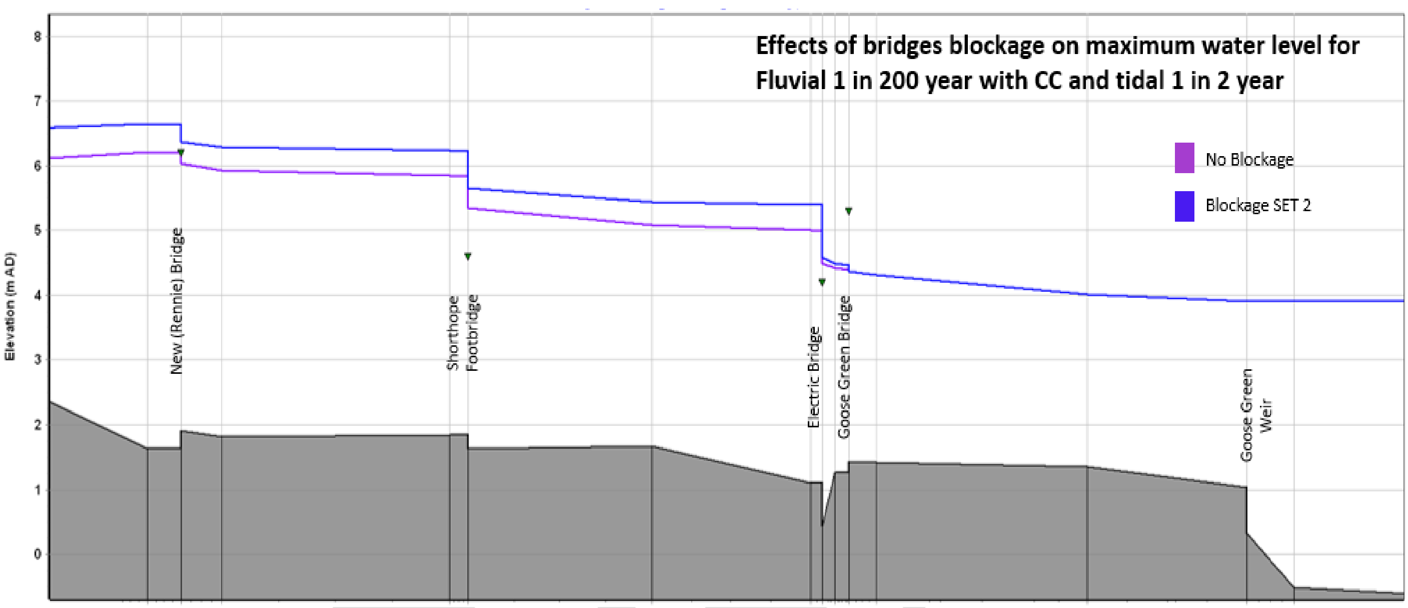

Figure 3.16 – effects of debris blockage between Rennie Bridge and Goose Green footbridge

Initial review of the height of direct defences upstream of the Electric and Goose Green bridges with the structures in place show that the cope of wall or top of embankment crest would be significantly higher than the general socially acceptable maximum height of 1.4m for both cells 3 and 4. Removal of these structures reduces the potential height of direct defences by up to 900mm, bringing the defence heights closer to the socially acceptable criteria.

The hydraulic modelling also demonstrated that, when carried out in combination with the removal of Shorthope Street footbridge, the removal of the Electric and Goose Green footbridges results in a cumulative reduction in flood levels at the Rennie and Roman Bridges, such that the flood levels associated with the "with direct defences" scenario are broadly comparable with the baseline scenario. This is a critically important observation, based on the objection risks associated with adverse hydraulic impacts at the Rennie and Roman Bridges.

Given its prominent location and important function as the further downstream crossing of the River Esk, it is highly probable that a new, higher single span structure will be required to replace the Electric and Goose Green bridges, the function of which may include a new vehicular crossing. Such a crossing may have some short-term impacts on the sensitive transitional waters in which it sits, as well as long term visual and environmental impacts on local communities (especially if a new vehicle bridge is provided).

It is therefore recommended that the removal and replacement of the Electric and Goose Green bridges are components of the preferred scheme. The form and function of the replacement crossing remains to be determined as part of Stage 4, but must take cognisance of the potential social and environmental impacts as well as ensuring the watercourse conveyance is improved.

Figure 3.17 Electric Bridge

Figure 3.18: Goose Green Footbridge

3.6 Cell 3: Town Centre West and Fisherrow

Cell 3 represents areas of the town which are subject to:

- fluvial flooding from the left hand bank of the River Esk;
- coastal flooding from the North Sea (to the west of the River Esk estuary), and
- Secondary flooding at low points or adjacent to direct defences, arising from surface water which derives from a pluvial event, surcharging sewer or burst water main.

The flood cell contains a total of 684 residential and business properties at risk from the 0.5% AEP + CC blended flood extent, as well as critical infrastructure such as 2 no. Scottish Water pumping stations, Loretto Newfield and the main A199 East Lothian coastal towns route into Edinburgh.

3.6.1 Fluvial Direct Defences

Refer to Figure 3.19 and shortlisted option 3.04. Direct defences are required to protect against the effects of the 0.5% AEP + CC fluvial flood event from the River Esk from a point which ties into high ground to the south of the Roman Bridge to a point where coastal flooding becomes the governing flood risk. The exact location of these points is dependent on the provision of other preferred scheme components, including bridge removal / replacement and / or upper catchment measures (Section 3.10). Similarly, the heights of the direct defences, and how they tie in to other structures, is a function of the provision of other preferred scheme components, but in all cases, tie-in to the upstream and downstream faces of the Roman Bridge, Shorthope Street bridge and Electric / Goose Green bridges is necessary. The need to tie-in to the Rennie Bridge is very much dependent on the provision of other components (see Section 3.14).

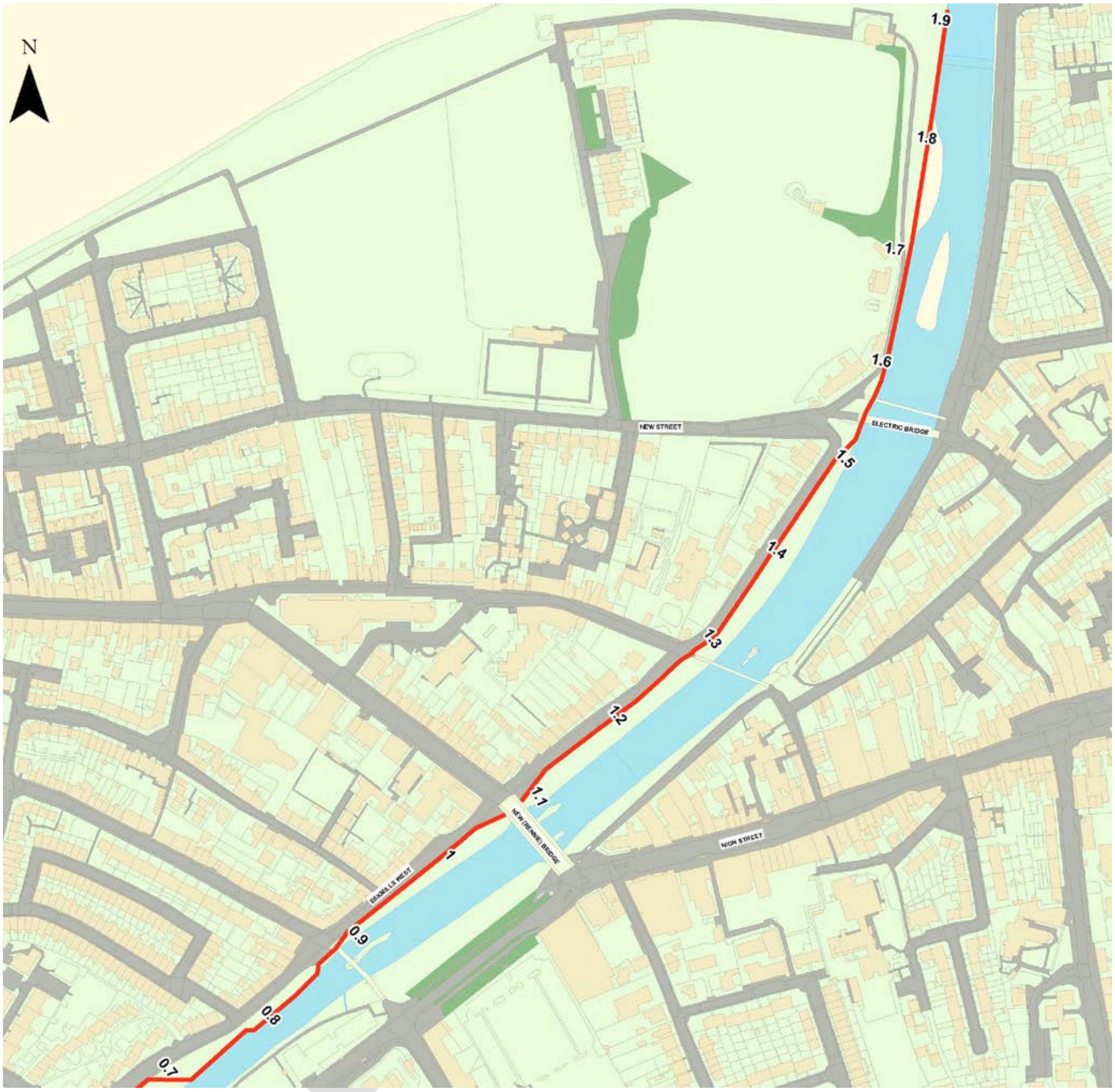

Figure 3.19: Potential alignment of direct defences at Cell 2.

Feedback from consultation exercises undertaken during the shortlisting process (including the Public Exhibition in July 2019) favoured defences set back from the river edge, primarily due to the fact said defences would be lower in height as a result of maintaining a larger proportion of the floodplain. Exact determination of the alignment of the flood defences will be undertaken during Stage 4 Outline Design but is assumed for the purposes of this section of the report that the defences (either toe of embankment or centre line of wall) will be offset 1m from the river edge of footpaths or roads.

Initial review of the 0.5% AEP + CC flood event shows that, in the worst case scenario with all existing bridges blocked with debris, the impact on baseline flood levels along the assumed defence alignment shown in Figure

3.19 is summarised in Table 3.3. The corresponding defence heights above adjacent dry side ground level are also shown, based on a 600mm freeboard allowance.

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
700	7.311	8.407	+1.096	-
800	7.048	7.494	+0.446	-
900	6.891	6.852	-0.039	1.117
1000	6.611	6.759	+0.148	2.936
1100	5.775	6.620	+0.845	2.266
1200	5.798	6.778	+0.980	2.600
1300	4.952	6.302	+1.350	2.706
1400	4.935	6.250	+1.315	2.791
1500	4.740	5.579	+0.839	2.149
1600	4.546	5.445	+0.899	2.155

Table 3.3: Impacts of Cell 3 direct defences on baseline fluvial flood levels and corresponding defence heights for the 0.5% AEP + CC flood event, with bridges blocked with debris in accordance with blockage set 2.

Table 3.3 highlights a number of potential issues with the provision of direct defences in Cell 2, with defence heights well above a generally acceptable maximum of 1.6m above adjacent footpath level. It should be noted that the influence of debris is significant and Table 3.4 highlights the change in flood levels at each chainage if no debris were present at any of the bridges which span the River Esk from Ivanhoe to Goose Green. Removal of the Shorthope Street and Goose Green bridges further reduces the flood levels and corresponding defence heights.

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
700	7.311	7.651	+0.340	-
800	7.048	7.297	+0.249	-
900	6.891	6.667	-0.224	0.967
1000	6.611	6.474	-0.137	2.540
1100	5.775	6.169	+0.394	1.800
1200	5.798	6.323	+0.525	2.151
1300	4.952	5.940	+0.988	2.337
1400	4.935	5.867	+0.932	2.405
1500	4.740	5.250	+0.510	1.820
1600	4.546	5.074	+0.528	1.783

Table 3.4: Reduction in Cell 3 direct defence heights and impacts on baseline levels as a result of assuming no blockage at any of the River Esk bridges

The fluvial direct defences for Cell 3 could be formed by walls or embankments, but it is noted that an embankment will require a crest which is approximately 100 – 150mm higher than a wall cope due the riverward embankment slope occupying a greater proportion of the flood plain. Other influences on the type and form of direct defences (including assessment of the defence aesthetics and the feasibility of demountable defences, hybrid defences, glass panels, flood gates, ramps and stepped accesses, etc) are further discussed in Section 3.14, but will ultimately be the focus of the Stage 4 Outline Design.

It is therefore recommended that the provision of direct defences to protect Cell 3 from the effects of the 0.5% AEP + CC fluvial flood event in the River Esk is a component of the preferred scheme. The current preference from feedback from stakeholders and the public is for walls set back from the river edge, but further work is required to determine the exact height, alignment and form of the defences, which will also be a function of other preferred scheme components.

3.6.2 Coastal Direct Defences

The factors influencing the consideration of the form and function of the coastal direct defences are different to those influencing fluvial defences. The main element to consider is whether or not the defences should protect against all wave overtopping, resulting in potentially unacceptably high defences, or to allow a degree of overtopping, resulting in much lower defences but a need to deal with the overtopped flood waters.

Goose Green footbridge to River Esk estuary

Refer to figure 3.20 and shortlisted option 3.04. The height of direct defences along the left hand bank of the River Esk is governed by coastal flood risk at a point just downstream of the Goose Green footbridge. A visual inspection of the existing retaining walls downstream of the Goose Green footbridge revealed that they were in relatively poor condition, with numerous cracks, bulges and other defects which would severely compromise the residual life of the walls. Whilst it is best practice to set back the defences for fluvial flood protection measures (reduce flood plain impact, lower defence heights), this does not apply to coastal defences, where there is no adverse impact on flood levels elsewhere. This combination of factors leads to the conclusion that, subject to detailed environmental impact assessment and mitigation where appropriate, the new defences downstream of Goose Green footbridge should be constructed in the river channel. This fulfils the dual function of flood protection and superseding infrastructure which will require replaced within the design life of the scheme.

Figure 3.20 Potential alignment of coastal direct defences from Goose Green Footbridge to River Esk Estuary.

It is noted that, downstream of the Goose Green footbridge, the left hand bank of the River Esk is up to 0.4m below the still water level of the 0.5% AEP + CC coastal still water level. Wave overtopping within the estuary is not as significant as along the coastline, but the defence heights would nonetheless be generally in the range of up to 1.6m above existing ground levels. It is expected that the defences along this section will be able to protect against the effects of still water and wave action for the 0.5% AEP + CC event, with no requirement to deal with overtopping volumes.

It is therefore recommended that the provision of flood defence / retaining walls in the River Esk channel, to protect against the effects of still water and wave overtopping and to replace the existing retaining walls, are a component of the preferred scheme from the Goose Green footbridge to a point approx. 100 metres downstream of the Goose Green weir.

River Esk estuary to Fisherrow Harbour

Refer to Figures 3.21 and 3.22. Heading west from the River Esk estuary, the alignment of the coastal defences will be subject to more detailed assessment during Stage 4 Outline Design but is expected to follow a route immediately landward of the dunes, and then to replace existing wall infrastructure near Fisherrow Harbour.

Figure 3.21 Potential alignment of coastal direct defences from River Esk Estuary to Fisherrow Harbour.

Figure 3.22 - Fisherrow Promenade

The coastal hydraulic modelling shows that, in general, the peak still water level for the 0.5% AEP + CC event is similar to the level of the top of the dunes, or top of retaining wall, thus the majority of flood risk is derived from wave overtopping. Calculation of the worst case wave heights during the 0.5% AEP + CC event demonstrate that a minimum 2.2m high defence would be required to ensure that wave overtopping volumes are kept to a negligible magnitude. Presentation of this option to the public resulted in widespread negative comments, especially in proximity to Fisherrow promenade. The second option, which involves a much lower height defence with a minimum height above ground level of 1.4m, which is designed to be overtopped, was preferred. This lower height option would also require an enhanced drainage network and series of pumping stations to be provided to ensure the overtopping flows do not cause property flooding. The relationship between defence height and overtopping flows is complex and will require additional modelling during Stage 4 to fully determine the optimum balance between acceptable defence height and size and number of pumping stations. It may be the case that a variable height defence is introduced, lower near the residential areas to preserve sea views, and higher nearer the grassed amenity areas. Refer to section 3.6.4 for further details of the pumping stations

It is therefore recommended that the provision of a variable height flood defence between a point 100m downstream of the Goose Green weir and the eastern end of Fisherrow Harbour is a component of the preferred scheme. A number of saline water pumping stations will be required to discharge wave overtopping volumes from the dry side of the defences.

Fisherrow Harbour

Fisherrow Harbour has been an operational harbour for over 400 years, with the current infrastructure having been constructed in phases, dating back as early as 1743. The harbour is created by two masonry piers which extend approximately 200m into the North Sea. Given the age and uncertain nature of the construction of these piers, it is not proposed to include or incorporate them into the preferred scheme, as there is a risk they will not perform as intended over the scheme's 100 year design life, compromising the standard of protection of this entire flood cell.

It is therefore proposed to continue the defences along the southern boundary of the harbour with access from the car park to the harbour provided for boat owners across the defence alignment. This could be in the form of demountable barriers, gates, ramps or a combination thereof. The height of the defences will be a function of the degree of wave attenuation provided by the east pier, and whether that can be relied upon over the design life of the project. The overall length of demountable or gated access to the harbour will be a function of discussion with the Harbour Trust and users.

It is therefore recommended that the provision of a mix of demountable and solid direct defences along the southern boundary of Fisherrow Harbour is a component of the preferred scheme, the height of which will be a function of further analysis of how the existing piers interact with the prevailing wave direction. It is a requirement, however, that the flood defences are structurally detached from the existing harbour wall, in the case of future planned pier demolition or as a result of storm damage.

Fisherrow Harbour to Brunstane Burn

This area of the town is west of Fisherrow harbour, and is mostly residential. Similar to areas east of the harbour, flood risk is principally derived from wave overtopping, where the back gardens of properties effectively back directly onto the beach. The flood mapping shows that the main A199 Edinburgh Road could also be inundated along with the Scottish Water Eastfield Pumping Station.

Analysis of the available options shows that the only feasible shortlisted option is to provide direct defences along the back of the beach to protect the properties, then turn south along the right hand bank of the Brunstane Burn (also known as Magdalene Burn) to tie in with the A199 bridge. Many of the properties in this area which face directly onto the beach have their own access and desirable sea views. Cognisance of these benefits to the property owners will form part of the outline design, along with selection of the appropriate defence height. It may be the case that the private residents accept a degree of residual flood risk along this stretch as it may be difficult to provide pumping provision within the private gardens, unless the defences are moved further into the Special Protected Area and create a buffer zone between the defences and the private garden boundary.

It is therefore recommended that the provision of direct defences along the back of the beach to replace or augment existing walls between Fisherrow Harbour and the Brunstane Burn at the City of Edinburgh boundary is a component of the preferred scheme. The alignment and height of the defences and standard of protection provided will be a function of discussion with the property owners and occupiers, as well as key environmental stakeholders. The defences must also run up the right hand bank of the Brunstane Burn to tie in with the downstream face of the A199 bridge. Work is not anticipated to be required to the bridge.

3.6.3 Secondary and surface water Pumping Stations

Refer to figure 3.23. The secondary and surface water flood risk to Cell 3 has still to be accurately modelled, and the severity of such flooding correspondingly ascertained. Musselburgh has recently experienced episodes of surface water flooding during torrential summer convective storms (August 2019), and there is a risk the scheme may exacerbate this flood risk by trapping surface water on the dry side of direct defences. Areas where surface water may accumulate have been derived by reviewing the low points from the LiDAR data and these areas have been identified as potential locations for pumping stations.

The impacts of surface water / secondary flooding in Cell 3 remain to be fully defined, but it is assumed that at least one automatic underground pumping station will be a component of the preferred scheme. Full modelling of the surface water flood risk will be required as part of Stage 4 Outline Design to ascertain the requirements, including location, flow rates, etc.

3.6.4 Coastal Pumping Stations

Further to Section 3.7.2, it is very likely that the preferred scheme for coastal flood protection will require measures to deal with wave overtopping, on the basis that full height defences are not desired by the residents.

Draining and subsequently pumping this overtopped sea water will require large diameter, high capacity pipework fed by a series of oversize gullies (recognising that waves are also likely to be depositing large quantities of sand, shingle, pebbles, driftwood and seaweed). Refer to figure 3.23..The pumps will require to be very durable and corrosion resistant. The numbers of pumping stations, locations and their flow rates will be a function of the coastal defence heights, all to be determined during Stage 4.

It is therefore recommended that saline water pumping stations will be a component of the preferred scheme. The number of pumping stations will be a function of the variable height defences identified in Section 3.6.2 and whether or not a pumping station is feasible west of Fisherrow Harbour will be subject to the alignment of the defences and their proximity to the existing property boundaries. Much further work is required during Stage 4 to review influencing technical factors such as drainage, pump rate, debris management and long term maintenance requirements.

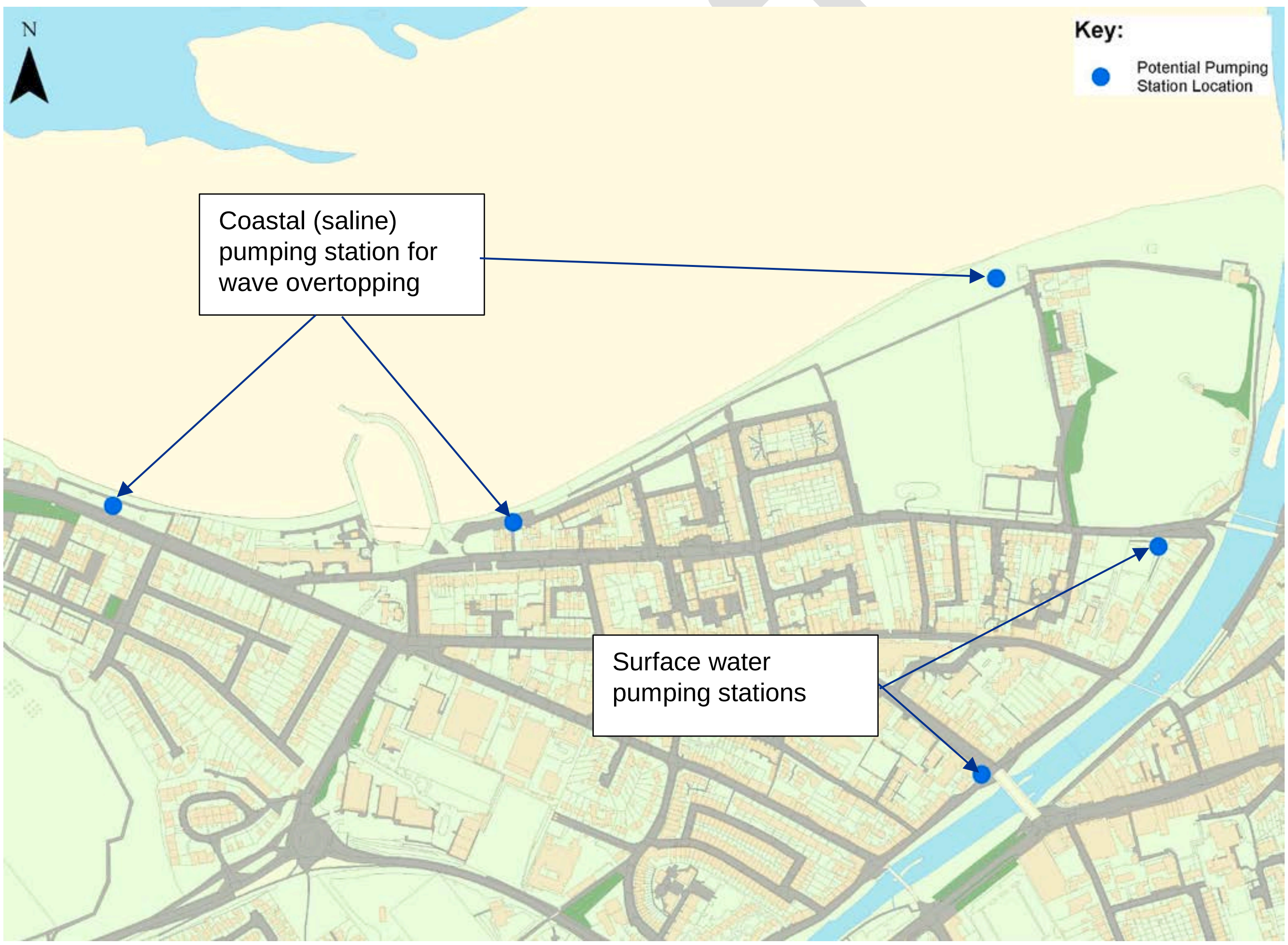

Figure 3.23 Potential pumping station locations in Cell 3.

3.7 Cell 4: Town Centre East

Cell 4 represents areas of the town which are subject to:

- fluvial flooding from the right hand bank of the River Esk;
- coastal flooding from the North Sea (within the River Esk estuary from the Goose Green footbridge to the Musselburgh Lagoons Sea Wall), and
- Secondary flooding at low points or adjacent to direct defences, arising from surface water which derives from a pluvial event, surcharging sewer or burst water main.

The flood cell contains a total of 1058 residential and business properties at risk from the 0.5% AEP + CC blended flood extent, as well as critical infrastructure such as large parts of the Loretto School, the A199 High Street and parts of Musselburgh Racecourse

3.7.1 Fluvial Direct Defences

Refer to Figure 3.24 and shortlisted option 4.10. Analysis of the hydraulic model shows that, with all the existing bridges retained in their current guise, continuous direct defences are required along the right hand bank to protect against the effects of the 0.5% AEP + CC fluvial flood event from the River Esk, from a point which ties into the downstream abutment of the Olive Bank Road Bridge to a point where coastal flooding becomes the governing flood risk (see section 3.7.2). The exact location of the downstream point is dependent on the provision of other preferred scheme components, including bridge removal / replacement and / or upper catchment measures (Section 3.10). Similarly, the heights of the direct defences, and how they tie in to other structures, is a function of the provision of other preferred scheme components, but in all cases, tie-in to the upstream and downstream faces of the Roman Bridge, Shorthope Street bridge and Electric / Goose Green bridges is necessary. The need to tie-in to the Rennie Bridge is very much dependent on the provision of other components (see Section 3.14).

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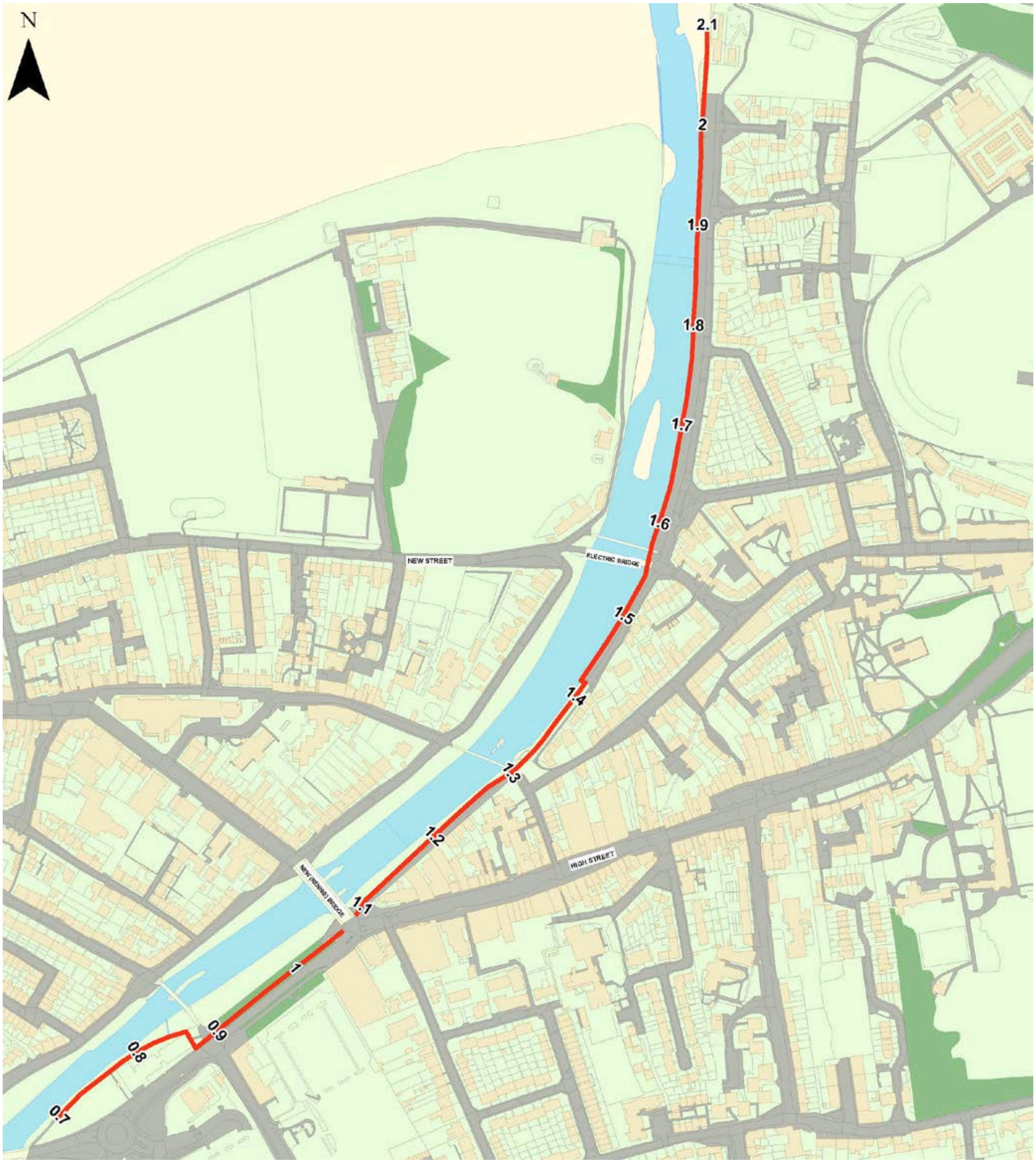

Figure 3.24 Potential alignment of direct defences at Cell 4

Feedback from consultation exercises undertaken during the shortlisting process (including the Public Exhibition in July 2019) favoured defences set back from the river edge, primarily due to the fact said defences would be lower in height as a result of maintaining a larger proportion of the floodplain. Exact determination of the alignment of the flood defences will be undertaken during Stage 4 Outline Design but is assumed for the purposes of this section of the report that the defences (either toe of embankment or centre line of wall) will be offset 1m from the river edge of footpaths or roads.

Initial review of the 0.5% AEP + CC flood event shows that, in the worst case scenario with all existing bridges blocked with debris, the impact on baseline flood levels along the assumed defence alignment shown in Figure 3.24 is summarised in Table 3.5. The corresponding defence heights above adjacent dry side ground level are also shown, based on a 600mm freeboard allowance.

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
700	7.497	7.949	+0.452	2.526
800	6.992	6.923	-0.069	0.942
900	6.792	6.958	+0.166	1.358
1000	5.823	6.679	+0.856	2.149
1100	5.897	6.681	+0.784	2.608
1200	4.934	6.287	+1.353	2.799
1300	4.915	6.772	+1.857	3.132
1400	4.659	5.580	+0.921	2.391
1500	4.529	5.441	+0.912	2.425
1600	4.507	4.536	+0.029	1.500

Table 3.5– Impacts of Cell 4 direct defences on baseline fluvial flood levels and corresponding defence heights for the 0.5% AEP + CC flood event, with bridges blocked with debris in accordance with blockage set 2.

Table 3.5 highlights a number of potential issues with the provision of direct defences in Cell 2, with defence heights well above a generally acceptable maximum of 1.6m above adjacent footpath level. It should be noted that the influence of debris is significant and Table 3.6 highlights the change in flood levels at each chainage if no debris were present at any of the bridges which span the River Esk from Ivanhoe to Goose Green. Removal of the Shorthope Street and Goose Green bridges further reduces the flood levels and corresponding defence heights.

Chainage (m)	Baseline flood level (maOD)	Level with defences in place (maOD)	Change (m)	Corresponding defence height (m)
700	7.497	7.642	+0.145	2.225
800	6.992	7.088	+0.096	1.138
900	6.792	7.088	+0.296	1.198
1000	5.823	6.228	+0.405	1.697
1100	5.897	6.229	+0.332	2.245
1200	4.934	5.921	+0.987	2.429
1300	4.915	6.069	+1.154	2.429
1400	4.659	5.239	+0.580	2.021
1500	4.529	5.071	+0.542	2.049
1600	4.507	4.446	-0.061	1.500

Table 3.6 – Reduction in Cell 4 direct defence heights and impacts on baseline levels as a result of assuming no blockage at any of the River Esk bridges

The fluvial direct defences for Cell 3 could be formed by walls or embankments, but it is noted that an embankment will require a crest which is approximately 100 – 150mm higher than a wall cope due the riverward embankment slope occupying a greater proportion of the flood plain. Other influences on the type and form of direct defences (including assessment of the defence aesthetics and the feasibility of demountable defences, hybrid defences, glass panels, flood gates, ramps and stepped accesses, etc) are further discussed in Section 3.14, but will ultimately be the focus of the Stage 4 Outline Design.

It is therefore recommended that the provision of direct defences to protect Cell 4 from the effects of the 0.5% AEP + CC fluvial flood event in the River Esk is a component of the preferred scheme. The current preference from feedback from stakeholders and the public is for walls set back from the river edge, but further work is required to determine the exact height, alignment and form of the defences, which will also be a function of other preferred scheme components.

3.7.2 Coastal Defences

From just downstream of the Goose Green footbridge to the western end of the Musselburgh Lagoons sea wall, the dominating flood risk is from the 0.5% AEP + CC coastal event. At some points along this stretch, the ground level is lower than the still water level during this event, resulting in significant inundation to the Goose

Green area and then towards Loretto, Musselburgh Racecourse and the High Street. Similar to Cell 3, the existing retaining walls from the Goose Green footbridge to the River Esk estuary are, visually, in fairly poor condition, with little confidence in a residual design life which can match the proposed scheme design life. Defence heights up to 1.6m above the existing ground level are required, with the new walls fulfilling a dual function of replacing the old structures and providing flood protection. Given the relatively sheltered nature of this stretch of defences from the prevailing waves, there is no requirement for wave overtopping pumping stations. Measures may be required to preserve sea views of the adjacent properties. A new outfall will be required to discharge the Pinkie Burn into the estuary.

It is therefore recommended that the provision of flood defence / retaining walls in the River Esk channel, to protect against the effects of still water and wave overtopping and to replace the existing retaining walls, is a component of the preferred scheme from the Goose Green footbridge to the western end of the Musselburgh Lagoons sea wall.

3.7.3 Goose Green Weir

Refer to figure 3.25 and option 4.12. The option appraisal and hydraulic modelling process has determined that maintaining or demolishing the Goose Green weir has little impact on fluvial flood risk. The presence of the weir, however, may serve to stabilise geomorphological responses in the lowest reaches of the River Esk and provides a minimum water level upstream of the weir at low tide, reducing the likelihood of visible mudflats (which are thought to be an undesirable feature). The weir may also serve to protect critical Scottish Water infrastructure which crosses the river bed upstream of the weir. Protecting the integrity of the weir is therefore desirable from an objection mitigation perspective and could be added to the multiple benefits register for the purposes of improving fish passage at low tide. Further investigation into the structural condition of the weir is recommended to inform the extent of intervention required to preserve its integrity.

It is therefore recommended that the existing Goose Green weir is preserved as a component of the preferred scheme.

Figure 3.25. Location of Goose Green Weir.

3.7.4 Secondary flooding Pumping Stations

The secondary and surface water flood risk to Cell 4 has still to be accurately modelled, and the severity of such flooding correspondingly ascertained. The surface water flood risk in the Goose Green area is complicated by the presence of a culvert surcharging flood risk from the Pinkie Burn / Mill Lade (See 3.8). Musselburgh has recently experienced episodes of surface water flooding during torrential summer convective storms (August 2019), and there is a risk the scheme may exacerbate this flood risk by trapping surface water on the dry side of direct defences. Areas where surface water may accumulate have been derived by reviewing the low points from the LiDAR data and these areas have been identified as potential locations for pumping stations. Refer to figure 3.26. The decision between a fully automated underground pumping station or manually deployed mobile pump set has yet to be formally determined, but given the potential traffic issues which will inevitably arise during such an event and the flashy nature of the rainfall, there is a significant risk that any trailer mounted mobile pump set will not be able to respond to the flood event in time.

Figure 3.26 Potential pumping station locations in Cell 4.

The impacts of surface water / secondary flooding in Cell 4 remain to be fully defined, but it is assumed that at least two automatic underground pumping stations will be a component of the preferred scheme, including one pumping station to assist with surcharging from the Pinkie Burn / Mill Lade, which may require to pump partially saline water (propose to locate near junction of Balcarres Road and Goose Green Crescent). Full modelling of the surface water flood risk will be required as part of the Stage 4 Outline Design to ascertain the requirements, including location, flow rates, etc.

3.8 Cell 5: Pinkie Burn

Following a rigorous analysis of all possible short-listed options for the Pinkie Burn, it was considered that the most appropriate course of intervention is to locally remodel the landscape within the Pinkie Playing Fields to contain flood waters which derive from either:

- The 0.5% AEP + CC flow in the Pinkie Burn being slightly higher than the capacity of the existing culvert, or
- The backing up effect of the 0.5% AEP + CC coastal event

The landscape remodelling up to 800mm above existing ground levels would ensure that ponded water could be stored safely within the northern portion of the playing fields, having little impact on the facilities or the layout of this important amenity area for the town and its schools and sports clubs. It is important to note that the culvert conveying the Pinkie Burn beneath Linkfield Road, Millhill and Goose Green has been assumed to be in a good condition. A full CCTV survey of the culvert is required to determine if these assumptions need to be changed – this may result in a greater volume of storage being required if the conveyance of the culvert is lower than modelled.

In addition, closer inspection of the Pinkie Burn / Mill Lade culvert flooding mechanism shows water escaping from surcharging manholes in the Racecourse grounds and on Goose Green Road. The volumes of water are relatively small, but would result in a negative perception of the Scheme, and could change if the conveyance of the culvert is found to be lower than modelled. It is therefore recommended that one of the pumping stations designed to alleviate Cell 4 surface water flood risk is also designed to accommodate the surface water flows deriving from the culvert surcharge. Watertight manholes, with bolt down covers could also be used to further alleviate the risk. A new series of chambers and pipework will be required to intercept the surcharging flow volume and convey flows to the pumping station, all of which will serve to future proof any further deterioration of the culvert condition. Note this component is not included in the short listed options due to the very recent discovery of the flooding mechanism from the hydraulic model.

It is therefore recommended that engineered remodelling of the Pinkie Playing Fields is a component of the preferred scheme, with the height and shape of the bund dictated by updated hydraulic modelling following the CCTV survey of the culvert. In addition, a combination of watertight, bolt down manholes and a dedicated overflow pipe from the culvert to the proposed Cell 4 pumping station at the junction of Balcarres Road and Goose Green Crescent are recommended as components of the preferred scheme.

3.9 Cell 6: Old Sea Wall and Lagoons

The short-listing exercise and hydraulic modelling have confirmed that the integrity of all the preferred scheme components on the right hand bank of the River Esk could be significantly compromised if the 3.0km length of the Old Sea Wall deteriorates in any way. A visual inspection of the 62 year old wall showed that it is generally in relatively good condition, with the lower revetment intact and few signs of subsidence or loss of interlock of the hexagonal sections. There is some evidence of local spalling and exposed reinforcement of the parapet concrete, but the topographic survey shows that the wall cope level is generally consistent, confirming that little settlement has occurred over the six decades since it was constructed. If the wall parapet fails, there is risk of the 0.5% AEP + CC coastal event inundating the ash lagoons and, ultimately, many properties (refer to figure 3.27). Saturation of the ash lagoon material has the potential to cause it to quickly liquefy, creating health and safety and environmental risks. Even if the wall and its parapet remain intact, there is still a risk of wave overtopping volumes being sufficient to create ponding and flow paths through the ash lagoon, however no properties are at risk.

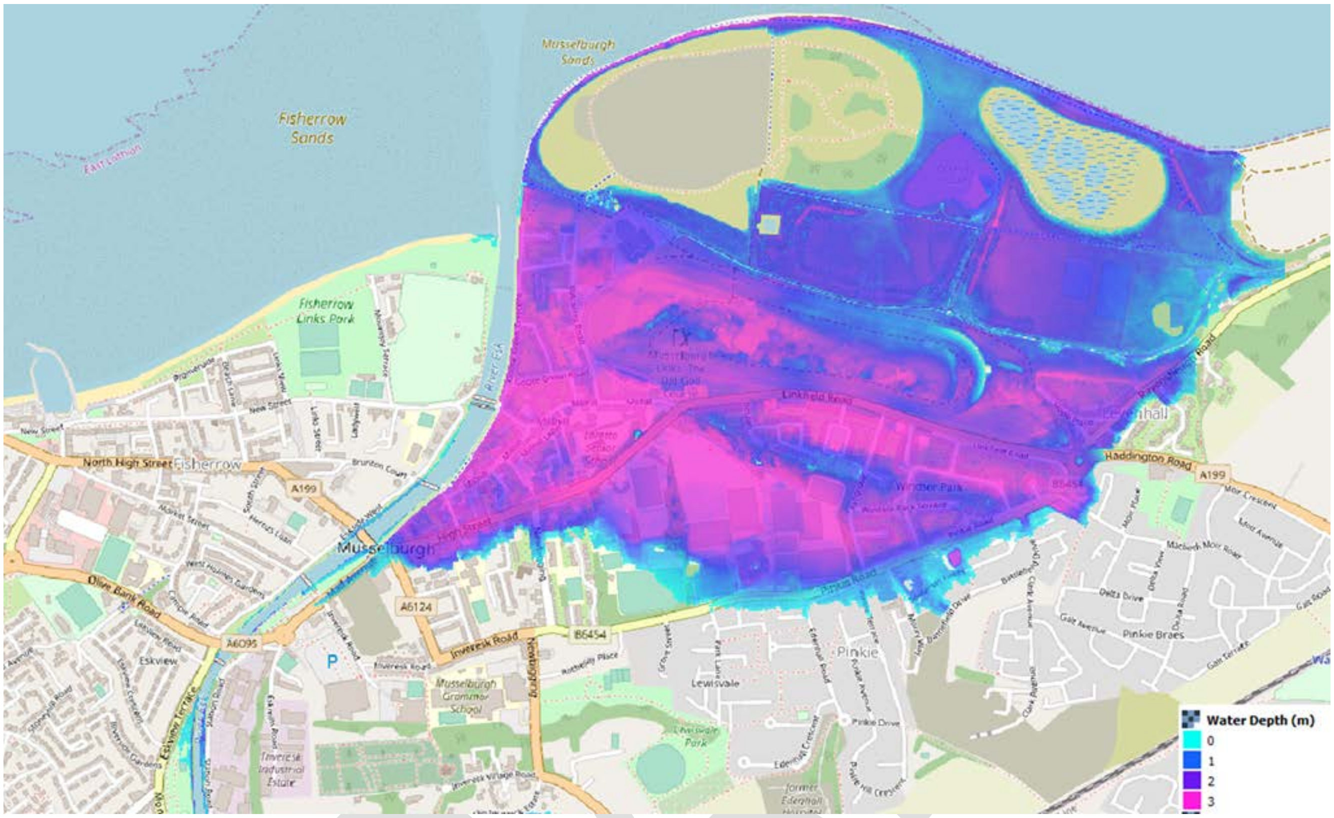

Figure 3.27 – Flood risk to the east side of the town due to potential failure of the entire Old Sea Wall

Short listed options to mitigate this failure risk included modifying the parapet to include a wave return wall (thereby virtually removing the wave overtopping risk at 0.5% AEP + CC), fully encasing the wall in concrete to extend its design life, installing a series of drains and pumps to the rear of the existing wall to convey wave overtopping volumes away from the lagoons, or entirely replacing the wall just behind its current location.

Discussion with East Lothian Council identified that Scottish Power currently own the wall and lagoons and, under the terms of the Musselburgh Agreement, transfer of ownership of the wall back to East Lothian Council requires further negotiation. Until the discussions and negotiations relating to the ownership of the wall are concluded, the Old Sea Wall and Lagoons cannot form part of the Scheme.

It is therefore recommended that Scottish Power are made aware of the flood risk to Musselburgh as a result of any future deterioration of the Old Sea Wall and that the condition of the wall continues to be monitored on a regular basis. Ground Investigation is recommended to prove the current condition of the ash deposits and determine how susceptible they may be to saturation, ponding and overland flow resulting from wave overtopping, in the event that the current Do-Minimum approach is maintained.

3.10 Cell 7: Upper Catchment (upstream of A1 Bridge)

Cell 7 represents the entirety of the River Esk catchment above the A1 Trunk Road bridge, with a contributing area of 330km^2 of principally rural land use which is mostly under the jurisdiction of Mid Lothian Council (a small area of the South Esk catchment lies within the Scottish Borders) – refer figure 3.28. The principal urban area upstream of Musselburgh is Dalkeith, which is located just upstream of the confluence of the North and South Esk Rivers. Flood risk to other areas upstream of Musselburgh is relatively limited, as most settlement is located away from the steeply incised valleys which characterise the central areas of the North and South Esk catchment.

Feasible options deriving from the shortlisting process include Natural Flood Management (option 7.02), Sustainable Flood Management through adaption of existing Scottish Water assets for the purposes of flood protection (option 7.03), engineered flood storage area(s) (option 7.04) and removal of weirs throughout the upper catchment (option 7.09). Feedback from the Public Exhibition was very much in favour of including some form of upper catchment flood risk management within the preferred scheme, to potentially reduce the visual impact of direct defences within the town.

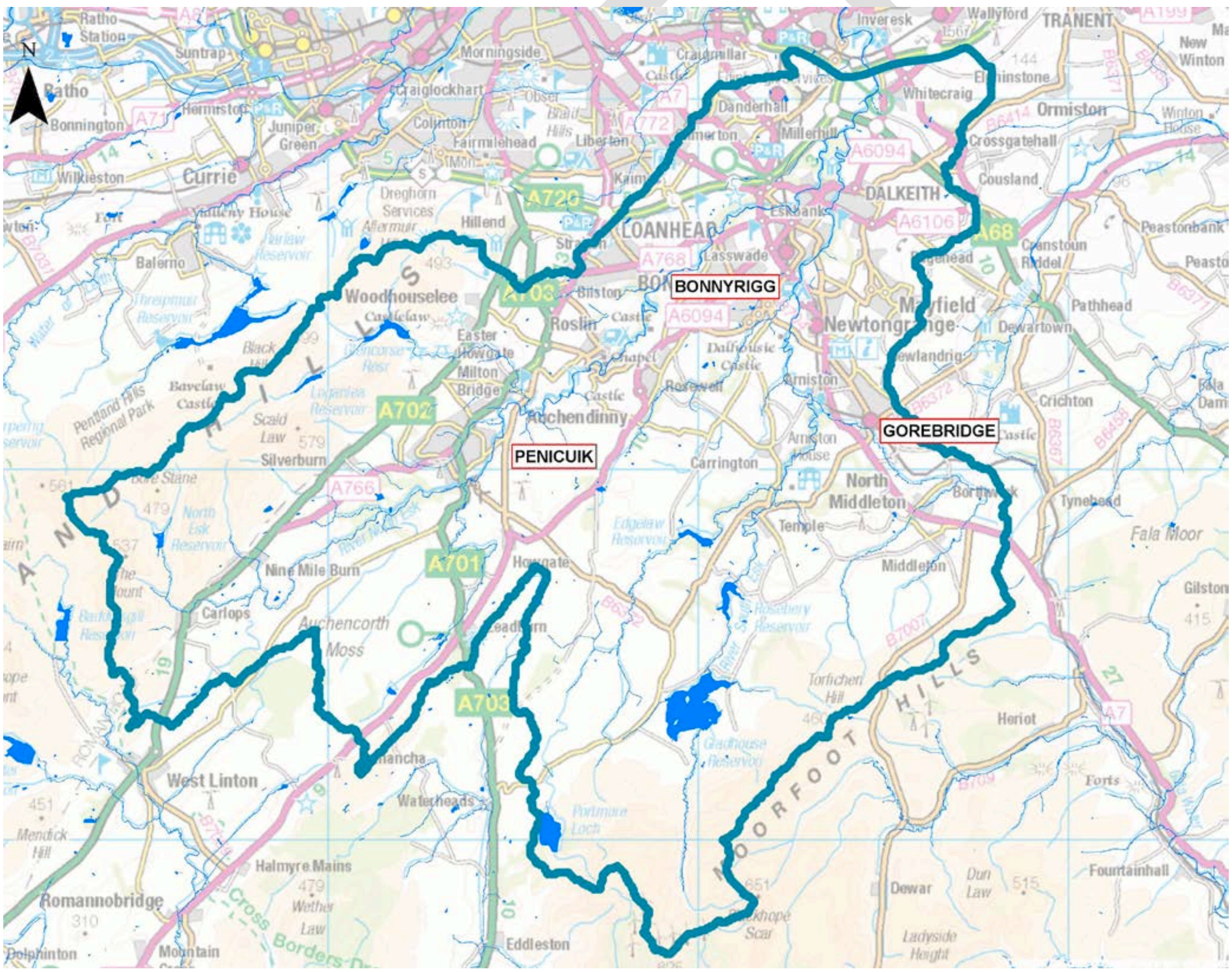

Figure 3.28 – catchment map

3.10.1 Natural Flood Management (NFM)

One of East Lothian Council's project objectives it to ensure that the Scheme includes catchment or natural flood management measures (refer section 1.3.5, objective 24). The Council commissioned Jacobs to investigate, under a separate study, the feasibility of working with nature in the upper catchment to reduce flood risk to all receptors along the North and / or South Esk. This separate report identifies possible locations where NFM runoff attenuation measures could be implemented to reduce peak flows, but the evidence for providing a tangible and measurable reduction in flood risk to Musselburgh is inconclusive. Such measures include the introduction of unmanaged buffer zones along the edges of the watercourse and Large Woody Dams (LWD) on smaller tributaries. These measures can work well on smaller catchments (e.g. Belford, Northumberland, 8km^2; Long Philip Burn in Selkirk, 6km^2), but unless there is a receptor which benefits from these measures at the downstream end of the small tributary, their effectiveness on the catchment as a whole is almost negligible. Flood plain recoupling or re-meandering on larger tributaries (e.g. like the Eddleston Water, north of Peebles, 70km^2) is limited due to the very narrow flood plain on the valley floor through the incised sections of the catchment. Implementing such measures in the areas upstream of the incised sections is likely to be controlling too small a proportion of the catchment to measurably reduce flood risk to Musselburgh. Catchment wide measures such as increased forestry cover to increase interception, infiltration and reduce surface water run off rates are feasible, but require a great deal of time to become fully effective.

The greatest barrier to NFM inclusion within a preferred scheme is the difficulty in quantifying the flood risk and economic benefits whilst justifying the expense of implementation.

It is therefore concluded that Natural Flood Management measures cannot be included as a component of the preferred scheme. Refer to the Jacobs report "Feasibility of working with nature to reduce flood risk to Musselburgh" for further details of measures which could be implemented, potentially as trial or research projects to help compile further evidence for quantifying flood risk reduction.

3.10.2 Sustainable Flood Risk Management: Adaption of Scottish Water Reservoirs

The Selkirk Flood Protection Scheme, delivered by Scottish Borders Council in 2016, included an Intelligent Water Management System which adapted the existing Scottish Water infrastructure (sluice gates and fish pass) at St Mary's Loch to both increase the flood storage capabilities of the loch (to reduce flood risk to Selkirk by up to 35% for minor floods and up to 5% for extreme events), and better manage water conservation during drought periods, to provide greater security of pass forward flow into the Yarrow Water, aiding fish passage.

The option appraisal process for Musselburgh identified that a similar approach could be taken with the existing Scottish Water Reservoirs on both the North and South Esk catchments – the candidate reservoirs were Gladhouse, Rosebery, Edgelaw and Portmore on the South Esk, and Glencorse and Loganlea on the North Esk. Early conversation with Scottish Water's Reservoirs team concluded that the only reservoirs which could be adapted for the purposes of flood storage were Edgelaw on the Fullarton Water (South Esk tributary) and Rosebery on the River South Esk.

High Level hydraulic modelling assumed that 1m of additional storage could be realised at each reservoir by lowering the spillway level, resulting in approximately 2% of the total flood volume during the 0.5% AEP + CC event at Musselburgh being stored. This resulted in reductions in baseline flood levels through Musselburgh of between 40 and 80mm. Increasing the available flood storage to 3m at each reservoir resulted in approximately 6.4% of the total flow volume being stored, reducing flood levels by between 100 and 250mm through the town. The effects on direct defence heights are even more pronounced, due to the effects of the defences channelling flow through the town, with reductions of up to 330mm possible at 0.5% AEP +CC, assuming none of the bridges are blocked with debris.

It is clear that significant amounts of additional data gathering and hydraulic modelling is required to further clarify the feasibility of this option. This will include topographic survey of the dam crest and spillway, ground investigation or sampling of the existing dam core and underlying soils to determine the geotechnical characteristics, more detailed hydraulic modelling to determine the true benefit to Musselburgh, and a full suite of ecology surveys to inform the subsequent screening and scoping exercise and Environment Impact Assessment. The hydraulic modelling will require to test a sequence of storms, to determine if the full storage potential can be relied upon (i.e. investigate if the reservoir can discharge sufficient water to bring back to “target” level after a wet spell of weather, which would often be the pre-cursor to a severe or extreme event).

It is therefore recommended that adaption of the existing Scottish Water reservoirs at Edgelaw and Rosebery are potential components of the preferred scheme, conditional on gathering a wide range of additional information including topographic survey, ground investigation, ecology surveys, ownership and operation, and more detailed hydraulic modelling. It may be the case that only one of the reservoirs proves feasible to adapt for the purposes of flood storage. It is unlikely that this option will be taken forward in conjunction with engineered flood storage due to the combined high capital costs.

3.10.3 Engineered Flood Storage Areas

The option appraisal process and high level hydraulic modelling identified that the only upper catchment measure which could yield a significant reduction in flood risk during the 0.5% AEP + CC event) to Musselburgh would be engineered flood storage, where up to 10% of the total flow volume (area beneath the hydrograph) could be stored, bringing a reduction of up to 650mm in direct defence heights. Experience from previous projects shows that the optimum location for engineered flood storage areas is within the middle of the catchment. This is because if the storage area is located too far upstream, the proportion of the catchment which is controlled and attenuated is insufficient, if too far downstream then the volume of flows requiring to be stored and passed forward becomes very difficult to manage. Another key aspect to consider in relation to controlling or attenuating flows in the catchment is to ensure that such measures do not have a detrimental effect on flood peak synchronisation, especially for long, linear catchments with a confluence near the estuary such as the River Esk. By attenuating the flood peak on one catchment, it may be the case that it now coincides with the flood peak on other catchment, making flood risk worse downstream of the confluence. Basic analysis of the flood peaks shows that the South Esk peaks slightly later than the North Esk and with a greater proportion of the total flow (see fig 3.29). It therefore follows that focusing efforts on reducing and delaying the peak flow volume on the South Esk would have the greatest effect on reducing flood risk to Musselburgh

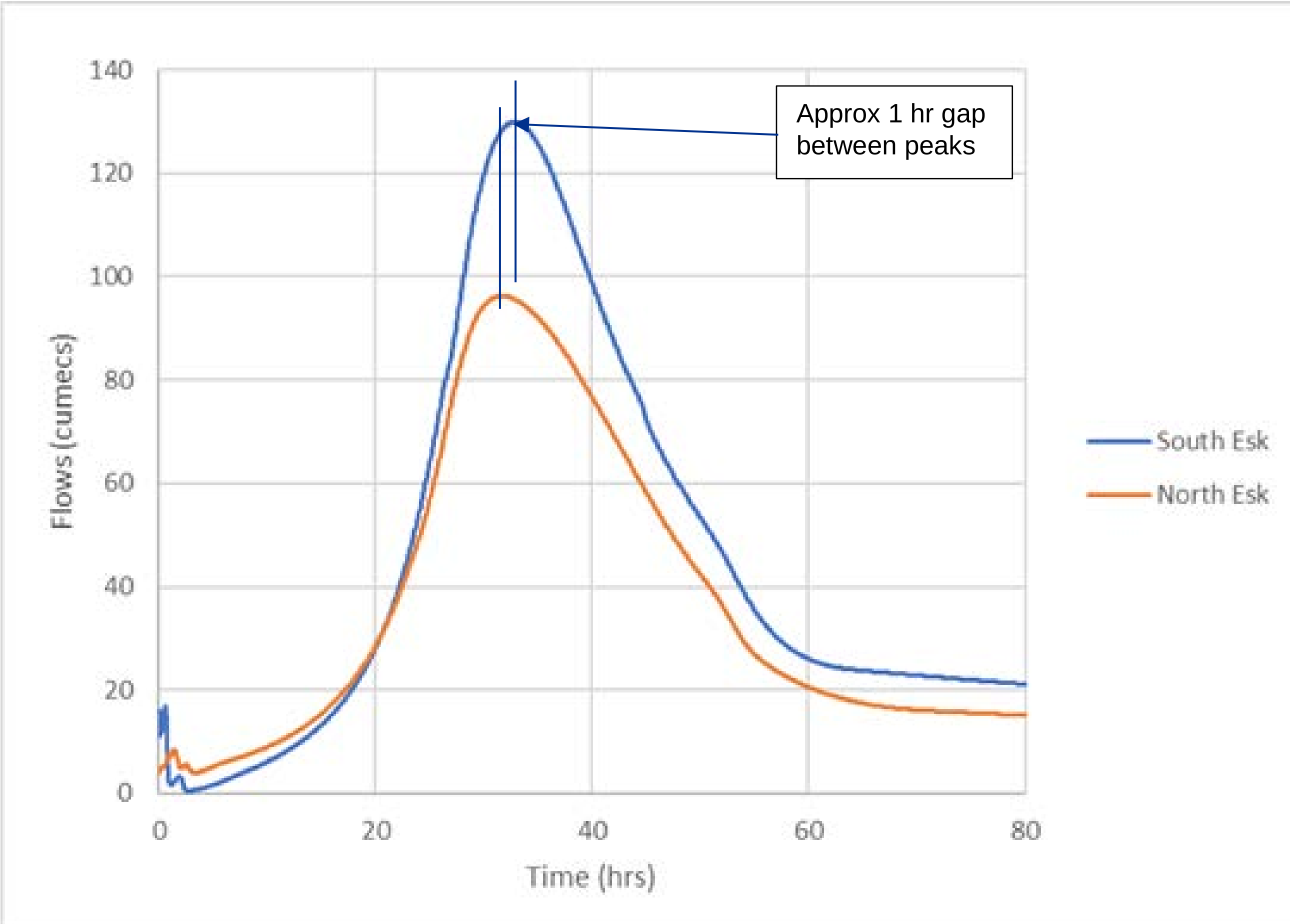

Figure 3.29 – 0.5% AEP Hydrograph at confluence of the North and South Esks

Suitable sites for such a storage area are limited, due to the incised nature of the middle of the catchment. Focus turned to the area near the existing Gladhouse, Rosebery and Edgelaw Reservoirs on the South Esk, as at this location there is the potential to control a reasonable proportion of the South Esk catchment as well as having some confidence in the underlying geology being capable of supporting a large raised reservoir due to the presence of 3 other such structures within close proximity.

Figure 3.30 shows the potential location for a new engineered flood storage area (FSA) on the South Esk, immediately downstream of Gladhouse Reservoir. The earth dam across the South Esk valley has a crest level up to 20m above the valley floor, is approximately 300m long and, when full, creates a temporary inundation with a surface area of 0.22 km^2. The land inundated is predominantly agricultural, with steep sided escarpments leading down to a tree lined channel, with varying width flood plain. There are no properties, significant public utilities or public roads within the inundation area. The FSA would be called Howburn FSA, due to the closest property being Howburn Farm.

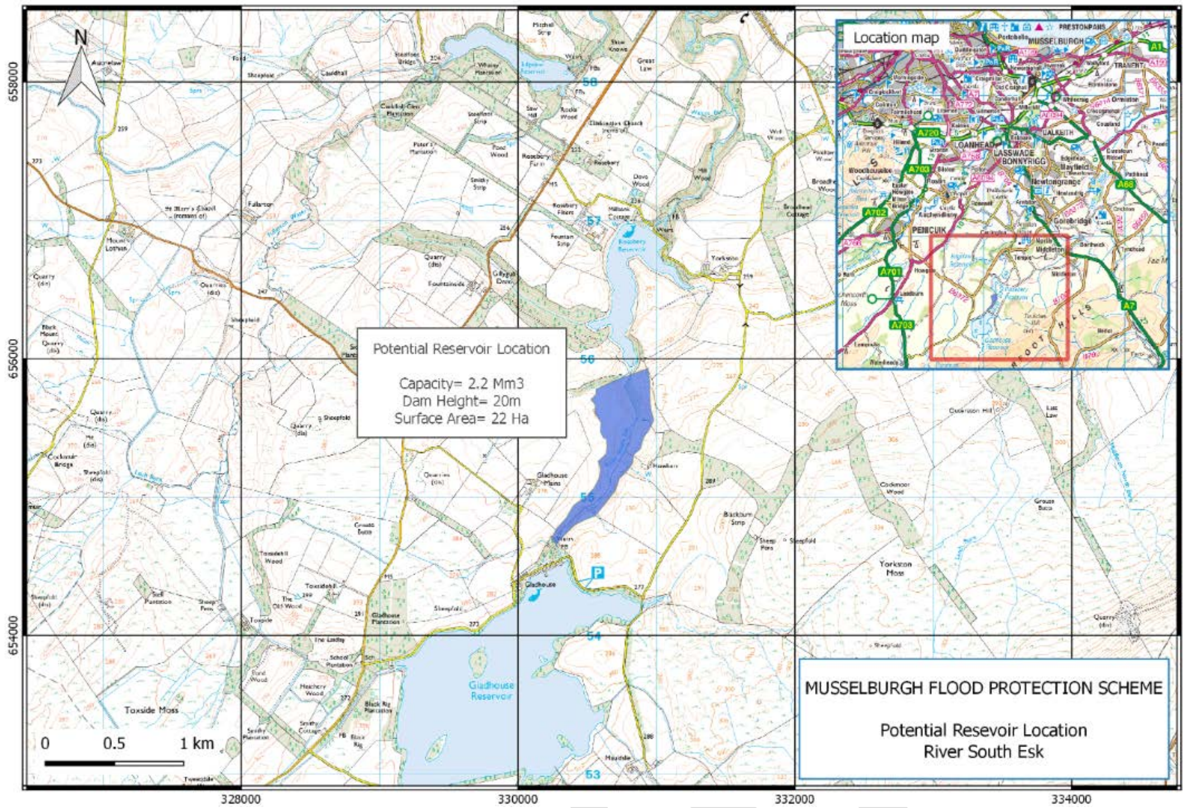

Figure 3.30 – Potential location for flood storage area at Howburn, on River South Esk

It is clear that significant amounts of additional data gathering, and hydraulic modelling is required to further clarify the feasibility of this option. This will include topographic survey and ground investigation of the area beneath the potential dam footprint, more detailed hydraulic modelling to determine the true benefit to Musselburgh, and a full suite of ecology surveys of the entire inundation area plus buffer zone to inform the subsequent screening and scoping exercise and Environment Impact Assessment. The hydraulic modelling will require to test a sequence of storms, to determine if the full storage potential can be relied upon (i.e. investigate if the reservoir can discharge sufficient water to bring back to "target" level after a wet spell of weather, which would often be the pre-cursor to a severe or extreme event). Investigation into land ownership will form an important part of the feasibility of this option, along with determination of the capital costs, which are likely to be significant.

It is therefore recommended that the potential construction of a new flood storage area at Howburn on the river South Esk is a component of the preferred scheme, conditional on gathering a wide range of additional information including topographic survey, capital costing, ground investigation, ecology and environmental surveys, land ownership and more detailed hydraulic modelling. It is unlikely that this option will be taken forward in conjunction with adaption of the Scottish Water reservoirs due to the combined high capital costs.

3.10.4 Removal of weirs throughout upper catchment

Both North and South Esk rivers are characterised by a large number of historical weirs which were built and adapted throughout the 18th and 19th Centuries, principally for the purposes of water abstraction via a network of lades for mills, farms and water supply. The weirs are in varying states of repair and recent partial collapses of some of the structures has highlighted the issue of ongoing maintenance. Often the ownership of weir is disputed and the lack of need for the water which once flowed down the corresponding lades means they are commonly (and understandably) neglected. The impacts of future planned or condition related removal or partial removal of these weirs on flood risk to Musselburgh has been briefly assessed. Whilst removal of the weir may have a local impact on flood risk (usually reduce risk upstream, increase downstream), the cumulative impact for flood risk in Musselburgh will be negligible. The greater impact in the short term may be a local change in geomorphology and release of sediment previously trapped behind the weir, but this is likely to balance out with time as successive high flow events redistribute the sediment.

It is therefore recommended that weir removal upstream of Musselburgh is not a component of the preferred scheme.

3.10.5 Debris Traps

The impact of debris on the bridges through Musselburgh was analysed as part of the later stages of the hydraulic modelling and, as such, measures to control the debris were only considered towards the end of the process. Analysis of the possible floating debris build up at all bridges was undertaken using three scenarios:

1) No debris,

2) Blockage Set 1 - blockage proportion calculated as percentage of the available space under the bridge, and

3) Blockage set 2- a blockage proportion assessed subjectively in relation to the risk of the bridge becoming blocked (e.g. low soffit, thick piers)

Table 2.4 identifies the blockage set calculations and percentages

The hydraulic model was run with all blockage sets to determine the relative impact for all bridges (assuming they remain in situ), with direct defences in place to prevent spill into the town. The results are shown in figure 3.31

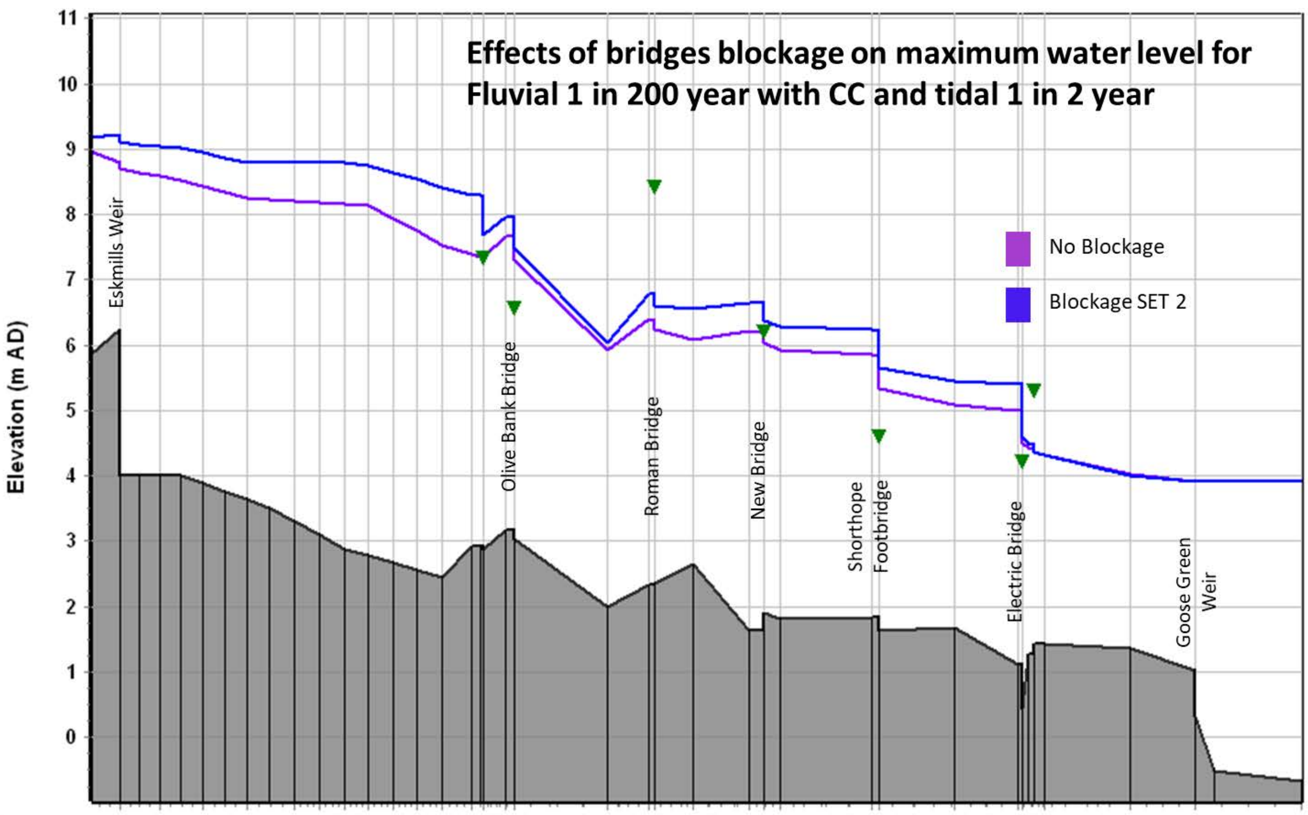

Figure 3.31 – impact of removal of debris blockage at bridges on water levels

It is clear from the analysis that the accumulation of debris at the bridges results in creation of an afflux across the structure which is much greater than in the unblocked case. At all bridges, the upstream water level increases regardless of the blockage set applied and it follows that wall heights could be reduced by up to 600mm if debris accumulation could be avoided. Whilst it may not be possible or practicable to trap all floating debris upstream of the town, the provision of a carefully designed structure or structures to remove a large proportion of the floating debris could result in a relatively inexpensive way of reducing wall heights through the town, thus satisfying a number of Scheme objectives.

Historical high flow and flood events have provided ample evidence of the potential for large volumes of debris travelling down both North and South Esk channels from Midlothian to become trapped against the bridge structures. The debris ranges from whole trees which fall into the river during high flows which erode river banks, to smaller twigs, branches and leaves which are swept off flood plains as the river swells in response to heavy rain. The incised valleys of both the North and South Esk are often heavily wooded, providing an ample supply of floating debris. Given that large woody debris (angular branches, tree trunks, etc) generally provides the catalyst for subsequent build up with twigs and leaves, focus on trapping the larger items would appear to be the most appropriate. Trapping this type of debris generally calls for large diameter, well spaced vertical poles driven into the river bed, to create a very coarse screen which does not impede fish passage or trap smaller items. Examples of this type of trap were installed on flood protection schemes at Rothes, Moray and upstream of a FSA on the River Gaunless in County Durham (see figure 3.32).

Figure 3.32 – Example of debris trap for large trees and debris at River Gaunless, County Durham

Key factors in determining the optimal location for the debris trap include:

- Proximity to Musselburgh to avoid large areas of uncontrolled catchment;
- In an area where inundation upstream of a fully blinded trap does not impact on property, roads or critical utilities;
- In an area where erosion and deposition as a result of flow outflanking a fully blinded trap does not impact on property, roads or critical utilities;
- Ease of access for cleaning and maintenance
- Avoid adverse impacts on landowner
- Comply with the requirements of environmental regulatory bodies (e.g. geomorphology, fish passage)

Taking all of the above into account, the trap must be located in the 1.6km stretch of river between the A1 bridge at the downstream end and the A68 bridge at the upstream end. Initial inspection of this stretch confirms that access may be difficult due to the steep sided, heavily wooded nature of the river banks and a new access would need to be forged down to river level for Council vehicles to access to clean the trap. Refer to figure 3.33.

Further information requires to be gathered in this area, including topographic and ecology surveys and additional hydraulic modelling to determine the likely inundation extent when the screen becomes blinded. Discussions with the landowner (Buccleuch Estates) and ELC maintenance and operation teams are necessary to understand how best to access and clean the debris trap. It is important to note that it will not always be possible to rely on the debris trap to remove all large floating debris and there is a likelihood that debris accumulated following a wet spell may not have been removed from the trap when the onset of an extreme event occurs. The Stage 4 Outline Design hydraulic model must take cognisance of this when assigning percentage blockages at each bridge.

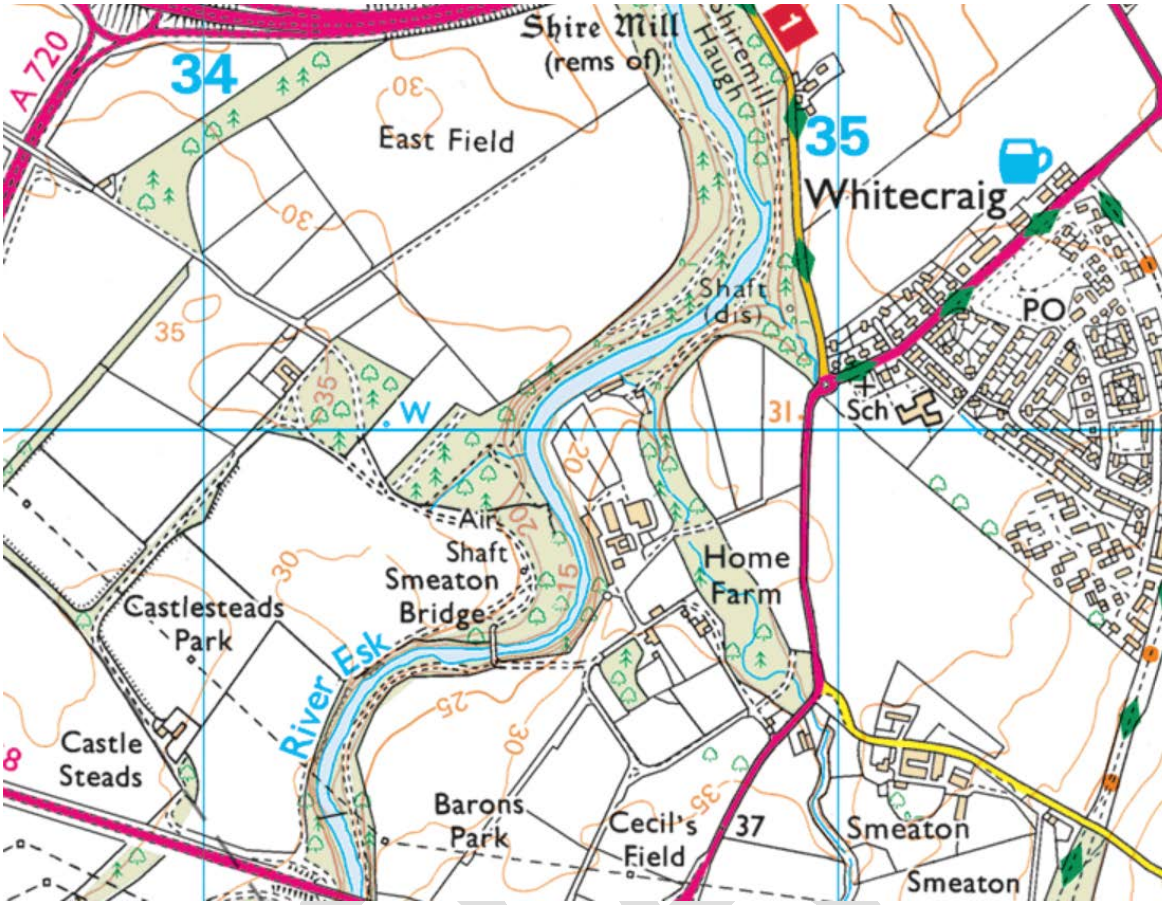

Fig 3.33 – stretch of River Esk where debris trap should be sited

It is therefore recommended that a debris trap upstream of the A1 bridge and downstream of the A68 bridge (within Mid Lothian) is considered as a component of the preferred scheme. The trap should only be designed to remove large floating debris and further work is required to determine how effective the trap will be in terms of the residual proportion of debris which may continue to accumulate at the bridges.

3.11 Cell 8: Fisherrow Sands and Coastal Management

This cell covers the area below Mean High Water Springs between the Brunstane Burn to the west and the River Esk estuary to the east. The single remaining short listed option for this cell is to introduce a true do-nothing approach to management of the Fisherrow Sands. Anecdotal evidence from local residents along with inspection of mapping and aerial photography would suggest that the Fisherrow Sands are experiencing a phase of recharge, potentially due to the construction of the Old Sea Wall in the early 1960s. This is a benefit to the degree of natural flood protection afforded by the vegetated dunes in the east of this area, which offer a degree of wave attenuation during the extreme events. West of Fisherrow Harbour, there is less compelling evidence for historical change in the beach characteristics, and it is possible that the direct defences required along this section encroach onto the beach – therefore a true do-nothing approach here is not possible.

It is therefore recommended that the Fisherrow Sands east of the harbour and below Mean High Water Springs are entirely left to natural processes. Periodic monitoring of the beach profile is recommended through repeat LiDAR or other survey method to ascertain long term trends. The Stage 4 outline design

of the coastal defences along Fisherrow should undertake a sensitivity analysis in relation to future positive and negative change in the beach profile.

3.12 Cell 9: The Inveresk Estate

This cell was introduced after the June 2019 shortlisting exercise when it became apparent that five properties within the Inveresk Estate were at risk from flooding above threshold level from the 0.5% AEP + CC flood event – refer figure 3.34. Because this area is geographically and hydraulically separated from Cell 2, the introduction of a standalone cell is necessary from an economic assessment perspective.

Figure 3.34 - Properties at risk in The Inveresk Estate.

Four options exist for alleviating the flood risk to these properties:

1) Upper catchment measures – there is a possibility that measures described in section 3.10 of this report could have sufficient impact on river levels to bring the flood level below threshold level at the affected properties. Which upper catchment option is selected for inclusion in the preferred scheme, if any, is subject to further review during Stage 4;

2) Property Level Protection (PLP) to provide specific local protection measures to each property. Given the relatively shallow flood depths, this could consist of flood proof doors and air brick covers;

3) Flood Protection local to the property – because the properties are set back a distance from the river, replacing the existing masonry boundary wall with a flood defence wall will be a very expensive option. By constructing direct defences closer to the property, the overall extent and apparent height of the defence is reduced, reducing the cost and environmental impact. This option may not be popular with residents as it will effectively sever their garden space.

4) Replace existing masonry boundary wall with flood defence wall – this option would involve the construction of over 400m of new flood defence wall, up to 2.2m above existing ground level to protect three properties – it is highly unlikely that the benefits of flood protection will be greater than the significant costs of implementing this option.

The decision on the course of action for the Inveresk Estate is a function of a range of activities which have yet to be undertaken:

1) Determine if upper catchment works are a component of the preferred scheme – the outputs from the detailed hydraulic modelling will determine if the PLP or direct defence options are necessary

2) Consult with the property owners – on the basis that upper catchment measures are not taken forward or are not sufficient to remove the 0.5% AEP + CC event flood risk and that the preferred scheme components downstream of this location do not adversely impact the flood risk, it is possible that the baseline flood risk is accepted by the residents.

It is therefore recommended that the decision on what form of flood protection is to be provided for the Inveresk Estate, if any, is taken following determination of the other components of the preferred scheme and subsequent execution of detailed hydraulic modelling and discussion with the affected residents.

3.13 Cell 10: Groundwater

This cell was introduced after the June 2019 shortlisting exercise to acknowledge the specific source of flood risk from groundwater in this area. The ground investigation (GI) works undertaken for this project and evidence from residents and Council officers show that the ground water level in parts of Musselburgh is very close to the ground level, particularly in parts of the Pinkie area. When Monktonhall Colliery was in operation, large volume pumps kept ground water around 100m below ground level. Since the colliery closed in 1997, the pumps no longer functioned, and ground water quickly rebounded to pre-mining levels. Since 2011, ELC has been recording groundwater levels at 13 piezometers installed in the Pinkie area (refer figure 3.35). In recent years, readings at the piezometers have shown no discernible change, with water levels remaining generally stable in all piezometers. One of the piezometers adjacent to Pinkie Road near Pinkie St Peters' Primary School has consistently shown ground water at ground level, and GI No1 encountered artesian pressure up to 2.2m above ground level in the north east corner of the Pinkie playing fields. It is therefore conceivable that a confined aquifer exists across this part of the town and that the boreholes sunk for GI No 1 or the installation of the piezometer at Pinkie Road effectively pierced the aquifer. There is no evidence to suggest that ground water levels or the risk of ground water flooding is increasing.

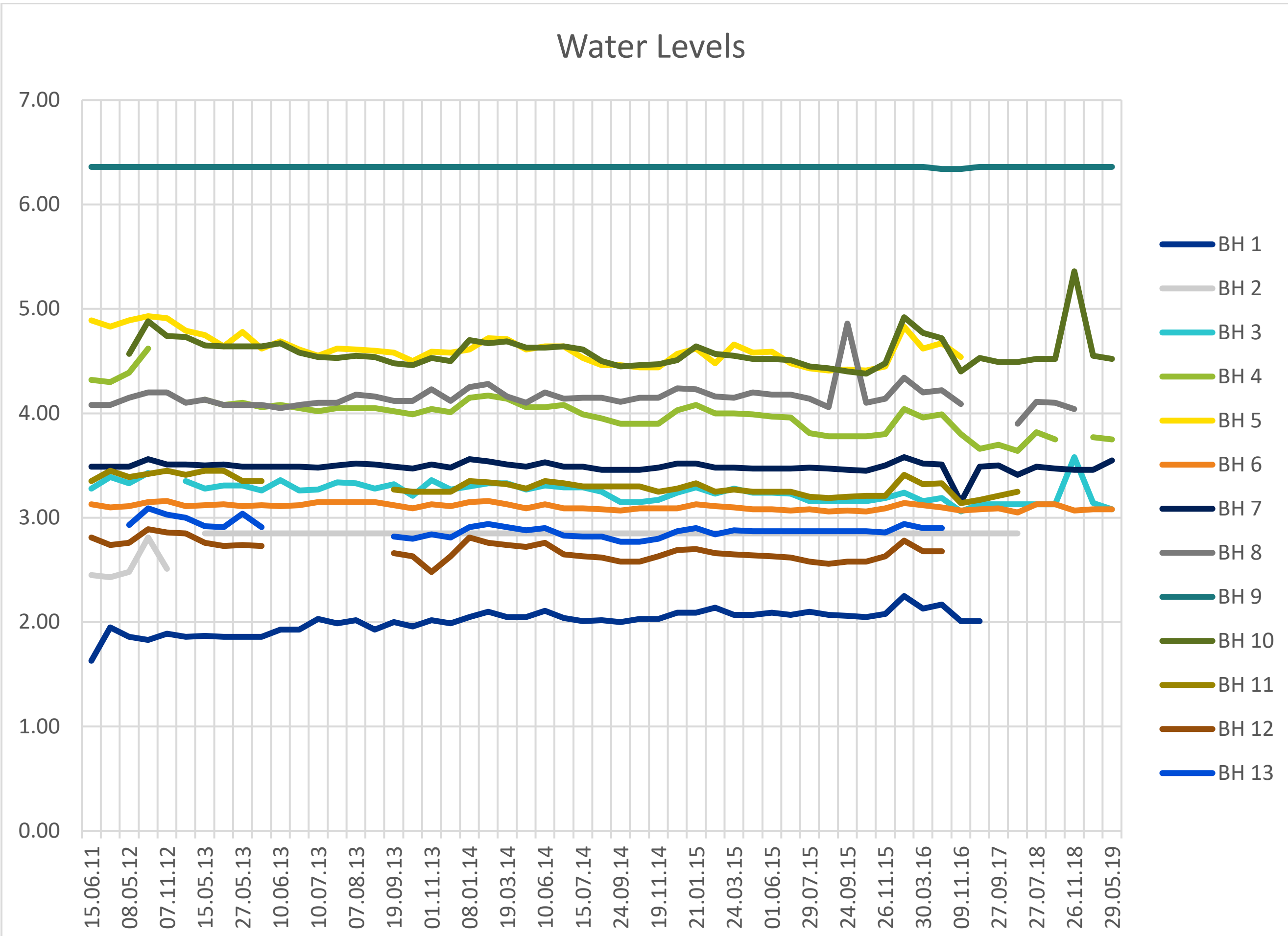

Figure 3.35– Groundwater level trends at 13 piezometers in the Pinkie area of Musselburgh

The observations show that groundwater levels in the Pinkie area are relatively consistent and do not change with high and low tides or in response to wet or dry spells. Whilst some properties have been observed to suffer the impacts of high groundwater, including dampness and subsidence, the risk of flooding above threshold level is not significant, and does not currently warrant intervention as part of the preferred scheme. The construction of other components of the scheme is not envisaged to adversely impact ground water levels, but it is recommended that the current monitoring regime continues and is improved by the installation of automatic level measuring equipment within the existing piezometers. This will enable any future change in the groundwater flooding risk to be identified at an early stage and measures introduced as appropriate.

It is therefore recommended that measures to control groundwater levels are not a component of the preferred scheme, due to the lack of evidence for widespread groundwater flooding causing inundation above threshold level. The ongoing regime of monitoring ground water level should be augmented by an automated system which can download the results for assessment on a regular basis. This is therefore deemed a Do-Minimum approach to dealing with this flood risk.

3.14 Component Combinations and Scenarios

3.14.1 Overview

Carrying out testing of the various options and a detailed review of all potential Scheme components has allowed a clear approach to be followed in defining the preferred scheme for Musselburgh. The Scheme shall consist of a series of **'core components'** which must be provided under all circumstances in order to deliver the desired 0.5% AEP + CC standard of protection. Those core components can be augmented with a number of **'supplementary components'** to create **'Scheme Scenarios'**, which incrementally reduce the height of direct defences required in the town.

This concept was presented at the final Option Appraisal Process workshop on the 3rd October 2019 which was attended by the project team as well as key stakeholders. During this workshop, attendees were invited to comment on the various options, combinations and scenarios that has been identified and where relevant suggest alternatives or amendments.

3.14.2 Core Components

The core components of the Scheme are defined as:

- **Approximately 5.5 km of direct defences** to protect against fluvial and coastal flooding
- A series of **8 no. pumping stations** to provide protection against surface water, secondary flooding and coastal wave overtopping
- Improvement works to the **Mill Lade and Pinkie Burn** culverts, headwall and outfalls

Refer to Figure 3-36, 37, Figure 3-38 below and plans in Appendix F for further details.

Although there are a number of different scenarios for fluvial direct defences (discussed in section 3.14.3), a single scenario exists for the coastal component of direct defences. This comprises a standard height coastal defence of approximately 1.5 metres above existing ground level, based on achieving a compromise between limiting wave overtopping while ensuring access to the beachfront is maintained.

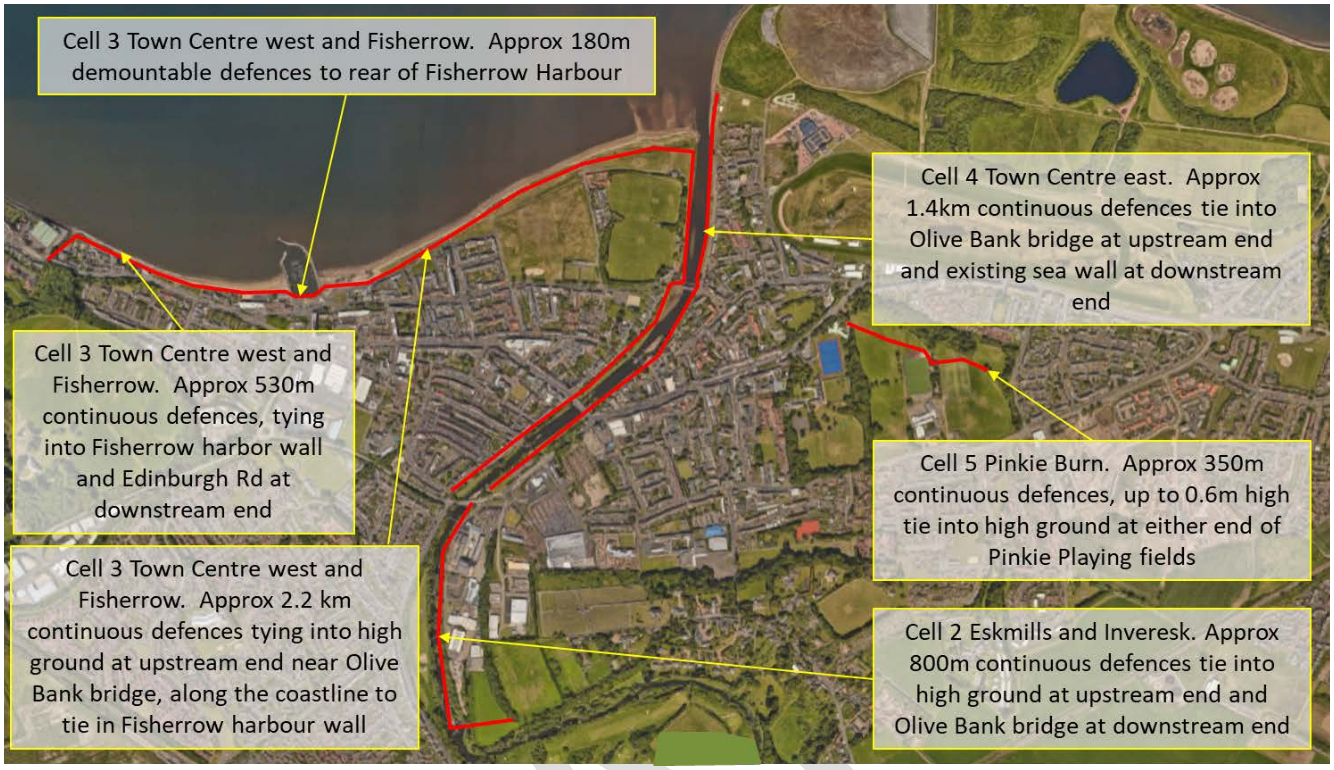

Figure 3-36: Summary of core components – direct defences

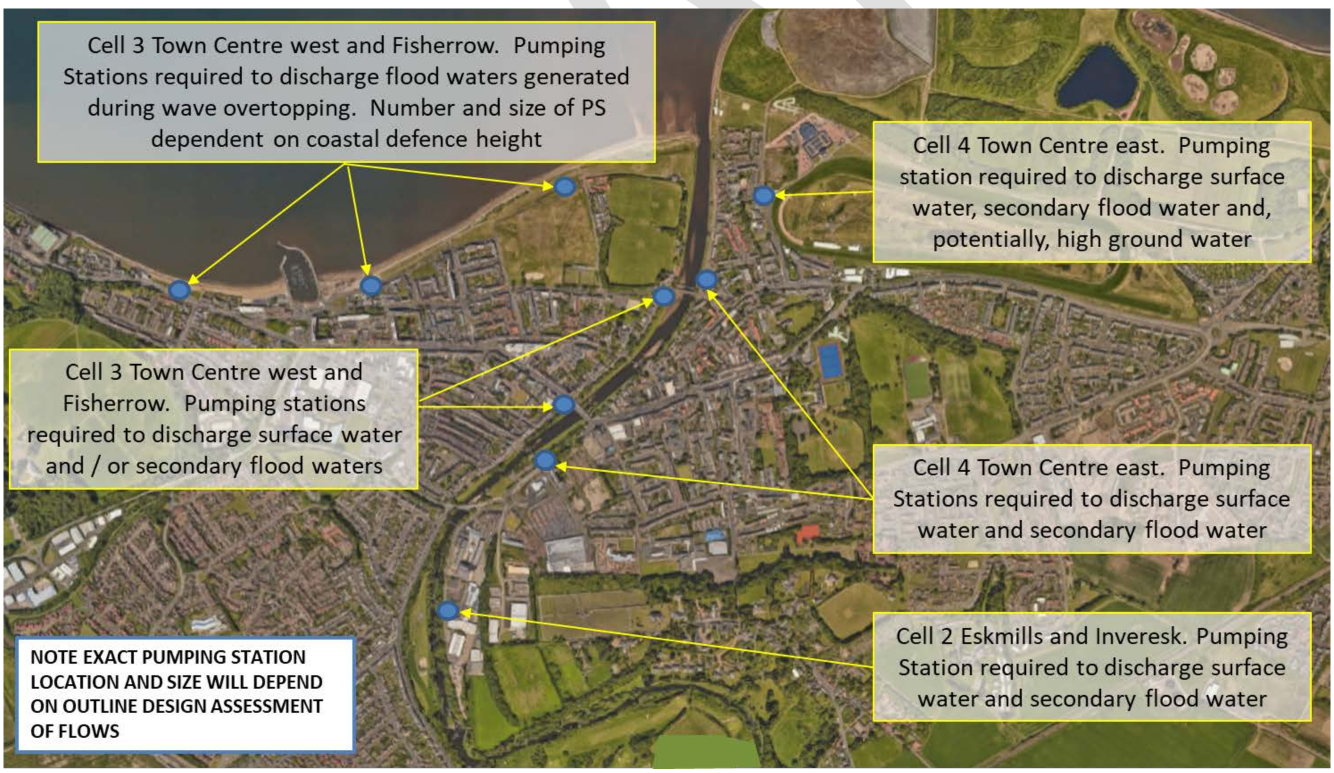

Figure 3-37: Summary of core components – pumping stations

Figure 3-38: Summary of core components – miscellaneous measures

3.14.3 Supplementary Components

From an analysis of the core components and based on public feedback, it is apparent that a very high risk of objection exists unless supplementary measures are included to reduce 0.5% AEP + CC defence heights. As such, a series of scenarios have been developed to demonstrate the impact that a range of supplementary flood protection components could have on fluvial defence heights. It is worth noting that there are no combinations of supplementary components that would remove the need for fluvial direct defences throughout the town.

The supplementary scheme components are:

- Removal and replacement of one or more of the bridges across the River Esk
- Upstream debris trap(s) to reduce the blockage risk to bridges
- Upstream flood storage created by adapting the operation of existing Scottish Water reservoirs on the River South Esk
- Upstream flood storage created by constructing a dam across the South Esk, complete with flow control features

Table 3-7 summarises the five (fluvial) scenarios that were identified to test the impacts of various combinations of components.

For all flood cells, these scenarios share a number of common features:

- Alignment and extent of direct defences (with varying heights)

- Standard freeboard provision (600mm) on all fluvial and coastal defences
- 0.5% AEP + climate change standard of protection

Scenario	Scheme components	Key features / considerations
A	5.5 km direct defences 8 no. pumping stations Mill Lade and Pinkie Burn improvements	Defence heights in most locations are significantly greater than a generally acceptable level of 1.4m above footpath level Impacts on undefended areas and existing structures (e.g. golf course, gas governor, bridges) are significant, in some cases over 1.0m when compared to baseline, including major upgrade to the upstream parapet of the Rennie Bridge Capital and maintenance costs of this scenario are the lowest of all scenarios
B	5.5 km direct defences 8 no. pumping stations Mill Lade and Pinkie Burn improvements Removal/replacement of Shorthope St. Footbridge, Electric Bridge and Goose Green Footbridge	With bridges removed, defence heights upstream are reduced in height by around 1.3m immediately upstream of Shorthope Street Bridge, with a reduction of up to 1 metre elsewhere when compared with Scenario A Although a significant reduction from Scenario A, works are still required to the upstream parapet of the Rennie Bridge Significant increase in capital cost, but significant reduction in defence heights reduces risk of objection No adverse impact on undefended areas
C	5.5 km direct defences 8 no. pumping stations Mill Lade and Pinkie Burn improvements Removal/replacement of Shorthope St. Footbridge, Electric Bridge and Goose Green Footbridge Upstream debris trap to reduce blockage risk	Majority of defences reduced to less than 2.0m in height, with town centre defences in the range of 1.1 to 1.6m No significant works required to Rennie Bridge Significant multiple benefits to the town due to new pedestrian and vehicle crossings Significant capital cost increase over scenarios A and B, but opportunities for match funding from other sources No change in flood levels upstream of Eskmills Weir and gas governor flood risk very similar to scenario A
D	Scottish Water Reservoir adaptation in conjunction with any of scenarios A, B or C	Further reduction in defence heights (dependent on available storage capacity) of up to 300mm Key constraint is that it may not be possible to realise the flood storage, depending on antecedent conditions

		Introduces new project risks such as reservoir adaptation will require ratification by Construction (Reservoir Panel) Engineer, CAR Licence consents and transfer of ownership from SW to ELC, environmental risks Complex and detailed hydrological assessment required to confirm storage can be realised and to ensure compensation flows are maintained
E	New flood storage area in conjunction with any of scenarios A, B or C	Potential location between Gladhouse and Rosebery Reservoirs Capable of storing up to 10% of South Esk hydrograph volume Dam anticipated to be up to 20 metres high with a storage volume of 2.2 million cubic metres, creating a temporary waterbody nearly 1km long over an area of 300 square km Potential to provide a reduction in defence heights of between 290 and 650mm Even when used in combination with scenario A, flood levels will not return to baseline Cost (based on previous experience) would be in the region of £15m

Table 3-7: Summary of Scheme (fluvial defence) scenarios and key features

From an analysis of each of the above scenarios, the resulting defence heights at key locations can be compared with the baseline. Refer to Table 3-8 for details. The following should be noted with reference to defence heights:

- Defence heights refer to right hand bank (looking downstream) on the River Esk above existing ground level
- Downstream of Goose Green Weir, coastal conditions dictate flood defence level
- +/- denotes increase/decrease from baseline conditions
- Scenarios D and E figures represent an additional reduction from the baseline which can be applied to any of A, B or C

Location	Scenario A		Scenario B		Scenario C		Scenario D		Scenario E	
	Height (m)	Change +/-	Height (m)	Change +/-	Height (m)	Change +/-	Height (m)	Change +/-	Height (m)	Change +/-
Eskmills Weir u/s	2.38	0.63	1.83	0.56	1.75	0.48	-0.05		-0.29	
Ivanhoe FB u/s	2.65	1.37	2.34	0.41	2.21	0.25	-0.07		-0.30	
Roman Br u/s	1.36	0.72	1.20	0.32	1.08	0.03	-0.09		-0.45	
Rennie Br u/s	1.12	1.15	0.44	0.71	0.02	0.22	-0.11		-0.54	
Electric Br u/s	2.43	0.90	2.05	0.49	1.56	-0.04	-0.10		-0.46	
Goose Green	1.50	0.03	1.50	-0.06	1.50	-0.14	0		0	
Fisherrow Prom.	1.40	0	1.40	0	1.40	0	0		0	

Table 3-8: Comparison of defence heights and change from baseline

4. Economic Appraisal

4.1 General

The methodology used for the economic assessment follows the Green Book[6], which is the standard guidance for appraising policies, programmes and projects to ensure optimum use of public resources. Guidance provided in the Multi-coloured Manual (MCM) and its supporting Handbook[7] is used to assess the flood damages, allowing for the calculation of benefit cost ratios (BCRs) and the Net Present Value (NPV) for each defence option.

The economic appraisal report is contained in Appendix I, however this section summarises the results of the assessment of flood damages, presents the estimated benefits (avoided damages) associated with the options, and compares these with the costs of each option to inform the cost-benefit analysis (CBA). The results of the CBA identify the preferred option from an economic perspective.

The appraisal period is 100 years for the CBA and economic assessment of the proposed options. This is in line with the design life of the defence options proposed. The costs and benefits have been discounted using the social discount rate according to Green Book guidance. All costs and benefits are presented in 2019 prices.

4.1.1 Assumptions

A number of conservative assumptions have been applied in the economic assessment which are important to note:

- In order to streamline the process, damages associated with events lower than the 2% AEP (1 in 50 year) plus climate change have not been included in the assessment;
- The economic assessment does not consider residual damages which would occur during events exceeding the design event of the 0.5% AEP + CC i.e. in reality, the addition of a flood protection scheme would reduce (but not completely eliminate) the damages from events more extreme than the level of SoP provided; however this effect has not been modelled hydraulically and is therefore not captured in the economic assessment;
- An upper bound value for optimism bias has been assumed at this stage (60%) as recommended in current guidance, however there is scope to significantly reduce this value during outline design and based on a detailed review of the quality of input data used in the assessment, and;
- A 12-hour flood duration has been assumed to assess coastal flood damages, which may have potential to underestimate inundation due to coastal flooding – in reality, an extreme coastal event could cause flooding over a 24-hour period due to tidal conditions, but this requires more detailed hydraulic modelling during Stage 4 to fully ascertain.

4.2 Benefits (Damages Avoided)

Table 4.1 presents the total estimated damages under the baseline (Do Nothing) scenario for each of the three modelled flood events, along with the number of properties flooded in each event. In the most extreme event modelled (a 0.5% AEP plus climate change blended flood event), there are 1,797 properties in Musselburgh shown to incur flood damages, comprised of 1,576 residential properties and 221 non-residential properties.

[6] HM Treasury (2018). The Green Book: Central Government Guidance on Appraisal and Evaluation.
[7] Penning-Rowsell *et al*., Flooding and Coastal Erosion Risk Management: Handbook for Economic Appraisal 2019.

Total damages	Cell 1	Cell 2		Cell 3	Cell 4	Cell 6	Total
	Stoneybank and Shirehaugh	Eskmills	Inveresk estate	Town Centre West and Fisherrow	Town Centre East	Old Sea Walls and Lagoons	
2% AEP + CC SoP	£0	£0	£0	£19,839,292	£42,968,635	£0	£62,807,928
1% AEP + CC SoP	£1,455,613	£1,793,570	£5,676	£22,952,297	£48,485,672	£0	£74,692,828
0.5% AEP + CC SoP	£1,846,366	£6,443,563	£251,082	£27,805,833	£52,746,950	£5,845,283	£94,939,077

Table 4.1: Total Do Nothing damages for modelled events

The number of residential and non-residential properties that experience flooding in each event are shown in Table 4.2 below. It should be noted that only ground floor property damage is considered in the assessment i.e. flats and other upper floor properties may be affected by ground floor flooding i.e. access, although not directly flooded themselves.

Wet Property Count						
	Cell 1	Cell 2		Cell 3	Cell 4	Cell 6
	Stoneybank and Shirehaugh	Inveresk estate	Eskmills	Town Centre West and Fisherrow	Town Centre East	Old Sea Walls and Lagoons
2% AEP + CC Event - Residential	0	0	0	480	753	0
2% AEP + CC Event – Non-residential	0	0	0	32	123	0
1% AEP + CC Event - Residential	0	0	0	564	867	0
1% AEP + CC Event – Non-residential	1	0	6	32	129	0
0.5% AEP + CC Event - Residential	0	3	0	643	930	0
0.5% AEP + CC Event – Non-residential	1	0	50	41	128	1

Table 4.2: Wet property count by flood cell

The economic benefits of a flood defence scheme are the flood damages avoided. Table 4-3 presents the present value benefits for each SoP separated by flood cell.

PV Benefits	Cell 1	Cell 2		Cell 3	Cell 4	Cell 6	Total
	Stoneybank and Shirehaugh	Eskmills	Inveresk estate	Town Centre West and Fisherrow	Town Centre East	Old Sea Walls and Lagoons	
2% AEP + CC SoP	£0	£0	£0	£2,962,340	£6,415,939	£0	£9,378,279
1% AEP + CC SoP	£0	£401,715	£1,271	£8,103,086	£17,275,529	£0	£25,781,601
0.5% AEP + CC SoP	£0	£1,363,847	£38,762	£12,254,964	£25,151,535	£0	£38,809,109

Table 4-3: Present value benefits by standard of protection

4.3 Costs and BCR

4.3.1 General

A high-level cost estimate was developed using basic construction cost rates from a number of sources and experience from similar works in other recent Scottish flood protection schemes:

- Tender returns from the Selkirk FPS updated to present day using appropriate inflation indices
- Detailed design cost estimates used to inform the Scottish Government bid estimate for the Hawick FPS
- Cost estimates and quotations obtained from specialist contractors
- Rates from Spon's Civil Engineering and Highway Works Price Book, updated to present day using appropriate inflation indices

Estimated Scheme costs include an allowance for:

- Preliminaries and general items (25%)
- Utility diversions (based on a review of potential clashes with defences)
- Pumping stations (based on a review of potential water ponding locations)
- Optimism Bias (60% as per current guidance for project appraisal and feasibility stage)
- Inflation (5% added to rates where relevant to bring estimates in line with appraisal date)
- Maintenance (presented as the present value for 100 years of maintenance)

Cost estimates at this stage do not include an allowance for:

- Social and environmental mitigation costs
- Decommissioning costs
- Carbon costs
- Design and construction supervision costs
- Compensation and land purchase

All costs are preliminary at this stage and are intended to give an initial assessment of the BCR of the options for flood protection in Musselburgh. The scheme cost assessment was initially carried out assuming a 0.5% AEP standard of protection with worst case defence heights for the Scheme (Scenario A). The costs were then adjusted where appropriate to represent the slightly reduced defence heights for the other scenarios considered in the assessment.

The Scheme BCR is derived by dividing PV benefits by PV costs; a BCR of 1 indicates a net neutral opportunity; that is there is no financial incentive or disincentive to progress that option. A BCR greater than 1.0 indicates a positive return on investment (from an economic standpoint) and should be considered.

4.3.2 Results

The results of the basic cost assessment for **Scenario A (direct defences only)** separated by flood cell are presented in Table 4-2.

Cost Category	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Total
	Stoneybank and Shirehaugh	Eskmills (excl. Inveresk)	Town Centre West and Fisherrow	Town Centre East	Pinkie Burn	Old Sea Walls and Lagoons	
Year 0 construction cost	£0	£5,128,800	£15,137,200	£9,109,200	£475,000	£0	£29,850,200
Years 1 - 3 annual maintenance cost	£0	£8,000	£24,000	£17,000	£6,500	£0	£55,500
Years 4 and 5 annual maintenance cost	£0	£6,500	£21,000	£15,000	£5,750	£0	£48,250
Year 5 onwards annual maintenance cost	£0	£5,850	£18,900	£13,500	£5,175	£0	£43,425
Year 50 major maintenance cost	£0	£20,000	£60,000	£42,500	£16,250	£0	£138,750

Table 4-4: Capital and maintenance cost estimates for direct defences by flood cell (Scenario A only, 0.5% AEP plus climate change)

Capital and annual maintenance costs were converted into present value costs and compared with present value benefits, to allow a BCR for each flood cell to be calculated. The results are presented in Table 4-5 and discussed further in section 4.4.

Cost Category	Cell 2 *Inveresk Estate (standalone, not included in total)*	Cell 2 Eskmills (excl Inveresk Estate)	Cell 3 Town Centre West and Fisherrow	Cell 4 Town Centre East	Cell 5 Pinkie Burn	SCHEME TOTAL
Capital cost (NPV)	*£1,200,000*	£5,128,800	£15,137,200	£9,109,200	£475,000	£29,850,200
Maintenance cost (NPV)	*£150,000*	£178,779	£571,512	£407,752	£156,250	£1,314,293
Total cost (NPV)	*£1,350,000*	£5,307,579	£15,708,712	£9,516,952	£631,250	£31,164,493
Benefits (NPV)	*£38,762*	£1,363,847	£12,254,964	£25,151,535	Negligible	£38,809,108
BCR	*0.03*	0.26	0.78	2.64	<0.1	1.25

Table 4-5: Present value costs, benefits and BCR for each flood cell (Scenario A only, 0.5% AEP plus climate change)

Cost estimates for direct defences were adjusted appropriately to consider the potential reduction in defence height that could be achieved through implementation of supplementary scheme components under each scenario, as described above in section 3.14. High level costs were estimated for these supplementary components, based on experience from previous flood protection schemes, and a final Scheme BCR was calculated using baseline benefits. A summary of costs, benefits and BCR is presented in Table 4-3 for each 'whole Scheme' scenario.

Scheme Cost	Scenario A	Scenario B	Scenario C	Scenario C+D	Scenario C+E
Direct Defences	£ 22,275,000	£ 21,100,000	£ 19,100,000	£ 18,800,000	£ 16,900,000
Pumping Stations (total 8 no.)	£ 4,000,000	£ 4,000,000	£ 4,000,000	£ 4,000,000	£ 4,000,000
Mill Lade / Pinkie works	£ 475,000	£ 475,000	£ 475,000	£ 475,000	£ 475,000
Debris Traps	-	-	£ 1,000,000	£ 1,000,000	£ 1,000,000
Replace Shorthope St bridge	-	£ 1,000,000	£ 1,000,000	£ 1,000,000	£ 1,000,000
Replace Elec / Goose Gr bridges	-	£ 4,500,000	£ 4,500,000	£ 4,500,000	£ 4,500,000

Scheme Cost	Scenario A	Scenario B	Scenario C	Scenario C+D	Scenario C+E
Adapt Rosebery / Edgelaw	-	-	-	£ 1,200,000	-
New Gladhouse FSA	-	-	-	-	£ 15,000,000
Service Diversions	£ 3,100,000	£ 3,100,000	£ 3,100,000	£ 3,100,000	£ 3,100,000
CAPITAL COST TOTAL	£ 29,850,000	£ 34,175,000	£ 33,175,000	£ 34,075,000	£ 45,975,000
MAINTENANCE COST TOTAL	£ 1,300,000	£ 1,800,000	£ 1,900,000	£ 2,000,000	£ 2,300,000
TOTAL COST (present value)	£ 31,150,000	£ 35,975,000	£ 35,075,000	£ 36,075,000	£ 48,275,000
BENEFITS (present value)	£ 38,809,109	£ 38,809,109	£ 38,809,109	£ 38,809,109	£ 38,809,109
SCHEME BCR	1.25	1.08	1.11	1.08	0.81

Table 4-6: Summary of costs, benefits and BCR (0.5% AEP plus climate change) for 'whole Scheme' scenarios

4.4 Conclusions and recommendations

Based on the results of the foregoing economic appraisal, the following can be inferred:

1. With reference to Table 4-3, it can be seen that the PV benefits increase significantly for the 0.5% AEP + CC event when compared with lower return periods. The benefits associated with the 2% AEP and 1% AEP are £9.4m and £25.8m respectively. However, the total PV costs associated with protection at these lower SoPs would be in excess of £25m for a number of reasons:

    a. The extent of defences i.e. lengths are not reduced at lower return periods

    b. The majority of the construction cost of direct defences is associated with the foundations and below ground structures, therefore even a moderate reduction in height of around 0.5m would not significantly reduce the cost of the Scheme

    c. Service diversion and pumping station costs would remain the same and account for a significant proportion of the total Scheme cost

    As such, it is clear that SoPs lower than the desired 0.5% AEP + CC will result in a whole Scheme BCR of less than 1.0 and should not be considered further.

2. Benefits of £39m can be considered as a lower bound as these do not include intangible losses, transport delays, social and environmental benefits, and the value is based on a number of conservative assumptions (refer to 4.1.1).

3. The benefits figure is lower than previous assessments as flood depths in the damage assessment are based on accurate threshold levels recorded during a detailed survey of properties, as opposed to a standard threshold level assumption of 150mm above ground levels obtained from LiDAR.

4. Cells 1 and 6 result in zero benefits as there are no defences proposed within these cells i.e. there are no damages 'avoided'. Damages within cell 1 are associated with the value of Musselburgh Golf Course only, while damages within cell 6 are associated with the Levenhall Links Leisure Park. It is worth noting that damages within cell 6 are considered to be an overestimation due to the indeterminate method by which the MCM Handbook deals with leisure and sports grounds.

5. Benefits for cells 2 and 4 can be combined because there is a hydraulic link between the two via Olive Bank Road and the roundabout at Tesco supermarket; combining the costs and benefits for cells 2 and 4 results in a BCR of 1.79.

6. Damages associated with the Pinkie Burn (Cell 5) are limited to sports pitches and surface water flooding of roads only i.e. no property flooding, therefore accrue negligible benefits. As such, any works proposed in this cell will not achieve a BCR above 1.0. However, protection measures can be justified on the basis of the public perception (social and stakeholder inputs) and the potential for future flood risk to be greater than currently determined, due to the possibility of the culvert being in poorer condition than presently modelled.

7. Costs associated with protection of the properties within the Inveresk Estate far exceed the benefits accrued due to the very low flood depths encountered at this location and as such results in a BCR of only 0.03.

8. Cell 3 (Town Centre West and Fisherrow) has a BCR of 0.78 as it includes the entire coastal extent of defences at a high cost. However, there is no situation in which the defences in cell 3 can be removed from the Scheme as a whole, due to the huge impact on flood risk to this area if works in other flood cells were to be progressed on a stand-alone basis.

9. Cell 4 (Town Centre East) contains the highest number of residential and non-residential properties and as such has the highest BCR of all flood cells, with a value of 2.64.

10. Inclusion of a new upstream storage area (Scenario E) results in a whole Scheme BCR of less than 1.0, therefore is not an economically viable solution and should not be considered as a component of the Preferred Scheme.

11. The scheme must include coastal defences in all scenarios, as protection from coastal flooding is required from return periods as frequent as the 50% AEP + CC coastal event.

Based on results of the economic assessment, it is recommended that:

a) Inclusion of a new upstream storage area (scenario E) is not considered as a component of the Preferred Scheme

b) 0.5% AEP + climate change standard of protection is uniformly applied to all flood cells

5. The Preferred Scheme

5.1 Summary

5.1.1 Overview

The foregoing chapters of this report have detailed the chronology of decisions made in relation to the preferred scheme for Musselburgh. It must be noted the preferred scheme should not be considered as the final scheme, and the opportunity for change exists throughout the project, even during construction. The preferred scheme does, however, set a direction of travel and it must be acknowledgement that changes to the scheme from this point on are likely to incur increasing impacts on the time and cost of delivering the project.

In deriving the proposed preferred scheme, a wide range of factors have been considered, including:

- Temporary and permanent impacts on the built and natural environment;
- Temporary and permanent impacts on the public and businesses of Musselburgh and upper catchment;
- Health, safety and wellbeing impacts;
- Feedback from the public and stakeholders from various consultation events;
- The technical feasibility and constructability of key elements of each component;
- The capital and maintenance costs of a range of components and combinations of components;
- The benefits of protecting the town against various return periods

The following sections provide further information on the core, supplementary and rejected components (5.1.2 to 5.1.4) and a more detailed discussion on the decision is provided in section 5.1.5. Table 5.1 summarises the outcome of the selection process.

The preferred Scheme consists of a combination of direct defences, pumping stations and bridge removal and replacement in Musselburgh town centre, combined with an upper catchment debris trap and adaption of two Scottish Water reservoirs to store greater volumes of water during a flood event, all to provide protection against the fluvial, coastal and surface water 0.5% AEP + CC events.

This is Scenario D and is the only economically viable scenario which, subject to more detailed hydraulic modelling and option testing during Stage 4, offers the potential to neutralise the increase in flood levels at structures through the town centre caused by the presence of direct defences. This scenario ensures that there is negligible impact on the Roman and Rennie Bridges and reduces flood levels through the town centre to visually acceptable levels.

The cost of Scenario D is estimated at £36.5 million and generates a Benefit Cost Ratio of 1.08.

Should Scenarios C or D prove to be undeliverable from a technical, economic, hydraulic or stakeholder issue, the minimum combination of components would be those represented by Scenario B. Careful analysis of the impacts on the Roman Bridge will require to be discussed with key stakeholders and a solution to incorporate the Rennie Bridge into the scheme will be required, along with consideration of the need to protect Cell 9 Inveresk Estate. The risk of objection due to unacceptably high direct defences is elevated compared to Scenario D, but Scenario B offers a more cost effective and economically beneficial solution, with a delivery cost estimate of £33.0 million and BCR of 1.18.

Objective	A	B	C	C+D	C+E
0.5% AEP + CC s.o.p	Yes	Yes	Yes	Yes	Yes
Cost £M (60% OB)	29.2	33.0	34.2	36.5	45.7
BCR (based on 39M ben)	1.33	1.18	1.14	1.07	0.85
Defence Heights	Very high	Moderate	High	Moderate	Lowest
Environmental Impacts	Moderate risks	Elevated Risk	Enhanced Risk	Elevated Risk	Significant Risk
Impact on undefended areas	Significant	Negligible	Moderate	Negligible	Reduced
Impact on structures	Significant	Negligible	Moderate	Negligible	Reduced
Multiple Benefits?	Few	Significant	Few	Moderate	Moderate
Impact on landowners	Moderate	Enhanced	Enhanced	Enhanced	Significant
Overall	REJECT	MINIMUM	CONSIDER	PREFERRED	REJECT

Table 5.1 – Summary of preferred scheme selection

5.1.2 Core Components and Standards of Protection

Based on the analysis of the above considerations and detailed discussion with the client, stakeholders and the public, it follows that the proposed preferred scheme will consist of the following core components and attributes:

- Provide a uniform standard of protection against the 0.5% AEP + CC blended flood event for fluvial and coastal flooding;
- Provide protection against surface water and secondary flooding as appropriate;
- Achieve an overall scheme BCR greater than 1.0, but accept that it will include flood cells which do not have a BCR > 1.0.
- Include as a minimum the components which make up Scenario B, which are:
    - Direct fluvial defences to Cells 2, 3 and 4 to protect against the effects of the 0.5% AEP + CC flood event in the River Esk, with 600mm freeboard, including a requirement to strengthen the Rennie Bridge;

- Direct coastal defences to the River Esk estuary section of Cells 3 and 4 to protect against the effects of the 0.5% AEP + CC coastal flood event, with no wave overtopping permitted;
- Direct coastal defences to the Fisherrow coastal section of Cell 3 to protect against the effects of the 0.5% AEP + CC coastal flood event, but with varying degrees of wave overtopping permitted;
- Direct partially demountable defences to the Fisherrow Harbour section of Cell 3 to protect against the effects of the 0.5% AEP + CC coastal event, with minimal degrees of wave overtopping permitted;
- Strengthening and upgrading works to Eskmills weir;
- Restriction to the volume of flow entering the Mill Lade at Eskmills weir and culverting of the existing open section at the upstream end of the lade;
- Up to eight surface water pumping stations at low points in Cells 2, 3 and 4 to assist with alleviation of surface water flood risk, including one pumping station near Musselburgh Racecourse to augment potential surcharge within the Pinkie Burn culvert;
- Up to three saline water pumping stations and associated high capacity drainage systems to discharge the volumes of sea water which overtop the variable height Cell 3 coastal defences;
- Remodelling of the existing parkland landscape within the northern extent of Pinkie Playing fields, to store excess water which cannot be conveyed through the existing Pinkie Burn culvert during the 0.5% AEP + CC event in the Pinkie Burn;
- Introduction of an overflow system (manholes and buried pipework) within the Pinkie Burn to link to one of the surface water pumping stations near Musselburgh Racecourse to prevent surcharging of the Pinkie Burn culvert manholes;
- Removal of the Shorthope Street pedestrian bridge and replacement with a new, higher soffit active travel compliant structure in a similar, but not necessarily identical location. It should be noted that a sub-option within this scenario should consider not replacing the bridge at all, subject to a review of the overall strategy for crossing the River Esk in Musselburgh, which is being taken forward by other projects and initiatives (e.g. SUSTRANS active travel studies);
- Removal of the Goose Green footbridge and support piers in their entirety;
- Removal of the Electric Bridge and support piers in their entirety;
- Replacement of the Goose Green and Electric Bridges with a new, higher soffit combined vehicle and active travel compliant structure in a similar, but not necessarily identical location;
- Continued monitoring of the ground water levels in the Pinkie Area;
- Continued monitoring of the condition of the Old Sea Wall;
- Continued monitoring and survey of the beach and dune profile along the Fisherrow Sands.

5.1.3 Supplementary Components

Depending on the results of further hydraulic modelling and stakeholder consultation during the remainder of Stage 3 and into Stage 4, the following supplementary components could form part of the preferred scheme and would provide significant potential additional benefits, including neutralising the impacts of direct defences on baseline flood levels, the protection of the Inveresk Estate and reducing the likelihood of intervention at the Rennie Bridge. In combination with the Scenario B core components, the additional measures to create Scenarios C and D could form part of the preferred scheme.

Scenario C

In addition to the core components identified as Scenario B in section 5.1.2, Scenario C adds the following measure which provides the potential to reduce flood levels upstream of the Ivanhoe, Olive Bank Road, Roman and Rennie Bridges, assuming all bridges downstream of the Rennie Bridge are to be removed and replaced and therefore at significantly reduced risk of debris blockage. Scenario C does not result in sufficient flood level reduction to preclude work to the Rennie Bridge from being included as part of the scheme.

- The provision of a debris trap across the River Esk, at a location between the A1 and A68 bridges, designed with widely spaced vertical poles to trap large floating debris, with associated ancillary works, including:
    - The provision of telemetry and CCTV to allow East Lothian Council to measure river levels across the trap and remotely identify whether the trap has become blocked;
    - Creation of a new access from Whitecraig to allow vehicular access to maintain and remove debris from the trap;
    - Bank protection works to protect against erosion when the debris trap becomes fully blinded and river flows outflank the trap
    - Measures to ensure that the free passage of migratory fish is maintained

Scenario D

In addition to either Scenario B or Scenario C, Scenario D adds the following measures which provides the potential to reduce flood levels through the populated areas of the River South Esk catchment and the River Esk through Musselburgh. This scenario could sufficiently reduce flood levels in Cell 9 Inveresk Estate to remove the 0.5% AEP + CC flood risk to those properties and, if combined with Scenario C, would effectively neutralise the impacts that direct defences have on the baseline flood levels. This is a major benefit insofar as it could remove any adverse hydraulic impact on the Roman Bridge and remove the need for intervention at the Rennie Bridge. Further studies into the dam structure, safety and operation are required to be undertaken along with detailed hydraulic modelling, to ultimately prove the beneficial impacts of these proposals. It is possible that the dam assessment / modelling results show that one or both of the reservoirs are capable of modification.

- Modifications to the dam structure and spillways at Rosebery reservoir, to reduce the normal operating level of the reservoir and increase the available storage capacity, along with the following ancillary works;
    - Modifications to the access bridge across the spillway;
    - Potential modifications to the compensation flow pipework to account for a reduced normal operating level;

- o Checks on the impacts of reducing reservoir operating level on the environment, ecology and reservoir users;

- Modifications to the dam structure and spillways at Edgelaw reservoir, to reduce the normal operating level of the reservoir and increase the available storage capacity, along with the following ancillary works;
    - o Modifications to the access bridge across the spillway;
    - o Potential modifications to the compensation flow pipework to account for a reduced normal operating level;
    - o Checks on the impacts of reducing reservoir operating level on the environment, ecology and reservoir users;

5.1.4 Rejected Scenarios

The analysis of Scenarios A to E showed that two of the scenarios cannot be considered as the preferred scheme, either in isolation or in combination.

Scenario A

By solely implementing fluvial and coastal direct defences without work on the lower bridges, along with surface water and wave overtopping pumping stations and weir and lade culvert improvements, the resulting height of defences to protect against the 0.5% AEP + CC event would in all likelihood be unacceptable to the public and stakeholders. This would probably result in a level of objection which could cause the scheme to become unfeasible. This Scenario does, however, provide the lowest cost and most economically beneficial way of providing a 0.5% AEP + CC standard of protection to over 3,000 properties.

Scenario E

Even with the proposed engineered flood storage area in operation, it is not possible to store sufficient flood water to significantly reduce the extent of direct defences in Musselburgh. Whilst their heights could be lowered by up to 600mm, the majority of costs associated with the defences are in the foundations, therefore a preferred scheme with lower height defences and upstream flood storage is estimated to cost more to construct than the benefits arising, for all standards of protection. It is therefore determined that this Scenario cannot be progressed due to lack of a positive economic assessment.

5.1.5 Discussion

The preferred scheme will therefore consist of up to 33 separately identified components, which in combination will provide protection to over 3,000 properties against the effects 0.5% AEP + CC blended River Esk / North Sea flood event and the effects of the 0.5% AEP + CC Pinkie Burn flood event.

The following points require to be observed when considering the core and supplementary components of the preferred scheme:

Direct Defences

- The alignment of the direct defences requires careful consideration during Stage 4 Outline Design, where a range of influencing factors will need to be fully evaluated and appraised. These factors include: avoiding the need to divert or protect services by not setting the defences back against the riverside footpaths of Eskside East, Eskside West, Mall Avenue, etc; the landscape and visual impact, the apparent height above footpath level, etc. Reconvening the specific Working Groups set up during Stage 3 will be pivotal in determining the outcomes of one of the Scheme's most important decisions.

- The form of the direct defences will also require careful consideration, where a blend of walls, embankments, demountables and flood gates are expected to be required. The finish and appearance must also be discussed in detail with the public and other relevant bodies, via the Working Groups and other events.

- The height of direct defences to protect against flooding form the River Esk incrementally reduces as the number of flood risk components increases, such that if Scenarios C or D are taken forward, the defence heights within cells 3 and 4 reduce to what would be considered as an acceptable height to the majority of the public. The final round of hydraulic modelling and subsequent consultation during Stage 4 will be able to accurately define defence heights at any point in the Scheme, informing the debate on whether or not to take forward initiatives such as raised footpaths or glass panels to reduce the visual impact;

- The provision of seepage protection in combination with the direct defences will be a function of the preferred method of construction. Determining the necessity for seepage protection will be defined as one of the early Stage 4 activities – if seepage protection is required or desired, and the ground conditions are conducive to sheet piling, then it is likely that sheet piles will form the preferred foundation construction technique.

- The height of coastal defences along Cell 3 must be balanced against the probable wave overtopping volumes and subsequent pumping requirements through detailed hydraulic modelling and public consultation.

Bridge removal / replacement

- The decision on whether or not Shorthope Street footbridge needs to be replaced at or near its current location will be a function of the outcome of an overall strategy to review how the public could be crossing the River Esk in the future, depending on outputs from a number of other infrastructure studies across the town and East Lothian. The principal focus of this is the consideration of an active travel corridor and overall improvements to circulation of vehicular traffic within the town, which may determine that a combined pedestrian / active travel crossing at a different location is of greater benefit.

- For the purposes of this report, it has been assumed that removal of the Goose Green and Electric Bridges will result in a replacement single structure which caters for vehicles, pedestrians and other active travellers. The bridge will require to be approximately 2.0m higher than the current structures and access ramps from the New Street and Goose Green sides will require to be carefully designed. Existing services and utilities will require to be temporarily diverted whilst the new bridge is constructed.

- Should the additional final preferred scheme analysis result in not being able to take forward Scenario D, then work will be required to the Rennie Bridge as flood defence level will be above carriageway level. This results in the potential for the bridge parapet and / or entire structure to require potentially expensive strengthening and adaption.

- Should the additional final preferred scheme analysis result in not being able to take forward Scenario D, then there is a risk that the increase in flood level at the Roman Bridge may result in an objection to the scheme from Historic Environment Scotland.

Pumping Stations

- The provision of surface water pumping stations within the preferred scheme is common to all scenarios and it has been assumed for the purposes of defining the preferred scheme that the solution which employs the least amount of operation and maintenance should be selected. The pumping stations will require to be automatically operated, with the ability to remotely monitor their status. Further surface water rainfall and modelling analysis is required to determine the flow rates which each pumping station must pump and where their discharge points will be located.

- The provision of saline water pumping stations within the preferred scheme is common to all scenarios and, similar to surface water, the solution which offers the least amount of operation and maintenance should be selected. When dealing with wave overtopping, a number of greater technical challenges are posed, including:

    - Dealing with the effects of saline water and ensuring all pump components are suitably corrosion resistant;

    - Dealing with the large volumes of debris which will be thrown onto the dry side of the defences by the waves, including seaweed, sand, pebbles and driftwood;

    - Dealing with highly variable flows along the length of the drainage system, if overtopped waves synchronise along the shore.

Debris Traps

The debris trap included in Scenario C requires a number of influencing factors to be fully evaluated prior to confirmation that it should be a component of the preferred Scheme. There is a risk that the assumed cost of the debris trap could increase, depending on the outcome of some of these factors:

- Impact on the aquatic environment, including free passage of and / or spawning territory for migratory fish, invertebrate habitat and Water Framework Directive categorisation;

- Impact on geomorphology upstream and downstream of the debris trap;

- Impact on flood risk upstream of the debris trap due to fully blinded trap and potential compensation risk;

- Impact on users of the river through this stretch (fishing, canoeing);

- Safe access for East Lothian Council employees to clean and maintain the trap, and;

- Agreement with landowner to take access

It should also be noted that there is a risk that the debris trap could be fully or partially blinded following weeks of wet weather which would often be the pre-cursor to a major flood event. In this case, unless the trap was cleaned on the forecasted build up to the flood event, there is a significant risk that the benefits of the trap may not be realised. It is therefore recommended that a full sensitivity analysis is undertaken on the final Stage 4 hydraulic model to test the status of the debris trap and impact on blockage percentage at existing and removed / replaced bridges in Musselburgh.

Scottish Water Reservoirs

Adaption of the Scottish Water reservoirs which define Scenario D require a number of influencing factors to be fully evaluate prior to confirmation that they can be included in the preferred scheme, including:

- Hydraulic modelling, including impacts on downstream flood risk

- Structural assessment of dam and spillway
- Environmental assessment
- Transfer of reservoir ownership to East Lothian Council

5.2 Multiple benefit opportunities

One of the Scheme's objectives is to strive to achieve multiple benefits. These are opportunities which would not contribute to a reduction in flood risk but which could still benefit the community. While the Scheme would not fund the multiple benefits, they might be able to be delivered via the Scheme's construction phase contract(s) to leverage economies of scale. Where it is not possible to deliver them this way, it might still be possible for the Scheme to include preparatory activities to ease delivery of the multiple benefits in the future.

5.2.1 Public spaces and amenities

The construction of a flood protection scheme has the potential to impact and temporarily occupy large areas of public space in proximity to the watercourse and coast. The reinstatement of these areas therefore brings the opportunity for public realm improvements and placemaking. Key areas of opportunity may include Musselburgh town centre, Fisherrow promenade, parkland along the riverbanks, and specifically areas adjacent to the Roman Bridge and Rennie Bridge.

5.2.2 Fish passage

Weirs can have a negative impact on watercourses by restricting fish passage, but they can also have a positive impact by stabilising riverbed morphology and riverbank erosion. Removal or failure of weirs can lead to changes in the riverbed and riverbank both upstream and downstream over considerable distances, which can in turn impact the stability of adjacent structures. While modifying or repairing weirs may not directly reduce flood risk, it may be necessary where flood defence structures are to be constructed adjacent to it to ensure the long term stability of the new structures. In this case, while work is being carried out to the weir to facilitate the flood defences, it may also then be possible to incorporate changes to improve fish passage, albeit without removal of the weir. Such opportunities may exist on the Eskmills weir and at upstream reservoirs, but not at Goose Green weir since it is within the tidal reach and fish passage is possible at high tide.

5.2.3 Active travel network

The construction of flood defences on riverbanks often impacts adjacent footpaths, roads, and bridges. Reinstatement of these may provide an opportunity for improvement of the built environment and provision of an active travel network. This may include cycle lanes, dedicated cycleways, cycleways shared with pedestrians, and cycle parking areas. Where an active travel network is to be incorporated, it is important to establish this as early as possible in the design development as they impose constraints on the design of adjacent flood defence structures, which can have considerable cost and programme implications when incorporated later.

5.2.4 Landscaping and habitats

Constructing flood defences often means temporary disruption to the watercourse. The reinstatement therefore presents an opportunity for ecological improvements and creation of habitats for fauna such as red squirrel, kingfisher, otter.

5.2.5 Archaeological investigations

The potential for archaeological watching briefs within the working areas of the Scheme will be assessed through the EIA at the appropriate stage, and with this comes the opportunity to gather data about the history of the town. Where archaeology is encountered during the construction phase, the work will be halted to allow investigation and data collection to take place. ELC can then take a decision whether to retain the finds or record them and then proceed with the works.

5.2.6 Cultural knowledge

During the course of engaging with statutory stakeholders and the local community, the project team often acquire a variety of local knowledge. This can include anecdotal information about changes to the area, photos of historical events, and other historical documents. This information could be stored by ELC and made available to the public through the relevant council departments or local libraries.

5.2.7 INNS

Invasive Non-native Species (INNS) present a risk to biodiversity and their dispersal in the environment is regulated under the Wildlife and Natural Environment (Scotland) Act 2011. There will be a need to identify and manage INNS within the working areas of the Scheme to comply with the legislation. Following completion of the Scheme this provides the opportunity for biodiversity to increase.

6. Conclusions and recommendations

6.1 'Preferred Scheme' summary and BCR

The preferred Scheme consists of a combination of direct defences, pumping stations and bridge removal and replacement in Musselburgh town centre, combined with an upper catchment debris trap and adaption of two Scottish Water reservoirs to store greater volumes of water during a flood event, all to provide protection against the fluvial, coastal and surface water 0.5% AEP + CC events.

This is Scenario D, which has an estimated capital cost of £36.5 million and generates a Benefit Cost Ratio of 1.08.

Should Scenarios D prove to be undeliverable from a technical, economic, hydraulic or stakeholder issue, the minimum combination of components would be those represented by Scenario B, with a delivery cost estimate of £33.0 million and BCR of 1.18.

6.2 Review of Scheme Objectives

Following completion of the option appraisal stage and recommendation for a 'Preferred Scheme' for Musselburgh, a review of the Scheme Objectives was carried out to assess compliance. Even at this relatively early stage in the development of the project, it is estimated that jst over 50% of the Scheme Objectives have been satisfied, including (amongst others):

1.2 To advance as many of the 'selected actions' identified within the Local Flood Risk Management Plan as possible and to a level that is reasonable through the project during the life-cycle of the project;

1.6 The Scheme will strive to consider all possible options for reducing the flood risk within the Option Appraisal Process

2.2 To ensure that a full analysis of BCR is undertaken during the Option Appraisal Process (during Stage 3 – the Option Appraisal Process) such that a full understanding of economic benefit and cost is achieved. The Scheme does not require to have the optimum BCR however economic benefit is to remain a key consideration

3.2 That the Scheme will aspire to meet a level of protection to protect against the 0.5% AEP (1 in 200 year) flood event including an allowance for climate change

3.3 To ensure that the Scheme addresses all sources of flood risk

5.3 To ensure that the Scheme considers the impact of climate change and includes appropriate provisions to mitigate any impact

A number of other objectives cannot be achieved at this stage of the project and it is recommended that a similar exercise is undertaken upon the conclusion of the Stage 4 Outline Design.

6.3 Next steps

6.3.1 Further information and surveys

To inform the outline design of the preferred Scheme it will be necessary to carry out:

- Further geotechnical investigation;
- Further topographic surveys;
- CCTV survey of the Mill Lade culvert;
- CCTV survey of the Pinkie Burn culvert; and
- Structural survey of Eskmills Weir
- Ecological and Environmental surveys

6.3.2 Further consultation/discussion

Further consultation will take place as the project progresses including the following:

- Further meetings with the following working groups, plus the introduction of new working groups as required
  - Environmental Working Group
  - Coastal and Watercourse Working Group
  - Roads, Access and Structures Working group
  - Planning, Landscape and Heritage Working Group
  - Services & Utilities Working Group
- Interaction with other projects planned / ongoing in the town
- Consultation with key stakeholders
- Planned public exhibition in summer 2020 to present preferred scheme

6.3.3 Outline design

The purpose of the outline design is to establish sufficient confidence in the deliverability of options within the preferred scheme such that an outline cost estimate can be prepared and ELC can publish the Scheme under the statutory approvals process. Activities within the outline design stage may include:

- Preparing a basis of design
- Establishing preferred forms of construction
- Refining alignment and preparing outline geometry of flood defence options

- Carrying out outline cost estimate of the Scheme

Appendix A. Hydrological assessment

Appendix B. Hydraulic modelling

B.1 Baseline Flood Maps

B.2 Freeboard

Appendix C. Engineering

C.1 Geotechnical risk register and location plan/sections

C.2 Schedule and plan of existing structures

C.3 Review of existing services/utilities

Appendix D. Consultation

Appendix E. Environment

E.1 Preliminary Environmental Appraisal Report – June 2019

E.2 Natural Flood Management Report – September 2019

Appendix F. Preferred Scheme plans

Appendix G. RAG analysis

Appendix H. Long List option plans

Appendix I. Economics