Grangemouth Flood Protection Scheme

Option Appraisal Report

B2386100-JEC-S3-ZZZ-XXX-RE-C-0002 | P01

August 10, 2021

Falkirk Council

Grangemouth Flood Protection Scheme

Project No:	B2386100
Document Title:	Option Appraisal Report
Document No.:	B2386100-JEC-S3-ZZZ-XXX-RE-C-0002
Revision:	P01
Document Status:	Draft
Date:	August 10, 2021
Client Name:	Falkirk Council
Client No:	B2386100
Project Manager:	Alan McGowan
Author:	Richard Meeson
File Name:	B2386100-JEC-S3-ZZZ-XXX-RE-C-0001_Option Appraisal Report P01

CH2M HILL United Kingdom

95 Bothwell Street
Glasgow, Scotland G2 7HX
United Kingdom
T +44 (0)141 243 8000
F +44 (0)141 226 3109
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
P01	12/08/2021	Draft issue	RM	RP	SS	AMcG

Contents

Executive Summary

Refer to separate document titled Option Appraisal Summary Report dated May 2021

1. Introduction

1.1 The need for a Flood Protection Scheme for Grangemouth

Grangemouth has a long history of industrial activity and is home to Scotland's only oil refinery and largest sea container port. The Grangemouth petrochemical plant is of UK-wide importance and is where the North Sea - Forties Pipeline System delivers, and where its outputs are initially processed. It is worth noting the strategic national importance of the Forties Pipeline, which conveys approximately 30% of the UK's oil from the North Sea oil fields. Additionally, the port of Grangemouth is the only port in the UK with the capability to receive imported liquid ethane gas, the product from the process of fracking shale gas.

This fundamental need to be close to the Forth Estuary brings its own risks. The plant's location on the shores of the Firth of Forth results in the potential for tidal flooding from wave overtopping and coastal inundation. Sea level rise predictions result in a heightened flood risk to not only to the port and petrochemical plant but also to the wider Grangemouth area. Additionally, the River Avon flows through the eastern part of the petrochemical plant and out into the Forth Estuary. There are both fluvial and tidal flood risks generated from the River Avon, the fluvial element is predominantly located around the Wholeflats Road area, with the tidal flood risk dominating the lower reaches of the river.

Two further watercourses also impact on flood risk within the area, the River Carron and Grange Burn. Flowing through a mixture of urban, undeveloped, and semi agricultural land both have been heavily modified over the last 200 years, principally for the purposes of improved navigation during the industrial revolution. The fluvial flood risk from these water courses is significant due to the intensity of urban development along their banks and the relatively flat topography of the area. It should be noted that both watercourses are influenced by tides on the lower reaches. Many residential properties are at risk of both fluvial and tidal flooding.

1.1.1 Potentially Vulnerable Areas

In September 2011, following completion of the National Flood Risk Assessment, the Scottish Environment Protection Agency (SEPA) published the Potentially Vulnerable Areas (PVAs) across all fourteen Local Plan Districts in Scotland. PVA's are areas where a significant flood risk exists now or is likely to occur in the future.

Grangemouth is located within Local Plan District 10 (Forth Estuary) which is one of fourteen districts in Scotland and there are 26 PVAs identified within the district. Within the Forth Estuary Local Flood Risk Management Strategy, PVAs 10 and 11 cover Falkirk, Grangemouth, Laurieston, Denny, Redding, Dunipace, Cumbernauld, Carron and Stenhousemuir. PVA datasheet 10/11 (See Appendix A) highlights that 2,000 residential and 330 non-residential and commercial properties are at risk of flooding from the River Carron, River Avon, Grange Burn and tidal sources during a 1 in 200-year event. The petrochemical plant and port area are also within the 1 in 200-year flood extent. The data used by SEPA to prepare the PVA Datasheet has been superseded by the work undertaken by Falkirk Council.

1.1.2 Background

1.1.2.1 Location

Grangemouth is a town on the south bank of the Forth Estuary. The town is located 3 miles to the east of Falkirk and 10 miles downstream, in a south easterly direction, from Stirling. Grangemouth is located within the local authority boundary of Falkirk Council, within central Scotland – and forms part

of what is commonly known as the 'Central Belt'. The town has a population of approximately 18,000 people. Although titled the 'Grangemouth FPS' the scheme covers a wider area including the surrounding urban areas of Larbert, Stenhousemuir (Carron), and Camelon, however for this report these towns are included when referring to the "Grangemouth area".

1.1.2.2 Grangemouth Layout and History

The Grangemouth area has a rich industrial heritage including ship building, mining and oil processing. There has been an operational port at Grangemouth since circa. 1800's, with significant development of the modern-day port and petrochemical site being carried out since the 1940's.

1.1.2.3 Sources of Flooding

1.1.2.3.1 Fluvial

Fluvial flooding can be defined as flooding which occurs as a direct result of the inability of a watercourse to convey the flow and volume of water within its channel. The fluvial flood risk to the Grangemouth area is primarily from three water courses: the River Carron, River Avon and Grange Burn.

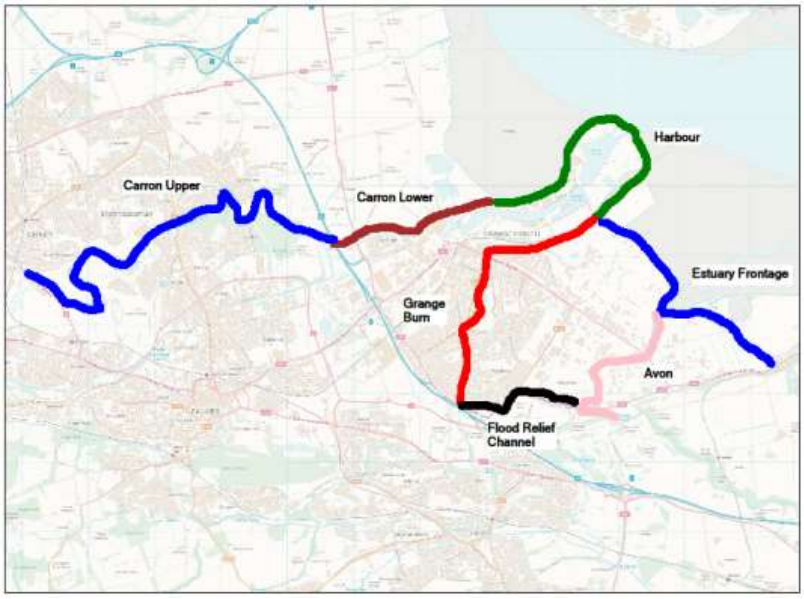

Figure 1: *Scheme extents with main water courses*

River Carron

The River Carron is approximately 35km in length and drains a catchment area of approximately 192 km^2, from its source in the Campsie Fells eastwards into the Firth of Forth at Grangemouth. The principle land use in the catchment is for moorland and plantation forestry, particularly along its upper reaches, while along the lower reaches land use is predominately pasture land with urban and industrial development on its banks. The geology, land-use and steep topography of the catchment results in the river channel having a relatively rapid response to rainfall events. There are several major pressures on the river within its catchment, including morphological alterations for renewable energy production and flow regulations for abstraction, purification and distribution of water at Carron Valley Reservoir on the upper catchment. In the lower catchment issues include point source pollution from sewage disposal and flow regulation due to aquaculture impounding weir / dam. Run-off and flow

patterns are significantly affected by the reservoirs and run-off is increased by effluent returns (CEH, 2016:3). The River flows through the Carron Glen Site of Special Scientific Interest (SSSI) and into the Firth of Forth SSSI. The Water Framework Directive (WFD) status of the River Carron between its source and Carron Valley Reservoir is 'Good', however, its status becomes 'Moderate' to 'Poor' downstream of Carron Valley Reservoir.

River Avon

The River Avon is approximately 41km in length and drains a lowland catchment area of approximately 188km^2, from its headwaters near Greengairs (North Lanarkshire) in a north easterly direction to the Firth of Forth near Grangemouth. Land-use is dominated by grassland, arable agriculture and woodland, with a few small former coal mining towns located along its reach. Major pressures include the extensive moorland drainage schemes in the upper catchment, industrial and agricultural abstractions and point source pollution from sewage disposal, particularly downstream of the Logie Water Confluence. Run-off into the channel is increased by effluent returns (CEH, 2016:3). There is some storage of water in the Linlithgow Loch, Forrestburn Reservoirs and Loch Ellrig. The River Avon flows through several SSSI's including the Slamannan Plateau, Jawhills, Carriber Glen and Avon Gorge before entering the Firth of Forth. The WFD status of the River Avon from source to Jawhills is categorised as 'Moderate'; 'Good' to the Logie Water confluence and 'Moderate' downstream from the Logie Water confluence.

Grange Burn

The Grange Burn is formed from the confluence of the Westquarter and Polmont Burns at the M9 motorway and is approximately 4km in length. Combined, these watercourses are approximately 14km in length and together drain a lowland area of approximately 24km^2 into the Firth of Forth. Land use in the upper catchment is pastural agricultural land and predominantly urban in the lower catchment. The watercourse is heavily modified with morphological alterations to both the channel bed and banks. Other pressures include diffuse pollution from livestock farming and sewage disposal. The Grange Burn Flood Alleviation Channel moderates discharge downstream; however, run-off is increased by several sewage and storm water outfalls into the channel. The Grange Burn is also an Urban Wastewater Treatment Directive (UWWTD) sensitive area; the WFD status of the Grange Burn is 'Moderate'.

1.1.2.3.2 Coastal

The two primary sources of tidal flood risk in Grangemouth are coastal inundation and wave overtopping. Coastal inundation is defined as flooding of low-lying coastal land, primarily caused by extreme weather events, which result in the still water level along the coastline becoming elevated. Wave overtopping occurs when a wave meets a submerged structure such as a reef or shallow body of water, which results in the wave height increasing above the surrounding ground level.

Grangemouth is in an area considered to be within the 'Outer Estuary' of the River Forth (Firth *et al.*, 1997), the upstream and downstream extents of the Outer Estuary being the Kincardine Bridge and Forth Bridges at Queensferry respectively. To the northwest beyond the Kincardine Bridge west lies the Inner Estuary and to the east beyond the Forth bridges lies the Firth of Forth. The estuary is around 2.5km wide but narrows markedly west of Grangemouth. The estuary has a NW-SE orientation at Kincardine, but curves to become oriented on a west to east axis east of Grangemouth with several embayments and promontories (Firth *et al.*, 1997 and Bird, 2003). It is estimated that around 50% of the intertidal zone of the Forth estuary has been reclaimed over the last 400 years.

The tidal prism upstream of Queensferry is approximately 3.5 x 10^8m^3 at mean spring tides (Webb and Metcalfe, 1987; SNH, 2001). The outer estuary is subject to a macrotidal regime, with tidal ranges at

mean spring tides shown in Table 2 (below). The ranges shown in Table 2 indicate an increase in tidal range further up-estuary, which is to be expected in an estuarine environment:

Location	Tidal Range	Mean High Water Spring Tide (MHWS)	Mean Low Water Spring Tide (MLWS)
Rosyth	5.0m	2.85m OD	-2.15m OD
Grangemouth	5.2m	2.95m OD	-2.25m OD
Kincardine	5.3m	2.95m OD	-2.35m OD

Table 1: Spring tides and tidal ranges in the Outer Forth Estuary

Wind direction in the Forth Estuary tends to be along its west-east axis, with westerly winds dominating in winter, with only occasional north easterly winds, whereas easterly and north easterly winds are more common in summer, making up 35% of the wind directions. The easterly and north easterly winds are a result of sea breezes during favourable synoptic conditions (Firth *et al.*, 1997).

These winds dominate the wave climate within the estuary since the enclosed nature of the estuary means that swell waves generated outside the estuary are rare and have little influence. Upstream of the Forth Bridges in the Outer Estuary, the maximum fetch is 15km though it is usually less than 5km. This restricted fetch limits the maximum wave size to 1.0m. In practice waves rarely exceed 0.3m (Firth *et al.*, 1997). The small size of wind-generated waves and the presence of saltmarsh and mudflats in the Outer Estuary around Grangemouth suggests that wave driven currents along the shore of the Outer Estuary are minimal.

SEPA (2015) states that, due to the sheltering effects of the estuary, the main influence on coastal flooding in the study area are storm surges. It states that the main areas at risk from coastal flooding are Grangemouth and Carronshore. The highest tide on record was 4.47m[1] at Grangemouth Docks on 30th September 1959. A more recent high tide event occurred on 4th January 2014, when a 'tidal surge' combined with a storm surge affected coastal areas across the east of Scotland.

1.1.2.3.3 Pluvial

Pluvial flood risk is defined as the inability of local surface water drains to convey the flows from rainfall events, which results in low lying areas being flooded. Historically the principal sources of flooding to Grangemouth are from fluvial and tidal sources, however the risk from pluvial flooding does exist. There is limited evidence to suggest pluvial flooding, due to incapacity of the surface water drainage system or combined storm water drainage system, within the Grangemouth area would affect properties. However, the indirect consequence of a pluvial flood event could result in roads being closed. Central Grangemouth is flat and low-lying and susceptible to pluvial flooding. Climate change predictions issued by UKCP in 2009 (and updated in late 2018), recognises the frequency and volume of rainfall of high intensity rainfall events is increasing along with the associated risk of flooding.

1.1.2.4 Flooding History

From analysis of recorded historical flood events in and around Grangemouth, it is possible to develop a chronology of flood history through the centuries, see Table 3

[1] Assumed O.D., given range of normal tides relative to O.D.

Date	Source of flood	Description	Information Source
1926	Grange Burn	Rose 5.5ft in 1 hour, Jackson Avenue flooded with 3ft of water	Electric Scotland
1927	Grange Burn	Abbotts Road, Kerse Road and Jackson Avenue flooded.	Electric Scotland
1959	Forth Estuary	Grangemouth Docks flooded with the highest tide recorded at 4.47m	Local Flood Risk Management Plan
2002	River Carron (Chapel Burn)	22 properties flooded on Alloa Road in Stenhousemuir	Local Flood Risk Management Plan
2006	River Carron	Widespread flooding throughout the Falkirk area, A883 at Checkbar closed, 2 properties flooded at Threepwood	Local Flood Risk Management Plan
2013	Grange Burn	Tidal surge coupled with high tide was predicted to affect the Forth Estuary, very high-water level in the Grange Burn	Falkirk Council

Table 2: Chronology of recorded flooding within the Grangemouth Area

Alone the anecdotal and recorded evidence of flooding within the Grangemouth area does not fully justify the need for a floor protection scheme. The flood risk identified through the National Flood Risk Assessment in 2014 highlighted the vulnerability of Grangemouth to future flooding and demonstrated the significant impact a flood event could have on the area. It should be noted that parts of the petrochemical plant and port area are classified as *National Critical Infrastructure* and should these areas be flooded, there would be significant economic and social consequences with both local and national impacts.

1.1.3 Surface Water Management Plans

The Local Flood Risk Management Plan has identified a Surface Water Management Plan is required for the Grangemouth area. This study will be undertaken separately from the FPS, however, there will be some interface between the Scheme's secondary drainage and surface water management.

1.1.4 Scottish Water - Integrated Catchment Model

The Grangemouth Flood Protection Scheme will need to be integrated with any outputs from Scottish Water's Integrated Catchment Study. Discussions throughout the Option Appraisal, Outline Design and Detailed Design will be required with Scottish Water.

1.1.5 Flood Protection Scheme

Prior to the commencement of the option appraisal, there was clear evidence suggesting that flood risk intervention in the form of a Flood Protection Scheme for the Grangemouth area is required and that any scheme would be eligible for Scottish Government Capital Grant Funding:

- It is located within a Potentially Vulnerable Area identified within the Local Flood Risk Management Plan.
- More than 3,550 properties are at risk from the 1 in 200-year flood, resulting in a significant risk to loss of life. This figure excludes the petrochemical plant and port area.
- 542 properties are at risk from the 1 in 20-year flood.
- Critical infrastructure assets within both the port and petrochemical plant are at risk from the 1 in 2-year flood, with any resulting reduction in output from the petrochemical plant or obstruction of sea freight being of national importance.

1.1.6 Flood Risk Management Legislation and Scheme funding

The Flood Risk Management (Scotland) Act 2009 introduces a more sustainable approach to flood risk management. It requires local authorities and other agencies including SEPA and Scottish Water to work together to deliver a robust flood risk management strategy that also considers the future impact of climate change. In addition to requiring organisations involved in flood risk management to develop a new framework for coordination and cooperation, the Act introduces:

- new responsibilities for SEPA, Scottish Water and local authorities in relation to flood risk management;
- a requirement to assess flood risk at catchment and local scales, and to prepare Strategic and Local Flood Risk Management Plans;
- a revised, streamlined process for flood protection schemes;
- new methods to enable stakeholders and the public to contribute to managing flood risk, and;
- a single enforcement authority for the safe operation of Scotland's reservoirs.

Changes in the eligibility criteria required for Capital Grant Funding of Flood Protection Schemes from Scottish Government mean that funding priority should be given to "*identified*" (named) Schemes within the Local Flood Risk Management Plans (LFRMP's). The Forth Estuary Local Plan District (10/11) identified Grangemouth as requiring a Flood Protection Scheme. Following the publication of the LFRMP's in 2016; Scottish Government and SEPA prioritised the 42 identified Flood Protection Schemes in Scotland and identified Grangemouth as the number 1 priority Scheme in Scotland based on the number of properties affected by flooding and the potential damages from a flood event.

1.1.7 Environmental Legislation

The Water Environment (Controlled Activities) (Scotland) Regulation 2005 is the principal environment legislation relating to construction work in or around watercourses in Scotland. The CAR regulations provide licensable constraints on engineering works and flow changes within watercourses. The requirements of the legislation are enforced by SEPA and include regulations on activities such as:

- abstraction from surface and groundwater;
- impoundment of rivers, lochs, wetland and transitional waters;
- groundwater recharge;

- engineering activities near rivers, lochs and wetlands which are likely to have significant impact upon the water environment;
- activities liable to cause pollution;
- direct or indirect discharge of List 1 substances to groundwater; and
- any other activities which directly or indirectly are liable to cause significant adverse impact upon the environment

Additionally, the Marine (Scotland) Act 2010 will require a Marine Scotland Licence to be granted for construction work below the Mean High-Water Springs.

The Forth Estuary is designated a Ramsar, Special Protected Area (SPA) and Site of Special Scientific Interest (SSSI). The SPA designation in the Grangemouth area is due to the inter-tidal habitats of mudflats and salt mash which support a wide range of bird species. The Firth of Forth is the second largest estuarine area for wintering birds in Scotland and supports abundant wildfowl and waders. Due to the environmental designations, restrictions will apply to engineering works under the EC Habitats Directive. The project Environmental Impact Assessment (EIA), Habitat Regulation Appraisal (HRA) and subsequent Appropriate Assessment (AA) are likely to be required to evidence that all feasible potential alternative options to constructing flood defences at the edge of Forth Estuary have been considered and discounted. It is considered highly likely that the HRA will identify the scheme as having a significant adverse impact on the SPA and potential environmental mitigation should be considered at every possible opportunity.

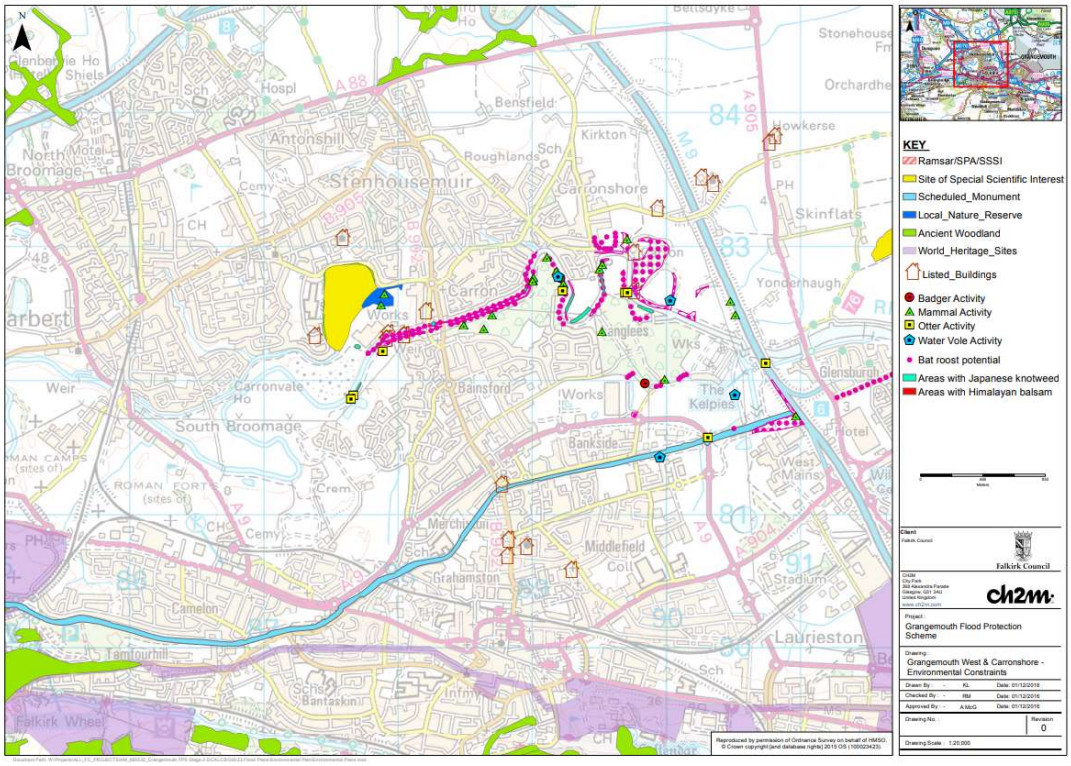

Figure 2: *Environmental constraints covering the western extents of the scheme*

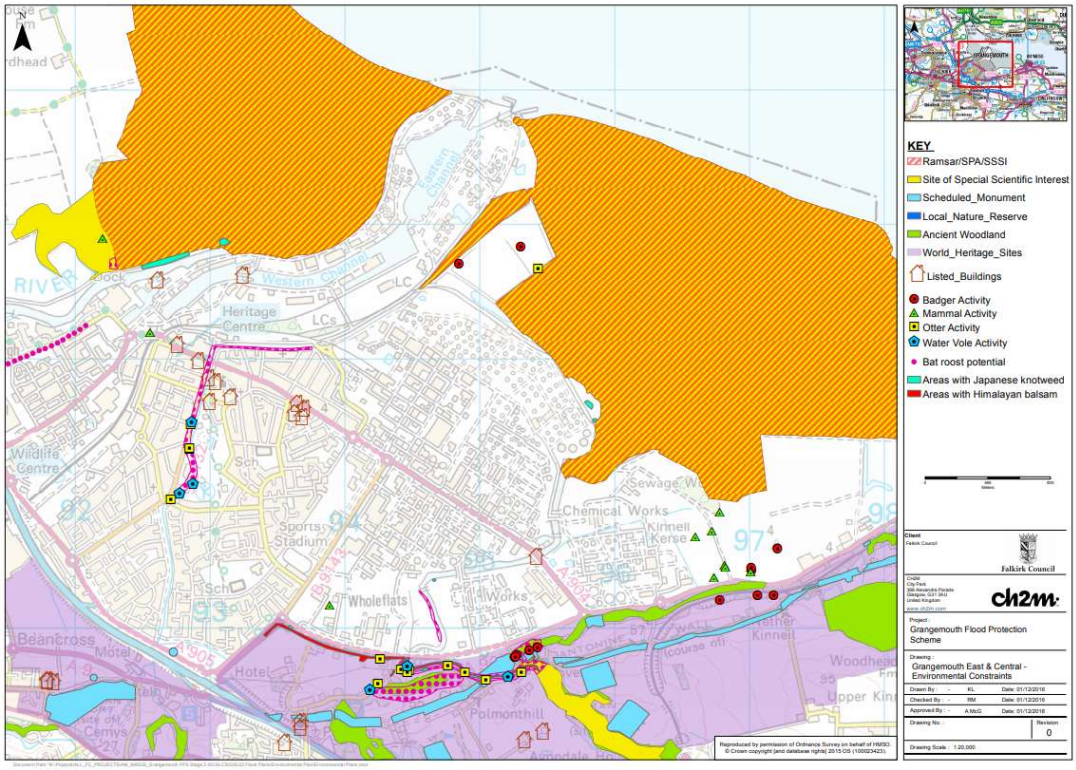

Figure 3: *Environmental constraints covering the eastern extents of the scheme*

1.1.8 National Planning Policy

Scottish Planning Policy compliments the Flood Risk Management (Scotland) Act 2009 by promoting flood risk management measures that aim to restore the natural features and characteristics of river catchments. The guidance refers to avoiding construction on the functioning floodplain and in cases where construction on the floodplain is unavoidable, measures should be taken to ensure the available floodplain storage capacity remains largely unaffected.

In line with the FRMA, Scottish Planning Policy uses a risk framework for flood risk probability and potential constraints which may be placed on them in the planning decision process.

Scottish Planning Policy does not exclude the provision of flood protection measures to enable new development, however, the policy is aimed at private development that is taken forward without public funding and not for named schemes under the FRMA. In the context of Grangemouth, a flood protection scheme should not be provided to solely allow new residential and commercial development.

By providing flood protection to the petrochemical plant and port area, significant redevelopment opportunities may be created which will impact strategic national policy and could be deemed of "*National Importance*" to Scotland and the UK.

1.1.9 Falkirk Council Local Development Plan 2

Falkirk Council published the Main Issues Report for Local Development Plan 2 in February 2017. The Grangemouth FPS is referenced in the plan and will complement several "*Place and Environment, Home and Communities and Infrastructure and Resources"* polices, with the benefit of enhancing "*Jobs and Economy*" within the area. The FPS forms part of the wider regeneration of Grangemouth and Falkirk and will seek to maximise potential benefits in line with the Local Planning Policy.

At the option appraisal stage, limited detail is available on the proposed scheme. Once a preferred scheme has been identified, more detail will be developed on specific flood defences and how they can complement policies in Local Development Plan 2.

1.1.10 National Planning Framework 3

National Planning Framework 3 (NPF3) sets the context for development planning in Scotland and provides a framework for development in Scotland over a 20 - 30-year timescale. Several key planning outcomes are proposed in NPF; *successful sustainable place* (economic growth, regeneration and well-designed places); *low carbon place; natural resilient place* and *connected place*. NPF3 identified 14 National Developments that are needed to help deliver Scottish Governments planning strategy, the *"Grangemouth Investment Zone"* is identified in NPF3 as one of the National Developments as nationally significant for industrial and freight purposes.

1.2 Purpose of this commission

The purpose of the option appraisal is to identify the preferred flood risk management measures which, if approved by Falkirk Council, will form the Grangemouth Flood Protection Scheme. The commission will review the range of options and assess these from economic, environmental, social and technical (feasibility) perspectives. This will help identify a preferred Scheme from the range of options, which should be taken forward to the outline design (Stage 4).

Liaison with key stakeholders and the public is crucial during this stage of the project to ensure the scheme is in line with the needs and expectations of stakeholders and to mitigate the potential for future delays and objections. A critical part of the option appraisal process is to allow stakeholders the opportunity to review and comment on the possible options prior to identifying the preferred scheme.

1.3 Scope

1.3.1 Context

The methodology for carrying out the option appraisal for Flood Protection Schemes in Scotland has been based on a variety of information sources, including the adoption of Defra guidance (in a Scottish context).

In February 2012, the Scottish Government published a document entitled, "*The Flood Risk Management (Scotland) Act 2009, Chapter 5: Project Appraisal: Assessment of economic, environmental and social impacts*". This document is an updated version of Chapters 5 & 6, which offered economic and environmental appraisal guidance under the old Flood Prevention (Scotland) Act 1961.

In May 2016, the Scottish Government published a document entitled, "*Option appraisal for flood risk management: Guidance to support SEPA and the responsible authorities*". This document provides guidance on effective decision-making that should underpin the option appraisal process.

1.3.2 Overview of approach

The "*Option appraisal for flood risk management: Guidance to support SEPA and the responsible authorities*", sets out a range of stages which should be progressed in sequence. The stages aim to ensure that the appraisal of options which are to be taken forward to outline design is undertaken fairly. The stages are summarized in figure 6.

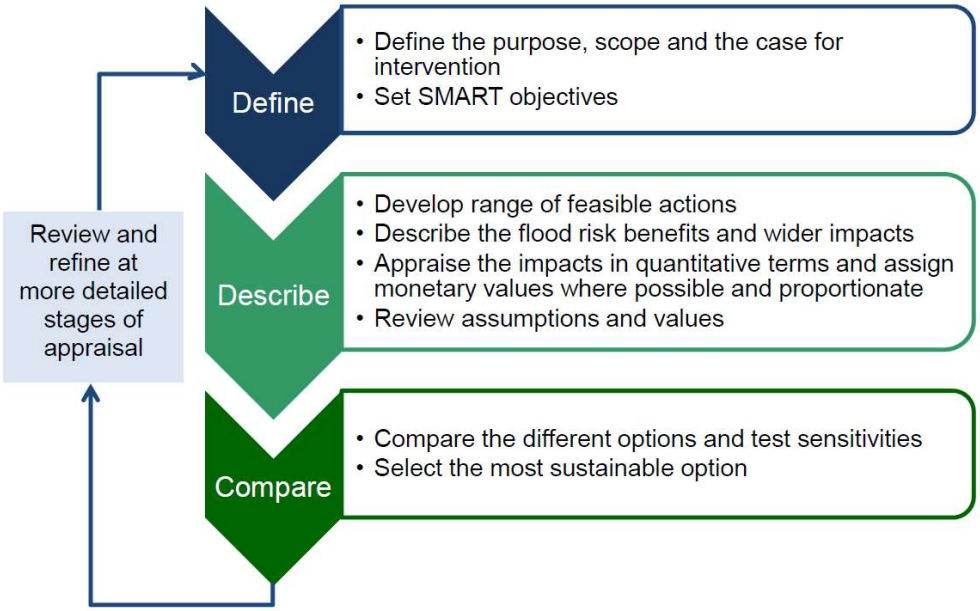

Figure 4: *Option Appraisal stages (reproduced from "Option Appraisal for flood risk management: Guidance to support SEPA and the responsible authorities*

The guidance allows a wide range of factors to be considered in the decision-making process, some of which can be defined in monetary terms, others that can't. The aim of the appraisal is to identify and assess options that achieve flood risk management objectives whilst delivering other economic, social and environmental benefits. The aim of this option appraisal is to help inform the decision-making process and identify a preferred scheme.

This options appraisal aims to achieve the following:

Sustainable solutions - A sustainable solution will take full account of economic, social and environmental impacts, and protect / enhance the natural and built environment for present and future generations. The solutions must be developed with consideration of catchment processes and characteristics, with all reasonable and practical efforts made to enhance the natural ability of the landscape to slow and store flood water. Sustainable flood risk management actions should take account of interactions between flooding mechanisms and other interventions in the catchment or in the coastal area. They should avoid as far as possible committing future generations into inflexible and expensive solutions.

Best use of public money - Demands for public funding always exceed the money available. When determining how to meet the objectives for managing flood risk, it is necessary to aim for economic efficiency, where the total of all forms of benefit are maximised relative to the resources used. The appraisal should not be limited to the consideration of priced benefits and resources. It should, where appropriate, also include unpriced benefits, such as the enjoyment gained from walks by a river, as well as the unpriced costs, such as degradation of landscape.

Accountability – A formal process of option appraisal can demonstrate that a wide range of options has been considered, and that the advantages and disadvantages of each have been fully and transparently considered. Appraisals also create an effective audit trail of decision-making.

Robustness - Robust appraisals ensure that data being used to support decision-making are appropriate for the decision being made. They recognise the assumptions, uncertainties and limitations in data, and test the sensitivity of results to these uncertainties. Good quality appraisals increase certainty and confidence in the outcome.

1.3.3 Scheme Objectives

Falkirk Council as a responsible authority need to manage flood risk in ways that will improve the environment at the same time as reducing the risks to people and property. Opportunities to do more, while still providing cost effective flood risk protection should be promoted. The Scheme objectives have been aligned with objectives set out in the Local Flood Risk Management Plan, which tackle national and local priorities.

Through dialogue with key stakeholders, Falkirk Council has formally identified the scheme objectives, which have been sub-divided into six headline categories.

General (1.0)

- To develop a Flood Protection Scheme (the Scheme) in accordance with measures set out in the Forth Estuary Flood Risk Management Strategy and Local Flood Risk Management Plan to reduce flood risk at Grangemouth (1.1);
- The Scheme will be promoted under the 2009 Act (1.2);

- The Scheme will consider all possible practical options for reducing flood risk (1.3);
- The Scheme will provide multiple benefits to the local community (1.4);

Social (2.0)

- The Scheme meets the goals and values of Falkirk Council (2.1), namely by:
  - further developing a thriving sustainable and vibrant economy;
  - continuing to improve the health, safety and wellbeing of citizens and communities;
  - increasing efforts to tackle disadvantage and discriminations;
  - enhancing and sustaining an environment in which people want to live and visit;
  - promoting public service, performance and partnership;
- The Scheme is aligned with Falkirk Council's priorities set out in the council's *Corporate Plan* and *Development Services – Service Performance Plan* (2.2);
- The Scheme is compliant with Falkirk Council's *Strategic Outcomes* and *Local Delivery Plan* (2.3);
- Community Benefits will be incorporated into the Scheme (2.4);

Economic (3.0)

- The Scheme has a Benefit Cost Ratio (BCR) greater than one (3.1);
- An Economic Assessment is undertaken to evidence the economic benefit and cost associated with the Scheme, this assessment is produced prior to the outline design stage (3.2);
- The preferred Scheme represents the best value for money for the Council (3.3);
- The Scheme is delivered in line with the National Planning Framework Action Programme for the Grangemouth investment zone (3.4);
- The Scheme aims to increase development activity in the Falkirk / Grangemouth corridor such as Falkirk TIF initiative (3.5);
- The Scheme provides a platform for the regeneration of Grangemouth (3.6);

Environment (4.0)

- The Scheme achieves a neutral impact on the environment (4.1);
- The Scheme incorporates appropriate natural flood management (NFM) measures (4.2);
- The scheme maximises environmental benefits (4.3);
- The Scheme is delivered sustainably with the followings aims (4.4):
  - minimise construction waste;
  - maximise reuse of materials;
  - adopt low carbon construction strategies;
  - minimise Carbon Footprint of the Scheme;

Hydraulics (5.0)

- The Scheme reduces overall flood risk (5.1);
- The Scheme delivers the required level of protection (5.2);

- The Scheme will not materially increase flood risk to residential and non-residential properties in Grangemouth (5.3);

Technical (6.0)

- The Scheme is technically viable (6.1); and
- Residual flood risk will be documented and identified to Falkirk Council (6.2);

1.3.4 Methodology

This option appraisal uses the following methodology:

- Identify a business case for a Scheme
- Identify the problem
- Identify Scheme Objectives – what are the principal aims of the scheme
- Identify and develop a short list of feasible options
- Identify constraints and benefits of short list options, quantify the value, cost and benefits
- Compare and select the preferred option

Having defined the criteria for the appraisal, it is now possible to fully describe the option appraisal methodology:

- Identify and describe the fluvial and coastal, geo-morphological, geological, topographical, environmental and infrastructural constraints which exist near Grangemouth. Grangemouth FPS will be divided into discrete flood cells.
- Identify basic design parameters which can be applied to various options to maintain a consistent approach to cost estimation.
- Identify and describe the broad range of possible options; create a *Long List* of feasible options, including the do something / do minimum scenarios.
- The do-something (maintain existing defences and banks – maintain the status quo) scenario should be classed as the baseline scenario, which options are compared to.
- A do-nothing (existing defences / banks fail) will be compared to the do something scenario. Using a do-nothing scenario as the baseline would increase the lengths of defences and not represent a realistic scenario.
- Undertake a screening exercise to filter the initial brainstorm list of options, with a high-level appraisal to remove those options which are clearly not viable or unfeasible – these will be classed as *Early Discounted Options.*
- Carry out a detailed appraisal on the remaining short list of options, including identification on how each option fits the Scheme Objectives.
- Consult with key stakeholders (Falkirk Council (FC), SEPA, SNH, MS, HES, Industrial landowners and utility companies) and the public to obtain feedback on the options for incorporation into the process.
- Use a multi-criteria analysis (MCA) on the proposed short list of options to identify the preferred options. The MCA can be used to combine a mix of both monetary and non-monetary benefits. The criteria of the MCA will be linked to the Scheme Objectives to ensure transparency between the principal aims of the project and the criteria used to identify the preferred Scheme.
- For ease of use the MCA has been divided into the following sub-headings:

- **Benefit Cost Ratio (BCR)**: includes capital costs, maintenance and whole life costings. This ratio is calculated by dividing the construction cost by the present-day benefits. The BCR for each option will be ranked against other options in that cell.
- **Utilities**: How practical is it in terms of cost, time and feasibility, to construct defences near known services. Each option will be scored using pre-defined criteria, with that score ranked against other options in that cell;
- **Environmental:** By considering significant opportunities and constraints, each option will be scored against the environmental objectives, with that score ranked against other options in that cell; and
- **Social:** By considering significant opportunities and constraints, each option will be scored against the social objectives, with that score ranked against other options in that cell;
- **Carbon Emission (CO^2e) Footprint:** The Environment Agency's Carbon Accountancy tool will be used to estimate the tonnage of Carbon Emissions based on dimensions of the structure. To ensure a fair and transparent approach was taken, all defences were classified as a wall structure with lengths and heights varying between the options.

The identified opportunities and constraints for each option will be compared to the baseline scenario (do minimum – maintain current structures). A narrative within the MCA will provide comments and comparisons between options.

Within the MCA, the Utility, Environmental and Social criteria have been allocated scores, which are related to the Scheme Objectives. The tables below outline the scores associated with the Utility, Environmental and Social aspects.

Utility Score Matrix	
Criteria	**Score**
Minor	5
Intermediate - single location <£1m	4
Intermediate - multiple locations > £1m	3
Major - single location <£2m	2
Major - Multiple locations >£2m	1

Table 3: Utility Criteria and Score.

The criteria used to score the utility matrix has been set 1 to 5, the range of scoring criteria has no relevance on importance and was principally developed with the scoring criteria in mind.

Environmental Score Matrix	
Criteria	**Score**
Option likely to meet all the Environmental Objectives.	4
Option is likely to achieve three of the Environmental Objectives.	3

Environmental Score Matrix	
Option is likely to achieve two Environmental Objectives.	2
Option is likely to meet one of the Environmental Objectives.	1

Table 4: Environmental Criteria and Scores

Social Score Matrix	
Criteria	**Score**
Option likely to meet all the Scheme's Social Objectives.	4
Option is likely to achieve three of the Social Objectives.	3
Option is likely to achieve two Social Objectives.	2
Option is likely to meet one of the Social Objectives.	1

Table 5: Social Criteria and Scores

Each option will be scored using the above criteria; the scores will then be ranked against other options within that cell. Within the MCA, some cells have been appraised for the 1 in 100 and 200-year level of protection, principally residential areas have been appraised with the 100 and 200-year levels of protection. The industrial areas have been appraised for the 1 in 200-year level of protection, as any lower standard of protection was deemed unsuitable by the client / project team. To ensure a like-for-like comparison, options that provided a 1 in 200-year level of protection were compared to other options that provide a 1 in 200-year level of protection.

The options identified with the overall highest rankings will be identified as the 'preferred scheme'. Guidance on multi-criteria analysis forms part of *HM Treasury Green Book supplementary guidance (Department for Communities and Local Government 2009).*

A Design life of 100-years has been deemed appropriate to enable comparisons of options.

Due to the large spatial area covered by the scheme, 6 discrete cells have been created. The purpose of creating '*Flood Cells'* is to define geographical areas which shall be considered separately in the option appraisal. Due to geographic location, sources of flooding and commercial activity, some cells have been merged for the option appraisal.

This report will clearly identify where cells have been merged to assist with the overall option appraisal.

The MCA will assist the project team in identifying the preferred Scheme.

2. Information Gathering

2.1 Review of previous information gathered

This section outlines previous investigation works which have been undertaken to gather information to assist in the option appraisal process and development of a flood protection scheme.

2.1.1 Phase 1&2 - Ground Investigation Pre-2017

Two previous Ground Investigations were undertaken on part of the River Carron and Avon.

2.1.2 Phase 3 Ground Investigation 2017/18

A ground investigation contract was undertaken in 2017/18. This covered some of the petrochemical plant, the banks of the River Avon and the coastal boundary to the north, between the Grange Burn and River Avon.

2.1.3 Structural Survey of existing banks / defences 2012

Falkirk Council have commissioned several studies to develop a detailed understanding of flood risk in Grangemouth. For one of these studies a baseline condition assessment was carried out on the existing banks and structures of the Flood Relief Channel, River Carron, River Avon, Grange Burn and the estuary frontage. The information gathered from this has been used to support decision making and to inform option assessment of the Grangemouth Flood Protection Scheme.

2.1.4 Utilities

At an early stage of the project development the interface between the proposed flood defences and existing utility apparatus was identified as a significant project risk with potential implications on identifying the preferred scheme. To help manage this risk, a Utility / Services Stakeholder Group was initiated. Table 6 identifies members of the group.

Organisation
Falkirk Council – Roads (Surface water / Roads drainage)
Falkirk Council - Street Lighting
Vodafone
Virgin Media
BT
SGN – Distribution*
ESSAR

*SGN Transmission will only be invited to join the Utility / Service Group if any of the options impact their apparatus. At the option appraisal stage, it is not envisaged any of the options will impact their apparatus. SGN Distribution will comment on Transmission network where required

Organisation
BOC
Ineos - Pipelines
Petroineos - Pipelines
BP - Pipelines
Scottish Power Energy Network – Transmission
Scottish Power Energy Network – Distribution (provide comments on transmission network as well)
Scottish Water

Table 6: Grangemouth FPS Utility Stakeholder Group

For the option appraisal stage, the principal aim of the Utility / Service Stakeholder Group was to assist in identifying a preferred scheme and to identify any significant service-related impacts which could have time and cost implication to the project. Section 4.1.2 of this report will provide more information relating to the Utility / Service Group.

2.1.5 Contaminated Land

Falkirk Council provided information on known locations of contaminated ground within the Grangemouth area. This information was reviewed, and cross referenced with historical land-use maps to highlight potential areas of contamination within the scheme extent. Issues identified include historical mining activity on the River Carron, along with former land-fill sites being located along the estuary frontage.

An Environmental Impact Assessment will review in more detail the historical land-use and potential for contaminated land, with furthermore detailed studies being undertaken during outline design stage.

The project shall develop proposals to investigate and remediate potential contamination which must include:

- A desk study and development of a conceptual site model, measurement of pollutant linkages through a detailed investigation of the nature and extent of contamination on site, and assessment of risk such contamination presents. The scope and method of this investigation is to be agreed in advance with the Council and be undertaken in accordance with PAN 33 (2000) and BS10175:2011.
- Remedial Strategy to treat or remove contamination to ensure that the site is fit for its proposed use. This shall include a method statement, programme of works, and proposed validation plan.

- Submission of a Validation Report, should remedial action be required. To be completed by the competent person employed by the developer who will validate and verify the completion of works to a satisfactory standard as agreed with Falkirk Council.
- Submission, if necessary, of monitoring statements at periods to be agreed with the Council, for such time as is considered appropriate.

Due to the industrial nature of the petrochemical plant and port area, information from individual landowners and stakeholders has been requested. However, the difficulty in accessing parts of the site due to physical obstructions mean assumptions need to be made on the level of contaminated land within these areas when considering the flood defence options.

2.1.6 Secondary Drainage

Direct defences on the banks of the Rivers Carron and Avon and Grange Burn, and along the estuary frontage are designed to prevent flood water from overtopping and flooding adjacent land. Following inundation these same defences could prevent surface water from returning to the channel / sea, surface water generated by surcharging sewers, burst water mains or high intensity rainfall events can all also be beyond the capacity of the current road drainage network. In turn this water trapped against the defence structures may result in flooding of adjacent properties and infrastructure.

Assessing the exact volumes of water which may be generated by the various sources of secondary flooding is complex and will be dealt with in Stage 4 (Outline Design). However, it is necessary to identify any potential sources of secondary flooding and quantitatively assess the risk of inundation arising from these, such that mitigation measures (e.g. pumping stations or an increased surface water drainage system) can be allowed for in the capital cost estimate for the scheme.

2.1.7 High intensity rainfall (pluvial flooding)

The topography of the Grangemouth area is characterised by low-lying land, with extensive flat floodplains next to the watercourses and estuary frontage. Currently, a high intensity, short duration rainstorm event would result in surface water runoff flowing into the road drainage network. In the event the road drainage network could not cope, flow would build up rapidly over impermeable surfaces and flow into the channel or sewerage system. Whilst ponding is inevitable at localised low points, the risk of inundation to property and infrastructure is potentially high due to the flat topography. Falkirk Council has no record of any properties in the Grangemouth area being inundated because of pluvial flooding. CHECK

From an initial assessment of the existing gravity drainage network in the Grangemouth area, pluvial flooding is not thought to pose significant flood risk from a high intensity rainfall event (convectional thunderstorms occur in the summer months).

2.1.8 Sewer Surcharge

The risk of the sewerage network becoming surcharged is greatest when water levels in the River Carron, River Avon and Grange Burn are high, and / or combined with a high tide; when Combined Sewer Overflows (CSO's) cannot freely discharge under gravity. In the current situation, if surcharge occurs it is likely that the River Carron, River Avon and Grange Burn would be on the verge of overtopping – the volumes of wastewater surcharging from the sewer will be small when compared with the volumes of water which would be generated as the River Carron, Avon, Grange Burn or tide over top the banks or frontage.

2.1.9 Integrated Catchment Study

The analysis of how the flood protection scheme will interface with Scottish Waters network will be undertaken at the outline design / detailed design stage.

2.1.10 Surface Water Management Plan

A surface water management study is to be commissioned by Falkirk Council to assess the impact of surface water flooding in Grangemouth and the surrounding area.

2.1.11 Overtopping Event

The nature of providing flood protection means there is always the possibility that flood defences will be overtopped by a flood event with a magnitude greater than the designed level, with flood water potentially becoming trapped behind the defences and no natural drainage path being available. In this case, given the likely magnitude of the inundation, emergency services would invariably be required to assist with pumping the trapped flood water away. Consideration should therefore be given to the provision of emergency release points by way of penstocks which can be opened or wall panels that are designed to fail and allow large volumes of water to be drained by gravity when suitable levels are reached. During the Outline Design stage, consideration will be given to these scenarios.

2.1.12 Climate Change

2.1.12.1 Purpose

The purpose of this section of the report is to review the latest guidance on the impacts of climate change, and to determine what that guidance means in terms of potential future change in precipitation, river flows, for the River Carron, River Avon and Grange Burn. This section will also consider sea level rise, wave height, and flood level for the Forth Estuary.

2.1.12.2 Introduction

Historically, the impact of climate change on climatic patterns relating to air / sea temperature, and precipitation have been studied and modelled by numerous academics and government funded bodies. Over the years, some conflicting evidence has been published on the extent and significance of a change in climate, but the prevalence of a wide range of factual data suggests that earth is warming e.g. 12 of the world's warmest years on record have occurred over a 19-year period since 1998. Since 2014, each consecutive year has been the warmest on record. Current evidence and predictions indicate this trend is likely to accelerate in future decades unless measures are implemented to cut the rate of greenhouse gas emissions.

2.1.12.3 United Kingdom Climate Projections (UKCP) 09

At present, the most recent study into the projected scenarios for climate change in the UK was conducted by a panel of organisations, including the Met Office Hadley Centre for Climate Research, the United Kingdom Climate Impact Programme, the Environment Agency and the Marine Climate Change Impacts Partnership. Collectively, this panel developed the UK Climate Projections 2009, known as UKCP 09. More information on UKCP 09 can be obtained from a range of sources, including: http://www.defra.gov.uk/publications/files/pb13274-uk-climate-projections-090617.pdf.

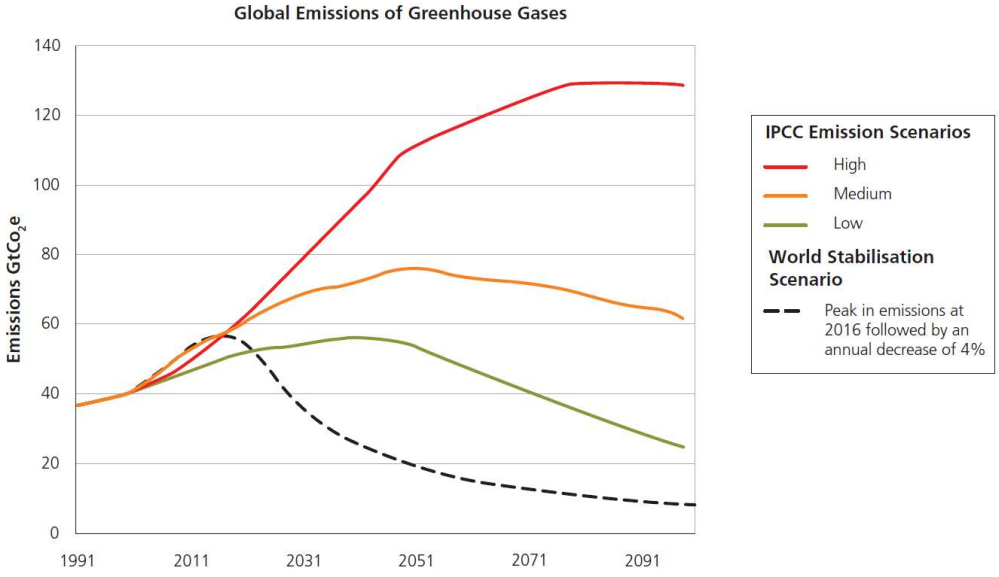

Figure 5: *IPCC emissions scenario used in UKCP09*

River basin region	Hydrometric Areas
North Highland	1,2,3,4,5,6,7,8
North east	9,10,11,12,13 (northern)
Tay	13 (southern), 14,15,16
Forth	17,18,19,20,21 (coastal)
Tweed	21
Orkney and Shetland	107,108
West highland	93,64,95,105,106
Argyll	87,88,89,90,91,92,104 (Kintyre), 105
Clyde	82,83,84,85,86,104 (Arran)
Solway	77,78,79,80,81

Figure 6: *Map of the UK CP09 river basin regions, based on the Water Framework Directive*

UKCP 09 projections show that in the 2080's, under a medium emissions scenario:

- All areas of the UK warm on average relative to the 1961-90 baseline; summers warm more than winters, particularly in Southern England. Mean daily maximum and minimum temperatures increase across the UK in both summer and winter. By 2080, it is expected that the average summer temperature in the Carron, Avon and Grange Burn catchments will have increased by 3-4°C.

- Average annual precipitation changes little across the UK, but winter precipitation increases in western regions while summer precipitation decreases in many, but not all, parts of the UK. By 2080, it is expected that the average summer precipitation will decrease by between 10 -20% within the Carron, Avon and Grange Burn catchments.
- By 2080, it is expected that the average winter precipitation will increase by between 10 – 20% within the Carron, Avon and Grange Burn catchments.
- Based on central estimates for sea level rise (considering land movement), sea level is projected to rise by 18cm by 2040 and 36cm by 2080 in London. Additionally, local information on sea level rise has been published by SEPA.

UKCP 09 is a tool which can be used to determine the impacts of a wide range of climate dependent factors. The projections highlighted above do not provide direct guidance for the assessment of the impact climate change will have on river flows. In late 2018, UKCP 18, was published which updated the climate change predictions, however, interpretation and implementation of UKCP 18 guidance is currently being assessed and will not be used in this option appraisal. Where possible, revised datasets will be used to increase the accuracy of this report.

2.1.12.4 UKCP 18

The Met Office published UKCP 18, which is an update on UKCP 09. UKCP 18 provides improved information on how climate change may affect short duration rainfall and sea level rise and reflects improvements in scientific understanding of climate change. However, at present there is limited guidance on how UKCP 18 should be implemented throughout the UK. SEPA and the Scottish Government have issued brief summaries on UKCP 18, but no quantitative figures on what uplifts should be used. Rather, the project team should identify the most appropriate uplift scenario for the specifics of the project.

2.1.12.5 SEPA Guidance on Climate Change

SEPA are the Hydrometric Authority for Scotland and monitor rainfall and river flow at hundreds of sites across Scotland. Since 1961, the average annual precipitation has increased by 27% across Scotland. Winter precipitation has risen in the north and west by 51% and 45% respectively.

2.1.12.6 SEPA Modelling Guidance (2016)

SEPA issued Flood Modelling Guidance for Responsible Authorities (Version 1.1) in December 2016. This document outlines the most up-to-date guidance accounting for climate change when creating a hydraulic 1d/2d model.

Fluvial

The SEPA guidance provides new information on how climate change may affect river flows. This information is probabilistic and varies between river basin regions. SEPA's flood modelling guidance suggests a 2080 high emission scenario with the 67th percentile (uplifts in peak flow are 'unlikely to be exceeded') is used. This scenario will produce significantly higher uplifts than the previously used DEFRA (2006) guidance. For this option appraisal the SEPA Flood Modelling Guidance for Responsible Authorities will be used.

			% change in flood peak (thresholded based on exceedence likelihood)									
Scenario	Probability (%)	Exceedence Likelihood	Orkney/ Shetland	N Highland	W Highland	NE Scotland	Argyll	Tay	Clyde	Forth	Solway	Tweed
LOW	10	very likely to be exceeded	15	7	12	2	12	4	8	5	6	5
	33	likely to be exceeded	20	14	23	10	23	12	16	13	13	11
	50	is as likely as not to be exceeded	27	18	30	13	30	16	20	17	18	14
	67	unlikely to be exceeded	30	24	36	16	36	20	26	22	23	19
	90	very unlikely to be exceeded	38	33	50	24	50	31	35	32	35	28
MEDIUM	10	very likely to be exceeded	16	10	15	3	15	7	11	7	8	6
	33	likely to be exceeded	27	18	29	11	29	15	20	16	16	13
	50	is as likely as not to be exceeded	30	23	36	14	37	20	27	21	22	17
	67	unlikely to be exceeded	34	29	44	18	45	25	32	27	28	22
	90	very unlikely to be exceeded	45	40	60	28	60	37	45	40	45	32
HIGH	10	very likely to be exceeded	18	12	20	4	20	11	15	11	13	9
	33	likely to be exceeded	29	23	36	12	36	20	27	22	25	18
	50	is as likely as not to be exceeded	33	29	45	17	45	26	34	28	32	23
	67	unlikely to be exceeded	41	37	56	24	56	35	44	40	44	33
	90	very unlikely to be exceeded	53	50	>60	33	>60	50	60	54	60	45

Table 7: Table from SEPA Flood Modelling Guidance for Responsible Authorities with percentage uplifts for high, medium and low emissions scenarios from 2080, with various probabilities.

Coastal

Climate change is likely to affect extreme still water levels through changes in mean sea level or changes in storminess which may affect the frequency and magnitude of surge events. The SEPA guidance for relative sea level rise uses the 2080 high emissions scenario with the 95th percentile. UKCP 09 projections for sea level rise to 2080 underestimate the potential range in sea level rise and do not cover the upstream extent of some estuaries and sea lochs. SEPA recently updated the Coastal Flood Boundary Dataset for Scotland, which has been included in the option appraisal modelling.

Pluvial

It is widely acknowledged that climate change will alter the duration and intensity of short rainfall events. The SEPA guidance suggests a 20% uplift from the DEFRA (2006) guidance for extreme rainfall events to 2080. The purpose of this 20% uplift is based on a better understanding of analysis of rainfall events that typically are responsible for surface water flooding.

2.1.13 Hydraulic Modelling

In late 2011 Falkirk Council commissioned CH2M to undertake a detailed flood risk mapping study of Grangemouth and the surrounding area. This investigation showed extensive and deep inundation of flood water (fluvial and tidal) for a 1 in 200-year return period event.

Following on from the flood risk mapping study an information gathering phase took place, which included a review of the hydrological assessment and an update to the existing 1D-2D linked model including extensions to some of the watercourses.

Full details of the 1d-2d model including the hydrological assessment, hydraulic model parameters and sensitivity test results can be found in the Hydraulic Modelling Report and the Hydrological Assessment Report.

2.1.13.1 Modelled Scaenarios

Numerous scenarios have been assessed during the option appraisal phase as noted below:

- A series of model runs to assess the baseline flood risk for differing return periods for fluvial and tidal events
- 1 in 200 and 1 in 100-year events, including the effects of climate change, to determine the expected increase in flood risk
- A 1 in 200-year event model run, excluding the effects of climate change, to determine flood defence level and the alignment of defences necessary to mitigate flood risk to properties.
- A 1 in 200-year event, including the effects of climate change, to determine the impact on flood defence level and length of defence alignment to mitigate flood risk to properties.
- A series of model runs to assess the impact / effectiveness of differing flood defence alignments.

2.1.13.2 Baseline Flood Risk

A 1D-2D hydro-dynamically linked hydraulic model has been created using the Global Flood Modeller suite to allow the flood extent, depths and flow paths to be identified. Table 8 identifies the number of properties at risk for various return periods in the baseline scenario. Note, none of the properties within the petrochemical plant have been included in the count of non-residential properties.

Return Period	No. of Residential Properties	No. of Non-residential Properties	Total
1 in 5-year	8	20	28
1 in 10-year	184	94	278
1 in 20-year	418	124	542
1 in 50-year	1,323	189	1,512
1 in 100-year	2,121	267	2,388
1 in 200-year	3,240	311	3,551

Table 8: number of properties at risk of flooding in Grangemouth

The flood risk is illustrated in Figures 7 and 8.

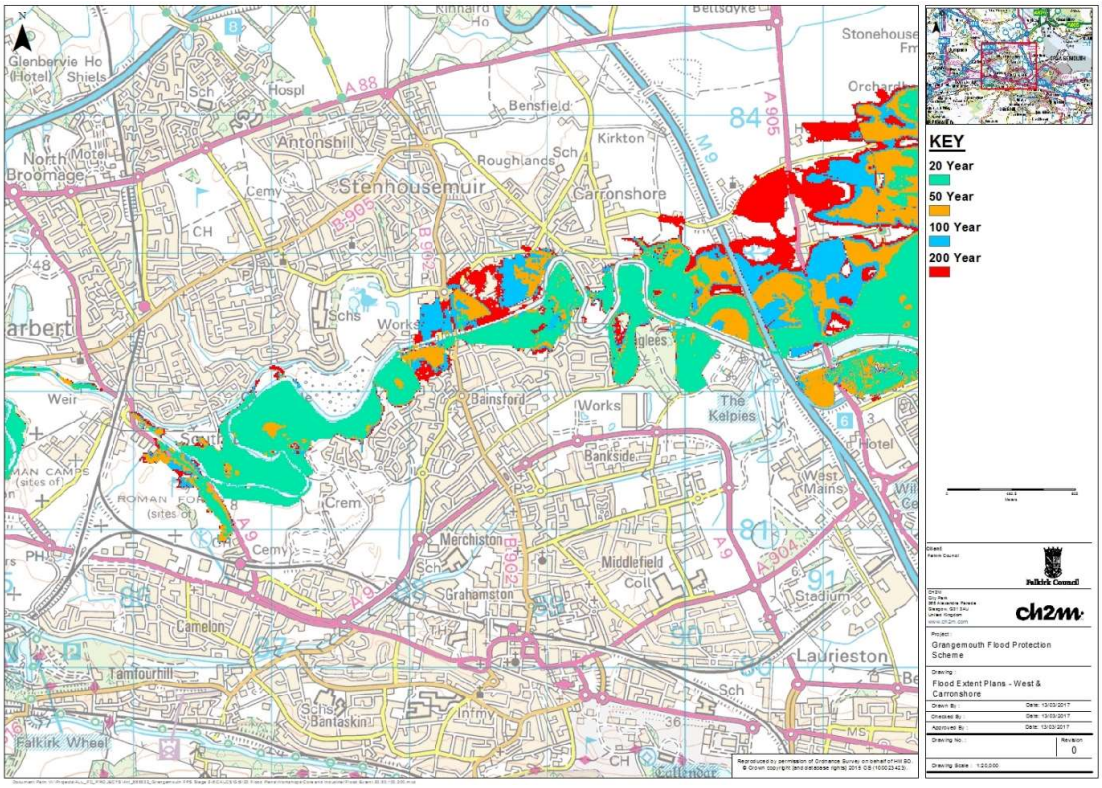

Figure 7: *Flood extents for western area*

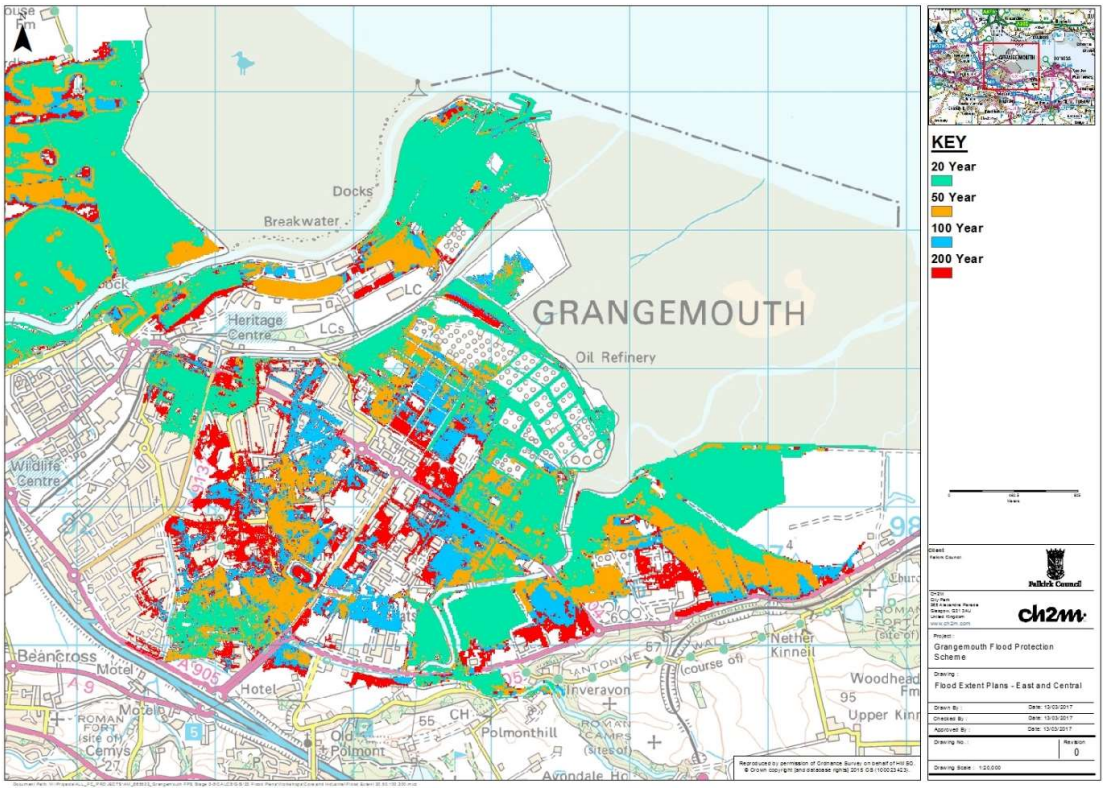

Figure 8: *Flood extents for eastern area*

2.1.13.3 Climate Change Sensitivity

Further to Section 2.1.12 and in accordance with guidance on the effects of climate change, the 1 in 200-year flow on the River Carron, River Avon and Grange Burn increased by 40%. The 1 in 200-year still water level in the Forth Estuary, which was based on 2080 levels, increased by 0.435m.

Table 8 illustrates the key difference in river flows at locations throughout the Scheme using the 1 in 100-year and 1 in 200-year flood events with and without the effect of climate change.

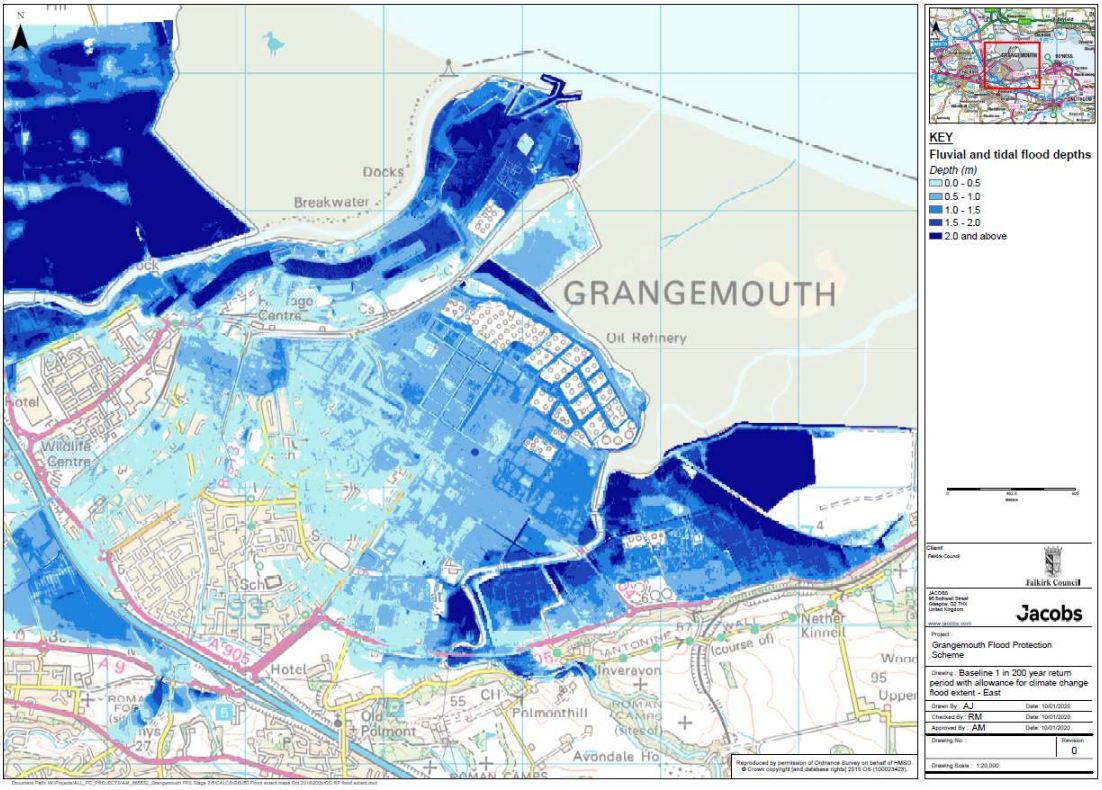

Figure 9: *200-year baseline flood extent and depths (eastern area)*

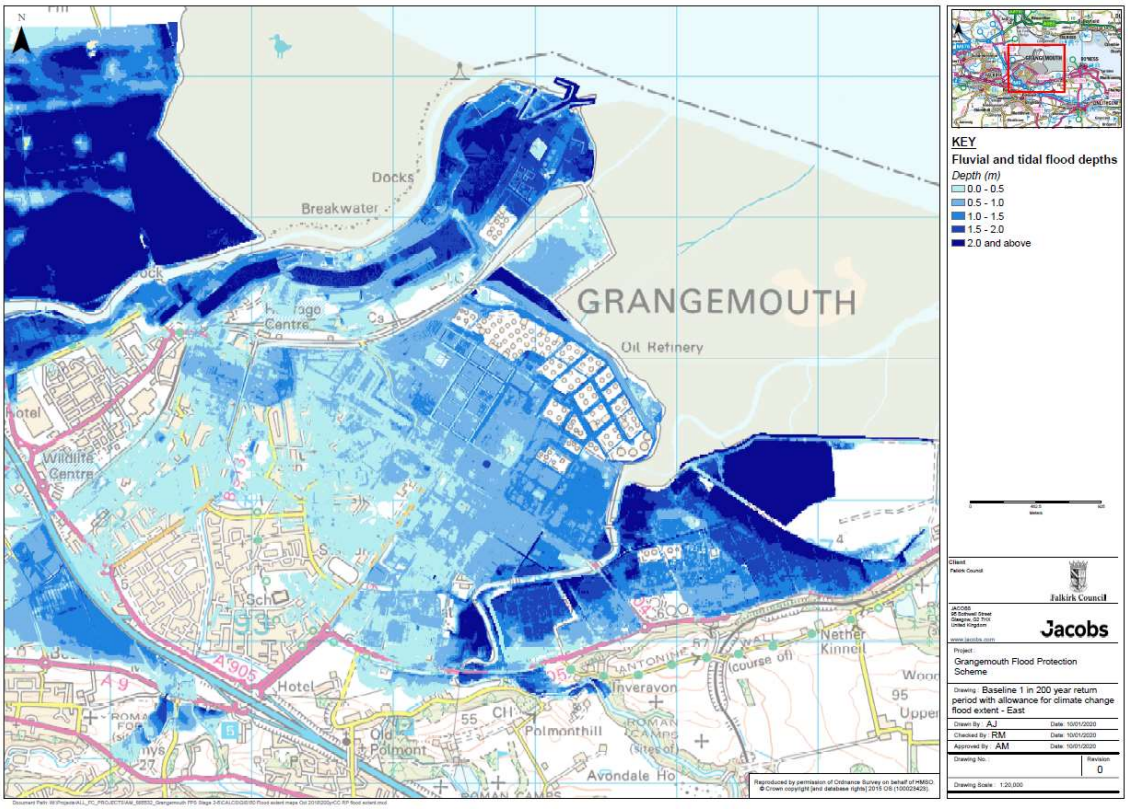

Figure 10: *200-year baseline with climate change flood extent and depths (eastern area)*

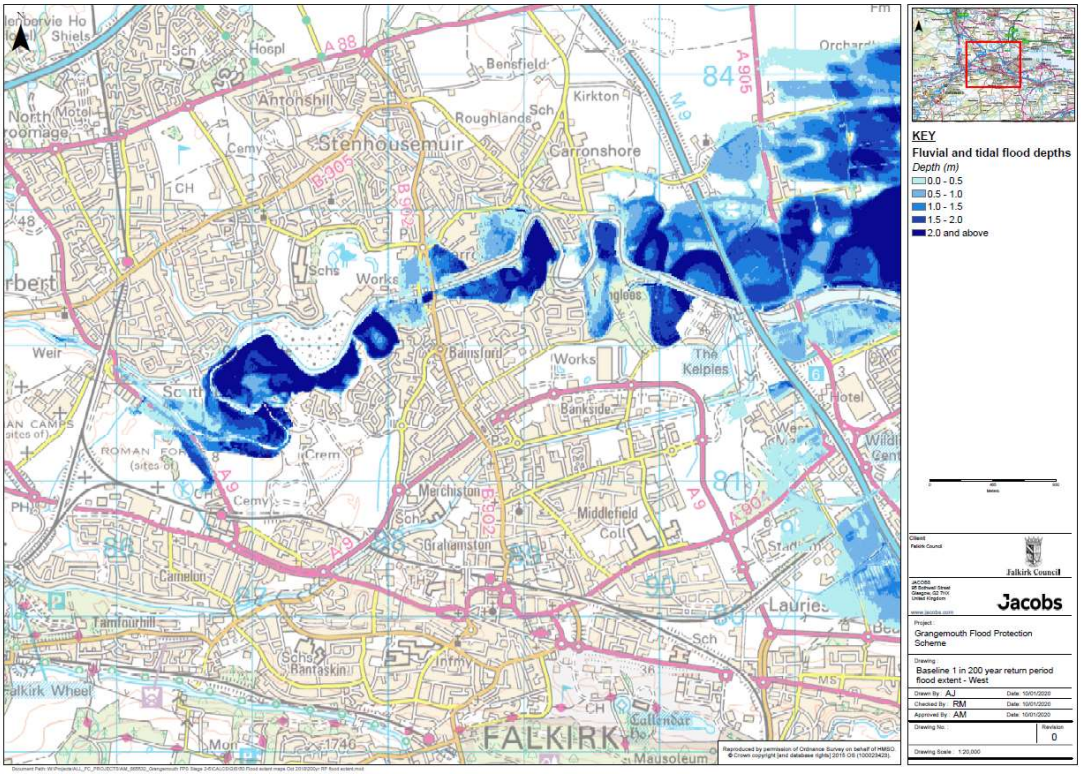

Figure 11: *200-year baseline flood extent and depths (western area)*

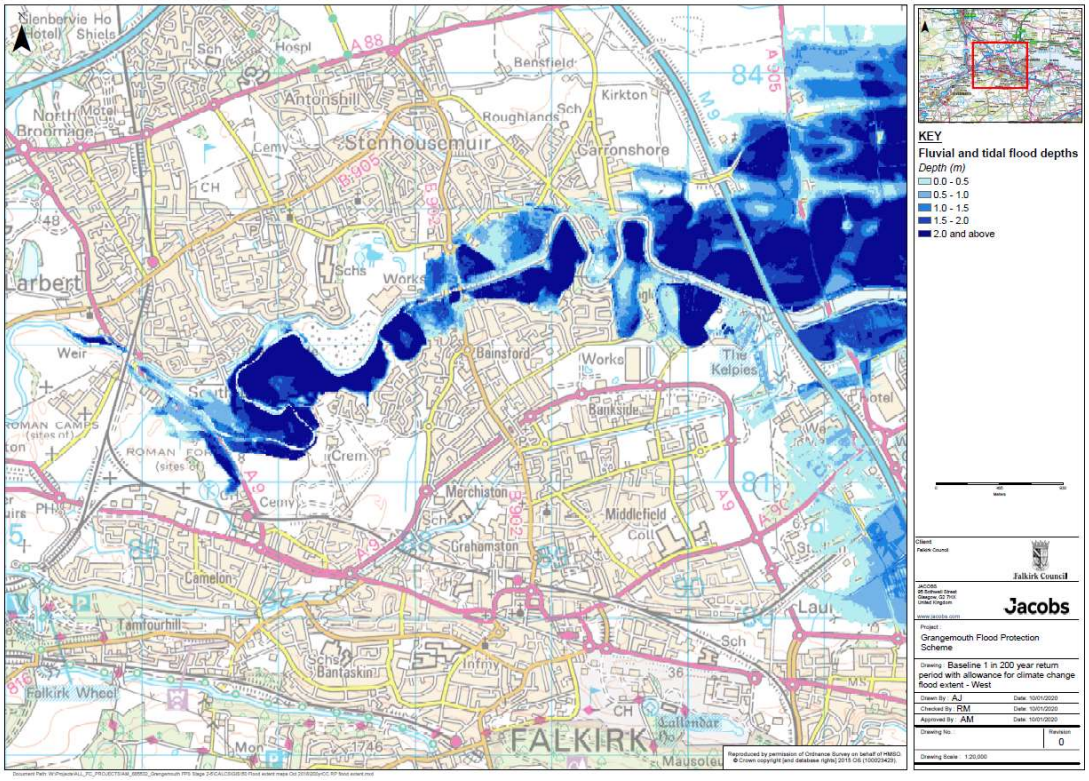

Figure 12: *200-year baseline with climate change flood extent and depths (western area)*

Including for the potential effects of climate change could lead to a significant increase in the height of defences and add a significant length. Rather than adopting a default position, an adaptability plan should be prepared to detail how the effects could be managed over the next century. This may result in some areas where is it sensible to include an allowance during the initial construction of defences whereas in other areas it may suggest designing foundations to allow for an easier raising of defence height in the future or alternatively it may suggest other actions that are currently not viable could be revisited in the future as the current constraints may not always apply.

2.1.13.4 Joint Probability

Due to the interaction between fluvial and coastal flooding, it was necessary to consider the impact of simultaneous events. Hypothetically, concurrent fluvial and tidal events of a lower return period could result in higher flood levels than solely the fluvial or tidal design case. Joint probability analysis is required to understand this interaction and identify the most significant flood event.

Since the target standard of protection for the scheme is a 1 in 200-year event, two scenarios were assessed with a combined 1 in 200-year return period. One is fluvial dominant and the other is tidal dominant. An excel tool and accompanying guidance document regarding use of joint probability methods in flood management, published by Defra and the Environment Agency, were used to identify the return period events.

Joint Probability Event	Tidal Return Period	Fluvial Return Period	Combined Return Period
1. Tidally Dominant	50 – Year	20 – Year	200 – Year
2. Fluvially Dominant	10 – Year	75 – Year	200 – Year

Table 9: *outline of joint probability events*

The joint probability modelling has not highlighted any areas where the interaction between tidal and fluvial events causes an increase of water level surpassing the both 1 in 200 year tidal or 1 in 200 year fluvial events.

2.1.14 Land Use

The map below gives a view of the typical land use in the scheme area. The area around Grangemouth comprises industrial, commercial, residential, and agricultural land. There are also some isolated areas of undeveloped land.

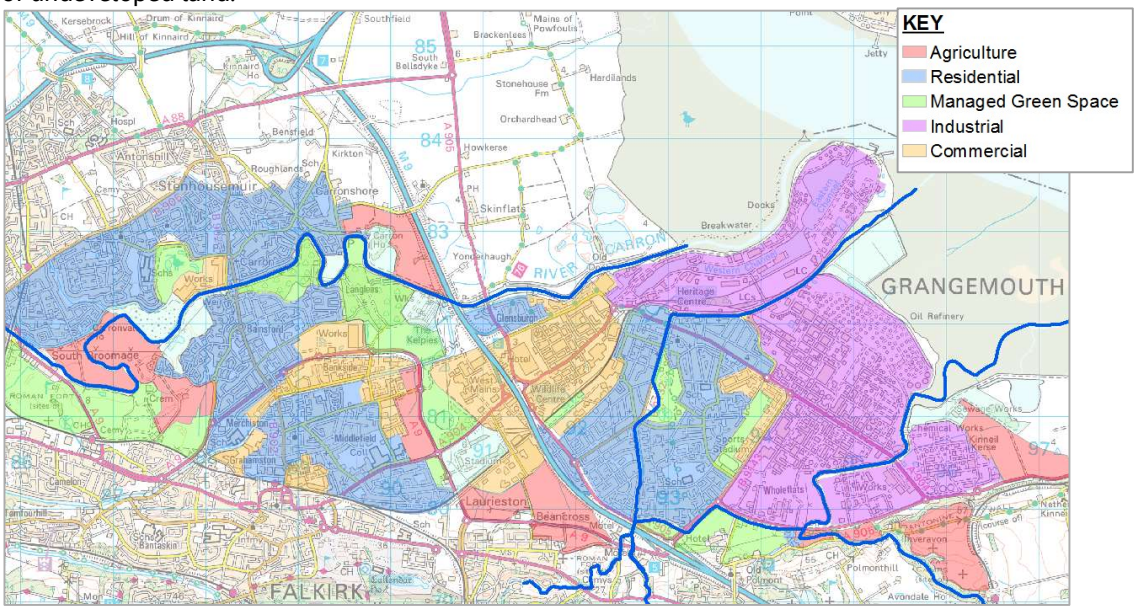

Figure 13: *Outlines the predominant land use categories for the scheme extents*

2.1.14.1 Industrial Area

Since the 19th century, Grangemouth has been a commercial centre for boat building, iron works and trade. During the early 20th Century, Grangemouth's port area and the land to the east was reclaimed and developed into an oil refinery and petrochemical plant. The expansion of the port into the Forth Estuary was undertaken to facilitate the increase in commercial marine traffic. The current petrochemical plant and port area are owned by the following companies:

- INEOS;
- Petroineos;
- INEOS Forties Pipeline System (FPS), formerly BP
- Versalis, and

- Forth Ports

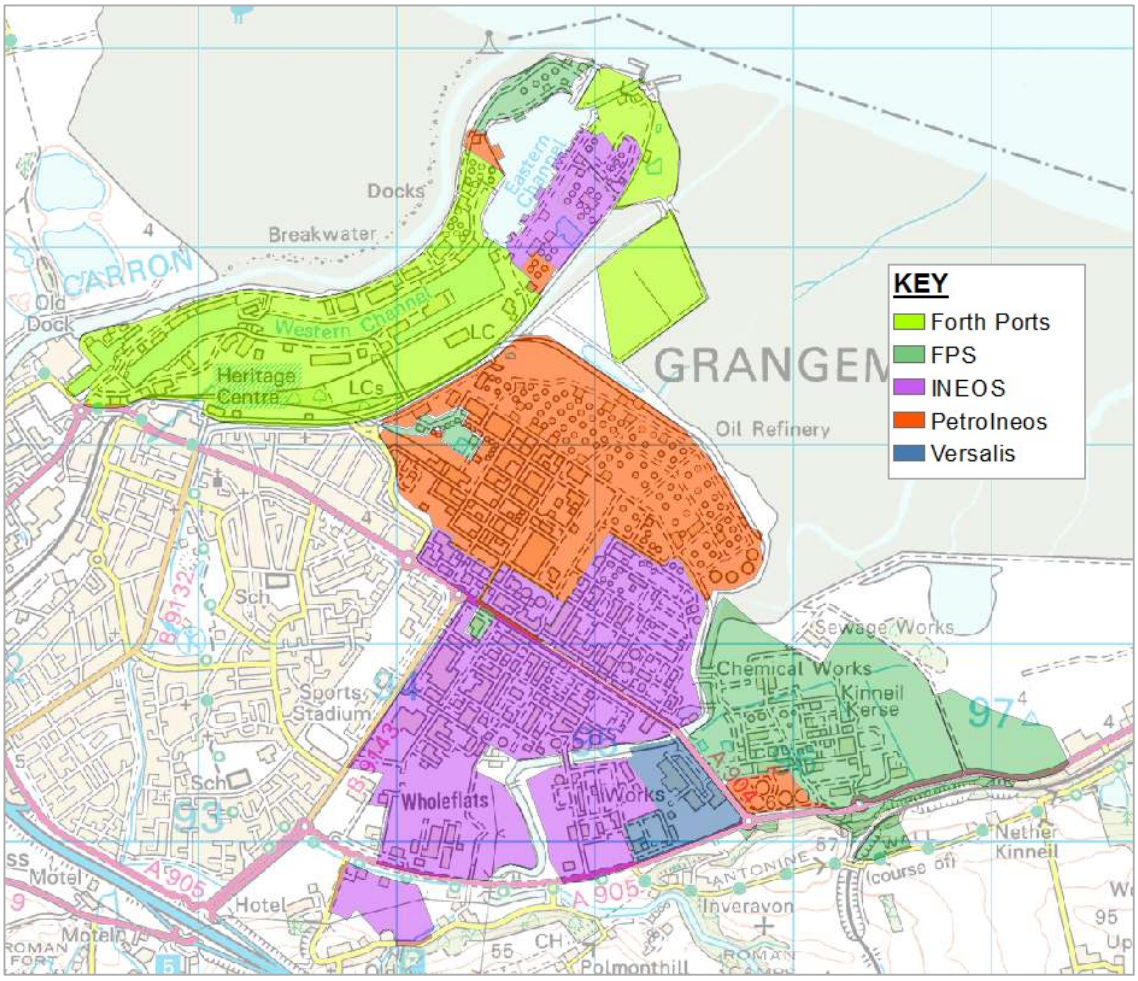

Figure 14: *Outlining the principal landowner/ occupier within the petrochemical plant and port area.*

The land here is heavily developed, with multiple large storage tanks, above and below ground pipework and specialist chemical processing equipment. Due to the high density of land-use, there is limited space on the existing banks within the Petrochemical plant. The River Avon runs directly through the petrochemical plant and the lower reach of the Grange Burn is directly parallel to part of the petrochemical plant. The site is bound to the north by the Forth Estuary.

The port of Grangemouth is currently the largest container port in Scotland and the only port in the UK with facilities to import shipments of LPG-Ethane. The port handles approx. 1,400 ship movements annually and is accessed from the Forth Estuary by a single sea lock with three sets of lock gates. A separate lock on the west side of the port entrance has been modified for the use of loading and unloading ships with no though-access possible.

2.1.15 Environmental

The Firth of Forth is an environmentally sensitive area and designated a Ramsar, Special Protected Area (SPA) and Site of Special Scientific Interest (SSSI). The SPA is a designation under the European Directive on the Conservation of Wild Birds which places a duty on responsible authorities to safeguard the habitat of migratory birds and threatened birds. The Ramsar designation comes from the Ramsar Convention - international treaty for the conservation and sustainable use of wetlands. The SSSI is a statutory designation for sites of national interest and importance relating to nature conservation.

Potential wider effects may exist on more distant SPA's or Special Areas of Conservation (SAC) whose mobile species may be present or close to the proposed scheme works. For example, fish migrating from the River Teith SAC use the Firth of Forth as a migration corridor.

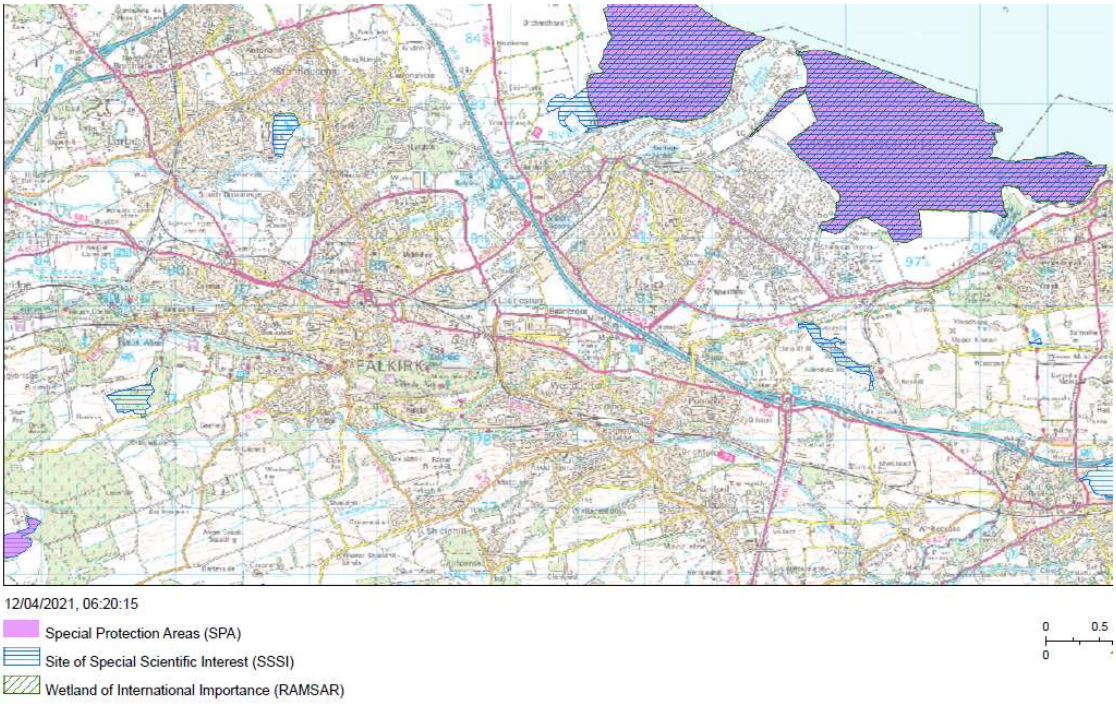

Figure 15: *Outline of SPA, SSSI and Ramsar sites*

2.1.15.1 Historical Ecologic Surveys – Phase 1 Habitat Survey

Echoes Ecology Ltd were commissioned to carry out an extended Phase 1 habitat survey in 2016. A Habitat Suitability Index Assessment for Great Crested Newts was completed on all suitable water bodies within the site. The site contains the following priority habitats:

- intertidal mudflats,
- saltmarsh,
- broad leaved and mixed woodland,
- swamp, rivers and streams, and

- standing open water.

The above habitats should be retained where possible as the habitats form important wildlife corridors through the urban extent of Grangemouth. A Habitat Management Plan should be produced once the preferred scheme is identified. This will provide details on how habitats will be protected, managed, and monitored during and after the scheme works. Appropriate management of non-native species should be carried out and the Code of Practice on Non-Native Species (Scottish Government, 2012) adhered to. Separate European protected species surveys have been conducted for badger, water vole and otter species. Further environmental and ecological surveys are recommended, particularly for bats; bat roost potential is likely to be identified throughout the scheme extents.

Figure 16: *Outline of the Phase 1 Habitat Survey area*

2.1.15.2 Birds / Ecology Surveys – Interim Environmental Report / Protect Species Survey /

An ornithological survey was carried out between August 2015 and April 2017 by MacArthur Green, to assess the current bird behaviour along a section of the Forth Estuary near Grangemouth. Information from the survey will help identify any potential effects of the proposed Scheme on ornithological receptors.

The survey recorded the following observations;

- abundance and spatial distribution of target species both permanent and temporary;
- behaviour of birds at different stages of the tidal cycle;
- baseline human activity;
- evidence of anthropogenic or other disturbance within the survey area; and
- breeding bird distribution for the seasons 2015-16 and 2016-17.

A total of 87 target species were recorded during the survey period; of these, 25 (out of a possible 27 species) were SPA qualifying species. Seven species were recorded in numbers reaching importance within a national context; shelduck, dunlin, redshank, bar-tailed godwit, black-tailed godwit, greenshank and red-breasted merganser. The distribution of species was relatively consistent between years, with the highest number of roosting waders recorded between December and March. Key roosting sites appear to be near Grangemouth Port and the petrochemical works; where despite there being high levels of background noise and activities, access to the foreshore is limited and disturbance is infrequent which make the area ideal for roosting.

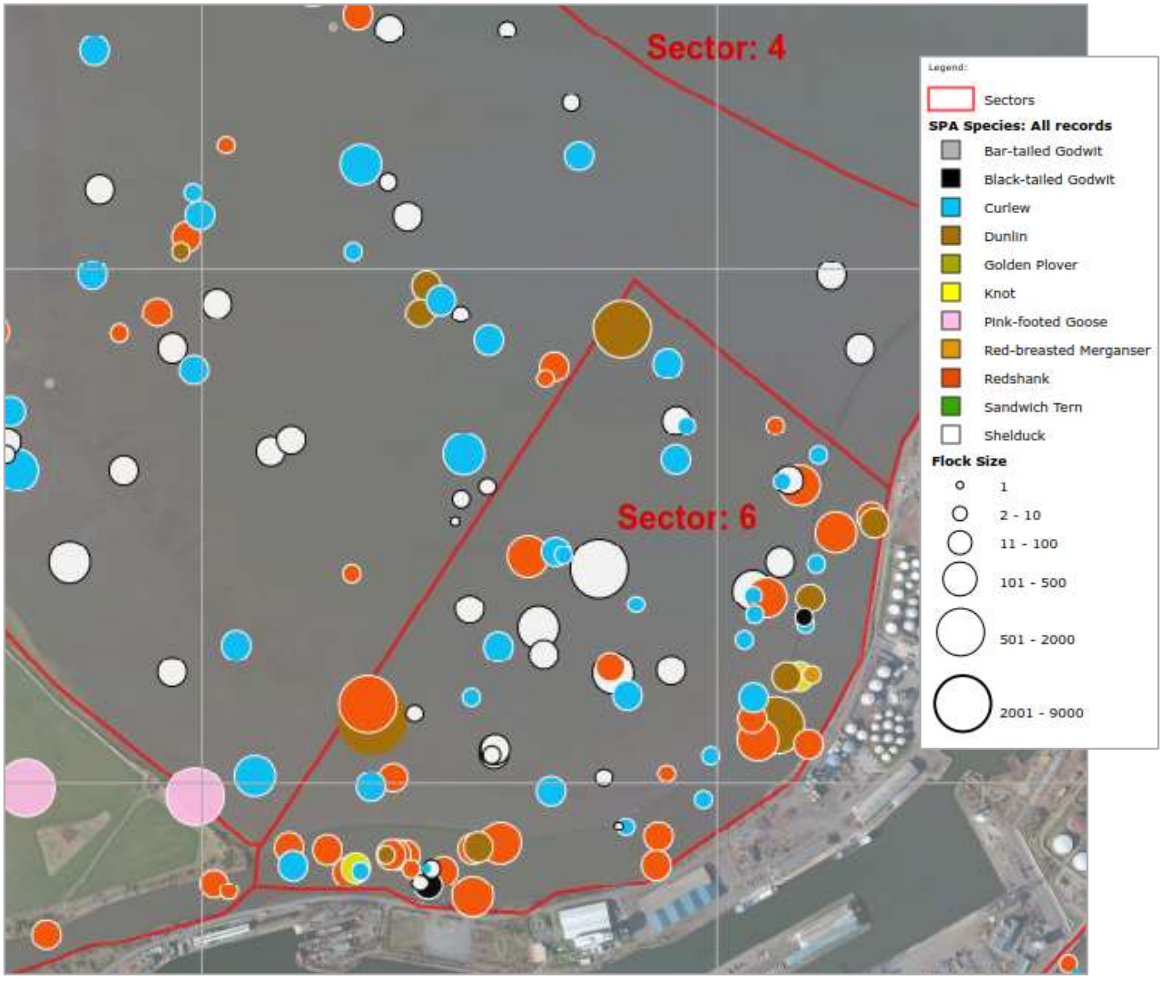

Figure 17: *Extract of a plan from the Ornithological survey, showing bird species and flock sizes*

2.1.16 Archaeology and Cultural Heritage

2.1.16.1 World Heritage Site

The Antonine Wall is an internationally designated UNESCO World Heritage site and scheduled monument. It is likely the alignment of flood defences will be within the World Heritage site buffer zone and possibly very close to the Antonine Wall. There is a general presumption against development within the vicinity of the buffer zone that may adversely affect the line, setting or amenity of the wall. Where this is unavoidable the scheme will look for opportunities to

sympathetically promote the Antonine Wall for tourism, recreation or purposes which may be beneficial to the local area.

Historic Environment Scotland (HES) have been consulted on all options which impact within the buffer zone. HES were invited to join the project *Core Stakeholder Group* (refer to section 4.1.1).

Figure 18: *Plan showing the World Heritage site*

2.1.16.2 Scheduled Monuments

In addition to the UNESCO World Heritage site designation and associated buffer zone, several other features are designated as scheduled monuments within the scope of scheme works.

The Forth and Clyde Canal is a scheduled monument between Castlecary and the M9 Motorway. It is unlikely the scheme will directly affect the Canal but consultation with Scottish Canals will be required. See comments in section 2.1.15.1 (above) relating to early consultation with Historic Environment Scotland.

2.1.16.3 Listed Buildings

There are several Listed Buildings within the vicinity of the scheme extents, including the Category A-Listed Dundas Church on Bo'ness Road. Several Category B and C-Listed Buildings could also be impacted by the alignment of direct defences.

The potential impacts of the Scheme on the fabric and setting of these Listed Buildings will be discussed in the Cultural Heritage Chapter of the EIA. Through dialogue with HES and Falkirk Community Trust the proximity of defences to the Category A, B or C-List Buildings is not considered to be a significant constraint at the option appraisal stage.

2.1.16.4 Historical Maritime Features

There are a number of maritime features of historical interest within the foreshore estuary bed, including several 19th Century vessels. None of the vessels are designated as Controlled Sites under the Protection of Military Remains Act 1986.

Nonetheless, any activities such as dredging or deposition of dredge material within water courses or estuary frontage may have an impact on these features. Once a preferred scheme has been identified, consultation with Marine Scotland will take place to seek advice on licence requirements.

2.1.16.5 Historic Environment Record and Archaeology

Since April 2016 consultation has taken place with HES and Falkirk Community Trust regarding the potential impact of proposed options on the Historic Environment.

Depending on the location of the proposed defences, and how much ground has previously been disturbed, archaeological investigation works may be necessary, particularly where construction work is taking place close to known Roman settlement ruins.

2.1.17 Ground Investigation

Previous Ground Investigation Studies have taken place and further investigations are planned over the coming months and years ahead. Once all Ground Investigation works are completed, an interpretive / design report will be produced.

2.1.18 Geomorphological Studies

A study was undertaken in to assess the current geomorphological status of the three fluvial catchments and the relevant section of the Forth Estuary. This included a desk study and a site walkover undertaken in March 2016.

The study confirmed both fluvial and estuarine environments have been modified through the realignment, re-sectioning and embankment construction carried out to accommodate expansion of the port of Grangemouth and surrounding industrial area. In the fluvial environment, the natural processes and locations of erosion and deposition within the channel have been altered; floodplain coupling has been reduced through much of the study area. However, there is still evidence of sediment inputs though erosion, transport and deposition of coarse and fine material within the channel resulting in some variety of bed morphology and associated flow diversity.

Principal conclusions about the estuarine environment are:

- The intertidal areas of the Firth of Forth have been vastly reduced over the past 150 years, either through the creation of embankments and subsequent drainage behind those embankments or through the addition of made-ground to the intertidal zone. This reclamation has in places created intertidal environments quite different to what previously existed, particularly at the Kinneil Kerse landfill where an intertidal lagoon exists behind the breakwater in an area that was previously mudflats.
- The lower estuarine reaches of the River Carron and Avon and the Grange Burn are also heavily modified, with all three (particularly the River Carron and Grange Burn) having been subject to extensive realignment. The lower reach (approx. 4km) of the Grange Burn is entirely a manmade channel.
- Where embankments and defences are in place, these are in a variable state of repair with clear evidence of erosion in the made ground which forms some of the reclaimed land. The signs of

erosion are greatest on the outside of meanders on the lower reaches of tributaries, and on exposed sections of estuary shoreline facing the greatest fetch such as the mud-cliffs on the promontory just north west of the mouth of the Grange Burn.

- The natural sediments present in the intertidal zone are dominated by silts and clays, with sands and gravels only present in small accumulations at the toe of embankments and in small embankments on those sections of shoreline more exposed to waves arriving from an easterly and north easterly direction.
- The most 'natural' sections of shoreline are the saltmarsh areas, for example the Skinflats area. Some of these are remnants of previous, more extensive saltmarsh environments or have developed following the reclamation of land such as near the Kincardine Bridge and in sheltered areas around the land reclaimed for the Grangemouth industrial area. However, these saltmarsh environments are overall very narrow, unable to develop fully as the embankments and made ground are creating 'coastal squeeze', a probable response to c.1mm per annum rises in sea level throughout the 20th century.

For further information relating to the Geomorphology of the area, consult the Geomorphology Baseline Assessment – February 2017.

2.1.19 Interaction with other projects

2.1.19.1 Zetland Park

Zetland Park was gifted by the Earl of Zetland to the people of Grangemouth in 1880. The Park is in the centre of Grangemouth, with the Grange Burn flowing along the western side of the park.

Falkirk Council have made an application to the Heritage Lottery Fund, to improve the drainage and landscape of the park. Subject to the application being successful, discussion between the flood protection scheme project team and Falkirk Council would be required. Fundamentally, the Heritage Lottery Fund works are likely to have a negligible impact on the scheme works, except for some possible landscaping on the banks of the Grange Burn.

2.1.19.2 M9, Junction No. 5 Improvements

Falkirk Council has aspirational plans to upgrade Junction 5 of the M9 at Beancross. Further discussion with Falkirk Council and Transport Scotland will be required to determine the exact scope and programme of works to determine its potential impact on the scheme.

2.1.19.3 Grangemouth Regeneration

Linked to National Planning Framework 3, the wider regeneration of Grangemouth needs to take cognisance of and be developed in conjunction with the proposed Flood Protection Scheme and the impact it will have on the area.

2.2 Future Petrochemical Plant/Port Stakeholder Projects

2.2.1 INEOS

INEOS are currently progressing through a site regeneration at Grangemouth, with redundant plant being demolished and new equipment proposed. Close consultation with INEOS will need to be maintained throughout the Option Appraisal and Outline Design Stages.

2.2.2 Petroineos

Petroineos, are currently progressing through a site modernisation / regeneration programme at Grangemouth, close consultation with Petroineos will need to be maintained throughout the Option Appraisal and Outline Design Stages.

2.2.3 Versalis

Following dialogue with Versalis, no significant changes to the current land use are planned over the coming years.

2.2.4 Forth Ports

Following dialogue with Forth Ports, no significant changes to the current land use are planned over the coming years.

2.2.5 BP / INEOS FPS

BP were taken over by INEOS in November 2017 and operate as INEOS FPS. At the time of writing it is assumed that no significant changes to the current operations at Grangemouth will occur but dialogue with INEOS FPS will be maintained throughout the Option Appraisal and Outline Design Stages.

2.2.6 Design Parameters

The following assumptions and parameters have been identified to allow high level designs and a degree of confidence in the capital cost estimate for options.

2.2.7 Design Life

Whilst no specific guidance for the minimum design life of a scheme exists, industrial standard has always adopted 100-year design life as the baseline assessment duration.

2.2.8 General Design Strategy

The general design strategies to be adopted when identifying the alignment, nature and extent of flood protection options include:

1. ***Attempt to locate direct defences as far back from the river / estuary frontage as possible –*** adopting this strategy can be difficult due to the proximity of the built environment to the River Carron, River Avon and Grange Burn, and the estuary frontage. There are several locations where there are already existing structures close to or forming part of the riverbank. However, proposed defences in locations where there are no existing structures close to the watercourse will be aligned as far from the bank as possible.

   River Carron – many structures have been built for residential and leisure purposes on the banks of the Upper Carron. In some locations, setting the alignment of defences back from the riverbank would encroach into the gardens of residential or grounds of commercial properties. In a few extreme cases where there is no viable alternative alignment buildings may need to be demolished.

   River Avon – for much of the lower reach of the River Avon setting the alignment away from the existing bank crest is not possible due to the proximity to the petrochemical plant. At isolated locations, where space allows, defences will be aligned back from the riverbank.

Grange Burn – the lower reach of the Grange Burn flows through an urban area of Grangemouth, due to the high-density land-use in this area, limited opportunity exists to set-back the alignment of defences from the river bank.

Estuary Frontage – the environmental designation of the Forth Estuary as a SPA, means that, where practical, the alignment of defences should be set-back from the estuary frontage. However, the proximity of the petrochemical plant and port leave little space to construct flood defences. Therefore, the alignment of defences is likely to encroach into the SPA. This will require detailed consultation with SNH during the Habitat Regulation Appraisal process.

2. ***Utilise existing infrastructure where possible –*** due to difficulties in accessing some of the water courses (particularly around the petrochemical plant and port area), it would be beneficial to utilise any existing structures. This is subject to the integrity and height being sufficient to provide the required level of protection.

3. ***Poor ground conditions*** – From initial geotechnical desk-studies, it is assumed the ground conditions (i.e. depth of rock head) deteriorate as you progress down the watercourses to the estuary frontage where Rock-head is believed to be more than 50-100m below ground level.

4. ***Provide seepage protection, where there is a substantial risk to property inundation or other serious scheme compromises as result of seepage flow –*** seepage is not anticipated to be a significant source of flooding and therefore will not be assessed until the outline design stage.

5. ***Provide freeboard protection in accordance with the Environment Agency Fluvial Freeboard Guidance Note –*** the addition of freeboard allowance increases the basic flood level (i.e. direct output from the hydraulic model) to the design flood level and provides a '*factor of safety*' on the desired level of protection. The freeboard determination allows for the following parameters which can affect the level of protection provided:

    - Modelling inaccuracies associated with micro scales features such as turbulent eddies and wave formation.
    - Local increases in flood level because of entrained debris trapped at constrictions.
    - Local changes in flood level because of changes in channel cross section during a major flood event.
    - Increase in flood level on the outside of a bend (super-elevation) due to the centripetal force.
    - Settlement of direct defences.

    Falkirk Council have intimated that flood defences that are required for freeboard only are not to be included in the scheme.

6. ***Dealing with services and utilities*** – section 2.1.4 of this report highlights the significant interaction with utility apparatus (pipes, cables and ducts) belonging to Scottish Water, Scottish Gas Networks, Scottish Power, Vodafone and BT. Additionally, several large diameter, high pressure (>50bar) privately owned pipelines traverse the Grangemouth area. Due to nature of the work at the petrochemical plant there are numerous buried and above ground pipelines located throughout this area. It is possible that the proposed defence alignment will interact

with other services and utilities (outfalls, old lades etc.) which have not been recorded on the plans.

In most locations, aligning the defences to avoid utilities is not possible and diversion or protection is likely. However, diversion of pipelines servicing the petrochemical plant and port is less likely. A number of these pipelines are classified as '*Major Accident Hazard Pipelines*' and therefore every effort will be made to align the flood defences away from these pipelines. It is acknowledged that there are likely to be places where flood defences are in the vicinity of '*Major Accident Hazard Pipelines*' and high-pressure pipelines. Discussions with pipelines operators will take place in due course.

During the design and alignment of flood defences, the footprint of construction work could be reduced to in some areas to accommodate utilities / services directly under the alignment of the flood defences. Additionally, gaps in below ground construction could be tolerated over short lengths to allow crossing of services.

7. ***Assessing environmental impacts –*** Due to the size, scale and nature of the scheme and the presence of multiple environmental designations, an Environmental Impact Assessment (EIA) will be required. The EIA will assess the potential impacts associated with the construction and operation of the Scheme. It will set out appropriate mitigation and, where feasible, possible enhancement measures. An EIA scoping study has been produced. The scoping report will summarise environmental data gathered to date, proposed environmental studies, planned consultation with stakeholders, assessment methodologies and decisions on which topics will be included in the main EIA. The scoping report will be circulated to statutory stakeholders for comment, to identify any further data available or issues missed, and to gain agreement on the proposed scope of the assessment. A Habitat Regulation Appraisal and Appropriate Assessment will also be undertaken to assess the impact on the SPA.

   Based on the Phase-1 Habitat Survey and Interim Environmental Report (2016), the following recommendations should be acted upon at the outline design stage of the project:

   - Fill any gaps in the Phase-1 Habitat survey
   - National Vegetation Classification is recommended
   - Overwintering Bird Survey
   - Bat, Badger, Otter Bat Roost, Great Crested Newt, Breeding Bird and Botanical surveys
   - Pre-Construction Survey
   - Liaise with SNH regarding the potential impact of the scheme on the Forth Estuary - Ramsar/SPA/SSSI site.
   - Produce a Habitat Management Plan to detail how affected habitats will be protected and monitored during and after the scheme works.
   - Liaison is being undertaken regarding the alignment of defences in relation to key habitats / trees with a view to minimising and mitigating the impacts.
   - Work to ascertain where possible habitat mitigation could be created.
   - Work to ascertain how the river corridor could be enhanced as part of the scheme.

From initial engagement with SNH regarding the impact of the proposed defences on the SPA, the project team have been advised a Habitat Regulation Appraisal and Appropriate Assessment will be required as a minimum. Further discussions with SNH are ongoing relating to this matter.

8. ***Assessing the social impact of flood protection in terms of visual severance from watercourses*** – it is unlikely that flood defences above 2m in height are going to be acceptable, therefore the design of flood defences will need to be aware of this. The finish of flood defences will be determined through the Environmental Impact Assessment.

9. ***Provide flood gates only where there is no other obvious alternative for flood Protection -*** flood gates can provide a simple and relatively low cost method of preserving access through a flood defence structure when compared to the cost and space required for alternatives. This is particularly relevant where flood defences cross roads. Demountable structures are another option which can be considered.

   The obvious drawback with floodgates is that manual intervention is required to operate; maintenance is also required to combat the effects of weathering and vandalism. Due to the number of bridge crossings throughout the scheme, the logistics of operating flood gates at all bridge openings will be considerable. Falkirk Council will need to be consulted on the use of flood gates across roads as this may have a significant impact on the local road network.

   Bespoke flood gates may also be required across the sea lock at the port entrance and across the railway line on the Grange Burn. These gated structures will be investigated at the outline design stage of the project.

10. ***Standard of finishes to be agreed with Falkirk Council Planning Department*** – the design strategy assumes the basic form of wall finishes will be concrete, with a liner finish, with exceptions to this for areas directed by Falkirk Council Planning.

11. ***Flood Storage Areas*** – the principal criteria for designing flood storage areas is to reduce peak flows on the River Carron, River Avon and Grange Burn. However, beyond the hydraulic requirements, a range of other criteria must be considered, even at this concept design stage:
    - Does not result in the inundation of residential or commercial property (agricultural land will not be protected),
    - Does not result in the inundation of any roads / access tracks,
    - Does not increase the flood risk to utility infrastructure,
    - Does not result in the obvious degradation of environmentally protected areas, and
    - Must be feasible when assessing existing utility apparatus.

12. ***Access to Grangemouth Port*** – access to the Port of Grangemouth is to be maintained. Discussions with Forth Ports will identify any restrictions on access to the port.

2.2.9 Specific Design Considerations

2.2.9.1 Seepage

Seepage occurs when a volume of water percolates beneath a structure. This effect can undermine flood defences. The key influence of the volume of seepage through soil is the ground condition and the driving head of water from either the watercourse or the estuary. A flow net allows the flow of water from one side of a structure to the other to be plotted using the appropriate equations.

A more detailed assessment of seepage will be undertaken at the Outline Design stage, using a risk and consequence matrix to identify critical areas which will require seepage protection.

2.2.9.2 Structural Stability

All existing wall structures should be structurally assessed on an individual basis to determine their suitability for re-use. The critical output parameter is to identify what form of additional work, if any, is required to ensure that a particular option can be constructed.

Traditional checks on the general stability of a wall structure relate to forces which are attempting to fail (disturbing) the structure in comparison to forces which are keeping the structure stable (restoring). The ratio of the restoring force against the disturbing force provides the factor of safety against failure. The checks rely on basic principles:

- Sliding - frictional resistance of the defence structure is greater than the applied disturbing force.
- Overturning – the mass weight of the structure is greater than the applied disturbing force.
- Bearing – the pressure applied by the structure on the underlying ground is less than the bearing capacity of the soil.

When analysing existing structures, experience of similar walls on flood protection schemes suggests it will be difficult to obtain 'design' factors of safety which are the range of 1.5 to 3.0 for the failure mechanisms identified above.

2.2.9.3 Drainage

It is assumed that all flood defence structures will be designed with some form of drainage system, this will serve two purposes:

- Reduce the build-up of hydrostatic pressure on the structure and improve the structural stability.
- Allow surface water to flow into the channel / estuary where new flood defences pose a physical barrier, assuming the water level in the channel / estuary is not high.

Whether the drainage is provided through gullies at appropriate spacing or SUDS techniques such as filter drains along the back of a wall will depend very much on:

- The inherent stability of the wall and whether the provision of full-length drainage would improve stability.
- The ground surface behind the wall defence. Hard standing would be more suited to gullies or channel drains, whereas soft landscaping might be more suited to filter drains.

SUDS techniques should be viewed preferentially to conventional drainage techniques. A holistic approach to surface water management should be developed which best allows surface water to mimic natural processes. It should be noted that SUDS techniques could be incorporated into some NFM measures.

2.2.9.4 Future Flexibility

It is vital to ensure that the preferred flood protection scheme could be modified at some point in the future to either:

- Increase the level of protection in response to an overtopping event or other factor (e.g. insurance industry requirements); and / or
- Maintain the current level of protection and offset the effects of climate change.

This future flexibility could be realised through:

- permanently raising flood defences, or
- providing demountable barriers, installed on top of the existing defences to temporarily increase the level of protection.

Both options will place additional forces on the existing flood defence structure. The need to increase the size and depth of foundations to accommodate a future increase in height of defence make these options costly.

2.2.9.5 Freeboard

Residual uncertainty allowance, more commonly termed '*freeboard*', is an allowance in the design of flood defences that considers the physical processes that may affect the design water level, see section 2.3.2. By including a residual uncertainty allowance, a safety margin has been introduced to ensure that flood defences perform to the required level of protection with a high degree of certainty.

It is considered best practice to estimate freeboard allowance using the Environment Agency's Fluvial Freeboard Guidance, published in 2000. The physical characteristics over the length of defences for the scheme vary, therefore it is appropriate to assess and allocate different allowances at different locations.

2.2.9.6 Structural Integrity of Existing Banks / Walls

From topographic and LIDAR surveys, several existing embankment and wall structures are higher than the required design level of flood defences. Where possible, existing structures will be incorporated into the preferred scheme design. This is subject to a geotechnical investigation being undertaken to determine structural integrity. The maintenance cost for existing structures will be reviewed at the outline design stage. Details relating to privately owned structures have been requested from stakeholders.

2.2.9.7 Grangemouth Port Lock Gates

Due to the restricted nature of access to the Port of Grangemouth, assumptions have had to be made regarding the lock-gates at the entrance to the Port; these assumptions include:

- Height of lock-gates is lower than the design level for flood protection.
- Any flood defences across the channel (lock) need to facilitate ships using the lock.
- Any flood defence across the lock needs to form a barrier that can withstand the hydrostatic pressure difference associated with lock gates.
- Proposed direct defences on land either side of the lock will need to tie-in with the lock-gates and maintain the required height of defence.
- The existing lock is to remain in-situ and operational.

2.2.9.8 Petrochemical Plant

Due to restricted access to the petrochemical plant, assumptions have had to be made regarding flood defences in this area, these assumptions are:

- Access through the petrochemical plant site is restricted, and likely to require extensive permitting.

- Crossing pipelines will require discussions with petrochemical stakeholders to determine the feasibility of this and the appropriate mitigation that would be required.
- An acceptable method of encasing above ground pipelines within the proposed flood defences will need to be developed.

2.2.9.9 Railway Line

Due to the restricted nature of access to the petrochemical plant, assumptions have had to be made regarding the proposed flood defences that would be required to cross the railway line. These assumptions are:

- A gate structure will be required to allow trains to through the flood defences.
- The railway line is operational and will be for the foreseeable future.
- The height of the gate will need to tie-in with the direct defences on either side of the gate.

2.2.9.10 Tributaries

Several tributaries join the River Carron, River Avon and Grange Burn. The Flood Estimation Handbook (FEH) catchment characteristics were used to derive inflow hydrographs for these catchments. These were subsequently input into the 1D/2D model as point inflows.

A separate 1D/2D model is currently being developed for the Chapel and Millhall Burns which will extend up to Roughlands Drive and for the Millhall Burn from the River Avon to Millhall Reservoir. The reason for these models is to better understand the flood mechanisms on both Burns and ensure the FPS does not increase flood risk in these areas.

The Grangemouth Flood Protection Scheme will not reduce flood risk within the whole PVA 10/11 area. Separate studies will be required on smaller watercourses within PVA 10/11 area to fully understand and mitigate flood risk. In all cases flood defences have been located to ensure they do not increase flood risk upstream or downstream. Nonetheless, some areas upstream or downstream of the scheme area may still be at flood risk.

2.2.9.11 Bridge Capacity

Numerous bridges cross the watercourses included in the scheme extents. Where bridges are within the scope of works, the hydraulic capacity has been assessed based on topographic survey information. Bridge structures on tributaries and upstream of the study area have not been assessed for hydraulic capacity.

There is therefore the potential that a storm event could result in flooding if the flow in the channel leads to a failure of an upstream structure which results in a wave event. The table below identifies bridges where further investigation is required once a preferred scheme has been identified,

3. Option Appraisal

3.1 Option Appraisal Methodology

3.1.1 General

This section of the report aims to simplify the plans, methods and outputs associated with the option appraisal.

This task is complex due to the wide range of interactions between:

- watercourses,
- tidal influences,
- levels of protection,
- stakeholder/ landowner requirements, and
- economic, environmental and legislative constraints.

The option appraisal is a systematic and logical thought process which can accommodate the inevitable variations to options that are developed. This process needs to be managed effectively and results must be conveyed to stakeholders and other project team members in a clear and concise manner.

3.1.2 Baseline for Option Appraisal

The purpose of the option appraisal is to identify opportunities and constraints for each option, that will be compared to the current baseline situation.

3.1.2.1 Do–Nothing

Represents the current baseline situation with no intervention, from which all flood damages are calculated. Further details on the economic appraisal are provided in section 5 of this report.

3.1.2.2 Do-Minimum

Assumes the current flood defences and embankments are maintained over time. This includes the removal of debris and sediment at structures and ensuring existing embankments and walls are maintained and fit for purpose. There are many embankments and walls which are privately owned by Forth Ports and stakeholders within the petrochemical plant. Falkirk Council is not responsible for any regular inspection and maintenance of these structures.

From a visual inspection of the watercourses it is assumed these will continue to be maintained due to the nature of the infrastructure they are protecting. The baseline scenario uses the do-minimum (maintain the existing structures).

Falkirk Council has a regular maintenance programme for removing the debris and sediment from culverts and bridges.

3.2 Preliminary Option Assessment

3.2.1 Long List Options

In line with the National Flood Risk Strategies, SEPA produced a 'long-list' of measures which should be considered as flood protection measures where appropriate. The following section will outline the reasoning for discounting some of these measures. Due to the large spatial extent of the scheme, and the convergence of three watercourses on the Grangemouth area, these sections will generically assess the options based on an overall assessment of the three catchments.

3.2.1.1 National and Local Planning Policies

Through the National and Local Flood Risk Management Plans - areas at flood risk have been outlined and appropriate measures (such as a flood protection scheme) identified. From the National Flood Risk Assessment, PVA's were identified and were incorporated into Local Flood Risk Management Plans to help inform the local development plan.

3.2.1.2 Runoff Control

Includes the following measures:

- Woodland planting
- Land Management – soil and bare earth improvement, change of agriculture in field drainage
- Cross slope woodlands
- Creation / restoration of wetlands / ponds
- Upland drain blocking
- Gully woodland planting

Due to the relatively short length and flat morphology of the catchments, land use within the catchments is predominantly moorland with arable farming along the lower reaches. The local Flood Risk Management Strategy identifies runoff control as not practical for the size of watercourses in the scope of the works. Creation / restoration of wetlands / ponds will be considered along with flood storage and channel realignment options.

3.2.1.3 River / Floodplain Restoration

Includes the following measures:

- Floodplain reconnection
- Placed large woody debris and boulders
- Floodplain woodland
- Riparian woodland
- Reach restoration
- Creation of wash lands (off-line storage)

Potential for floodplain reconnection through small scale channel realignment of a section of the Rivers Carron and Avon. Large scale river and floodplain restoration measures are not deemed to be suitable principally due to land use pressure. The local Flood Risk Management Strategy identifies River / Floodplain restoration as not practical for the watercourses within the scope of works.

3.2.1.4 Sediment Management

Includes the following measures:

- Sediment removal (dredging) or other in-channel management
- Sediment traps
- Bank Restoration

There is no evidence of excessive sediment deposition in the channels and this option is not cost effective or sustainable without an ongoing management plan. The tidal influence on lower reaches of the watercourses makes sediment removal unsustainable. All of the existing banks are vegetated due to high land use pressure (urban environment) so there is limited available space for bank restoration.

3.2.1.5 Wave Attenuation

Includes the following measures:

- Beach Recharge
- Shingle Re-profiling
- Sand Dune Restoration
- Coastal Vegetated Shingle Restoration
- Machair Restoration

The above is deemed not practical due to the proximity to the Port of Grangemouth and potential adverse impact on port operations.

3.2.1.6 Surge Attenuation

Potential for some restoration of intertidal habitat, depending on the HRA. From a flood management perspective, surge attenuation measures would not reduce flood levels due to the large land take required and fluvial influence of the watercourses.

3.2.1.7 Online and Offline Storage

Generally, online and offline storage has been discounted as a standalone option due to insufficient space (due to land use pressure) to create storage areas capable of storing the volume of flood water required. However, online storage has been considered on the Westquarter Burn (tributary of the Grange Burn);

3.2.1.8 Modification of Conveyance

Includes the following measures:

- Channel modifications – deepen / widen channel
- Relief / Diversion of Channel
- Realignment of Channel
- Culvert Modifications
- Removal of hydraulic constrictions
- Bridge Modifications

Due to the urban environment, measures to modify conveyance are limited. Small realignments on the Rivers Carron and Avon have been considered. Bridge conveyance (and modification) has also been investigated. The flood relief channel already exists on the Grange Burn and forms part of proposed options.

3.2.1.9 Fluvial Control Structures

Includes the following measures:

- Sluice gates / penstocks / flap valves
- Weirs
- Trash Screens
- Pumping Stations

Due to the size and predicted flows on the watercourses in the scope of works, it is not practical or feasible to install fluvial control measures. Some of the fluvial control measures will be re-assessed as secondary drainage measures.

3.2.1.10 Coastal Control Structures

Includes the following measures:

- Revetments
- Groynes
- Breakwaters
- Artificial Reefs
- Gates and Tidal Barriers

Due to the land take required and sensitive environmental classification of the Forth Estuary; principally coastal control measures are not thought to be practical or technically viable as a standalone measure. However, revetments and a tidal barrier are included as part of a measure that is incorporated into some options.

3.2.1.11 Sustainable Urban Drainage Systems - SUDS

Are deemed to offer no benefit in reducing flooding from fluvial and tidal sources due the large, predicted flows. SUDS will be re-assessed for the secondary drainage aspect of the scheme.

3.2.1.12 Watercourse Maintenance

Falkirk Council undertake regular watercourse inspections, and maintenance activities to ensure compliance with the FRMA.

3.2.1.13 Property Level Protection (PLP)

As a standalone measure this is not practical, however, when combined with other measures, PLP will be re-assessed.

3.2.1.14 Flood Forecasting / Warning

SEPA have implemented a flood forecasting and warning system on the River Carron, River Avon, Grange Burn and the Forth Estuary.

3.2.1.15 Self Help

Includes raising awareness, development of Flood Action Group and Business continuity plans. These measures will not be standalone items but addressed through the scheme and promoted by Falkirk Council.

3.2.1.16 Emergency Plan

As a standalone item, it will not address flood risk. Falkirk Council already have an emergency flood plan; however, this will need to be updated to account for the scheme defences.

3.2.2 Early Discounted Options

At the initial optioneering stage, a high-level brainstorming exercise was undertaken. Following this it was possible to discount some options on the basis they were not feasible, practical, economical or beneficial based on the scheme objectives.

Examples of reasons for discounting options from the Long List include:

- lack of hydraulic benefit;
- very high capital costs (>£100M, per option);
- significant likely adverse environmental, social or cultural heritage impact;
- lack of space to construct defences;
- not practical; and
- other significant difficulties in construction of defences.

Options which clearly do not meet the general scheme objectives identified in Section 1.3.3 of this report have been discounted from the option appraisal process. Table 10 summarises the results of the high-level assessment for each of the options with a brief description of the advantages and disadvantages, and reasoning to reject the option from the option appraisal.

Option Description	Flood Cell no.	Key advantages	Key disadvantages	Reason for rejection
Diversion of channel /pipe on the River Carron to the north of Larbert and Stenhousemuir	1 – Carron Upper	• Could provide up to 1 in 200-year level of protection. • Construction work away from residential areas.	•Very high capital costs. •Still requires defences on tidal reaches, including part of the Upper Carron. •Severe geo-morphological impacts. •Tidal flows could back-up diversion channel / pipe. •Severe environmental impact.	Principally due to lack of economic viability and negative environmental impact
Dredging up to 1.0m deep on all three watercourses	All	• Reduces flood levels in the channel for a 1 in 200-year event. • Reduce height / extent of defences in urban area.	• Ongoing management plan required otherwise flood protection diminishes. • Unsustainable due to tidal influence on lower reaches of watercourses. • Need to identify site to deposit /dispose of dredged material. • Severe environmental impact. • Still requires some defences to provide the 1 in 200-year level of protection. • Potential issues with erosion at bridge structures.	Principally due to lack of economic and logistic viability and lack of site to deposit dredged material
Diversion of channel / pipe to the north of M9 motorway bridge on the Grange Burn	4 – Grange Burn	• Could provide up to 1 in 200-year level of protection • Reduce height / extent of defences in urban area.	• Very high capital costs. • Still requires defences on tidal reach of the Grange Burn, up to Zetland Park. • Severe environmental impact. • Tidal flows could back-up diversion channel / pipe.	Principally due to lack of economic viability and negative environmental impact
Diversion of channel / pipe to the south of the A905 bridge	5 - Avon	• Could provide up to 1 in 200-year level of protection	• Very high capital costs. • Still requires defences on tidal reach of the Avon.	Principally due to lack of economic viability and negative environmental impact

Option Description	Flood Cell no.	Key advantages	Key disadvantages	Reason for rejection
		• Less defences required on the banks of the River Avon.	• Severe environmental impact. • Tidal flows could back-up diversion channel / pipe.	
Increase the storage volume of Carron Valley Reservoir	1 – Carron Upper	• Potential reduction in flood risk downstream	•Very high costs for relatively few benefits. •Still requires flood defences to be built downstream of reservoir. •Consent required from Scottish Water. •Limited reduction on peak flows from the 1 in 200-year event due to large catchment.	Lack of economic viability, limited benefits in reducing the need for flood defences in Grangemouth
Property level protection	All	•Low capital costs. •Reduced disruption to local residents compared to direct defences.	•Cannot guarantee the 1 in 200-year level of protection. •Still requires considerable lengths of direct defences. •Roads and other infrastructure will still be at flood risk – access to properties during flood event would be difficult. •Requires advanced warning of flood event for PLP to be installed in time, potential liability issue with organisation responsible for installing PLP. •Logistical issue of installing PLP in a densely-populated area. •PLP equipment will need replacing, ongoing maintenance cost.	Level of flood protection cannot be guaranteed and flooding of roads would still cause significant disruption to Grangemouth.

Option Description	Flood Cell no.	Key advantages	Key disadvantages	Reason for rejection
Realign the Carron channel downstream of M9 Bridge into Skinflats area	2 – Carron Lower	• Environmental and ecological benefits.	•Limited benefits as the major source of flooding on this reach is tidal. •Increased risk of flooding on the Skinflats area. •High capital costs. •Still requires direct defences upstream of Skinflats.	Due to limited benefit in reducing flooding extent, and high capital costs.
Upstream (beyond Denny and M9 respectively) storage on the Rivers Carron and Avon	1 - Carron Upper and 5 - Avon	•Reduces the need for direct defences within residential areas.	•No suitable locations found to provide any significant volume of storage, without the need to construct considerable dam and embankment structures. •Limited suitable sites due to land use and historical contaminated land. •Very high capital costs to create storage area. •Storage area would be classified as a reservoir and need to comply with Reservoir (Scotland) Act 2011, to reduce to height of direct defences downstream. •Still requires significant lengths of defences downstream.	Due to limited benefit in reducing flood extent downstream, limited suitable areas to create storage and very high capital costs.
Tidal Storage area	2 - Lower reaches of River Carron, 5 - Avon and	•Creates new sustainable habitat. •Could be linked to wide habitat creation in the Estuary.	•Minimal / no impact on tidal flood level due to size of the estuary. To have any impact on tidal flood level, a substantial area of land would be required – major	Limited hydraulic benefit to reducing tidal flood levels and very high capital costs in purchasing sufficient area of

Option Description	Flood Cell no.	Key advantages	Key disadvantages	Reason for rejection
	4 - Grange Burn	• Potential for eco-tourism. • Compensates for some loss of habitat from other cells.	relocation of commercial / residential and agricultural properties. • Very high capital costs, requires land to be purchased or land owner compensated if existing banks are breached and new defences constructed. • Unknown filled ground along the frontage to the east of the petrochemical plant. • Major construction work for limited hydraulic benefits.	land to impact tidal flood levels.
Coastal realignment (creation of salt mash) – Skinflats area and east of petrochemical plant	2 – Lower Carron & 6 – Estuary Frontage	• Creates new sustainable habitat. • Could be linked to wider habitat creation on the Estuary. • Potential for eco-tourism. • Compensates some loss of habitat from other cells.	• No impact on tidal flood level. • Requires buy-in from local land owners, or purchase land – possible financial implications. • May require residential and commercial properties to be relocated. • Major construction work to breach / demolish existing bank and create new set-back defences. • Very high capital costs.	No hydraulic benefit to reducing tidal flood levels and very high capital costs in purchasing sufficient areas of land to impact tidal flood levels. Possible mitigation to defences along the Estuary frontage and provides enhanced habitat.
Tidal Barrier (barrage) across Forth Estuary	N/A	• Could provide tidal flood protection to a 1 in 200-year level of protection. • No defences required for tidal flows.	• Very high capital cost. • Major construction work across the across the Forth Estuary – designated Ramsar, SPA and SSSI site. • Significant impact on environment.	Very high capital costs compared to other options, environmental impacts would be substantial, still requires defences to protect against

Option Description	Flood Cell no.	Key advantages	Key disadvantages	Reason for rejection
		• Potential for tidal power to be harnessed or infrastructure crossing incorporated into design.	• Barrier requires opening to allow ships to pass through. • Visual impact. • Only provides tidal flood protection, fluvial defences still required. • Need to assess the impact of fluvial flooding.	fluvial flooding on all three watercourses.

Table 10: Summary of the early discounted options

For the purposes of this option appraisal the above options will not be taken further and have been classified as '*early discounted options*'.

3.2.3 Flood Storage Areas

The concept of flood storage areas is to attenuate peak flows sufficiently to reduce the length and height of direct defences downstream. Often a storage area will be created by building a dam structure across a watercourse with a culvert running through the structure to allow normal flow.

To control the forward flow, various methods can be used. Ideally, the downstream flow is contained within the existing channel without the need for direct defences downstream of the Flood Storage Area (FSA). When the flow in the channel entering the FSA rises, floodwater will begin to impound behind the dam structure for a short duration due to the flow control device restricting the pass forward flow. Delaying the peak flow downstream lowers peak water levels. The size of the FSA is dictated by the volume of water that can be held behind the dam until the water level overtops the dam. Once the inflow into the storage area is lower than the maximum pass forward flow, the storage area will begin to empty.

The FSA(s) outlined in this report are designed to begin attenuating flows from very high intensity rainfall / flow events. Under normal flow conditions water would stay within the channel and pass through the FSA, see the hydrograph in Figure 16.

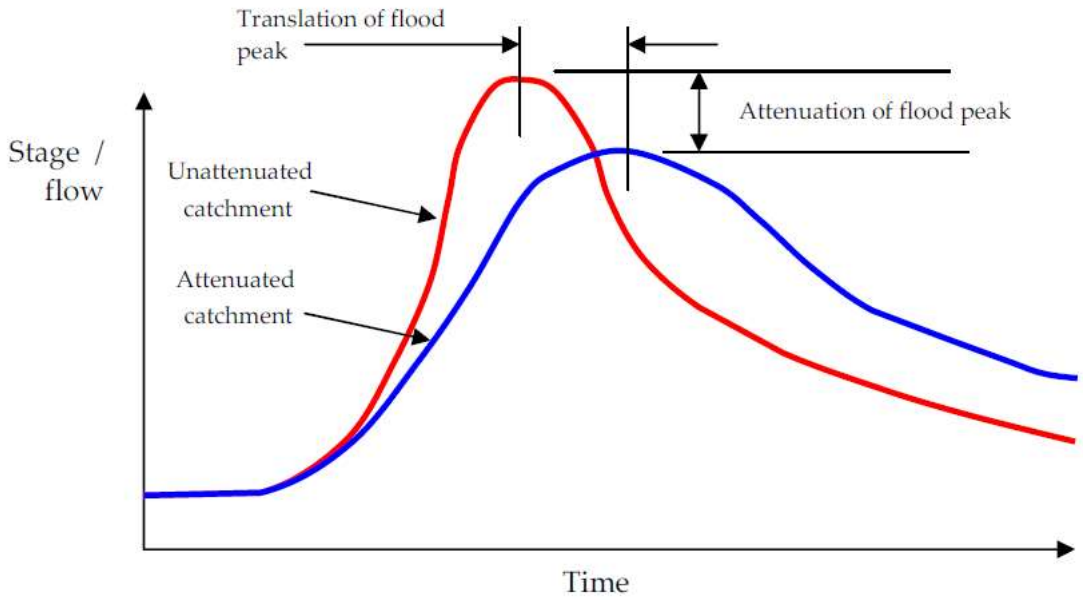

Figure 19: *Typical hydrograph showing peak flow and attenuated peak flow*

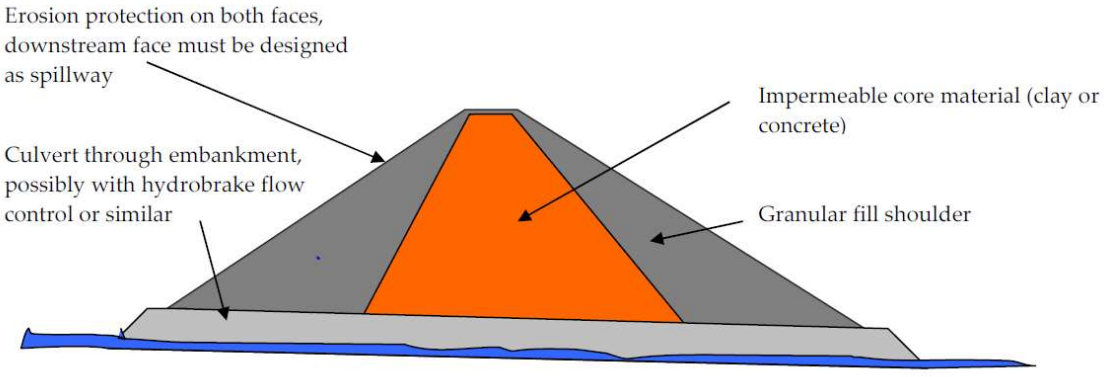

Figure 20: *Typical embankment for a flood storage area*

The provision of large earth dam structures and the inundation extent of the storage area (during a flood event, see figure 17) will present the following issues that need to be addressed:

- Access for construction;
- Inundation of land during flood event;
- Impact on environment during inundation of storage area;
- Impact on aquatic environment, e.g. fish migration routes;
- Impact on property and roads during inundation of storage area, and
- Impact on utilities during inundation of storage area

Some direct defences may be required around the FSA, to ensure that floodwater is impounded and that flood risk is not increased elsewhere.

3.2.3.1 Flood Storage Areas – River Carron

Following an initial desk study using LiDAR survey data, two potential flood storage areas were identified, FSA 1 – directly upstream from the Carron Dams site and FSA 2 – upstream from Stirling Road, see figure 18. These sites were identified due to the natural morphology of the floodplain, which would allow water to be impounded if a dam structure was introduced across the channel. Additionally, approx. 3km of structures would be required around the FSA's to impound water and not increase flood risk elsewhere. Several constraining factors determined the size and shape of the FSA's, these include:

- Infrastructure – multiple A and B-Class roads are located around the boundary of the FSA's;
- Proximity to residential and commercial properties;
- Proximity to electrical Sub-Station;
- Existing Culvert under M876 at Checkbar;
- Camelon Cemetery; and
- Land-fill site, next to '*Carron Works*' site;

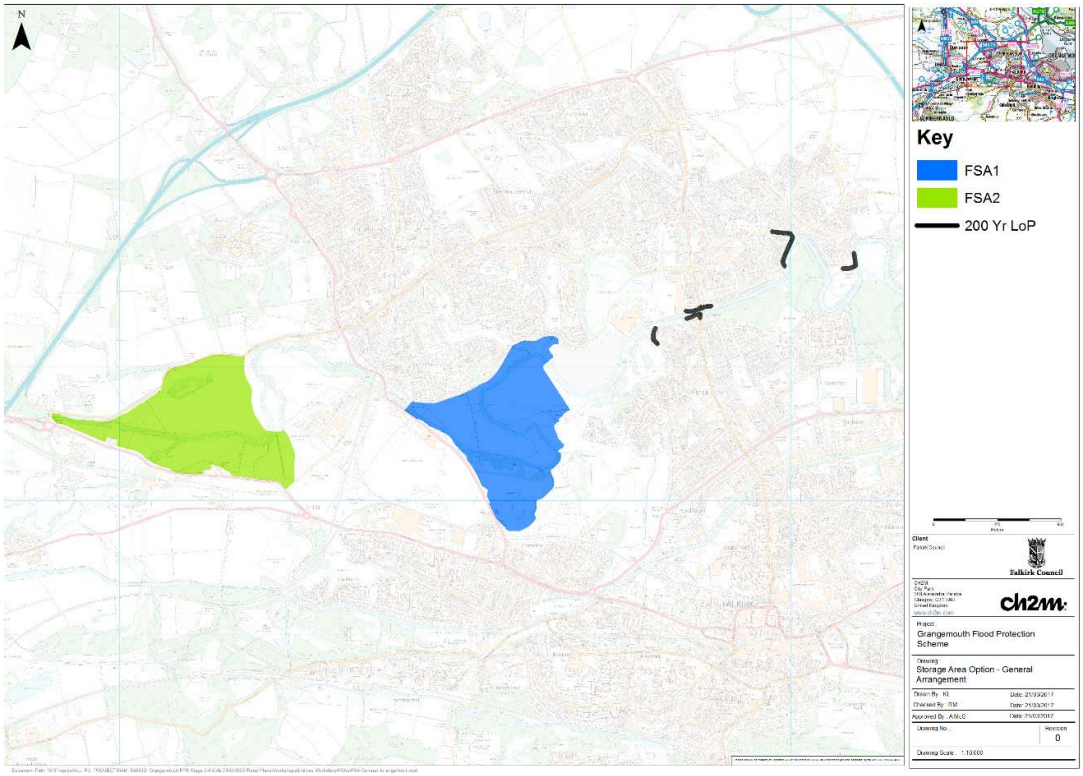

Figure 21: *Location of flood storage areas on the River Carron*

On the River Carron the 1 in 200-year flow was estimated to be ~342m^3/s. To gain any significant benefit of reducing the length and height of direct defences downstream, two FSA's would be required to reduce flow in the channel to 252m^3/s. However, reducing to a discharge of 252m^3/s would still require ~2km of direct defences downstream and ~5km of embankments around the storage areas (including dams).

Both FSA's were sized to store the 1 in 200-year event flow on the River Carron whilst still allowing a pass forward flow of 252m^3/s downstream on the River Carron. Due to requirements originating from the Reservoirs Act 2011, it was also necessary to consider how the Probably Maximum Flow (PMF) could be safely passed by the storage areas.

Table 11 outlines some key figures relating to the two FSA's on the River Carron.

	FSA 1	FSA 2
Area of storage area - km^2	0.8	0.9
Stored volume of flood water - m^3	872,739	897,471
Dam Length - m	415	400
Dam Height (from Ex GL) - m	7.1	6.2

Total Embankment Length – m (surrounding FSA's)	2,500	2,130
Possible maximum flow - m^3/s	957	921

Table 11: Key Factors relating to FSA 1 and 2 on the River Carron

The capital construction cost estimate for the dam structure and associated direct defences downstream is summarised in the table below. For comparison purposes the construction cost estimate of direct defences only on the Upper Carron have been included based on providing 1 in 200-year level of protection. These estimates do not include utility diversion costs, which would be significant for the storage option (£10's M).

	Flood Storage Area		**Direct Defences only**
	FSA 1	**FSA 2**	
Construction cost estimate of dam structure and embankments surrounding FSA - £M	38		
Construction cost estimate of direct defences downstream of FSA - £M			22
Total construction cost estimate - £M	**38**		**22**

Table 12: Estimate capital construction costs

A desk-top survey of utilities near the FSA's was undertaken which identified several potentially significant issues:

- Scottish Power Energy Network – Transmission; multiple pylons are located within both FSA's which support numerous 'High Voltage Transmission Lines'. Several towers would directly clash with the proposed dam structures. The safety clearance required for construction works was a concern to Scottish Power and would require further detailed calculations to be undertaken. Access to the overhead power lines and towers when the FSA's are impounding flood water was an additional concern. Through various meetings with Scottish Power, a ball-park figure to move the towers and associated overhead power lines was given as £2M per tower with up to no. 10 towers requiring moving. Scottish Power would have major concerns about programming such work. To progress this option Scottish Power requested a Feasibility Study be undertaken at an initial cost estimate of £20K with potential to increase the scope of the study if further investigation or survey were required.
    - Scottish Power Energy Networks – Distribution; (network for power lines <132KV) have multiple poles and 11KV power lines through FSA 1. These would need to be raised or moved.
    - Due to the significant issues raised in relation to Scottish Power's Transmission network no further information was requested for the distribution network.

- Scottish Gas Networks – Transmission; have a transmission gas main through the middle of FSA 2 operating at pressures up to 40-bar. From initial meetings with SGN Transmission, the gas main is estimated to be 1.2m below existing ground level and slightly deeper as it passes under the

channel of the River Carron. A budget estimate to divert the gas main out with the FSA was at £2M for a 2km diversion. SGN – Transmission indicated a 4-year lead-in period would be required for such a diversion and to progress this option further a feasibility study would be required at a £30K cost estimate. SGN raised concerns relating to the proposed embankments over the gas main and the potential effect of buoyancy on the gas main when the FSA is impounding water.

- National Grid – have twin DN 900 National Transmission Gas Mains operating at up to up to 70-bar pressure through part of FSA 2. These pipelines are classified as 'major accident hazard pipelines' and form part of a national gas pipeline throughout the UK. From initial discussions with National Grid, their main concern is buoyancy of the mains and potential floatation. A budget estimate to divert both mains was put at £6M per main, however, as these pipes are classified as '*major accident hazard pipelines*' no construction work can take place within 150m of the main. Finding a suitable location in the surrounding area to divert the mains to is likely to be prohibitive and increase the budget estimate significantly.
- From initiating the Utility / Service Stakeholder Group, an Options Workshop was held on 3 April 2017. This workshop allowed statutory providers the opportunity to comment on the proposed options being considered by the project team, including the FSA's. From this Workshop, Scottish Water raised concerns over some of their apparatus within FSA 1. More details relating to comments from the Utility / Service Workshop can be found in section 4.2.2 of this report.

Conclusion

From analysing all the relevant information relating to flood storage on the River Carron, the project team will not pursue this option on the grounds of:

- high construction costs relative to the cost of providing downstream direct defences only;
- substantial feasibility concerns from utility companies;
- feasibility studies required to be undertaken by SGN, National Grid and Scottish Power – initial cost estimate for studies is £100K, but likely to increase. Risk that due to the complexities associated with diverting and working adjacent to major utility apparatus, there is the potential for the feasibility studies to identify no suitable alternative locations to divert the utility apparatus, and
- proximity of FSA 1 to Scheduled Monument (Roman Camps) would require Scheduled Monument consent.

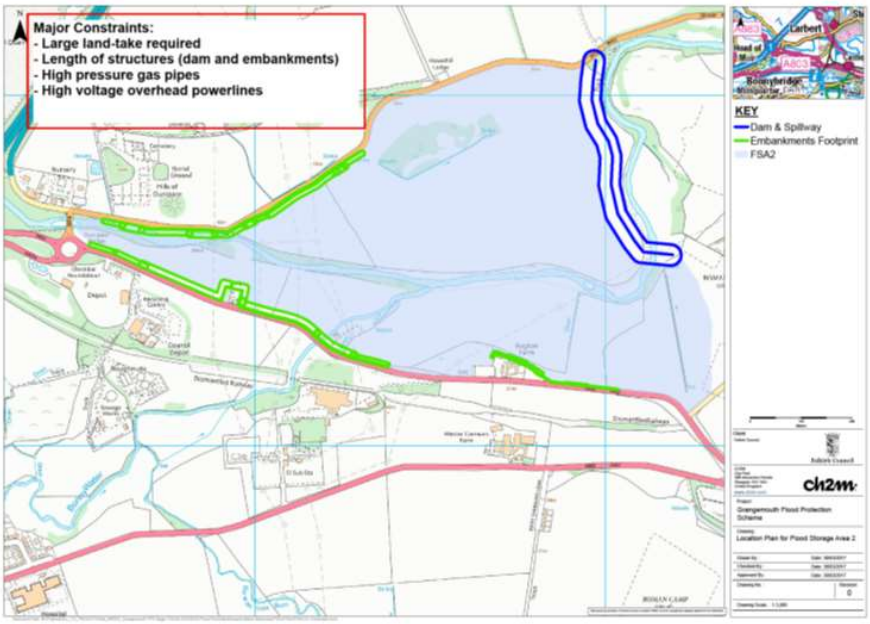

Figure 22: *Layout of Flood Storage Area 1*

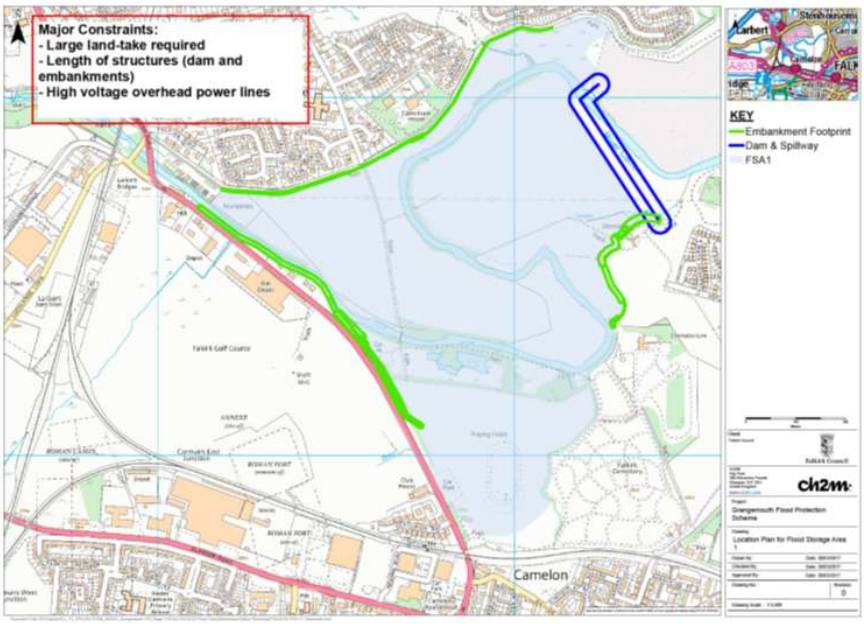

Figure 23: *Layout of Flood Storage Area 2*

3.2.3.2 Flood Storage Area – Grange Burn

Following an initial desk study using LIDAR survey data, a potential storage area was identified directly south of the M9 motorway, between the A9 and the industrial estate off Laurieston Road.

Control gates would need to be installed on the Westquarter Burn, upstream of the A9. During high flow events, the gates would be closed to redirect flows into the FSA, which would fill up and discharge at a controlled rate. Due to the relatively flat topography, embankments would be required around the whole perimeter of the FSA. The dam structure would be located directly upstream of the Almond Pow culvert under the M9. A controlled outfall from the FSA would flow into the Almond Pow, which is then culverted until it joins the Grange Burn. The capacity of the Almond Pow culvert and capacity of the Grange Burn is a critical feature in determining the discharge from the FSA.

To limit tidal flows backing-up the Grange Burn, a tidal barrier would be required at the mouth of the Grange Burn. The barrier would be mechanically controlled and would rise when the tidal level reaches a threshold point. A consequence of installing a barrier across the channel means no flows can pass through the structure when the barrier is raised which could result in the potential for fluvial flows to increase water levels upstream of the barrier.

The capital construction estimate for this option was £10M. This included the dam structure, embankments, direct defences on the Flood Relief Chanel and short lengths on the Grange Burn and a tidal barrier.

The FSA is within the UNESCO – World Heritage Site of the Antonine Wall, which is classified as a Scheduled Monument by Historic Environment Scotland. Any connection between the Westquarter Burn and the FSA would need to cross the alignment of the Antonine Wall. From discussions with Falkirk Community Trust and Historic Environment Scotland, both organisations would have major concerns with construction work on or under the Antonine Wall.

A desk-top survey of utilities around the FSA was undertaken. This identified a potential clash with apparatus of Scottish Power Energy Networks - Transmission. Multiple pylons are located within the FSA which support 275KV overhead power lines. Scottish Power Energy Networks – Transmission had concerns relating to the safety clearance of power lines and access to towers and lines when the FSA is inundated. The design team were advised against diverting the power lines, as these are critical to the petrochemical plant.

No other utility services were known to directly clash with the proposed FSA.

Figure 24: *Layout plan of flood storage area 3*

Conclusion

Having reviewed and analysed all information relating to the FSA, the project team decided to not purpose this option on the grounds of:

- high capital construction costs,
- requirement for embankments around the perimeter of the FSA,
- difficult to incorporate an emergency spillway to deal with PMF,
- increase in flood risk upstream due to water essentially being stored above ground,
- substantial concerns from Scottish Power Energy Network – Transmission - feasibility study would need to be undertaken; risk the feasibility study could identify no suitable alternative locations to divert apparatus. Additionally, the complexities and practicalities of undertaking diversion work are significant, as the power lines are critical to the petrochemical plants operation,
- impact on the Antonine Wall (Scheduled Monument) - new pipe / channel from Westquarter Burn to FSA,
- limited conveyance capacity of the Almond Pow Culvert and channel capacity of the Grange Burn when the tidal barrier is closed would mean the drain down time of the FSA would be considerable.

3.2.4 Bridge Removal

3.2.4.1 River Carron

From the initial baseline model runs, the hydraulic capacity of the Stenhouse Road and Carron Road (B902) Bridges were shown to restrict flow sufficiently to create a hydraulic jump to water level in the channel. Three scenarios were modelled relating to the size of the bridge openings:

- removing the bridges,
- installing a relief culvert (3 x 2.5m), and
- raising the bridge decks.

All three scenarios reduce water level in the channel upstream, however the reduction was not sufficient to stop overtopping of the existing banks. All three scenarios would have a significant impact on the local road network and the numerous utilities are located on Carron Bridge. To reduce water levels in the channel sufficiently, to avoid the need for direct defences upstream of the bridges, the bridge openings would need to be significantly enlarged. This is not feasible due to the surrounding residential environment.

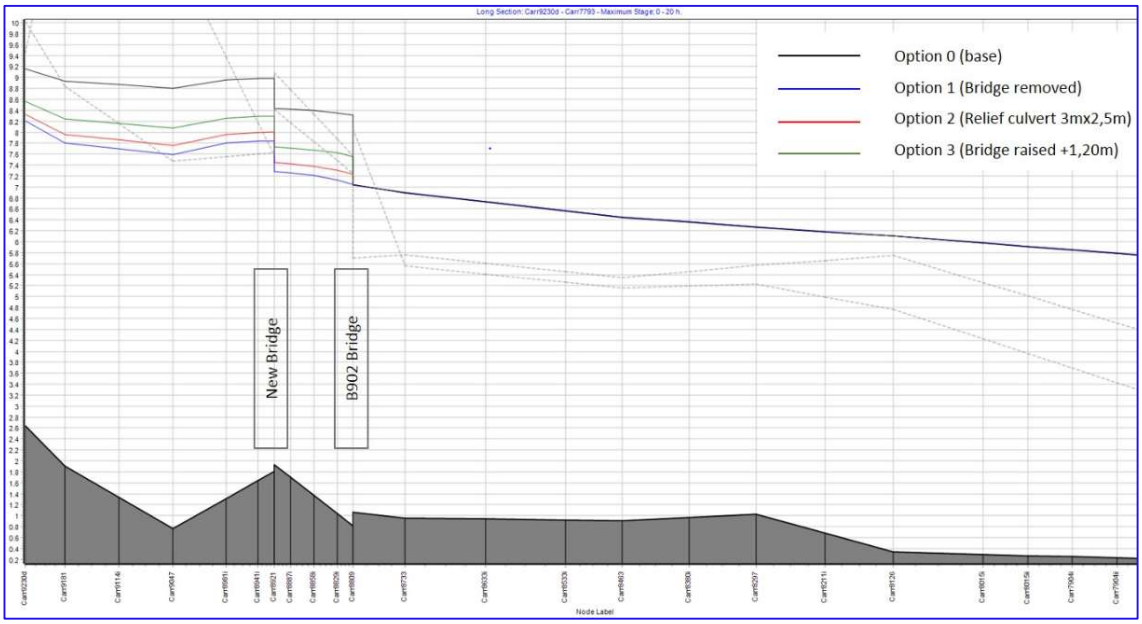

Figure 25: *Water level in the channel for the three options considered at Stenhouse and Carron Road Bridges.*

3.2.4.2 Grange Burn

Several bridges cross the Grange Burn as it flows through Grangemouth. Due to the confined urban environment, there is little opportunity to alter the level of the bridge decks or increase openings as any changes would typically require alterations to the surrounding environment e.g. road junctions, footpaths or property entrances, which are not practicable.

3.2.5 Pipe Bridges

Numerous pipe bridges cross the River Carron, River Avon, Grange Burn and Flood Relief Channel. It is not feasible to move or divert these pipes due to the:

- size (up to DN 1050);
- some pipes are strategic mains, others are related to the petrochemical plant and are pressurised up to 50-bar; and
- number of pipe bridge crossings required;

For the purposes of this option appraisal all pipe bridge crossings are to remain in-situ. The proposed flood defences will be integrated with existing pipe bridges.

3.2.6 Natural Flood Management

Through the Flood Risk Management (Scotland) Act 2009; the Flood Risk Management Strategies identify Natural Flood Management (NFM) as not appropriate for PVA 10/11 (Grangemouth). NFM measures are not being considered as a standalone option as part of the Scheme, however, they will be considered on the grounds of habitat creation and biodiversity improvements. The calculated peak flows for the catchments of the River Carron, River Avon and Grange Burn limit opportunities for NFM. The primary reasons for not including NFM as a standalone option are:

- it is difficult to quantify the reduction in flood risk;

- it is difficult to quantitatively assess the benefits and include in Scheme benefit cost ratio;
- there is no clear guidance on funding NFM measures;
- the lower reaches of all three catchments are affected by tidal flooding, NFM provides no reduction in flood water levels here;
- NFM would require buy-in from land owners and cultural change in land management practices throughout the catchments, and
- the limited impact of NFM reducing peak flows in the Rivers Carron, Avon and Grange Burn due size of catchment and predicted flows.

NFM may be considered for part of the scheme design at the outline design stage, or on some of the smaller tributaries that join the main watercourses. It is difficult to quantify the financial benefit of implementing NFM measures, as NFM on its own will not remove the need for flood protection measures but could offer multiple benefits through the creation of habitat and biodiversity improvements.

3.3 Flood Cells

To simplify the option appraisal and due to the geographical size of the catchments, the scheme has been divided into 6 geographic areas, termed '*flood cells*', see appendix F.

Figure 23 and Table 13 identify the six Flood Cells which have been considered in the option appraisal. More detail on individual Flood Cells and subsequent options can be found in section 3.4 of this report.

Flood Cell No.	Flood Cell Name	Principal Watercourse	Primary Source of flooding	Location
1	Carron Upper	Carron	Fluvial	From Stirling Road to M9 motorway bridge
2	Carron Lower	Carron	Tidal / Fluvial	Downstream from M9 motorway bridge to Harbour breakwater
3	Harbour	N/A - Forth Estuary	Tidal	Harbour breakwater to mouth of Grange Burn
4	Grange Burn	Grange Burn and Flood Relief Channel	Fluvial / Tidal	Westquarter village to mouth of the Grange Burn (includes Flood Relief Channel)
5	Avon	Avon	Fluvial / Tidal	From Avondale Road Bridge to mouth of the River Avon

Flood Cell No.	Flood Cell Name	Principal Watercourse	Primary Source of flooding	Location
6	Estuary Frontage	N/A – Forth Estuary	Tidal	From mouth of the Grange Burn to Kinneil Business Park (on A905)

Table 13: outlines the Six Flood Cells in the Grangemouth Flood Protection Scheme

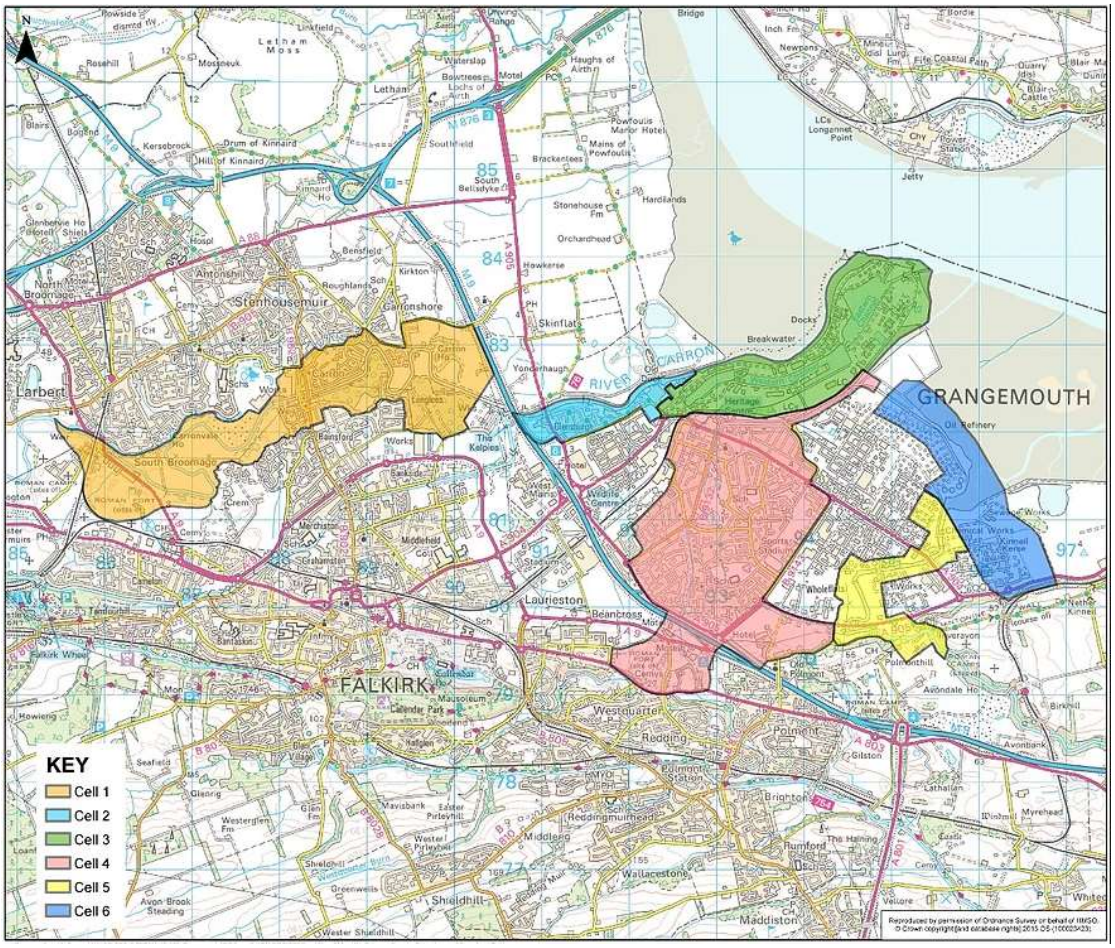

Figure 26: *Flood cell layout*

3.4 Proposed Options

3.4.1 Defining Defence Options

3.4.1.1 Direct Defences

For the purposes of this report, direct defences are defined as wall or embankment structures which are designed to a height to stop water overtopping them. Typically, these structures consist either of

an earth embankment with an impermeable core or a concrete wall. At the option appraisal no assumption has been made on the requirement for a seepage barrier. This may be required to prevent water seeping under the defences when the water level is elevated above the ground level on the other side. Through Ground Investigation works, the seepage rates will be determined which will allow the depth of seepage barrier to be calculated.

For the option appraisal, the sketches below outline a typical flood wall:

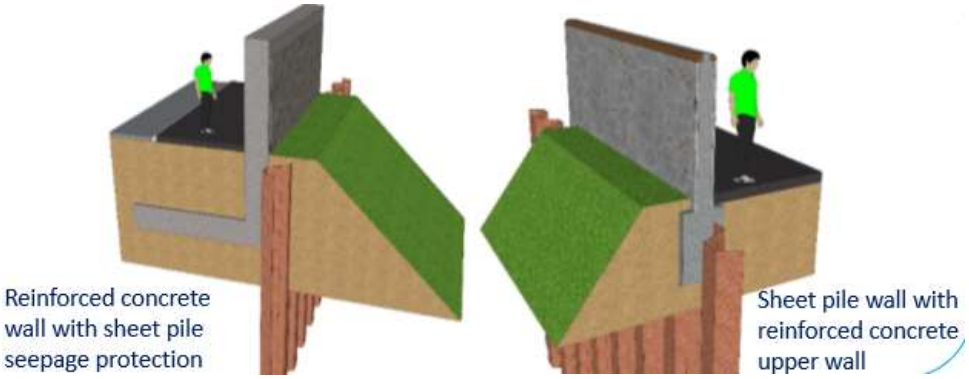

Figure 27: *Typical Flood Wall with sheet-piles.*

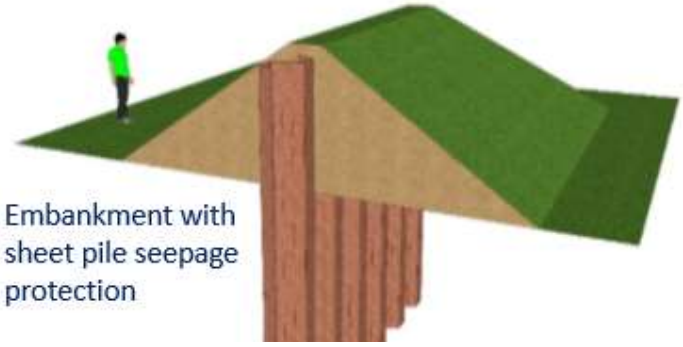

Figure 28: *Typical embankment with sheet pile seepage integrated into structure.*

3.4.1.2 Property Level Protection

For the option appraisal, property level protection is defined as temporary barriers that are installed at individual buildings to prevent water ingress through doorways, air-bricks and other voids. Property level protection is deemed appropriate for flood depths less than 0.6m, subject to low velocities and building structure being of a suitable construction. If property level protection is deemed appropriate, the following need to be considered:

- access to install;
- storage;
- sufficient warning required for property level protection to be installed;
- maintenance;

- ownership and responsibility for items;
- emergency plan for exceedance;

Property level protection maybe deemed appropriate when used in conjunction with other options but will not be considered as a standalone measure.

3.4.1.3 Temporary Direct Defences

These are defences that can be installed in a short period to stop the majority of flood water from inundating an area with no permanent infrastructure installed. They can take many forms from water filled tubular structures to structures constructed from steel frames with polythene sheeting.

3.4.1.4 Introducing the Options

Following the brainstorming exercise, the remaining options were taken forward for detailed appraisal. Table 14 ; briefly sets out each of the proposed options. More detail of each option can be found in section 3.4.1.7 of this report.

Flood Cell No.	Flood Cell Name	Option No.	Description	Level of Protection
1	Upper Carron	1a	Direct defences on both existing banks	1 in 200 years
		1b	Direct defences on both existing banks	1 in 100 years
		1c	Realign part of the River Carron (right bank), direct defences next to realigned channel	1 in 200 years
		1d	Realign part of the River Carron (right bank), direct defences next to realigned channel	1 in 100 years
2	Lower Carron	2a	Direct defences on existing right bank only	1 in 200 years
3	Harbour	3a	Direct defences on existing bank	1 in 200 years
4	Grange Burn (and FRC)	4a	Direct defences on both existing banks of the Grange Burn and some defences on the FRC	1 in 200 years
		4b	Direct defences on both existing banks of the Grange Burn and some defences on the FRC and PLP for some properties in Grangemouth	1 in 100 years
		4c	Create FSA on Westquarter Burn, some direct defences on FRC and Grange Burn, tidal barrier and control gate on Grange Burn / FRC	1 in 200 years
		4d	Create FSA on Westquarter Burn, some direct defences on FRC and Grange Burn, tidal barrier and control gate on Grange Burn / FRC	1 in 100 years
		4e	Direct defences on existing banks of the Grange Burn and around Zetland Park and some of the FRC and PLP for some properties in Grangemouth	1 in 200 years
		4f	Direct defences on existing banks of the Grange Burn and around Zetland Park and some of the FRC and PLP for some properties in Grangemouth	1 in 100 years
		4g	Some direct defences on the banks of the Grange Burn, with a flow control structure at the FRC limiting flows down the Grange Burn. Defences are required along the majority of the FRC.	1 in 200 years
		4h	Flow control structure at the FRC limits flows on the Grange Burn. Additionally, a tidal barrier at the mouth of the Grange Burn limits tidal flows up the Grange Burn. Some direct defences are required	1 in 200 years

Flood Cell No.	Flood Cell Name	Option No.	Description	Level of Protection
			on the Grange Burn, as well as the banks of the FRC. This option utilises Zetland Park for flood storage.	
		4i	Flow control structure at the FRC limits flows on the Grange Burn and a tidal barrier at the mouth of the Grange Burn limits tidal flows up the Grange Burn. Additionally, a flow control structure at Zetland Park would limit flow on the lower section of the Grange Burn and reduce the extent of direct defences. Some direct defences are required on the FRC and on a short section of the Grange Burn.	1 in 200 years
5	Avon	5a	Direct defences on both existing banks	1 in 200 years
6	Estuary Frontage	6a	Direct defences on existing bank	1 in 200 years

Table 14: Outlines the options considered in the option appraisal

3.4.1.5 Merged Flood Cells

Estimated damages within the petrochemical plant and port area are intrinsically linked. Therefore, the options for Flood Cells 3, 5 and 6 have been merged for the option appraisal. Table 15 outlines the proposed options within Flood Cells no. 3, 5 and 6 being appraised in this report.

Flood Cell No.	Flood Cell Name	Option No.	Description	Level of Protection	Merged Options
3	Harbour	3a	Direct Defences on existing bank	1 in 200 years	3a, 5a & 6a
5	Avon	5a	Direct Defences on both existing banks		
6a	Estuary Frontage	6a	Direct defences on existing banks		

Table 15: Identifies the cells with have been merged.

3.4.1.6 Standard of Protection for appraised options

The Scottish Government's '*Option appraisal for flood risk management: Guidance to support SEPA and the responsible authorities´* states that varying the level of protection for a flood protection scheme can be difficult to justify. It is recommended that flood protection schemes maintain the same level of protection between all flood cells. It may be more practical to define a minimum level of protection which the scheme will provide, e.g. the scheme will provide a minimum 1 in 100-year level of protection.

Falkirk Council have defined the minimum level of protection for the scheme to be 1 in 200-year, being the minimum standard of protection, they would require for any new development. Adopting 1 in 200 years for the scheme aligns with this requirement and will also ensure the scheme can assist in the future regeneration of the Grangemouth area. This will be reviewed on a cell-by-cell basis, as some cells may require a lower level of protection e.g. due to stakeholder concerns with the height of defences.

There may be areas which have a higher level of protection than the defined minimum standard, driven by legislation and the practicalities of constructing flood defences. For Flood Cells no. 3, 5 & 6 (petrochemical plant and port area), there may be justification to provide greater than1 in 200-year level of protection. Ongoing dialogue with petrochemical plant stakeholders is taking place to determine the most appropriate level of protection for this area.

3.4.1.7 Appraising the options

A multi criteria analysis (MCA) has been used to help evaluate the proposed options and identify a preferred scheme. The MCA uses the following topics to evaluate options:

- Benefit Cost Ratio – this assesses the potential flood damages against the estimated capital cost of constructing flood defences;
- Environmental – assesses the option against environmental criteria linked to the scheme objectives, with options scored and ranked against other options in that cell;
- Social – assesses the option against social criteria linked to the scheme objectives, with options scored and ranked against other options in that cell;

- Utility – assesses the option against criteria relating to impact on the existing utility network, with options scored and ranked against other options in that cell;
- Operational Risk – assess the operational risks associated with each option, these will be scored against criteria determined by the project team and Falkirk Council;
- Carbon Footprint – estimate the Carbon footprint of flood defences based on a wall structure
- Included in the capital cost estimate is an uplift on rates to account for difficult access, significant temporary works etc.

Operational risk has been scored and recorded in the MCA but is not included in the overall option scoring. The operational risk associated with some options is considerable and therefore requires Falkirk Council's input into the decision-making process. Any option that is assigned an operational risk score of 3 – High Operational risk (scores 3) will be reviewed by Falkirk Council and potentially discounted from the option appraisal. Falkirk Council may veto any of the proposed options if they deem the option is not practical from an operational risk perspective.

A 100-year appraisal period will be used, except for the petrochemical plant which will be appraised over a 50-year period. The justification for the lower appraisal period is due to the bespoke nature of work undertaken at the petrochemical plant and evidence from similar sites which deem a 50-year period appraisal period as appropriate. Based on this, the damage figures for the petrochemical plant quoted in this option appraisal are conservative as buildings and infrastructure would be affected by flooding from 51-years onwards.

3.4.1.8 Flood Cell 1 - Carron Upper

The principal source of flooding in this cell is fluvial, (River Carron overtopping its banks); tidal flows do influence the lower sections of this cell.

Within Flood Cell 1 there are four options being proposed, 1a, 1b, 1c and 1d.

Within this cell, the 1 in 100-year and 200-year levels of protection have been included in the option appraisal. Consideration of a lower-level protection is driven by the height and extent of direct defences. The limited space on the banks of the River Carron mean it is likely that some defences will be within the rear gardens of residential properties. To reduce the extent and height of defences near residential properties the 1 in 100-year level of protection was assessed.

All options are likely to interface with Scottish Waters Carronside Pumping Station and Abbots Road Sewerage Treatment Plant.

3.4.1.8.1 Option 1a

Introduction

Requires the construction of intermittent defences from Stirling Road to Carron House, on both the left and right banks. Space for constructing defences is particularly restricted on the banks from the Old Carron Dams site downstream. Construction work may need to take place in the watercourse, with significant temporary works required. A wall may be the preferred type of flood defence due to reduced land take, however, there are some opportunities for embankments which offer additional environmental benefits such as habitat improvements and enhancing biodiversity.

Flood Extents

The main onset of flooding for Stirling Road is around the 20-year event with Stirling Road (A9) underwater, this which would have a significant impact on the bus depot on Stirling Road. The onset of

flooding along Beaumont Drive is around the 50-year event, however once flooding occurs, the residential area to the north of Beaumont Drive is inundated with many properties flooded. The onset of flooding for Carronshore (near Carron House) occurs at around the 20-year event level.

Key Factor for this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	3.5	2,732	1 in 200-year	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimate of Carbon footprint* (Rank, compared to other options)
1.4 (4)	2 (3)	2 (1)	3 (1)	1028 (2)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £20.9M; this is based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential and the estimated Present-Day Benefits (damages avoided) are £30.1M.

Environmental

Some direct defences are within the buffer zone of a Local Nature Reserve, SSSI – Carron Dams and of Listed Buildings. It is likely that temporary construction work will be required within the channel. Limited opportunity for enhancing habitat due to limited space on the existing bank; proposed alignment of defences is very close to/ along the boundary of residential properties therefore significant disturbance is likely. Requires existing vegetation on the banks to be cleared. Defence structure will be engineered to be sympathetic to the local environment where possible. Potential for some defences to be embankments but limited in extent due to land-use pressure.

This option is likely to meet 2 of the 4 environmental objectives

Social

Provides flood protection and improves safety and wellbeing for communities along the River Carron. Limited opportunity for local path network to be incorporated into defences due to limited space on the existing bank for the alignment of defences (potential for defences to be on the boundary of residential properties). Limited opportunities for positive integration between communities on either bank of the River Carron due to the alignment of defences on either bank. Height of defences likely to

be more than 1m above existing ground level at crest of existing bank. These defences will have an impact on the aesthetics of the surrounding area. No work is proposed within the Community Woodland area downstream of the Old Carron Works.

This option is likely to meet 2 of the 4 social objectives

Utilities

Multiple utility diversions required; Scottish Power Transmission overhead power lines are parallel to the right bank, defences are likely to be constructed directly beneath these. Scottish Water have multiple sewers (including a syphon) and rising mains within the cell, some defences maybe near such apparatus. Some utility apparatus will need protecting. New headwall structures required at the Mungal Burn and Chapel Burn outfalls.

The existing stone retaining wall on left bank (upstream of Stenhouse Bridge) will need to be assessed to determine its structural condition, this will be reviewed at the outline design stage. Some bridge parapet walls will need to be assessed to determine structural integrity and parapet height. Flood gates may need to be installed across the carriageway at either end of the bridges.

This option has been scored as a 3 out of 5, as there are multiple intermediate utility diversions required which are likely to cost > £1M.

Operational Risk

Scored as 1 out of 3, this option has low operational risk as most of the proposed defences are wall / embankment structures. All headwalls would be fixed with non-return values to limit flows backing up the pipe / channel. Possible need for flood gates.

Conclusion

Access to construct defences will require significant enabling work, out-with and within the channel. The alignment of defences will require consultation with multiple stakeholders and residents; potential for numerous compensation claims. Potential for significant opposition to defences which are within the rear gardens of residential properties. Significant disruption caused to local community through construction period.

3.4.1.9 Option 1b

Introduction

Requires the construction of intermittent flood walls and embankments from Stirling Road to Carron House, on both the left and right banks. Space for constructing flood defences is particularly limited on both banks from the old Carron Dams site downstream. Construction work may take place in the watercourse with a wall structure being the preferred method of defence due to reduced land take. Potential to replace direct defences with property level protection near Carron House. There is some opportunity for embankments which offer additional environmental benefits such as habitat improvements and enhancing biodiversity.

Flood Extents

The main onset of flooding for Stirling Road (A9) is around the 20-year event with the carriageway under water by the 50-year event which would have a significant impact on the bus depot. The onset of flooding along Beaumont Drive is around the 50-year event, however, once flooding occurs, the

residential area to the north of Beaumont Drive is lower than the bank level and results in many properties flooding. The onset of flooding for Carronshore (near Carron House) is around the 20-year event.

The level of protection offered by this option is lower than option 1a. There is a reduction of between 0.2m – 0.7m in baseline water levels from the 100-year (option 1b) to 200-year (option 1a) events within this cell.

Key Factor for this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	3.5	2,467	1 in 100-year	Yes

Option Matrix Scores

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.8 (1)	2 (3)	2 (1)	3 (1)	928 (1)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £12.8M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential, the estimated the Present-Day Benefits (damages avoided) is £23.3M.

There is the potential for some PLP to properties in Carronshore; this would reduce the capital cost of this option and increase the benefit cost ratio, however, for this report, only direct defences will be included.

Environmental

Some direct defences are within the buffer zone of a Local Nature Reserve, the SSSI – Carron Dams and of Listed Buildings. It is likely that temporary construction work will be required within the channel. There is limited opportunity for enhancing habitat due to limited space on the existing bank; the proposed alignment of defences is very close to / within the boundary of residential properties (significant disturbance likely). Requires existing vegetation on the banks to be cleared. Defence structure will be engineered to be sympathetic to the local environment where possible. Potential for some defences to be embankments but limited in extent due to land-use pressure.

This option is likely to meet 2 of the 4 environmental objectives

Social

Provides flood protection and improves safety and wellbeing for communities along the River Carron. Limited opportunity for local path network to be incorporated into defences due to limited space on the existing bank for the alignment of defences (potential for defences to be within the gardens of residential properties). Limited opportunities for positive integration between communities on either bank of the River Carron due to the alignment of defences on either bank. Defence structures are likely to less than 1m above existing ground level at the top of the existing bank which will have an impact on the aesthetics of the surrounding area. No work is proposed within the Community Woodland.

This option is likely to meet 2 of the 4 social objectives

Utilities

Multiple utility diversions required; Scottish Power - Transmission overhead power lines are parallel to the right bank, defences are likely to be constructed directly beneath power lines. Scottish Water have multiple sewers (including syphons) and rising mains within the cell, some defences will need to be aligned away from such apparatus, some apparatus will need protecting. Headwall required at Mungal Burn and Chapel Burn outfalls.

The existing stone retaining wall on left bank (upstream of Stenhouse Bridge) will need to be assessed to determine its condition and the feasibility of raising the height of the existing wall, if this is not possible flood gates will be required.

This option has been scored as a 3 out of 5, as there are multiple intermediate utility diversions required which are likely to cost > £1M.

Operational Risk

Scored as 1 out of 3, low operational risk as most of proposed defences are wall / embankment structures. All headwalls would be fixed with proprietary non-return values to reduce the risk of water backing up the channel.

Conclusion

Access to construct defences will require significant enabling work, out-with and within the channel. The alignment of defences will require consultation with multiple stakeholders and residents; potential for numerous compensation claims, depending on the structure of defence and required access to construct defences. The extent and height of defences is reduced when compared to option 1a, which is beneficial. Potential for significant opposition to defences which are within the rear gardens of residential properties. Significant disruption caused to local community through construction period.

3.4.1.10 Option 1c

Introduction

Requires the construction of intermittent direct defences from Stirling Road to Carron House, on both the left and right banks. Space for constructing defences is particularly limited on both banks from the old Carron Dams site downstream, due to dense land-use. Realign part of the River Carron, directly downstream of Carron Bridge (B902) into the Community Woodland area on the right bank. Realigning the channel would increase the potential for flood defences to be constructed further away

from residential properties on the left bank. Less construction work would take place in the channel, defences downstream of Carron Bridge would be set-back from the channel edge. Space for constructing flood defences upstream of Carron Bridge is still limited on both banks, some construction work may take place in the watercourse. There is more likely to be opportunities for embankments which offer additional environmental benefits such as habitat improvements and enhancing biodiversity with this option.

Flood Extent

The main onset of flooding for Stirling Road is around the 20-year – Stirling Road (A9) with the road underwater by the 50-year event which would have significant impact on businesses on Stirling Road. The onset of flooding along Beaumont Drive is around the 50-year event, however once flooding occurs the residential area to the north of Beaumont Drive is lower than the bank level and results in many residential properties flooding. The onset of flooding for Carronshore (near Carron House) is around the 20-year event.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment with realigned channel	3.5	2,732	1 in 200-year	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.4 (4)	3 (1)	2 (1)	1 (4)	22,199 (4)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £21.8M, this based on an optimum bias of 60% and includes whole life costs. This cell is predominantly residential, the estimated the Present-Day Benefits (damages avoided) is £30.1M.

Environmental

Some direct defences are within the buffer zone of a Local Nature Reserve and SSSI – Carron Dams. Some also directly impact some Listed Buildings. Likely that temporary construction work will be required within some parts of the channel. Realigning the channel would have significant impact on the right bank (Community Woodland), however, this would allow defences on the left bank to be constructed further away from residential properties. Potential for enhanced bank habitat to be created, opportunities for wider habitat enhancements through the creation of additional banks. Requires existing vegetation on the banks to be cleared. Defence structure will be engineered to be sympathetic to the local environment where possible. Potential for some defences to be embankments but limited in extent due to land-use pressure.

This option is likely to meet 3 of the 4 environmental objectives.

Social

Provides flood protection and improves safety and wellbeing for communities along the River Carron. Opportunity to expand foot / cycle path networks within area of realigned channel. Potential for the alignment of some defences downstream of Carron Bridge to be set-back from residential properties. Majority of defence structures are approx. 1.0m above existing ground level at crest of bank; these will have an impact on the aesthetics of the surrounding area. Limited opportunities for positive integration between communities on either bank of the River Carron due to the alignment of defences on either bank.

This option is likely to meet 2 of the 4 social objectives.

Utilities

There would be major utility clashes with Scottish Water sewers and the realigned channel. Additionally, high voltage overhead power lines are within the area of the realigned channel. Both (sewers and power lines) apparatus have potential time and cost implications regarding diversions. There is potential for proposed defences on the left bank of the River Carron, downstream from Carron Bridge, to be aligned further away from Scottish Water apparatus, however, utility clashes remain upstream of Carron Bridge.

Access to Carronside Pumping Station will need to be assessed when considering this option.

This option has been scored as a 1 out of 5, with major utility diversions required at multiple locations which are likely to cost > £2M and have considerable time implications.

Operational Risk

Scored as 1 out of 3, low operational risk as most of proposed defences are wall / embankment structures. All headwalls would be fixed with proprietary non-return values to reduce the risk of flood backing up the channel.

Conclusion

A significant benefit of this option is aligning some of the defences further away from residential properties along part of the River Carron, which would have social benefits. Realigning part of the River Carron is likely to result in major utility clashes, which will have significant time and cost implications and will require further consultation with statutory operators to determine the feasibility of this option. This option would have a significant impact on existing Community Woodland and surrounding area

but does offer an opportunity for creating new habitat on the realigned channel and reprofiled existing bank. Some temporary construction work is likely to take place within the channel but reduced in length compared to Options 1a and 1b.

3.4.1.11 Option 1d

Introduction

Requires the construction of intermittent direct defences from Stirling Road to Carron House, on both the left and right banks. Space for constructing defences is particularly limited on both banks from the old Carron Dams site downstream, due to dense land-use. Realign part of the River Carron, directly downstream of Carron Bridge (B902) into the Community Woodland area on the right bank. Realigning the channel would increase the potential for defences to be constructed further away from residential properties on the left bank. Less construction work would take place in the channel, defences downstream of Carron Bridge would be set-back from the channel edge. Space for constructing flood defences upstream of Carron Bridge is still limited on both banks so some construction work may take place in the watercourse. There are more likely to be opportunities for embankments which offer additional environmental benefits such as habitat improvements and enhancing biodiversity with this option.

Flood Extent

The main onset of flooding for Stirling Road is around the 20-year – Stirling Road (A9) with the road underwater by the 50-year event which would have significant impact on businesses in the area. The onset of flooding along Beaumont Drive is around the 50-year event, however once flooding occurs, the residential area to the north of Beaumont Drive is lower than the bank level and results in many residential properties flooding. The onset of flooding for Carronshore (near Carron House) is around the 20-year event.

The level of protection offered by this option is lower than option 1a & 1c. There is a reduction of between 0.2m – 0.7m in baseline water levels from the 100-year (option 1b) to 200-year event within this cell.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment with realigned channel	3.5	2,467	1 in 100-year	Yes

Option Matrix Scores:

Benefit / Cost Ratio	Environmental Score	Social Score	Utility Score	Estimated Carbon

(Rank, compared to other options)	(Rank, compared to other options)	(Rank, compared to other options)	(Rank, compared to other options)	footprint* (Rank, compared to other options)
1.7 (2)	3 (1)	2 (1)	1 (4))	22,100 (3)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £13.8M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential and the estimated the Present-Day Benefits (damages avoided) is £23.3M.

There is the potential for PLP which would reduce the capital cost of this option and increase the benefit cost ratio. However, for this report, direct defences will be included near Carron House.

Environmental

Some direct defences are within the buffer zone of a Local Nature Reserve and SSSI – Carron Dams and directly impact Listed Buildings. It is likely that temporary construction work will be required within some parts of the channel. Realigning the channel would have significant impact on the right bank (Community Woodland), however, this would allow defences on the left bank to be constructed further away from residential properties. Potential for enhanced bank habitat to be created, opportunities for wider habitat enhancements through the creation of additional banks. Requires existing vegetation on the banks to be cleared. Defence structure will be engineered to be sympathetic to the local environment where possible. Potential for some defences to be embankments but limited in extent due to land-use pressure.

This option is likely to meet 3 of the 4 environmental objectives.

Social

Provides flood protection, improves safety and wellbeing to communities on the River Carron. Potential for improved path network in the area, particularly parallel to the realigned channel. Alignment of proposed defences could be further away from residential properties which would have visual benefits. Increased potential opportunity for embankments rather than wall structures, which would be more sympathetic to the surrounding area and local community.

This option is likely to meet 2 of the 4 social objectives.

Utilities

Major utility clashes with Scottish Water sewers and the realigned channel. Additionally, Scottish Power high voltage overhead power lines are within the area of the realigned channel. Both apparatuses have significant time and cost implications if diversions are possible. Potential for proposed defences on the left bank of the River Carron, downstream from Carron Bridge to be aligned further away from Scottish Water apparatus, however utility clashes remain upstream of Carron Bridge.

Access to Carronside Pumping Station will need to be assessed when considering this option.

This option has been scored as a 1 out of 5, with major utility diversions required at multiple locations which are likely to cost > £2M and have considered time.

Operational Risk

Scored as 1 out of 3, low operational risk, most of proposed defences are wall / embankment structures. All headwalls would be fixed with proprietary non-return values to reduce water backing up the channel.

Conclusion

A significant benefit of this option is aligning some of the defences further away from residential properties along part of the River Carron, which would have social benefits. Most of the defence heights would be approx. 1.0m above ground level at the crest of the existing bank. Realigning part of the River Carron is likely to result in major utility clashes, which will have significant time and cost implications and require further consultation with statutory operators to determine the feasibility of this option. This option would have a significant impact on existing Community Woodland and surrounding area but does offer an opportunity for creating new habitat on the realigned channel and reprofiled existing bank. Some temporary construction work is likely to take place within the channel, but reduced extent compared to Options 1a, 1b & 1c.

3.4.2 Flood Cell 2 - Lower Carron

Only one option has been appraised for Flood Cell 2. Most of the land-use in this cell is classified as commercial, with one building classified as a '*Major accident hazard site'*. The 1 in 200-year level of protection was deemed by Falkirk Council as the most appropriate level of protection that should be afforded to this cell. This is the only level of protection that has been included in this appraisal.

Several walls and embankments have been surveyed and are shown in the model to be at sufficient heights to prevent overtopping. Currently, these structures have been included in the scheme. At the outline design stage, further investigation will be required to determine the integrity of the existing banks.

3.4.2.1 Option 2a

Introduction

Requires construction of direct defences on the right bank of the River Carron, from the Scottish Water pumping station at Clyde Street to North Shore Road, beyond the Leisure Harbour. No defences are proposed on the left bank (Skinflats).

Space on the existing bank is very limited, due to commercial activity close to the riverbank. The existing riverbank is a mixture of sloping mud-flats and ad-hoc historic quay walls, the majority of which are in an extremely poor state or have failed completely. Most of the defences in this cell are likely to be wall structures due to the limited space on the existing bank. Due to the poor structural condition of existing quay walls, it is likely that any new flood defence will have to be constructed in front of the existing structure or the flood defence will have to be designed to retain the existing bank. Access to the Leisure Harbour will need to be maintained, possibly by using flood gates.

Flood Extents

The onset of flooding for this cell is around the 1 in 20-year return period; the principal source of flooding is from the Forth Estuary. Defences within this cell, provide flood protection to commercial and residential property. It is worth noting that without flood defences, a significant number of residential properties in the Glensburgh area remain at flood risk. The height of proposed flood defences in this cell are up to 1.5m above existing ground level.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.5	1,355	1 in 200-year	Yes - around leisure harbour to maintain access to channel

*based on sheet-pile concrete wall construction

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
3.1 (1)	3 (1)	4 (1)	1 (1)	495 (1)

Benefit Cost Ratio

The Capital cost estimate for this option is £6.4M, based on an optimum bias of 60% and including whole life costs. Property in this cell is predominantly commercial the estimated the Present-Day Benefits (damages avoided) is £20.4M.

Environmental

The alignment of the proposed defences is out-with the SPA site; however, construction work associated with the defences may impact the functionality of qualifying species to the SPA. An HRA will been undertaken assess the impact of the proposed works on the SPA. There is the opportunity for some habitat creation, particularly where embankment structures are used. Direct defences in this cell are likely to be a mixture of walls and embankments, with a revetment structure in front of any flood defence.

Some construction work is likely to be required within the channel due to the poor condition of some existing bank structures. Any work in the channel will require consent from the appropriate consenting body.

This option is likely to meet 3 of the 4 environmental objectives.

Social

Provides flood protection and enhances the safety and wellbeing of communities in Grangemouth. Improves business confidence in the area, which has positive direct and indirect impacts on the wider community. Supports National Planning Framework 3 which identifies investment as a key part of the Grangemouth Regeneration Strategy '*to attract more commercial activity to the area to ensure a vibrant economy that is sustainable and attractive for commercial and residential purposes*'. Potential links to wider footpath network and opportunity to promote local history through interpretation boards.

This option is likely to meet 4 of the 4 social objectives.

Utilities

There are a significant number of utility clashes around the leisure harbour and limited space on the existing bank to divert utilities. It is therefore likely that the alignment of the flood defences may need to be at the channel edge which would require construction work to take place in the channel or set back significantly from the channel edge which would leave some properties at flood risk. Work to protect some utilities in this cell may also be required.

The interface between proposed flood defences and Dalgrain Pumping Station on the banks of the River Carron will need to be managed so discussions with Scottish Water will be required.

This option has been scored as a 1 out of 5, with major utility diversions required at multiple locations which are likely to cost > £2M and have considerable time implications to plan/ programme utility works.

Operational Risk

Scored as 1 out of 3, low operational risk as most of proposed defences are wall / embankment structures. All headwalls would be fixed with proprietary non-return values to reduce water backing up.

Conclusion

For the purposes of this option appraisal, the existing embankment / wall to the rear of the canal (downstream of A905 – Glensburgh Road) and stop-log will be assumed to be in good working condition and functioning as a flood defence. Further discussion with Falkirk Council will be required on how the flood protection scheme interacts with existing Falkirk Council flood defences.

The extent and height of flood defences within this cell is dictated by the 1 in 200-year level of protection. More detail on the exact alignment of defences will be developed at the outline design stage. Through discussions with landowners, access points may need to be incorporated into the design of flood defences to maintain access to the channel.

3.4.3 Flood Cells 3, 5 and 6 (Port, Avon and Estuary Frontage)

Due to the complex nature of work within the petrochemical plant and port area, options relating to these cells have been merged together. From discussions with stakeholders it became apparent that industrial sites within these three cells are intrinsically linked and it would be difficult to separate the cells when calculating the Benefit Cost Ratio.

Due to the nature of work undertaken within Flood Cells 3, 5 & 6, it was deemed by Falkirk Council that the 1 in 200-year level of protection should be viewed as the minimum level of protection offered with an allowance for Climate Change included in the defence heights.

Within the Flood Cells an assumption has been made that all existing banks and walls that are at the required height to prevent flooding are incorporated into the scheme. At the outline design stage, further structural and Ground Investigation work will be required to determine the structural make-up and integrity of these structures.

Discussions are ongoing with Forth Ports to determine the how the height of the existing lock-gates can be raised. The proposed alignment of defences at the Harbour entrance mean direct defences need to tie-in with the lock gates. A separate appraisal will be undertaken of the options to protect the lock entrance. For the purposes of this report, flood defences across the lock will be assumed to be the same height as the flood defences on the surrounding land.

The Forth Estuary is designated a Ramsar, SPA, and SSSI site; discussions are ongoing with Scottish Natural Heritage regarding the HRA process.

3.4.3.1 Option 3a, 5a and 6a

Introduction

Requires direct defences on nearly all banks and along the entire estuary frontage:

3a -Direct defences aligned around the edge of the Harbour, from the breakwater on the River Carron to the mouth of the Grange Burn.

5a - Direct defences on both banks from the Jinkabout Road Bridge near Wholeflats Road to the mouth of the River Avon.

6a - Direct Defences along the entire Estuary Frontage, from Powdrake Road at the mouth of the Grange Burn to A904 Road at the eastern boundary of petrochemical plant.

The alignment of direct defences within these cells will predominantly be determined by the available space on the banks. The nature of work undertaken within the petrochemical plant is likely to determine how close the alignment of direct defences can be to the site boundary.

Direct defences within these cells are likely to be a mixture of wall and embankment structures. Along the estuary frontage wave overtopping will require a revetment to be constructed in front of the proposed defence. There is some opportunity for embankment structures in these cells, which would have environmental benefits.

Flood Extents

The onset of flooding for these cells is in places as low as the 1 in 5-year period event. The principal source of flooding is from the Forth Estuary.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from	Length of defences required - m	Level of Protection	Flood Gates Required

	existing ground level)			
Wall and Embankment	3.5	10,744	1 in 200	New raised lock gates at entrance to port, flood gates across the railway line into Petroineos's site.

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
37.4 (2)	1 (1)	4 (1)	1 (1)	1,210 (2)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £102M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly non residential and the estimated present-day benefits are in excess of £3.8Bn. The damages avoided accounts for direct and indirect damage costs which are based on a temporary closure of the petrochemical plant for 2 weeks. This estimate does not account for indirect damage to infrastructure out with the port area and petrochemical plant sites.

Environmental

It is highly likely construction work will encroach into the SPA. The alignment of proposed defences is dictated by multiple pipelines along the estuary frontage and the banks of the River Avon. There is the potential for the scheme to impact the functionality of qualifying species / habitat of the SPA, therefore an HRA will be undertaken.

Where possible, the alignment of defences will be outside the SPA boundary. However, this is unlikely to be possible in all instances due to the location of buried utilities and above ground pipelines associated with the petrochemical plant. With reference to Cell 5 there is limited space on the bank crest to align defences. To reduce the footprint of the defence structure, it is likely that a wall will be the favoured structure.

Interaction between the scheme and the SPA is primarily at Cells 3 and 6. Through initial discussions with SNH, the project team have been advised that an HRA is required with the potential for an appropriate assessment to determine whether the scheme will have a significant adverse impact on the integrity of the SPA.

Bo'ness Road Bridge is a Listed Building so direct defences are required either side. Some direct defences along Wholeflats Road (cell 5) are within the World Heritage Site Buffer Zone.

This option is likely to meet 1 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth including the industrial area by providing flood protection. The Grangemouth industrial area is of national significance to Scotland and the UK and locally important to the local community through employment and investment. The scheme is identified in National Planning Framework 3 as part of the regeneration of Grangemouth and Grangemouth Investment Zone which is of national importance to the Scottish and UK economies.

This option is likely to meet 4 of the 4 social objectives.

Utilities

- **Cells 3 and 6**

  Numerous above ground pipelines are located near the entrance to the port and along the petrochemical plant boundary. These pipelines are owned and operated by stakeholders from the petrochemical plant.

  Most pipelines in these areas are pressurised and provide critical links between the port area and the petrochemical plant. Diverting pipelines in most cases should be avoided due to the financial and practical implications of turning-off the pipelines and limited locations to divert pipeline to. Where possible the alignment has been selected to avoid known pipelines.

  Along the Estuary Frontage several existing outfalls will need to be maintained and incorporated into the defence structure with proprietary non-return valves fitted.

- **Cell 5**

  Multiple large diameter (>DN500) pipes. Some of these pipelines are classified as '*major accident hazard pipelines*'. It is not feasible for these pipelines to be moved, therefore the alignment of direct defences will need to account for them.

  Numerous pipe bridges traverse the River Avon. The scheme will need to incorporate above ground pipes into the defence structures.

  Scottish Water have two DN 1050 Strategic mains on the banks of the River Avon. From initial discussions with Scottish Water, moving these mains is not feasible as these serve the town of Grangemouth.

  Scottish Power has a sub-station on the banks of the River Avon. As mentioned in section * of this report, there are high voltage overhead power lines near a section of the left bank and buried high voltage cables along a section of the right bank. There is very limited space to divert the buried power lines, therefore where possible the alignment of the direct defences will be away from utilities; if this not possible, additional protection may be required where defences are constructed directly over utilities.

  In 2016 INEOS began importing Ethane (sourced from shale gas in the USA) at Grangemouth. A new Ethane tank and pipeline has been constructed which runs from the mouth of the River Avon, along the estuary frontage to the port of Grangemouth. The pipeline is above ground and within the site boundary of INEOS and Petroineos's site. Discussions are ongoing with INEOS to determine how close construction work can be to the Ethane pipeline.

Within the petrochemical plant site, there are number of flare stacks. The safety requirements (minimum safety distance) for working close to flare stacks may determine the alignment of direct defences in parts of this cell. Discussions with INEOS and INEOS FPS are ongoing to determine the minimum required safety distance.

This option has been scored as a 1 out of 5, with major utility diversions required at multiple locations which are likely to cost > £2M and have considerable time implications to plan/ programme utility works.

Operational Risk

Scored as 2 out of 3, moderate operational risk, some mechanical control gate structures are required. Most of the proposed defences are wall / embankment structures, however, flood gates across the ship lock (at the entrance to the port) and railway line (at Petroineos's site) will be required. All headwalls would be fixed with proprietary non-return values to reduce water backing up.

Conclusion

There are limited alternative options for these cells, due to the utility (pipelines) and environmental constraints. It should be noted that several external stakeholders are likely to have a significant input into the alignment of flood defences in these Flood Cells.

- SNH and other responsible authorities may have significant input into the alignment of defences in these cells.
- Discussions with petrochemical plant stakeholders is ongoing; it is likely more detail on pipelines will become available which will ultimately determine the alignment of the defences in these cells.
- The 1 in 200-year level of protection was deemed the minimum level of protection which should be afforded to these cells, by the project team.
- An allowance for Climate Change should be included in the design of flood defences.
- It is likely that significant temporary works will be required for these cells, which may involve construction work within the channel / estuary (SPA) site.

3.4.4 Flood Cell 4 – Grange Burn / Flood Relief Channel

Within Flood Cell 4, initially, no. 9 options have been appraised; this cell mainly covers the residential area of Grangemouth.

The following points need to be considered when reviewing options in cell 4:

- Wider disruption to Grangemouth during the construction phase;
- Consider flooding from fluvial and tidal sources and review joint probability of tidal and fluvial events;
- Significant number of utilities within Grangemouth;
- Extent and height of defences is likely to have a significant impact on the local environment / community;
- Ongoing maintenance and operational risk associated with components of that option; and
- The level of protection for some options in this cell varies.

3.4.4.1 Option 4a

Introduction

This option consists of direct defences on both banks of the Grange Burn from Rannoch Park to Powdrake Road, on the left bank of the FRC from Rannoch Park to Grange Road and on the right bank around the residential properties on Reddoch Road (confluence of the FRC and the River Avon). No structures are proposed in the channel.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	8,158	1 in 200-year	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.7 (8)	1 (9)	2 (8)	1 (9)	3,070 (8)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £48.8M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) are £84.0M (based on flood extents as known at this time). The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

The proposed alignment of defences will have a significant environmental impact on the urban area of Grangemouth; many of the trees on the existing bank would need to be felled and replaced (to allow construction work to take place on the existing bank / channel edge). Felling trees within an urban environment may have a perceived negative impact and would require some compensatory planting / replanting.

Opportunities to reduce the environmental impact and incorporate environmental enhancements are limited due to existing utilities and urban location (land-use). Most of the defences for this option would be walls due to limited space on the existing bank. Potential for significant impact upon the fabric and setting of Grangemouth. Some of the proposed direct defences are located within the World Heritage Site Buffer Zone of the Antonine Wall, no defences would directly impact the Antonine Wall (Scheduled Monument). There are several Listed Buildings in Grangemouth, some of which are near the proposed alignment of defences, however, at this stage it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

The proposed alignment of defences would have an impact on Zetland Park and require some re-landscaping of the park. If this is the preferred option, the re-landscaping would be assessed in more detail at the outline design stage.

The height and appearance of defences for this option is likely to be contentious, due to the potential environmental and social impact of the defences on communities in Grangemouth. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Most of the defence heights are likely to be 1.0 - 1.5m, above existing ground levels. Due to the urban environment it is likely the height of defences will have a significant aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 1 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection, increased commercial confidence for businesses in the town centre of Grangemouth. Proposed alignment of defences will have significant impact on local communities; potentially forming a physical barrier between communities. Limited space for community enhancements to be incorporated into the defence structure due to limited space on the existing banks (urban environment). Not fully compliant with National Planning Framework 3 or Falkirk Corporate documents / strategies.

All road and foot bridge crossings will need to be maintained and require either flood gates or flood defences. An assessment of the bride integrity should be undertaken to determine the potential impact of flood water on the overall bridge structure.

This option is likely to meet 2 of the 4 social objectives.

Wider Disruption to Grangemouth

Construction of over 8,000m of direct defences through a densely populated urban area will result in some disruption. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partial / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Utilities

Significant clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to number of utilities that require diverting. Proposed alignment of defences on the FRC will be near pressurised oil pipelines.

Scottish Water have a Pumping Station in Zetland Park with an outfall into the Grange Burn. Discussions with Scottish Water will be required to determine what impact the scheme would have on their apparatus. From initial discussions it is not thought to be a significant issue. Scottish Water have multiple (>DN750) mains that cross the FRC along Wholeflats Road, via above ground pipe bridges. Any proposed direct defences on the FRC need to account for these pipe bridges in the design.

Petroineos have two pipelines (DN 300 and 550) which are located parallel to the FRC. From Inchyra Road and Wholeflats Road, one pipe is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly over the pipeline is unlikely to be allowed, with the exception of areas where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipes to, and /or it is not practical to switch the pipelines off due to economic impactions. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

This option has been scored as a 1 out of 5, with major utility diversions required at multiple locations which are likely to cost > £2M and have considerable time implications to plan/ programme utility works.

Operational Risk

The operational risk associated with this option has been categorised as 1 – low operational risk since the proposed flood defences are wall and embankment structures with no mechanical elements.

Conclusion

This option would have significant adverse impacts on environment and social aspects, due to the extent and height of proposed direct defences through Grangemouth. There would be a major impact on Grangemouth during the construction phase. Significant construction work is likely to be required on the existing banks which would entail many trees being felled and replanted. The operational risks associated with this option are low.

3.4.4.2 Option 4b

Introduction

Direct defences on parts of both banks of the Grange Burn from Rannoch Park to Powdrake Road. Additionally, direct defences are required on the left bank of the FRC from Rannoch Park to Grange Road and on the right bank around the residential properties on Reddoch Road (confluence of the FRC and the River Avon). No structures are proposed in the channel.

Flood Extent

The main onset of flooding for this cell is around the 1 in 20-year return period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.6	8,158	1 in 100 years	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.6 (9)	2 (8)	2 (8)	2 (4)	3,070 (8)

*based on sheet-pile concrete wall construction

Benefit / Cost Ratio

The capital cost estimate for this option is £42.2M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) is £68.7M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders. Property level protection has been identified as appropriate for some properties in this cell where flood depths are below 0.6m. The practicalities of installing PLP would need to be assessed if this option is taken forward. The economic assessment for this option does not include PLP as it was deemed not appropriate to be included into the appraisal matrix at this stage.

Environment

The proposed alignment of flood defences will have a substantial adverse environmental impact on the urban area of Grangemouth; a significant number of trees on the existing bank would need to be felled (to allow construction work to take place on the existing bank / channel edge). Felling such a length of trees within an urban environment, is likely to have a perceived negative impact and would require some compensatory planting.

Opportunities to reduce the environmental impact and incorporate environmental enhancements are limited due to existing utilities and urban location (high density land-use). The majority of the defences for this option would be walls due to limited space on the existing bank. There is potential for significant adverse impact upon the fabric and setting of Grangemouth. Some of the proposed direct defences are located within the World Heritage Site Buffer Zone of the Antonine Wall, although no defences would directly impact the Antonine Wall (Scheduled Monument). Several Listed Buildings are near the proposed alignment of defences, however at this stage it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

The proposed alignment of defences would have an impact on Zetland Park and would require some re- landscaping of the park. The full impact of the proposed defences on Zetland Park would be assessed at the outline design if this is the preferred option.

The height and appearance of defences for this option is likely to be contentious, due to the adverse environmental and social impact of the defences are likely to have on communities in Grangemouth. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Most of defence heights for this option are likely to be 1.0m above existing ground levels. There is potential for property level protection along part of the Grange Burn which would reduce the extent of defences required and increase opportunities for environmental enhancements. Due to the urban environment, it is likely the height of defences will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 2 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. Proposed alignment of defences will have an adverse impact on local communities; potentially forming a physical barrier between communities, however the potential for PLP would reduce the extent of defences (physical barriers). Limited space for community enhancements to be incorporated into the defence structure due to limited space on the existing banks (urban environment). Not fully compliant with National Planning Framework 3 or Falkirk Corporate documents / strategies.

This option is likely to meet 2 of the 4 social objectives.

Wider Disruption to Grangemouth

Construction of over 8,000m of direct defences through a densely populated urban area will result in some disruption. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partial / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Utilities

Major clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with the alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to the number of utilities that require diverting. The proposed alignment of defences on the FRC will be near pressurised oil pipelines.

Scottish Water have a Pumping Station in Zetland Park, which has an outfall into the Grange Burn so discussions with Scottish Water would be required.

Petroineos have two pipelines (DN 300 and 550) which are located parallel to the FRC. From Inchyra Road to Wholeflats Road, a pipe is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly over the pipeline is unlikely to be allowed, with the exception of locations where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipes to, and /or it is not practical to switch the pipelines off due to economic impactions. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

Scottish Water have multiple (>DN750) mains that cross the FRC along Wholeflats Road, via above ground pipe bridges. Any proposed direct defences on the FRC need to account for these pipe bridges which limits the potential for enlarging the FRC.

This option has been scored as a 2 out of 5, with major utility diversions required at a single location which are likely to cost > £2M and have considerable time implications to plan/ programme utility works.

Operational Risk

The operational risk associated with this option has be categorised as 1 – low operational risk since the proposed flood defences are wall and embankment structures with no mechanical structures proposed.

Conclusion

Significant adverse impact on environment and social aspects, due to the extent and height of proposed direct defences through Grangemouth. Major impact on Grangemouth during the construction phase. Likely to require significant construction work on the existing banks which will require many trees to be felled and replanted. The operational risks associated with this option are low.

3.4.4.3 Option 4c

Introduction

Create a Flood Storage Area (FSA) on the Westquarter Burn between Polmont Road and the A9, parallel to Grandsable Cemetery on Salmond Inn Road. A flow control structure (e.g. hydrobrake, orifice etc.) will be required at the outfall to control the pass forward flow.

The principals behind the FSA are to:

- only attenuate the peak flows on the Westquarter Burn from high intensity rainfall / high flow events;
- in normal conditions, flow would remain in the channel and would pass through the dam (flow control) structure;
- only when high flows occur would the flow control structure begin to restrict the outfall flow from the FSA, resulting in water attenuating in the FSA;

A control gate (flow restricting structure) at the confluence of the Grange Burn and flood relief channel (FRC) would direct most of the flow from the FSA down the FRC. Some direct defences would be required on the banks of the FRC and surrounding area. Additionally, some short lengths of direct defences would be required in Grangemouth. A tidal barrier at the mouth of the Grange Burn is required to stop tidal flows backing up the Grange Burn. The control gate at the confluence of the Grange Burn and the FRC will need to be synchronised (coordinated telemetry) with the tidal barrier to ensure no increase in flood risk for Grangemouth.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn. The principal source of flooding here is from the Forth Estuary, however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key factor for this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	3,131 + Dam Structure	1 in 200 years	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank,

				compared to other options)
2.3 (2)	4 (1)	4 (1)	3 (2)	1,191 (2)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £35.9M, based on an optimum bias of 60% and including whole life costs. The cost estimate includes the various structures included in this option. It is envisaged that only the land required for the dam structure would be purchased by Falkirk Council. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) are £84.0M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

Provides opportunity for habitat enhancement on the Grange Burn, due to short length of defences. New wetland habitat could be created within the Flood Storage Area, which would represent a positive impact on the environment. Potential for direct defences to be a mixture of wall and embankment structures. Potential significant impact on World Heritage Site, discussions with Historic Environment Scotland are ongoing. From initial correspondence, Historic Environment Scotland have intimated concern about this option on the grounds of '*significant and detrimental effects on the Outstanding Universal Value of the World Heritage Site and the setting of the schedule monument*'. Further information on this can be found in section ** of this report. Some defences are within the WHS buffer zone, however HES do not deem this to be a significant concern.

This option requires a tidal barrier which would be located out-with the Firth of Forth -Ramsar / SPA / SSSI site. The structure would cover the width of the channel and tie-in with direct defences on the right bank and existing ground on the left bank. Discussions with SNH are ongoing, regarding the HRA.

A control structure on the Grange Burn / FRC would be positioned within the channel where an existing weir is. Constructing the control structure will require some work within the channel.

Due to increased flows being directed down the FRC, some retro-fitting of the existing channel is likely to be required. There is the potential for environmental habitat enhancements on the banks of the FRC, if soft engineering techniques are used. Potential for limited re-meandering of the FRC through Rannoch Park and a short section of the Grange Burn from the M9 to Kingseat Avenue, however, these are classed as small-scale enhancements. Most of the defences on the FRC are aligned away from residential properties.

This option is likely to meet 4 of the 4 Environmental objectives.

Social

Provides flood protection and improves safety and wellbeing to communities. The short length of defences through Grangemouth maintains connectivity between communities on either bank which has the additional benefit of creating a positive and sustainable environment. Potential for enhanced tourism opportunities and public realm work linked to National Planning Framework 3 and the regeneration of Grangemouth. Opportunity to enhance / promote local and national heritage sites; potential for interpretation / information boards near the Antonine Wall.

This option is likely to meet 4 of the 4 social objectives.

Wider Disruption to Grangemouth

The short length of direct defences through Grangemouth will be beneficial to reducing disruption in and around Grangemouth town centre. Some disruption to Grandsable cemetery is expected.

Utilities

Due to the reduced extent of direct defences, the risk of utility clashes is low, however, there is still a risk of utility clashes and the need to divert / protect utilities.

A Scottish Water combined DN600 sewer is located within the FSA and will need to be diverted / protected. From initial discussions with Scottish Water there is the possibility of diverting the sewer out-with the FSA or providing protection to the sewer. The proposed direct defence alignment on the lower sections of the FRC will require construction work close to pressurised pipelines. From initial desk studies, it may be practical to align part of the direct defences within the footprint of the FRC to avoid clashing with pressurised pipelines.

The utilities were scored 3 out of 5 for this option.

Operational Risk

This option has been categorised as 3 - high operational risk; there are multiple flow control structures required for this option combined with direct defences and a flood storage area. Due to the layout of the mechanical flow control structures, some of the flow control structures need to be synchronised to ensure there is no increase in flood risk to Grangemouth.

Conclusion

This option requires several mechanical flow control structures which Falkirk Council would be responsible for (operation, maintenance and inspection). Additionally, a level of redundancy (factors of safety) would need to be built into the system. There would be limited opportunities for future resilience. The tidal barrier and flow control gate / structure at the confluence of the Grange Burn and FRC need to be synchronised to avoid increasing flood risk to Grangemouth.

Following initial correspondence with HES, they have indicated they may object to this option on the grounds of the adverse impact on the character and setting of the Antonine Wall - World Heritage Site. Discussions with HES are ongoing to determine what would be deemed acceptable from their perspective and a Heritage Impact Assessment has been undertaken, please see section ** for more information on this.

It should be noted that this option has significant positive social and environmental aspects when compared to other options.

3.4.4.4 Option 4d

Introduction

Create a Flood Storage Area (FSA) on the Westquarter Burn between Polmont Road and the A9, parallel to Grandsable Cemetery on Salmond Inn Road. A flow control structure (Hydrobrake, orifice etc.) will be required at the outfall to control the pass forward flow.

The principals behind the FSA are to:

- only attenuate the peak flows on the Westquarter Burn from high intensity rainfall / high flow events;
- in normal conditions, flow would remain in the channel and pass through the dam (flow control) structure;
- only when high flows occur would the flow control structure begin to restrict the outfall flow from the FSA, resulting in water attenuating in the FSA;

A control gate (flow restricting structure) at the confluence of the Grange Burn and flood relief channel (FRC) would direct most of the flow from the FSA down the FRC. Some direct defences would be required on the banks of the FRC and surrounding area. Additionally, some short lengths of direct defences would be required in Grangemouth. All flow from the Polmont Burn will be directed into the FRC. A tidal barrier at the mouth of the Grange Burn is required to stop tidal flows backing up the Grange Burn. The control gate at the confluence of the Grange Burn and the FRC will need to be synchronised (co-ordinate telemetry) with the tidal barrier to ensure flood risk does not increase in Grangemouth.

Flood Extents

The main on-set of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn. The principal source of flooding here is from the Forth Estuary, however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.6	2,733 + dam structure	1 in 100 years	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
2.2 (3)	4 (1)	4 (1)	3 (2)	1,097 (1)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The capital cost estimate for this option is £31.0M, based on an optimum bias of 60% and including whole life costs. The cost estimate includes the various structures involved in this option. It is envisaged that only the land required for the dam structure would be purchased by Falkirk Council. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated the Present-Day Benefits (damages avoided) is £68.7M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

Provides opportunity for habitat enhancement on the Grange Burn, due to short length of defences. New wetland habitat could be created within the Flood Storage Area, which would represent a positive impact on the environment. Potential for direct defences to be a mixture of wall and embankment structures. Potential significant impact on World Heritage Site, discussions with Historic Environment Scotland are ongoing. From initial correspondence, Historic Environment Scotland have intimated that they may object to this option on the grounds of '*significant and detrimental effects on the Outstanding Universal Value of the World Heritage Site and the setting of the schedule monument*'. Further information on this can be found in section ** of this report. Some defences are within the WHS buffer zone, however HES do not deem this to be a significant concern.

This option requires a tidal barrier which would be located out with the Firth of Forth -Ramsar / SPA / SSSI site. The structure would cover the width of the channel and tie-in with direct defences on the right bank and existing ground on the left bank. Discussions with SNH are ongoing regarding the HRA.

A control structure on the Grange Burn / FRC would require some work within the channel.

Due to increased flows being directed down the FRC, some retro-fitting of the existing channel will be required. There is the potential for environmental habitat enhancements on the banks of the FRC, if soft engineering techniques are used. Potential for limited re-meandering of the FRC through Rannoch Park and a short section of the Grange Burn from the M9 to Kingseat Avenue, however, these are classed as small-scale enhancements. Most of the proposed defences on the FRC are aligned away from residential properties.

This option is likely to meet all 4 of the Environmental objectives.

Social

Provides flood protection and improves safety and wellbeing to communities. The short length of defences through Grangemouth maintains connectivity between communities on either bank, this has the additional benefit of creating a positive and sustainable environment. Potential for enhanced tourism opportunities and public realm work linked to National Planning Framework 3 and the regeneration of Grangemouth. Opportunity to enhance / promote local and national heritage sites; potential for interpretation / information boards near the Antonine Wall.

This option is likely to meet all 4 of the social objectives.

Wider Disruption to Grangemouth

The short length of direct defences through Grangemouth will be beneficial to reducing disruption in and around Grangemouth town centre.

Utilities

Due to the reduced extent of direct defences, the risk of utility clashes is low, however, there is still a risk of utility clashes and the need to divert / protect utilities.

Scottish Water have a combined DN600 sewer within the FSA which will need to be diverted / protected. From initial discussions with Scottish Water there is the possibility of diverting the sewer out-with the FSA or provide protection to the sewer. The proposed direct defence alignment on the lower sections of the FRC will require construction work close to pressurised pipelines. From initial desk studies, it may be practical to align part of the direct defences within the footprint of the FRC to avoid clashing (working close to) with pressurised pipelines.

The utilities were scored 3 out of 5 for this option.

Operational Risk

This option has been categorised as 3 - high operational risk; multiple flow control structures are required for this option combined with direct defences and a flood storage area. Due to the layout of the mechanical flow control structures, some of the flow control structures need to be synchronised to ensure there is no increase in flood risk to Grangemouth.

Conclusion

This option requires several mechanical flow control structures which Falkirk Council would be responsible for (operation, maintenance and inspection). The tidal barrier and flow control gate / structure at the confluence of the Grange Burn and FRC need to be synchronised to avoid increasing flood risk to Grangemouth.

Following initial correspondence with HES, they have indicated they may object to this option on the grounds of the adverse impact on the character and setting of the Antonine Wall - World Heritage Site. Discussions with HES are ongoing to determine what would be deemed acceptable from their perspective. Details of the design development work undertaken and can be found in Appendix B.

It should be noted that this option has significant positive social and environmental aspects when compared to other options

3.4.4.5 Option 4e

Introduction

Construct intermittent direct defences through Grangemouth, most of defences are 1.0m – 1.5m above existing bank level. Construct up to a 1.5m high embankment around Zetland Park (along Drummond Place, Abbotsgrange Road and Bowhouse Road, to the rear of properties on Kingseat Avenue), to provide temporary flood storage within Zetland Park. The embankment around Zetland Park means no direct defences are required on the right bank of the Grange Burn through Zetland Park.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn. The principal source of flooding here is from the Forth Estuary, however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	7,612	1 in 200 years	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint emissions* (Rank, compared to other options)
1.9 (5)	3 (6)	3 (4)	2 (4)	2,865 (6)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The capital cost estimate for this option is £45.0M, based on an optimum bias of 60% and includes whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated the Present-Day Benefits (damages avoided) is £84.0M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

The proposed alignment of defences may have a substantial adverse environmental impact on the urban area of Grangemouth, however, there is the opportunity for habitat creation on slopes of embankments in Zetland Park and potential for a footpath on embankment crest. Some trees are likely to be felled and replanted, and existing bank vegetation cleared to allow direct defences to be constructed. Potential environmental mitigation will be necessary as defences would be a mixture of walls and embankments, subject to available space on the existing bank (defences in Zetland Park would be embankments). Space on the existing bank downstream of Zetland Park is limited, due to the urban environment and number of utilities, therefore a wall is the most likely structure here. Potential for adverse impact upon fabric and setting of Grangemouth.

Some of the proposed defences are located within the WHS buffer zone, but no defences would directly clash with the Antonine Wall (Scheduled Monument). Several Listed Buildings are in Grangemouth some near the proposed alignment of defences, however it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

The height and appearance of defences for this option is likely to be contentious, due to the adverse environmental and social impact of the defences are likely to have on communities in Grangemouth. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Most of the defence heights for this option are likely to be 1.0m - 1.5m, above existing ground levels. Due to the urban environment, it is likely the height of defences will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 4 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. Proposed alignment of defences will have an adverse impact on local communities; potentially forming a physical barrier between communities. Limited space for community enhancements to be incorporated into the defence structure due to limited space on the existing banks (urban environment). Not fully compliant with National Planning Framework 3 or Falkirk Corporate documents / strategies.

This option is likely to meet 3 of the 4 social objectives.

Wider Disruption to Grangemouth

Construction of over 7,500m of direct defences through a densely populated urban area will result in some disruption. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partially / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Powdrake Road is classified as a '*Wide Loads'* route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Utilities

Major clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with the alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to the number of utilities that require diverting. Proposed alignment of defences on the FRC, will be near pressurised pipelines.

Scottish Water have a Pumping Station in Zetland Park, which outfalls into the Grange Burn. Discussions with Scottish Water will be required at the outline design stage to determine the impact of the scheme on their apparatus.

Petroineos have two pipelines (DN 300 and 550) which are located parallel to the FRC. From Inchyra Road and Wholeflats Road, one pipe is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly over the pipeline is unlikely to be allowed, with the exception where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipes to, and it is not practical to switch the pipelines off for economic reasons. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

This option has been scored as a 2 out of 5, with major utility diversions required at a single location which are likely to cost > £2M and have considered time implications to plan/ programme utility works.

Operational Risk

The operational risk associated with this option has been categorised as 1 – low operational risk, the proposed flood defences are wall and embankment structures will no mechanical gate structures proposed.

Conclusion

Likely adverse impact on environment and social aspects, due to the extent and height of proposed direct defences through Grangemouth. Significant impact on Grangemouth during the construction phase. Likely construction work on the existing banks which will require many trees to be felled and replanted. The embankment in Zetland Park will need careful planning to ensure the structure is integrated into the park landscape in the best possible manner to be visually un-intrusive. There is the potential for planting native species on the embankments, which could have wider ecological benefits.

It is worth noting that Falkirk Council deem Zetland Park to be an important feature in Grangemouth and any proposal that impacts the park are unlikely to viewed positively.

3.4.4.6 Option 4f

Introduction

Construct intermittent direct defences through Grangemouth, most of which are 0.5m - 1.0m above existing bank level. Construct a 1.0m high embankment around Zetland Park (along Drummond Place, Abbotsgrange Road and Bowhouse Road, to the rear of properties on Kingseat Avenue), to provide temporary flood storage. The embankment around Zetland Park means no direct defences are required on the right bank of the Grange Burn through Zetland Park. Property level protection (where flood depths are less than 0.6m) may be suitable subject to type and practicality of installing PLP. For this option appraisal, PLP will not be included, but will be reviewed at the outline design stage if this is identified as the preferred option.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn. The principal source of flooding here is from the Forth Estuary, however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.6	7,020	1 in 100 years	Yes

Option Matrix Scores:

Benefit Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.8 (7)	3 (6)	3 (4)	2 (4)	2,642 (6)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £37.3M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) are £68.7M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

The proposed alignment of defences may have an adverse environmental impact on the urban area of Grangemouth; however, there is the opportunity for habitat creation on slopes of embankments in Zetland Park and potential for a footpath on the embankment crest. Some trees are likely to be felled, and existing bank vegetation cleared to allow direct defences to be constructed. Some potential to mitigate environmental impact as defences would be a mixture of walls and embankments, subject to available space on the existing bank (defences in Zetland Park would be 1.0m high embankments). Space on the existing bank is limited, downstream of Zetland Park due to the urban environment and number of utilities, therefore a wall is the most likely structure here. Potential for adverse impact to the fabric and setting of Grangemouth.

Some of the proposed defences are located within the WHS buffer zone, but no defences would directly clash with the Antonine Wall (Scheduled Monument). Several Listed Buildings in Grangemouth are close to the proposed alignment of defences; however, it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

The height and appearance of defences for this option is likely to be contentious, due to the adverse environmental and social impact on communities in Grangemouth. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Most defence heights for this option are 0.5m - 1.0m above existing ground levels. Due to the urban environment, it is likely the height of defences

will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 4 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. Proposed alignment of defences will have an adverse impact on local communities; potentially forming a physical barrier between communities. Limited space for community enhancements to be incorporated into the defence structure due to limited space on the existing banks (urban environment). Not fully compliant with National Planning Framework 3 or Falkirk Corporate documents / strategies.

This option is likely to meet 3 of the 4 social objectives.

Wider Disruption to Grangemouth

Construction of over 7,500m of direct defences through a densely populated urban area will result in some disruption. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partially / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to allow for the current carriageway clearance width to be maintained.

Utilities

Major clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to the number of utilities that require diverting. Proposed alignment of defences on the FRC, will be near pressurised pipelines.

Scottish Water have a Pumping Station in Zetland Park, which outfalls into the Grange Burn. Discussions with Scottish Water will take place at the outline design phase regarding their apparatus.

Petroineos have two pipelines (DN 300 and 550) which are located parallel to the FRC. From Inchyra Road and Wholeflats Road, one pipe is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly over the pipeline is unlikely to be allowed, with the exception where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipes to and it is not practical

to switch the pipelines off on economic grounds. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

his option has been scored as a 2 out of 5, with major utility diversions required at a single location which are likely to cost > £2M and have considered time implications to plan/ programme utility works.

Operational Risk

The operational risk associated with this option has been categorised as 1 – low operational risk, the proposed flood defences are wall and embankment structures with no mechanical gate structures proposed.

Conclusion

Likely adverse impact on environment and social aspects, due to the extent and height of proposed direct defences through Grangemouth. Significant impact on Grangemouth during the construction phase. Likely construction work on the existing banks which will require many trees to be felled and replanted. The embankment in Zetland Park will need careful planning to ensure the structure is integrated into the park landscape in the best possible manner to be visually un-intrusive. There is the potential for planting native species on the embankments, which could have wider ecological benefits.

It is worth noting that Falkirk Council deem Zetland Park to be an important feature in Grangemouth and any proposal that impacts the park are unlikely to viewed positively.

3.4.4.7 Option 4g

Introduction

Construct direct defences downstream of Zetland Park on the right bank, with intermittent defences on the left bank. The height of defences ranges from 0.5m to 1.5m above existing bank level. Most of the defences through the centre of Grangemouth are only 1.0m above the existing bank. Defences are also required on the FRC. A flow control structure at the confluence of the Grange Burn and FRC would control flow on the Grange Burn and reduce the extent and height of fluvial defences on the Grange Burn. The defences on the FRC are primarily there to stop fluvial flooding from the increased flows being diverted down the FRC.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing	Length of defences required - m	Level of Protection	Flood Gates Required

	ground level)			
Wall and Embankment	1.8	5,365	1 in 200 years	Yes

Option Matrix Scores:

Benefit Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint emissions* (Rank, compared to other options)
2.2 (3)	4 (1)	3 (4)	2 (4)	2,019 (4)

*based on sheet-pile concrete wall construction

Benefit Cost Ratio

The Capital cost estimate for this option is £37.4M, based on an optimism bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) are £847M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

The proposed alignment of defences may have an adverse environmental impact on Grangemouth, due to the extent of defences. It should be noted that the height of defences within the centre of Grangemouth are all less than 1.0m above the existing bank. Most trees and vegetation on the banks downstream of Zetland Park would need to be cleared to allow direct defences to be constructed, with some replanting taking place. There is some opportunity for habitat improvement work, including the potential for small scale NFM on the Grange Burn, directly downstream from the M9.

The direct defences on the FRC are similar in extent and height to option 4c, some vegetation on the banks will need to be cleared, there is limited opportunity for habitat creation / enhancement on the FRC. Some of the proposed defences are located within the WHS buffer zone, but no defences would directly clash with the Antonine Wall (Scheduled Monument). Several Listed Buildings in Grangemouth are close to the proposed alignment of defences; however, it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

Due to the extent of the proposed direct defences, the height and appearance of defences for this option may be contentious. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Due to the urban environment, it is likely the height of defences will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;

- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option requires a flow control structure to be constructed within the channel at the confluence of the Grange Burn and FRC, this will require some construction work to take place within the channel with appropriate mitigation.

This option is likely to meet all of the environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. Proposed alignment of defences will form a physical barrier between communities on the lower reach of the Grange Burn and have an adverse impact on the local community; however, no defences are proposed on the Grange Burn upstream of Zetland Park (no change to the current situation). Potential for some community enhancements to be incorporated, particularly upstream of Zetland Park. Not fully compliant with National Planning Framework 3 or Falkirk Council policies, opportunities for enhancing the environment with social benefits.

This option is likely to meet 3 of the 4 social objectives.

Wider Disruption to Grangemouth

Constructing 5,365m of direct defences through Grangemouth is likely to cause some disruption, however the disruption is likely to be focused on roads parallel to the Grange Burn downstream of Zetland Park. A partial road closure would be required to allow some of the direct defences to be constructed. Some disruption is likely on roads parallel to the FRC and at the edge of Rannoch Park where a flow control structure is proposed.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore the current carriageway clearance width must be maintained with defences in place.

Utilities

Major clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to the number of utilities. Proposed alignment of defences on the FRC will be near pressurised pipelines.

Petroineos have two pipelines (DN 300 and 550) which are located parallel to the FRC. From Inchyra Road and Wholeflats Road, one pipe is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly over the pipeline is unlikely to be allowed, with the exception of where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipes to and it is not practical to switch the pipelines off on economic grounds. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

This option has been scored as a 2 out of 5, with major utility diversions required at a single location which are likely to cost > £2M and have considerable time implications to plan/ programme utility works

Operational Risk

This option has been categorised as 2 – medium operational risk as a flow control structure on the Grange Burn would be required to divert some flows down the FRC. To maintain the current flow regime in the Grange Burn the flow control device may need to be a mechanical gate which only becomes active in extreme events. If a mechanical flow control gate is selected, the operational risk would increase to category 3 – significant operational risk.

Conclusion

Extent and height of defences is likely to have some adverse social impact; however, this option provides opportunity for some environmental enhancements as defences are focused on two areas; on the banks of the FRC and downstream of Zetland Park on the Grange Burn; there are opportunities for environmental enhancements out-with these areas. The utility diversions required for this option are likely to be significant with limited space on the banks of the Grange Burn downstream of Zetland Park. This option does require a flow control structure at the confluence of the Grange Burn and the FRC. Falkirk Council will be responsible for operating and maintaining the flow control structure.

3.4.4.8 Option 4h

Introduction

Construction of direct defences downstream of Zetland Park on the Grange Burn (and around the perimeter of Zetland Park) and on the FRC. Two flow control structures are required; one at the mouth of the Grange Burn – which limits the tidal flows backing up the Grange Burn, this would have mechanical gates which would need to be closed when required. The flow control structure at the Grange Burn / FRC confluence would have mechanical gates to control the fluvial flows on the Grange Burn. The two flow control structures would need to be synchronised to avoid increasing flood risk to Grangemouth.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	5,486	1 in 200 years	Yes

Option Matrix Scores:

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.9 (5)	4 (1)	3 (4)	2 (4)	2,065 (5)

*based on sheet-pile concrete wall construction

Benefit / Cost Ratio

The Capital cost estimate for this option is £45.2M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated Present-Day Benefits (damages avoided) are £84M. The cost of defences downstream from Powdrake Road have been included in the options for Cells 3, 5 and 6, as these defences provide flood protection to petrochemical plant stakeholders.

Environmental

The proposed alignment of defences is likely to have an adverse environmental impact on Grangemouth, due to the extent of defences. It should be noted that the height of defences within the centre of Grangemouth are all less than 1.0m above the existing bank. Most trees and vegetation on the banks downstream of Zetland Park would need to be cleared to allow direct defences to be constructed and replanted. Defences around the perimeter of Zetland Park would provide the potential opportunity for some habitat improvement work, potential for small scale NFM on the Grange Burn, directly downstream of the M9.

The direct defences on the FRC are similar in extent and height to option 4c, with some vegetation on the existing bank needing to be cleared, there is limited opportunity for habitat creation / enhancement on the FRC. Some of the proposed defences are located within the WHS buffer zone, but no defences would directly clash with the Antonine Wall (Scheduled Monument). Several Listed Buildings in Grangemouth are close to the proposed alignment of defences; however, it is not envisaged there will be any direct impact on any of the Listed Buildings in Grangemouth.

Due to the extent of proposed direct defence, the height and appearance of defences for this option is likely to be contentious. To reduce the footprint of the defence, a wall is likely to be the preferred defence type. Due to the urban environment, it is likely the height of defences will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option requires two flow control structures to be constructed within the channel at the confluence of the Grange Burn and FRC and the mouth of the Grange Burn, this will require some construction work to take place within the channel with appropriate mitigation.

This option is likely to meet all of the environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. Proposed alignment of defences will potentially form a physical barrier between communities on the lower reach of the Grange Burn and have an adverse impact on the local community; however, no defences are proposed on the Grange Burn upstream of Zetland Park (no change to the current situation). Potential for some community enhancements to be incorporated, particularly within and upstream of Zetland Park. Not fully compliant with National Planning Framework 3 or Falkirk Council policies, opportunities for enhancing the environment with social benefits.

This option is likely to meet 3 of the 4 social objectives.

Wider Disruption to Grangemouth

Constructing 5,486m of direct defences through Grangemouth is likely to cause some disruption, however the disruption is likely to be focused on roads parallel to the Grange Burn downstream of Zetland Park. A partial road closure would be required to allow some of the direct defences to be constructed. Some disruption is likely on roads parallel to the FRC and at the edge of Rannoch Park where a flow control structure is proposed.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Access to construct the tidal barrier will need to be investigated and will require access to restricted areas within Forth Ports and / or Petroineos land.

Utilities

Major clashes with utilities in Grangemouth; parallel to the Grange Burn and the FRC. Some utilities will need to be diverted or protected due to clashes with alignment of direct defences; there is very limited space to divert utilities within Grangemouth due to the number of utilities that require diverting. Proposed alignment of defences on the FRC will be close to pressurised pipelines.

Petroineos have two pipelines (DN 300 and 550) which are parallel to the FRC; from Inchyra and Wholeflats Roads, one pipeline is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly next to the pipelines is unlikely to be allowed, with the exception of where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations to move the pipelines to and it is not practical to switch the pipelines off due to financial impactions. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

This option has been scored as a 2 out of 5, with major utility diversions required at a single location which are likely to cost > £2M and have considered time implications to plan/ programme utility works.

Operational Risk

This option has been categorised as 3 – significant operational risk as there are two flow control structures, both of which would require mechanical gates which need to be synchronised to ensure flood risk to Grangemouth is not increased.

Conclusion

Extent and height of defences is likely to have an adverse social impact; however, this option provides opportunity for some environmental enhancements as defences are focused on two areas; banks of the FRC and downstream of Zetland Park on the Grange Burn. There is the opportunity for environmental enhancements on the proposed defences around the perimeter of Zetland Park, with an embankment likely to be constructed. However, this option does require construction work within Zetland Park.

This option does require two flow control structures; at the confluence of the Grange Burn and the FRC and at the mouth of the Grange Burn. Both flow control structures are likely to require mechanical gates which close once a certain water level is reached. Both flow control structures will need to be synchronised to each other to ensure no increase in flood risk. The responsibility for the flow control structures will be with Falkirk Council. The operational risk associated with this option is significant and would require Falkirk Council to manage the risk appropriately.

3.4.4.9 Option 4i

Introduction

Construction of direct defences along a short length of the Grange Burn and around the perimeter of Zetland Park; and on banks of the FRC. Three flow control structures are required; a tidal barrier at the mouth of the Grange Burn to limit tidal flows up the Grange Burn; a flow control structure at Zetland Park to throttle the downstream to ensure no fluvial flow would overtop the existing banks downstream of Zetland Park – a consequence of this control structure is that water (during high flow events) is likely to pond within Zetland Park hence the need for defences around the perimeter to contain the flood water; and a flow control structure at the confluence of the Grange Burn and the FRC, to limit flows on the Grange Burn and increase flows on the FRC. Two of the three flow control structures will require mechanical gates and need to be synchronised to ensure flood risk does not increase due to the control structures.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn. The principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Key Factor of this option:

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required

Wall and Embankment	1.8	3,328	1 in 200 years	Yes

Option Matrix Scores

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Carbon footprint* (Rank, compared to other options)
2.7 (1)	4 (1)	4 (1)	5 (1)	1,252 (3)

*based on sheet-pile concrete wall construction

Benefit / Cost Ratio

The Capital cost estimate for this option is £30.6M, this based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated the Present-Day Benefits (damages avoided) are £84M.

Environmental

The proposed alignment of defences is likely to have a neutral environmental impact on Grangemouth as most of the proposed defences are within Zetland Park or on the banks of the FRC. Most of the defences are between 1.0 - 1.5m above the existing bank level. Due to the limited length of defences on the Grange Burn, most of the existing bank vegetation can remain. The defences within Zetland Park are likely to be embankment structures, with the potential for habitat enhancement. Some small-scale NFM on the Grange Burn directly downstream of the M9 is possible.

The direct defences on the FRC are similar in extent and height to option 4c, with some vegetation on the existing bank needing to be cleared, there is limited opportunity for habitat creation / enhancement on the FRC. Some of the proposed defences are located within the WHS buffer zone, but no defences would directly clash with the Antonine Wall (Scheduled Monument).

This option requires three flow control structures to be constructed within the channel at the confluence of the Grange Burn and FRC; mouth of the Grange Burn and at Zetland Park of the Grange Burn, this will require some construction work to take place within the channel with appropriate mitigation.

This option is likely to meet 4 of the 4 environmental objectives.

Social

Improves the safety and wellbeing to communities in Grangemouth by providing flood protection. The short alignment of defences within Grangemouth will reduce the potential for a physical barrier between communities. Potential for some community enhancements to be incorporated, particularly upstream of Zetland Park. Compliant with National Planning Framework 3 and Falkirk Council policies, opportunities for enhancing the environment with social benefits.

This option is likely to meet 4 of the 4 social objectives.

Wider Disruption to Grangemouth

Constructing 3,328m of direct defences through Grangemouth is likely to cause some disruption, however most defences are on the banks of the FRC or within Zetland Park. Some disruption is likely on roads parallel to the FRC and at the edge of Rannoch Park where a flow control structure is proposed.

Access to construct the tidal barrier will require access to restricted areas within Forth Ports and Petroinoes sites.

Utilities

Minor clashes with utilities, predominantly on the FRC; some utilities will need to be diverted or protected due to clashes with alignment of direct defences. Petroineos have two pipelines (DN 300 and 550) which are parallel to the FRC; from Inchyra and Wholeflats Roads, one pipeline is located within the bank of the existing FRC. From initial discussions with Petroineos, construction work directly next to the pipelines is unlikely to be allowed, with the exception where direct defences cross perpendicular to the pipelines. Moving / diverting the pipelines is not feasible due to limited alternative locations; it is not practical to switch the pipelines off due to financial impactions. Therefore, the alignment of direct defences will need to be reviewed at the outline design stage.

This option has been scored as a 5 out of 5 for utility scores.

Operational Risk

This option has been categories as 3 – significant operational risk, three flow control structures are required, two of which will require mechanical gates to control flows. All three control structures will need to be synchronised to ensure flood risk is not increased in Grangemouth. Additionally, weather forecasts and localised fluvial flow models will need to be assessed on a case-by-case basis to determine when flow control structures need to operate.

Conclusion

Extent and height of defences should have a minimal adverse social impact; additionally, there are opportunities for environmental enhancements, particularly for the embankments within Zetland Park. This option does require three flow control structures; at the confluence of the Grange Burn and the FRC; at the mouth of the Grange Burn and in Zetland Park on the Grange Burn. Flow control structures will need to be synchronised to each other to ensure no increase in flood risk. The responsibility for the flow control structures will be with Falkirk Council. The operational risk associated with this option are significant and would require Falkirk Council to manage the risk appropriately.

3.4.4.10 Summary of Cell 4 Options

Table 15 outlines the scores and rankings for each of the options considered in the option appraisal matrix.

Option	Benefit / Cost		Environmental		Social		Utility		Carbon Footprint	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
a	1.7	8	1	9	2	8	1	9	3,070	8

b	1.6	9	2	8	2	8	2	4	3,070	8
c	2.3	2	4	1	4	1	3	2	1,191	2
d	2.2	3	4	1	4	1	3	2	1,097	1
e	1.9	5	3	6	3	4	2	4	2,865	6
f	1.8	7	3	6	3	4	2	4	2,642	6
g	2.2	3	4	1	3	4	2	4	2,019	4
h	1.9	5	4	1	3	4	2	4	2,065	5
hi	2.7	1	4	1	4	1	5	1	1,252	3

Table 16: Summary of options for Cell 4

4. Appraising the Options

This section of the report provides discussion on the option appraisal process and follows the methodologies set out in section 3.1 of this report. This section will:

- Outline stakeholder consultation on the proposed options
- Report on feedback from stakeholders on proposed options
- Determine whether any of the options can be discounted (from stakeholder feedback) without further analysis
- Determine the feasibility of the options
- Identify the recommended preferred option

4.1 Stakeholder Consultation

Consultation with key stakeholders and the public is an integral and very important component of the option appraisal process. It is important to get a wide range of views and comments on the proposed options before a preferred scheme is identified. The Project Team have undertaken a wide range of formal and ad-hoc consultation exercises with stakeholders, where key aspects of a potential scheme design were discussed.

Consultation will be undertaken with a range of different stakeholders for:

- gathering existing information;
- sharing new information;
- discussing options;
- seeking approvals; and
- seeking partnerships

A stakeholder is defined as 'any individual or group who is believed to hold data relevant to the project; and / or any individual or group who is potentially affected by a project or can themselves affect a project'.

Stakeholder identification establishes which organisations and individuals may be directly or indirectly affected (positively and negatively) by the project and who may have an impact or influence on the success of the project. Stakeholder identification is an ongoing process requiring regular review and updates.

To assist with the option appraisal, process several stakeholder groups will be developed to help identify the preferred Scheme. All stakeholder engagement prior to Consultation Event No. 1 was undertaken in a confidential nature.

To structure and focus the consultation process, the Project Team developed several stakeholder groups:

Figure 29: *Identifies the Stakeholder Groups set up by the project team.*

Core Stakeholder Group – comprising of members representing:

- SEPA
- SNH
- Historic Environment Scotland
- Marine Scotland
- Scottish Water
- Forestry Commission
- Falkirk Community Trust
- Scottish Government, and
- Falkirk Council - Roads, Planning, and Economic Development departments

One of the key objectives of stakeholder engagement is to ensure that all those parties affected by the scheme, or will have a substantial interest in its effects, have an opportunity to input into the scheme design at an early stage, such that the risk of a significant objection can be identified and appropriately mitigated. Some of these consultees will be consulted as part of statutory consenting process.

Utility / Service Stakeholder Group – comprising of members representing:

- Scottish Water
- Scottish Power – Transmission and Distribution
- Scottish Gas Networks – Transmission and Distribution
- Virgin Media
- BT
- Petroineos
- INEOS
- BOC
- BP (now INEOS FPS)
- Vodafone
- ESSAR

- Falkirk Council – Roads and Street Lighting department

Statutory utility stakeholders and others (stakeholders who have services near possible flood defences), will be consulted at the option appraisal stage of the project to ensure 'show-stopping' constraints have been identified / removed and assist with identifying residual (major) risks associated with utility / service apparatus.

Industrial Stakeholder Group – comprising of members representing:

- Forth Ports
- BP (now INEOS FPS)
- INEOS
- Petroineos
- Versalis
- Scottish Power – Transmission

Due to the large number of the proposed flood defences within the Port of Grangemouth and the petrochemical plant an 'Industrial Stakeholder Group' was initiated. During the option appraisal process, this group's primary aim is to assist with identification of options that are feasible and potential show-stopping constraints within the Port and petrochemical plant area. It is envisaged the group will meet at various stages throughout the Scheme's development. However, due to the complexity and sensitive nature of discussions with members of the Industrial Stakeholder Group, individual (One-2-One) meetings with members of the Industrial Stakeholder Group will be required. It is imperative that continuity is developed between members of the Industrial Stakeholder Group and the Project Team to help progress development of the scheme.

At the Outline design stage, Design Workshops will be organised with members of the Industrial Stakeholder Group. The aim of the design workshops is to develop the design of flood defences to account for any restrictions which may be imposed by Industrial Stakeholders.

4.1.1 Core Stakeholder Group

The Project Team outlined the following programme of meetings for the Core Stakeholder Group:

- Initiate Core Stakeholder Group - spring 2017
- Half day workshop on potential options – spring 2017
- Individual meetings with Stakeholders if required – summer 2017 to summer 2018

Following the half day workshop, a master set of plans were created with the group's comments marked on. These plans can be found in Appendix C.

4.1.2 Utility Stakeholder Group

The Project Team outlined the following programme of meetings with the Utility / Service Stakeholder Group:

- Initiate Utility / Service Stakeholder Group – spring 2017
- Half day workshop on potential options – spring 2017
- Individual meetings with Stakeholders if required – summer 2017 to summer 2018

Following the half day workshop, a master set of plans were created with the group's comments marked on. These plans can be found in Appendix D.

4.1.3 Industrial Stakeholder Group

The Industrial Stakeholder Group (ISG) initially met as one single group, however it is envisaged that after the initial meeting, individual meetings with each stakeholder will be held to discuss specific requirements relating to each stakeholder's operations at Grangemouth. After these meetings, further discussions will be undertaken with members of the Industrial Stakeholder Group as and when required to develop the outline design.

The Project Team outlined the following programme of meetings for the ISG:

- Initiate Industrial Stakeholder Group - spring 2017
- One-2-One Meetings – ongoing after summer 2017
- Individual meetings with Stakeholders if required – summer 2017 to summer 2018

4.1.4 Falkirk Council

Prior to the formation of the stakeholder groups, two events were held with officers from Falkirk Council. The first meeting (December 2016) was an overview of the scheme and options considered at the option appraisal stage. This was followed up with a workshop event on the options being considered in February 2017. A master plan of comments from this workshop are included in Appendix E of this report.

4.1.5 Public Consultation on Option Appraisal

Two public Consultation Events took place in 2018, one on Tuesday 27 February 2018 and the other on 19 April 2018. Both consultation events were open to members of the public to attend, with representatives from the project team on hand to answer any questions.

A feedback report from the Consultation Events was produced and issued to Falkirk Council. A copy of the report was uploaded to the scheme website, which can be found here http://www.grangemouthfloodscheme.com/consultation-event-no-1/

4.2 Feedback from Stakeholder Groups

From the Utility / Service and Core Stakeholder Group meetings, a set of master plans were drafted up after the Workshop events, which incorporated the main comments / issues raised from the Workshops. Each organisation had opportunity to comment.

A master set of plans were issued to the respective groups after the Workshop for final review. The following sections outline the main / significant comments raised from the Workshops.

Options 4g, 4h and 4i were discussed with stakeholder groups individually rather than in a group format.

4.2.1 Core Stakeholder Group

Table 16 identifies who attended the Core Stakeholder Group Workshop on 25 April 2017.

Stakeholder	Attended Workshop on 24 April 2017	Comment Reference
SEPA	Yes	A
Scottish Water	Yes	B
Forestry Commission	No	-
Falkirk Community Trust	Yes	C
Marine Scotland	No	-
SNH	Yes	D
Historic Environment Scotland	Yes	E
Scottish Government	No	-
Falkirk Council (FC) - Roads	Yes	F
Falkirk Council (FC) - Planning	Yes	G
Falkirk Council (FC) - Economic Development	Yes	H

Table 17: Attendees at the Core Stakeholder Group Workshop

To help simplify and correlate the comments from the Core Stakeholder Group Workshop, a brief note of major issues / significant comments from the Workshop is below.

Options 1a, 1b, 1c & 1d

- Falkirk Community Trust – concern about historic docks at Carronshore and impact of proposed defence alignment.
- Falkirk Council – Roads –request more details on interface with road drainage system and maintenance of the proposed scheme.

Flood Storage Areas 1 & 2

The two FSA's proposed on the River Carron were identified in section 3.2.3.1 of this report as being an '*early discounted option*'. Part of the reason for this option being discounted was comments and feedback from the Core and Utility / Service Stakeholder Group Workshops. The comments below only relate to the Core Stakeholder Group.

- SEPA – Concern on the impoundment of water and potential impact of dam failure.
- FC Planning – positive impact as it reduces the length of direct defences downstream.
- Historic Environment Scotland – Concern over archaeological sites close to FSA 2 and possible impact.

For more information relating to the Flood Storage Areas please see section 3.2.3 of this report.

Option 2a

No major issues / concerns – SNH noted the proximity to the SSSI and SPA sites. SEPA noted that they would not be supportive if a change of land use was proposed due to the flood defences.

Options 3a, 5a, 6a

- 3a
  - FC Planning – confirm whether flood defences are required around land that has been identified through the LDP as potential development sites.
- 5a, 5a & 6a
  - SNH – Impact of defences on SPA – compensatory mitigation habitat is likely to be required.
  - Historic Environment Scotland – some defences are within the World Heritage Site Buffer Zone.
  - Scottish Water- Strategic water main on the banks of the River Avon.

Options 4a & 4b

- FC – Roads – concern over the availability of road network during construction.
- FC – Planning – Major impact on townscape, visual impact and appearance, potential loss of open space in Rannoch Park.
- SEPA – significant impact on the Grange Burn.

All Cell 4 Options

Comments relate to flood defences on the Flood Relief Chanel

- Historic Environment Scotland – proposed defences with World Heritage Site buffer zone, possible excavation of Scheduled Monument – consent required.
- Scottish Water – multiple large mains crossing the FRC.

A full copy of all the option plans with comments from the Workshop can be found in Appendix C. The above text only related to major / significant comments relating to the alignment of defences for that option.

4.2.2 Utility / Service Stakeholder Group

Table 18 identifies who attended the Utility / Service Stakeholder Group Workshop on 3 April 2017.

Utility Company	Attended Workshop on 3 April 2017	Comment Reference
BT Openreach	Yes	A
SGN - Transmission	Yes	B
SGN - Distribution	Yes	C
Scottish Power - Transmission	Yes	D

Utility Company	Attended Workshop on 3 April 2017	Comment Reference
Scottish Water - Water	Yes	E
Scottish Water - Waste	Yes	F
FC- Street Lighting	Yes	G
Virgin Media	Yes	H
Ineos	Yes	I
Petroineos	Yes	J
Scottish Power - Distribution	No – but SP – Transmission provided information	K
National Grid	No – but have had separate correspondence	-
BP	No	-
FC - Roads	No	-
Vodafone	No	-
ESSAR	No	-
BOC	No	-

Table 18: Identifies attendees at the Utility/Service Stakeholder Group workshop

To help simplify and correlate the comments from the Utility / Service Stakeholder Group Workshop, a brief note of major issues / significant comments from the Workshop is below.

Options 1a, 1b, 1c & 1d

- SP Transmission – High voltage overhead power lines near alignment of defences – potential issue with clearance.
- Scottish Water – Sewer crossings.
- SGN – Distribution – Mains in the area around Old Carron Bridge.

Flood Storage Areas 1 & 2

The two FSA's proposed on the River Carron, were identified in section * of this report as being an '*early discounted option*'. Part of the reason for this option being discounted was comments and feedback from the Core and Utility / Service Stakeholder Group Workshops. The comments below only relate to the Utility / Service Stakeholder Group:

- National Grid – concern over twin DN900 mains within FSA 2.

- SGN – Transmission – concern over DN 315 main within FSA 2.
- SP – Transmission – High voltage overhead power lines through FSA's, potential issues with clearance and access.
- Scottish Water (Waste) – CSO and Pumping Station close to dam for FSA 1 and sewer clashes with dam structure for FSA1.
- Scottish Water (Water) – Water main may need protecting or require diverting.

For more information relating to the Flood Storage Areas please see section * of this report.

Option 2a

SGN – Distribution – Low pressure gas main near Old Dock, any excavation within 5m of main will need to be supervised by SGN.

Options 3a, 5a, 6a

- 3a
  - No major concerns / issues noted; above ground pipelines at the port entrance will need to be addressed through the Industrial Stakeholder Group and individual meetings.
- 5a
  - Scottish Power – Transmission – Significant issues, high voltage overhead cables near alignment of defences.
  - Scottish Water (Water & Waste) – Strategic mains are likely to clashes with alignment of defences, limited opportunity to divert mains or move alignment of defences.
  - INEOS & Petroineos – Significant issues, multiple large buried pipelines in the area and above ground pipelines crossing the watercourse. These issues will be discussed at the meeting.
- 6a
  - Proximity of defence alignment to above ground pipelines within the Petrochemical plant and pipe bridge crossings.

Options 4a & 4b

Nothing significant noted, but there was general concern regarding the number of utilities within Grangemouth town centre which may require protection / diversion depending on the footprint of the defence structure.

All other Cell 4 Options

Comments relate to flood defences on the Flood Relief Chanel

- Scottish Water – Water – Strategic mains cross the existing flood relief channel.
- SGN – Distribution – mains are parallel to the proposed alignment of defences.
- Petroineos – significant issues with major pipelines within the banks of the Flood Relief Channel.

A full copy of all the plans (with options) with comments from the workshop can be found in Appendix D. The above text only relates to major / significant comments on the alignment of defences for a particular option.

4.2.3 Industrial Stakeholder Group

Table 19 identifies who attended the Industrial Stakeholder Group meeting on 20 March 2017.

Industrial Stakeholder Group	Attended meeting on 20 March 2017
Forth Ports	Yes
INEOS FPS (BP)	Yes
INEOS	Yes
Petroineos	Yes
Versalis	Yes
Scottish Power - Transmission	Yes

Table 19: Identifies industrial stakeholder group attendees

Following this meeting several One-2-One meetings were arranged with the individual organisations to discuss in more detail the alignment of defences and any potential concerns / issues. Over the previous year, several meetings with industrial stakeholders have taken place to develop the principals of the option appraisal design.

4.2.4 Falkirk Council

A meeting with officers from Falkirk Council took place in December 2016; the following departments attended; Development Services (includes Flooding, Environmental Health, Growth & Investment teams) and Planning & Environment.

Following the initial meeting in December 2017 a workshop in February 2017 was attended by representatives from Falkirk Council covering the following teams:

- Economic Development
- Flood Officer
- Outdoor Access
- Contaminated Land
- Property and Asset
- Development Plan
- Road & Design
- Heritage Engagement – Antonine Wall custodian
- Growth and Investment
- Bridge and Structural Design
- Planning & Environment
- Area Estates

- Transport Planning
- Planning -General
- Biodiversity
- Climate Change
- Planning – LDP
- Waste Services

A Workshop summary report was produced for Falkirk Council, which correlated the comments from the Workshop. A copy of this report is included in Appendix E of this report.

4.3 Discounted Options from Stakeholder Consultation

As outlined in section 3.2.2 (Early Discounted Options) of this report, FSA 1 & 2 on the Upper Carron were discounted along with FSA on the Grange Burn.

4.4 Cell 4 Model Extension

4.4.1 Options Matrix

Historically, Flood Protection Schemes mainly considered the BCR to quantify the selection of the preferred Scheme. This option appraisal uses a multi-criteria matrix, which includes a range of criteria to assess options against to identify a preferred option.

4.4.2 Operational Risk

Following discussion with Falkirk Council, options that were identified as having an operational risk score of 3 – significant operational risk, will be discounted from the option appraisal matrix. The justification for discounting these options is that:

- Mechanical flow control structures are required. Mechanical gates are required to control fluvial or tidal flows, some options require multiple gates which will need to be synchronised to one another.
- Bespoke models may be required to model predicted flows based on weather forecasts to determine when control gates should be closed or opened. Falkirk Council are unable to operate these models internally and would rely on external expertise, which would need to be on stand-by 24-hrs a day, 365 days a year.

Options that require flow control structures offer limited opportunity to adapt structures to account for future climate change predictions. A factor of safety would need to be incorporated into the design.

Falkirk Council will be responsible for managing, operating and inspecting structures related to the flood protection scheme, therefore options 4i, 4h, 4c and 4d will be discounted from the option appraisal. Option 4g, was noted to have intermediate (scored 2) operation risk but will remain in the option appraisal.

4.4.3 Additional Technical Issue with Options 4h and 4i

Through more detailed modelling of these options, the synchronisation between the flow control gates required for the tidal and fluvial reaches is very complex. Using the water level as a threshold to close the gates could result in a low return period event (2-year) causing more flooding than compared to a 200-year event, as the threshold to close the gates is never met (for the 2-year event),

but water in the channel would overtop the bank. To stop this, a manual override function would be needed, which would require an operative to assess weather forecasts and decide when to close the gates.

The tidal barrier at the mouth of the Grange Burn is principally there to stop tidal flows backing up the Grange Burn. By closing the barrier, the fluvial flows coming down the Grange Burn cannot flow out into the Forth Estuary. If the barrier is closed too late on the incoming tide, no storage volume in the Grange Burn channel is available to accommodate the fluvial flows and water would overflow the banks. To stop this, additional direct defences would be required on the banks of the Grange Burn. If the tidal barrier is closed too early in the tidal cycle, consideration is required to ensure fluvial flows do not overtop the banks.

4.4.4 Maintain Level of Protection

As outlined in section 3.4.1.6 of this report, guidance on developing the option appraisal for flood protection schemes suggests the same level of protection is maintained throughout the scheme. The 1 in 200-year level of protection has been deemed appropriate by Falkirk Council as the minimum level of protection the scheme should provide.

Flood Cell No. 1

Through the option matrix, option 1b was identified as having the top ranked overall score. However, since the level of protection for options 1b and 1d is lower than the minimum 1 in 200-year level of protection determined by Falkirk Council, they will be omitted from the option appraisal process. **Option 1a has been identified as the preferred option, based on the better overall option ranked scores in Cell 1.**

Option no.	Description of defence	Level of Protection (year)	Overall ranked Option Score (lowest ranked score = preferred option)
1a	Direct Defence on existing banks	200	11
1b	Direct Defence on existing banks	100	5
1c	Realign Channel with Direct Defences on existing banks	200	14
1d	Realign Channel with Direct Defences on existing banks	100	11

Table 20: Identifies the options for Flood Cell no. 1 with their overall ranked total scores.

4.4.4.1 Flood Cell No. 4

A range of options have been included in the option scoring matrix for this cell, with both the 100 and 200-year level of protection appraised initially. To maintain the same level of protection throughout the scheme, options 4b, 4d and 4f have been discounted as they do not provide a 1 in 200-year level of protection.

Option No.	Benefit Cost Ratio		Utilities		Environmental		Carbon emissions (CO^2e)		Social		Overall totalled rankings (Lowest figure = top rank)	Operational Risk
	Actual Score	Rank compared to other options in cell	Actual Score	Rank compared to other options in cell	Actual Score	Rank compared to other options in cell	Amount (Tonnes)	Rank compared to other options in cell	Actual Score	Rank compared to other options in cell		
4a	1.7	6	1	6	1	6	3,070	6	2	6	**30**	**1**
4c	2.3	2	3	2	4	1	1,191	1	4	1	7	3
4e	1.9	5	2	3	3	5	2,865	5	3	3	**21**	**1**
4g	2.2	3	2	3	4	1	2,019	3	3	3	**13**	**2**
4h	1.9	5	2	3	4	1	2,065	4	3	3	16	3
4i	2.7	1	5	1	4	1	1,252	2	4	1	6	3

Table 21: Identifies the scores and rankings of option for Cell 4 for the 1 in 200-year level of protection

4.4.5 Cell 4 Options

Reviewing the remaining options 4a, 4e and 4g; option 4g is the best overall ranked scored option according to the option matrix. Option 4g does require a flow control structure and has been scored as 2 - medium operational risk, Falkirk Council does have concerns about the operation risk / long term maintenance of flow control structures as well as the permanent changes to flow regime on the Grange Burn, however, this is not justification to rule this option out. Options 4a and 4e were the least favoured options by Falkirk Council, as considerable lengths of direct defences were required through Grangemouth for both these options. Option 4e requires direct defences around the perimeter of Zetland Park. From the option appraisal consultation event, concern was raised by the local community about this option. Falkirk Council stated, any flood defences in or around Zetland Park may prove to be problematic due to strong public opinion that Zetland Park should not form part a flood protection scheme. Option 4a is not favoured by Falkirk Council with similar comments noted from appraisal consultation event due to the length of defences through Grangemouth.

Having reviewed in more detail the water levels associated with option 4g, there was concern that the water levels in the culvert under the M9 were higher (when compared to the baseline flow) which would have resulted in water levels upstream of the M9 culvert increasing. Under the FRMA, the scheme cannot increase flood risk elsewhere, therefore the project team needed to investigate how the water level in the channel behaved upstream of the M9 culvert. Additionally, from feedback received at the option appraisal consultation event, a decision was taken by the Project Team and Falkirk Council to review the point in-flows into the 1d/2d model and look to extend the current 1d/2d model upstream of the M9 culvert to gain a better understanding of water levels entering the M9 culvert and flood flow paths between the Westquarter and Polmont Burns.

4.4.6 Cell 4 - Model Extension

As outlined earlier, the options identified in Cell 4 through the option scoring matrix were not deemed acceptable by Falkirk Council on the grounds of feedback received from the public and potential for increasing the flood risk upstream. The project team took the decision to review the extent of the 1d/2d model and investigate the possibility of extending the model upstream of the M9 culvert. Initially, the M9 culvert was the upstream boundary of the model with inflows from the Westquarter and Polmont Burns inserted here as point inflows.

The Cell 4 1d/2d model was extended from the M9 culvert to Polmont Road on the Polmont and Westquarter Burns. Several structures were surveyed, along with tops of banks.

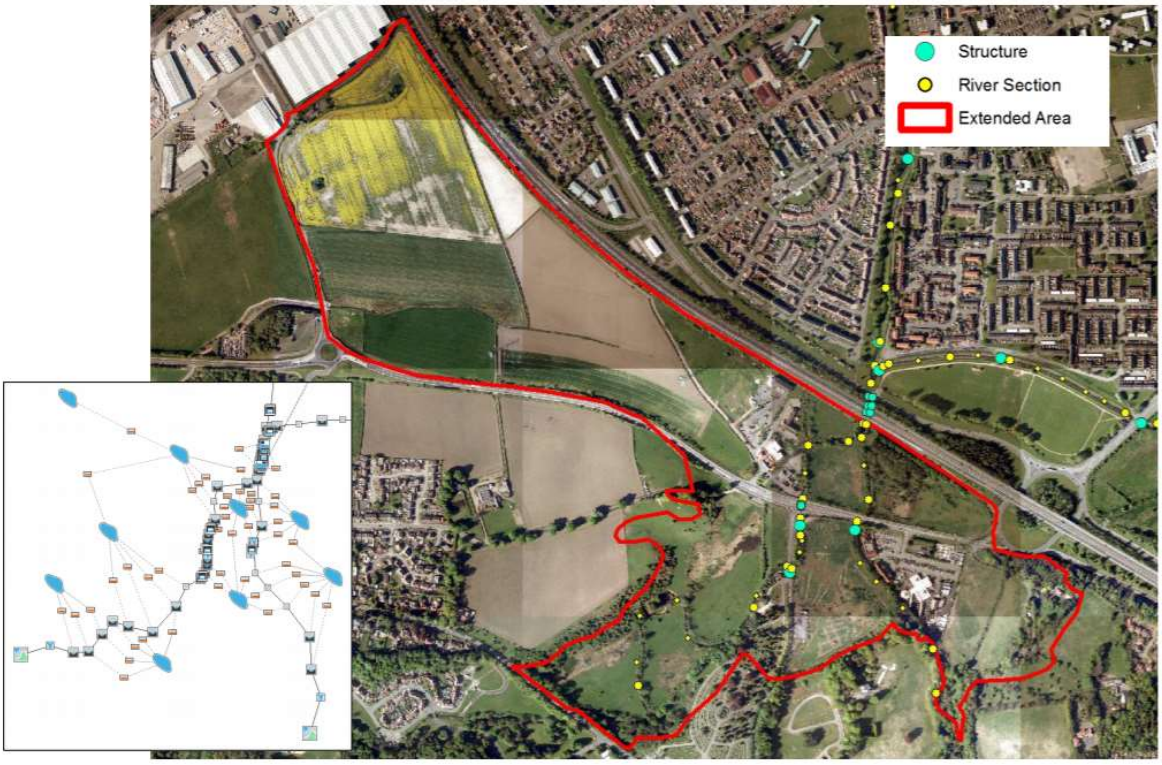

Figure 30: *Outlines the Cell4 model extension area*

4.4.7 Refine Baseline

Following the model extension, a change to the baseline flow was observed. Storage within the existing floodplain and a pedestrian underpass under the A9 had significant effects on the baseline flows in Grangemouth. Water from the Westquarter Burn flows through the underpass and then into a large field to the north-east which acts as a basin attenuating water. In the model, some water from this field enters the Almond Pow Burn which flows back into the Grange Burn at Zetland Park. The volume of water being conveyed by the Almond Pow will not significantly alter water levels on the Grange Burn as flow from the Almond Pow is restricted by a 900mm diameter culvert under the M9. A pedestrian underpass (at Primrose Avenue) and the railway line were identified as significant overland flood flow pathways which convey flood water into the centre of Grangemouth.

There is some interaction between the Polmont and Westquarter Burns, particularly where the watercourses share floodplains. This interaction between the two watercourses means flood water could leave one channel and enter the other channel prior to passing through the M9 culvert.

One of the main consequences of extending the model was changes to be baseline. For the 200-year event, no fluvial flooding from the Grange Burn occurred between the M9 and Zetland Park. Downstream of Zetland Park, flooding in Grangemouth is from tidal flows backing up the channel from the Firth of Forth.

4.4.7.1 Key finding from Model Extension

Extending the model has changed the baseline model; the key findings of the model extension are:

- Pedestrian Underpass under the A9 – key flood flow path, defences are required here to stop flow path;
- Flood defences are required next to Klondyke on the Polmont Burn and Beancross on the Westquarter Burn to stop water over topping the banks;
- Fluvial flood risk to Grangemouth has changed, but overall number of properties affected by flooding remains the same;
- The tidal flood risk on the Grange Burn remains the same;

4.4.8 Revised Cell 4 Options

Following the model extension, options 4a and 4e were identified by the project team as not being relevant as:

- most flows from the Westquarter and Polmont Burns will be directed down the FRC to reduce the lengths of direct defences in Grangemouth.
- direct defences on the lower Grange Burn are required to provide flood protection from tidal flooding and are not impacted by options which protect against fluvial flooding.

Option 4g was revised to account for the model upstream of the M9, and was developed into the following options:

Option 4gi – Flood Storage Area

- Construction of a flood storage area on the Westquarter Burn, with a dam up to 200m long and up to 5.5m high above the existing floodplain. The principal of the flood storage area is to limit the downstream flow on the Westquarter Burn during high rainfall (peak flow) events
- Construction of direct defences, on the bank next to the Polmont Burn parallel to Klondyke Garden Centre
- Construction of direct defences, on the bank next to the Westquarter Burn parallel to Beancross and the Travelodge
- Install a non-mechanical flow control structure on the Grange Burn, limiting flow down the Grange Burn to 10.5 m^3/s (this is the equivalent to a 1 in 5-year event)
- Construction of intermittent direct defences, on the banks of the FRC and surrounding area

Option 4gii – No Flood Storage Area

- Construction of direct defences, at the back of the footway next to Grandsable Road from the Grandsable Cemetery to the Junction with the A9 and parallel with the A9 to tie-in with high ground
- Construction of direct defences, on the bank next to the Polmont Burn parallel to Klondyke Garden Centre
- Construction of direct defences, on the bank next to the Westquarter Burn parallel to Beancross and the Travelodge
- Install a non-mechanical flow control structure at the confluence of the Grange Burn and FRC, limiting flow down the Grange Burn to 10.5m^3/s.
- Construction of intermittent direct defences, on the banks of the FRC and surrounding area

4.4.8.1 Option 4gi

Introduction

Construction of a flood storage area on the Westquarter Burn, and direct defences on the bank of the Polmont Burn at Klondyke and on the bank of the Westquarter Burn at Beancross. Intermittent direct defences on the banks of the flood relief channel and surrounding area. A flow control structure is required at the flood storage area to limit the downstream flow on the Westquarter Burn. A separate flow control structure at the confluence of the Grange Burn and Flood Relief Channel is required to limit the maximum flow down the Grange Burn to 10.5m^3/s, this is equivalent to a 1 in 5-year event. Most of flow from the Westquarter and Polmont Burns will be diverted down the Flood Relief Channel.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur further up the Grange Burn and the FRC.

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	7362	1 in 200 years	Yes
Flood Storage Area	Max height of dam = 5.5m	Dam length = <200	1 in 200 years	N

Option Matrix Scores

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank,

				compared to other options)
1.3 (1)	4 (1)	4 (1)	3 (2)	2781 (1)

*based on sheet-pile concrete wall construction

Benefit / Cost Ratio

The Capital cost estimate for this option is £49.6M, based on an optimum bias of 60% and including whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated the Present-Day Benefits (damages avoided) is £62M.

Environmental

Provides opportunity for habitat enhancement on the Grange Burn, due to the length of defences on the banks of the Grange Burn and Flood Relief Channel. New wetland habitat could be created within the Flood Storage Area, which would represent a positive impact on the environment. Potential for direct defences to be a mixture of wall and embankment structures. Given the potential significant impact on the World Heritage Site, discussions with Historic Environment Scotland are ongoing. From initial correspondence, Historic Environment Scotland have intimated concern about this option on the grounds of '*significant and detrimental effects on the Outstanding Universal Value of the World Heritage Site and the setting of the Scheduled Monument*'. Some defences are within the WHS buffer zone, however HES do not deem this to be a significant concern. Several Listed Buildings are in Grangemouth some near the proposed alignment of defences, however it is not envisaged there will be any direct impact on the Listed Buildings in Grangemouth.

A flow control structure on the Grange Burn / FRC would be required to direct most flows down the FRC. Up to 10.5m^3/s will be allowed to flow down the Grange Burn which represents at 1 in 5-year event.

Due to increased flows being directed down the FRC, some retrofitting of the existing channel is likely to be required. There is the potential for environmental habitat enhancements on the banks of the FRC, if soft engineering techniques are used. Potential for limited re-meandering of the FRC through Rannoch Park and a short section of the Grange Burn from the M9 to Kingseat Avenue. Most of the defences on the FRC are aligned away from residential properties.

To reduce the impact of the proposed flood defences though Grangemouth, a wall is likely to be the preferred type of flood defence. The height of most defences for this option are likely to be *1.8m, above existing ground levels. Due to the urban environment, it is likely the height of defences will have a substantial aesthetic impact on the surrounding environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;

- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 4 of the 4 Environmental objectives.

Social

Provides flood protection and improves safety and wellbeing to communities in Grangemouth. The short length of defences through Grangemouth maintains connectivity between communities on either bank, this has the additional benefit of creating a positive and sustainable environment. Potential for enhanced tourism opportunities and public realm work linked to National Planning Framework 3 and the regeneration of Grangemouth. Opportunity to enhance / promote local and national heritage sites; potential for interpretation / information boards near the Antonine Wall.

This option is likely to meet 4 of the 4 social objectives.

Wider Disruption to Grangemouth

The short length of direct defences through Grangemouth will be beneficial to reducing disruption. Some disruption upstream of the M9 is to be expected, but this will be localised to specific areas where flood defences are proposed. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partially / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Utilities

Due to the short extent of direct defences, the risk of utility clashes is low, however, there is still a risk of utility clashes and the need to divert / protect utilities.

Scottish Water have a combined DN600 sewer within the proposed FSA, this will need to be diverted / protected. From initial discussions with Scottish Water there is limited opportunity to divert the sewer out-with the FSA, therefore the sewer will need protecting. The proposed direct defence alignment on the lower sections of the FRC will require construction work close to pressurised oil pipelines and other utilities. From initial desk studies, it may

be practical to align part of the direct defences within the footprint of the FRC to avoid directly clashing with pressurised pipelines.

The utilities were scored 3 out of 5 for this option.

Operational Risk

The operational risk associated with this option has be categorised as 2 – medium operational risk. The proposed flood defences are wall and embankment structures with a flood storage area that requires a flow control structure to limit the downstream flow. The flow control structure will not require mechanical gates; however, a grill structure will be installed at the rear of the dam to stop large debris passing through the control structure. The grill will require maintenance to remove debris that may have accumulated.

A flow control device is required at the confluence of the Grange Burn and Flood Relief Channel, a passive (non-mechanical) structure is likely to be preferable and may require a grill structure to limit the risk of blocking the structure.

Conclusion

This option requires a mixture of direct defences, a Flood Storage Area and passive flow control devices. The short length of flood defences through Grangemouth, combined with the positive social and environmental scores are favourable aspects of this option. Following initial correspondence with Historic Environment Scotland, they have indicated they may object to this option on the grounds of the adverse impact on character and setting of the Antonine Wall and impact on the Outstanding Universal Value of the World Heritage Site. Discussions with HES are ongoing to understand and address their concerns. A series of Design Workshops were held from in 2018 and 2019 to discuss the design of the FSA. The findings can be found in Appendix B.

4.4.8.2 Option 4gii

Introduction

Construction of direct defences on the bank of the Polmont Burn at Klondyke, on the bank of the Westquarter Burn at Beancross and parallel to Grandsable Road and the A9. Direct defences on the bank of the flood relief channel and surrounding area. A flow control structure at the confluence of the Grange Burn and Flood Relief Channel is required to limit the maximum flow down the Grange Burn to 10.5m^3/s, equivalent to a 1 in 5-year event. Most flow from the Westquarter and Polmont Burns will be diverted down the Flood Relief Channel.

Flood Extents

The main onset of flooding for this cell is around the 1 in 20-year period along the lower section of the Grange Burn; the principal source of flooding here is from the Forth Estuary; however, fluvial flooding does occur to the south of the M9 and along the FRC.

Direct Defence Type	Maximum Defence height - m (from existing ground level)	Length of defences required - m	Level of Protection	Flood Gates Required
Wall and Embankment	1.8	7787	1 in 200 years	Yes
Flood Storage Area	Max height of dam = 5.5m	Dam length = <020	1 in 200 years	N

Option Matrix Scores

Benefit / Cost Ratio (Rank, compared to other options)	Environmental Score (Rank, compared to other options)	Social Score (Rank, compared to other options)	Utility Score (Rank, compared to other options)	Estimated Carbon footprint* (Rank, compared to other options)
1.3 (1)	4 (1)	4 (1)	4 (1)	2931 (2)

* based on sheet-pile concrete wall construction

Benefit / Cost Ratio

The Capital cost estimate for this option is £49.3M, this is based on an optimum bias of 60% and includes whole life costs. This cell is predominantly residential (with some commercial property in the town centre of Grangemouth); the estimated the Present-Day Benefits (damages avoided) is £62M.

Environmental

Opportunity for habitat enhancement on the Grange Burn, due to short length of defences on the banks of the Grange Burn and Flood Relief Channel. Potential for direct defences to be a mixture of wall and embankment structures. A flow control structure on the Grange Burn would be required to direct most flows down the FRC. Up to 10.5m^{3}s will be allowed to flow down the Grange Burn which represents at 1 in 5-year event.

Potential significant impact on the World Heritage Site, as direct defences parallel to Grandsable Road and the A9 are in very close proximity to the Antonine Wall. Discussions with Historic Environment Scotland are ongoing

to assess the impact the proposed flood defences would have on the *World Heritage Site*. Some of the defences are within the WHS buffer zone, however HES do not deem this to be a significant concern. Several Listed Buildings in Grangemouth are near the proposed alignment of defences; however, it is not envisaged there will be any direct impact on the Listed Buildings in Grangemouth.

There is limited opportunity to move the alignment of defence away from the WHS, as the proposed flood defences need to cross perpendicular to the Antonine Wall. At this stage the height of flood defences has been calculated using ground levels at the back of the existing footway, if the flood defences were to move further away from the footway and carriageway, this would increase the overall height of the defences as the ground is considerably lower the further away from the carriageway. If the flood defence were aligned further back from the carriageway, they could be very close to the historical alignment of the Antonine Wall.

Due to increased flows being directed down the FRC, some retrofitting of the existing channel is likely to be required. There is the potential for some environmental habitat enhancements on the banks of the FRC, if soft engineering techniques are used. Potential for limited re-meandering of the FRC through Rannoch Park and a short section of the Grange Burn from the M9 to Kingseat Avenue, however, these are classed as small-scale enhancements. Most of the defences on the FRC are aligned away from residential properties.

To reduce the impact of the proposed flood defences though Grangemouth, a wall is likely to be the preferred type of flood defence. Most defences are likely to be 1.8m, above existing ground levels. Due to the urban environment. To reduce the visual appearance of walls through Grangemouth, it may be feasible to:

- raise some of the footways next to the direct defences, or incorporate a footway within the direct defence structure;
- incorporate artwork into the wall structure;
- include glass panels on the top or windows within the wall structures;
- clad the wall (with stone), and
- use a form liner when casting the wall.

This option is likely to meet 4 of the 4 Environmental objectives.

Social

Provides flood protection and improves safety and wellbeing to communities in Grangemouth. The short length of defences through Grangemouth maintains connectivity between communities on either bank, this has the additional benefit of creating a positive and sustainable environment. Potential for enhanced tourism opportunities and public realm work linked to National Planning Framework 3 and the regeneration of Grangemouth. Opportunity to enhance / promote local and national heritage sites; potential for interpretation / information boards near the Antonine Wall.

This option is likely to meet 4 of the 4 social objectives.

Wider Disruption to Grangemouth

The short length of direct defences through Grangemouth town centre will be beneficial to reducing disruption in and around Grangemouth. Some disruption upstream of the M9 is to be expected, but this will be localised to specific areas where flood defences are proposed. Approx. 600m of the defences are directly parallel to the B9132 (Abbots Road – main road in Grangemouth) and would likely require at least a partial (possibly a full) closure of the Road to allow the defences to be constructed. Partial closure of this road would cause disruption and require careful traffic management planning. Other minor / residential Roads in Grangemouth would similarly need to be partially / fully closed to allow the direct defences to be constructed. The phasing of construction works will be critical to maintaining access to residential / commercial properties.

Some additional disruption would occur in Rannoch Park and near Grandsable Road / A9 as flood defences need to be constructed in these areas.

Powdrake Road is classified as a '*Wide Loads*' route for vehicles using the port, therefore direct defences in this area need to maintain the current carriageway clearance width.

Utilities

Due to the short extent of direct defences, the risk of utility clashes is low, however, there is still a risk of utility clashes and the need to divert / protect utilities.

The proposed direct defence alignment on the lower sections of the FRC will require construction work close to pressurised oil pipelines and other utilities. From initial desk studies, it may be practical to align part of the direct defences within the footprint of the FRC to avoid directly clashing with pressurised pipelines. The flood defences downstream from Zetland Park will be close to numerous utilities which are located mainly in the carriageway, depending on the type of construction method used will determine if utilities need diverting or protecting.

The utilities were scored 4 out of 5 for this option.

Operational Risk

The operational risk associated with this option has be categorised as 1 – low operational risk. The proposed flood defences are wall and embankment structures with a passive flow control structure on the Grange Burn. A grill structure maybe required on the upstream side to stop large debris obstructing the control structure. The grill will require maintenance to remove debris that may have accumulated.

Conclusion

This option requires direct defences and a flow control devise. The short length of flood defences through Grangemouth, combined with flood defences aligned away from residential areas provides significant positive social and environmental aspects. Following discussions with HES, they have indicated a preference for this option over then the flood storage area option, for more information on this refer to Appendix B.

4.4.9 Comparison of options 4gi and 4gii

Table 22 outlines the option matrix scores for options 4gi and 4gii

Option	4gi	4gii
Description of option	Flood Storage Area	No Flood Storage Area
BCR Score	1.3	1.3
BCR Rank	1	1
Utility Score	3	4
Utility Rank	2	1
Environmental Score	4	4
Environmental Rank	1	1
Social Score	4	4
Social Rank	1	1
Estimated Carbon Footprint CO2e (t) m^3/m	2781	2931
Carbon Footprint Rank	1	2
Overall Score Ranked	6	6

Table 22: Outlines options 4gi and 4gii

Options 4gi and 4gii have the same overall ranked scored, the findings of the Heritage Impact Assessment, identified option 4gii as the preferred option from HES's perspective.

Further analysis of each component of the option matrix will be undertaken in section 3.4 of this report.

5. Economic Appraisal

A full economic appraisal of the short listed (excluding any discounted) options was carried by the project team. The economic appraisal is essential to determine the outright viability of the scheme and provide evidence / justification for determining the level of protection. This section will outline the methodology, assumption and results of the initial assessment of the costs associated with construction of each option and assess the potential flood damages avoided by constructing the scheme. This will ultimately result in a benefit cost ratio being identified, along with optimum level of protection.

5.1 Flood Cells

Due to the large spatial extent of the Grangemouth Flood Protection Scheme, several flood cells have been created. For each of the flood cells a representative benefit cost assessment has been undertaken. This allows the damages relative to that specific cell to be accurately assessed and compared to the costs of constructing / implementing flood protection measures; from this a representative benefit cost ratio can be calculated. The flood cells are identified in section 3.3 of this report and Appendix F shows the location of flood cells.

5.2 Estimation of Costs

5.2.1 Methodology

In line with the Scottish Government's current guidance, Flood Protection Schemes – Guidance for Local Authorities, Chapter 5, and Project Appraisal: Assessment of economic, environmental and social impacts (hereafter referred to as Chapter 5), an assessment of all costs associated with the project should be undertaken and include both capital and maintenance costs. Decommissioning costs are not considered to be significant due to the nature of the structures (walls and embankments), these have not been included in the overall cost assessment.

An estimation of basic construction costs has been undertaken using a combination of data contained within the Civil Engineering and Highway Works Price Book (Spon's 2012), experience from similar works in other recent Scottish flood protection schemes and the Environment Agencies Costing Tool for Flood Schemes. All costs are preliminary at this stage and have developed to allow an initial assessment of the benefit-cost ratio to be calculated.

The costs developed using Spon's (2012) are based on data gathered during the second quarter of 2011, and as such all costs have been updated using the "Constructed Civil Engineering Cost Index" to bring them in line with the damage assessment base date of July 2011.

The height and spatial extent of defences will determine the level of protection. The costs included in the economic appraisal will clearly state what Level of protection is being costed. No favourable bias has been used for a higher level of protection. An assumption has been made that all direct defences will be reinforced concrete walls with sheet piled foundations. This is based on the project teams experience of working on previous flood

protection schemes, it is too difficult to determine the exact type of flood defence at the option appraisal stage, therefore a worst case, more option has been selected.

5.2.2 Maintenance Costs

An assessment of maintenance costs was undertaken for the proposed defences, based on the likely annual maintenance activities and resources required. The detailed maintenance cost estimate used rates from the Environment Agency Costing Tool for Flood Schemes. Maintenance costs were calculated on an average annual cost basis for a 100-year period following the implementation of the scheme.

A breakdown summary of maintenance costs for the full scheme is provided in Appendix G

5.2.3 Carbon Cost

Carbon costs allow a mechanism for quantifying the impacts that heavy engineering construction can have on the release of carbon dioxide into the environment. These are generally relevant where a significant amount of concrete is required (e.g. floodwalls), or large amounts of earthworks involving high volumes of cut/fill to be transported to/from site.

The Environmental Agency has developed a tool for calculating the carbon footprint of a project (the Carbon Calculator). The Carbon calculator measures the greenhouse gas impacts of construction activities in terms of carbon dioxide equivalency (CO2e (t) m^3/m). The calculator estimates the embodied CO2e if material plus the CO2e associated with its transportation. For simplicity and consistency all defences were assumed to the concrete walls with sheet piled foundations, with the height of defence not included in the assessment.

5.2.4 Appraisal Period

In line with current guidance (FCERM-AG), an appraisal period of 100 years should be used for the economic assessment of a conventional flood protection scheme, however, the petrochemical plant will use a 50-year period for estimating the damages as this is in line with current best practice. The scheme will have a design life of 100 years.

5.2.5 Optimism Bias

Optimism bias should be included in the construction costs to account for unknowns. At the option appraisal stage the optimism bias should be 60%.

5.2.5.1 Methodology

The HM Treasury appraisal guidance recognises that there is a tendency for appraisers of all kinds of projects to be overly optimistic in their early assessment of project costs, time scales and benefits, when these are compared with final outturn values. This is termed ‘Optimism Bias’.

To counter this HM Treasury issues guidance in the form of a percentage to increase the costs by depending on the uncertainty surrounding the estimates. An optimism bias of 60% is typically used for projects at an early stage of consideration. This percentage is added to the original estimate and used in cost benefit calculations.

For the option appraisal stage of the Selkirk and Hawick FPS's, an optimism bias of 60% was deemed appropriate and it is not considered necessary to further assess the project risks to alter this value when creating a robust business case for the scheme. Where appropriate, included within the cost estimate the 80th and 50th percentile (from the EA Costing Tool for Flood Schemes) rate has been used to account for difficult access, unknown ground conditions, economies of scale, differing material and landscaping requirements.

Table 22 outlines the rate used for the 50 and 80 percentiles.

Wall Height (m)	**0-0.5**	**0.5-1**	**1-1.5**	**1.5-2**	**2-2.5**	**2.5-3**	**3-3.5**	**3.5-4**
50th percentile	£2,919.35	£3,615	£4,310.65	£5,006.3	£6,071.6	£7,136.9	£8,202.2	£9,267.5
80th percentile	£3,396	£4,270	£5,144	£6,018	£8,538.5	£11,059	£13,579.5	£16,100
Embankment Volume (m^3)	< 500	500-5,000	5,000-15,000	> 15,000				
Embankment	£219	£109	£75	£38				

Table 23: Rates used for wall and embankment construction

5.2.6 Return Period

To ensure the robustness of the benefit cost analysis, for certain flood cells the estimation of construction costs and damages has been undertaken for two return periods; the 1 in 200-year and 1 in 100-year. This will allow the most economically advantageous option to be identified. For some of the options, it was considered unnecessary to assess different return periods given the low variance and the large benefit cost ratio.

5.2.7 Climate Change

From discussions with Falkirk Council it was agreed that Climate Change should be included in the design of flood defences for Cells 3, 5 and 6. The flood defences in Cells 1, 2 and 4 will not account for climate change in their design.

5.2.8 Capital Cost

5.2.8.1 Assumptions

An assessment of costs has been undertaken for each potential option identified in the appraisal process (in Section 5.2.8.3 of this report). It should be noted that all costs quoted include:

- Capital costs,
- Design costs,
- Allowance for location of works (logistics of providing construction access to a petrochemical plant),
- Supervision cost,
- contractors profit and overheads,
- 60% optimum bias,
- allowance for services / utilities,
- current Scottish Government / SEPS advice on climate change which corresponds to a 40% uplift on peak flood flows and sea level based on 2080 levels.
- all defence costs are based on a 100-year design life,
- all defences are constructed on a cell by cell basis,
- All costs represent the 'present day value',
- The Consumer Price Index has been used from 2011 with a proportional uplift applied to Oct 2016 (latest data available);
- An 50th percentile uplift on the linear unit rates has been included in the cost estimates to account for difficult access; an interpolated rate was developed from the EA Costing Tool as it was deemed the rates in the EA Costing Tool were not appropriate for wall structures over 2m high.
- some flood cells are constructed as separate construction contracts, and
- an allowance has been included for secondary drainage (including Pumping Stations)

5.2.8.2 Exclusions

The following exclusions are not included in this cost estimate:

- Location, logistics of providing construction access to some flood cells, it is felt that the optimum bias of 60% is enough to account for logistics of providing construction access;
- land purchase;
- compensation;
- Non-economic costs such as social and environmental etc

A summary of the cost breakdown is included in Appendix G, Table 22 summarises the results.

5.2.8.3 Costed Options

Table 24 outlines the capital cost estimate for each of the options.

Flood Cell	Option no.	Level of Protection (years)	Cost Estimate (includes 60% optimum bias) - £
1	1	200	21,228,498
	1b	100	12,915,944
	1c	200	22,181,378
	1d	100	13,866,702
2	2a	200	6,723,963
3, 5 & 6	3a, 5a & 6a	200	96,778,272
4	4a	200	46,980,109
	4b	100	41,497,962
	4c	100	32,618,140
	4d	200	36,354,814
	4e	100	35,656,912
	4f	200	45,666,312
	4g	200	37,472,563
	4gi	200	49,657,086
	4gii	200	49,307,188
	4h	200	45,251,875
	4i	200	30,652,729

Table 24: Cost estimate for the options

5.2.8.3.1 Cost Definitions

- Enabling costs:
  - Costs incurred between the decision to proceed with the procurement and the entry of the FCERM asset to operational use.
- Capital costs:
  - Costs incurred during detailed planning, design and construction of an asset or service.

- Operation and Maintenance costs:
  - The costs incurred through the day-to-day management of an operation, and maintenance of an asset or a scheme. This includes work that sustains the desired condition and intended performance of an asset. In some circumstance's maintenance, may accept a gradual decline in standard. For existing assets that have no residual life, maintenance may not result in an acceptable Standard of Service and only refurbishment or replacement will reinstate an acceptable Standard of Service.
- Present Value:
  - The present-day value of a future stream of costs or benefits. Calculated by discounting a stream of future costs or benefits.
- Optimism bias:
  - The demonstrated systematic tendency for appraisers to be over-optimistic about key project parameters, including capital costs, operating costs, works duration and benefits delivery.

5.2.8.3.2 Type of defences

The figures included within the costing table represent the best estimate of capital construction costs. At this stage of the option appraisal process a conservative approach has been taken to base the capital costs on constructing a wall rather than an embankment structure. It is acknowledged that the general cost of constructing an embankment is lower than that of a wall. Due to the spatial extent of each flood cell, it is highly likely that the type of flood defences within each flood cell will vary between an embankment and wall structure. Where physically possible an embankment would be the preferred defence structure, however, due the spatial constraints of constructing flood defences within an urban area a wall structure may be preferred from a land take perspective. It is therefore reasonable to assume a mixture of walls and embankment will be constructed within each flood cell, however it is not possible to quantify the exact length of walls and embankments for each cell at this stage. Therefore, for the option appraisal a conservative approach has been adapted with the higher capital construction cost associated with a wall structure have been used.

The design of the wall structure accounts for the use of sheet piles for the foundations and reinforcement for the wall structure. It should be noted that some of the flood walls, may require foundations to be to a sufficient depth to retain the existing bank.

5.3 Estimation of Damages

A damage assessment has been carried out to determine the economic value of benefits that can be accrued through flood mitigation / protection measures. By calculating the damage caused to residential and non-residential properties compared to the benefits gained by avoiding these damages a benefit cost analysis can be carried out.

Due to the large scope of works, some threshold survey information has been interpolated using imagery and LIDAR data. In general, the threshold survey area covers the 200-year flood extents.

5.3.1 Context

This part of the report outlines the data, methodology, assumptions and results of an indicative assessment for the baseline damage scenario for Scheme. The principal aim of undertaking a damage assessment is to determine the economic value of damages caused by flooding. Consideration is given to damages to both residential and non-residential properties. This is particularly relevant for the Scheme as several flood cells cover the petrochemical plant and port area.

The results of the damage assessment will be used along with the costed flood scheme options to determine the benefit cost ratio of a range of flood protection methods for Grangemouth. Historically, Scottish Government set an arbitrary target of a benefit cost ratio greater than 1, under the FRMA this has been removed. However, it is generally perceived that the benefit cost ratio should be greater than 1 to be eligible for Capital Grant funding. Where possible each flood cell will be assessed separately, no cell will subsidise another cell. The exception to this, are Cells 3, 5 and 6 which covers the petrochemical plant and port area, it is not possible to split the economic assessment in these cells as the business operations are intrinsically linked through their activities. It should be noted that the benefit cost ratio for some cells may be considerably higher than others, due to land-use and business operations.

The economic value of damages avoided is a key benefit to the principal of a flood protection scheme, however, this is not the only factor appraised in the option appraisal process. Social, Environmental, Utility aspects and potential Carbon footprint will also be appraised along with the benefit cost ratio to help identify a preferred scheme. The operational risk will also be categorised for each option, with Falkirk Council deciding if the operational risk for a specific option is too high for the option to be taken any further.

When calculating the max water level from tidal and fluvial sources, a merged tidal and fluvial raster (max water levels) was used to determine the maximum water level. It would be very hard to distinguish between the max water level from tidal and fluvial sources. For consistency the damages calculated have used a fluvial depth damage curve used, using a salt water depth damage curve would give slightly higher damages, however, it is difficult to distinguish between fluvial and tidal damages and a conservative approach was deemed appropriate.

5.3.2 Data Collection

Data used for the damage risk assessment are outlined below.

5.3.2.1 Flood Maps and Depth Grids

Flood outlines and depth grids for the 100 and 200-year events were produced using hydraulic modelling, LIDAR and topographic survey data.

Flood outline / extents were produced for the 2, 5, 10, 20, 50, 100, 200 & 1000-years, using the results from a 1D/2D hydraulic model. The flood extents include fluvial and tidal flood water. The DTM ground model has been created using topographic survey information (to obtain the top of bank (crest) for the ID model, and LIDAR for the 2D model. It is assumed the topographic and LIDAR data is an accurate representation of the ground conditions within the study area.

5.3.2.1.1 LIDAR

LIDAR DTM ground elevation data and aerial imagery was commissioned by Falkirk Council. The LIDAR ground elevation data is produced using a 1m x 1m grid.

5.3.2.1.2 Topographic Survey

CH2M commissioned a topographic along the banks of the Rivers Carron, Avon and Grange Burn, including the estuary frontage to accurately obtain data relating to the crest level on the bank.

5.3.2.1.3 Threshold Surveys

CH2M commissioned threshold surveys of approx. 1,500 Properties within the scheme area, these were predominantly on the River Carron. The survey also classified the type of property. Each property was given a building footprint, primarily based on the OS Master Map building outline and modified where required based on the topographic survey information. The area of this (building) footprint was also calculated.

Two approaches were used to determine thresholds for properties that were out with the threshold survey:

- For properties that were close to the surveyed properties, the minimum LiDAR level in the building footprint was calculated, and a value between 0.1m and 0.6m was added to this, based on the similar properties in the area that were included in the threshold survey and had their minimum LiDAR level in the building footprint measured as well.
- For properties that were outside the threshold survey, the minimum LiDAR level in the building footprint was calculated, and 0.3m was added to this.

Table 25 lists the number of properties for which thresholds were calculated using the three methods in each cell:

Threshold Source	1 - Upper Carron	2 - Lower Carron	4 - Grangeburn
Survey	679	127	780
LiDAR + survey estimate	113	289	664
LiDAR + 0.3m	11	0	4051

Table 25: Source of property threshold data

As per the MCM guidance, it is assumed that the cumulative present value damages do not exceed the risk free market value of the property; damages to a property should therefore be capped at the risk free market value.

For residential properties, these were assumed to be the average house prices in Scotland that type of property in Q1 2017. The cost of non-residential buildings was calculated using commercial property Rate Value per m^2 based on Q4 2016 prices for England and Wales, uplifted to Q2 2017 using RPI. The assessment of non-residential properties does not include any premises within the Petrochemical plant and port area. Damages to the buildings within these areas will be dealt with separately, within section 5.3.3.2 of this report.

5.3.3 Methodology

At the time of undertaking the damage assessment, the Scottish Government's guidance is based on Defra's "Flood and Defence Project Appraisal Guidance: Economic Appraisal" (FCDPAG3) which was updated in March 2010 by the EA as the "Flood and Coastal Erosion Risk Management - Appraisal Guidance" (FCERM-AG). Thus, following this guidance in a Scottish context, and current best practice, the potential scheme benefits, or damages avoided have been assessed using the *"The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques"* (Flood Hazard Research Centre, 2013), often referred to as the *Multi Coloured Manual* or *MCM*. It is recognised that Chapter 5 now supersedes this guidance, but the methodology for evaluating damages remains unchanged.

The MCM method provides the user with mechanisms to estimate likely damages caused by flooding. It is based on detailed analysis of real post-flood damages recorded in several locations across the UK over the past decade. The manual includes methods to assess the following types of damages:

- Damage to residential properties and the expense of post-flood clear up
- Damage to non-residential properties and the expense of post-flood clear up
- Intangible damage caused by flooding
- Damage to agricultural land
- Damage because of the closure of transport links
- Expense incurred by emergency services
- Damage caused by the loss of energy supply

Following the assessment of damages, a process capping the value of properties is undertaken to prevent the cost of implementing any proposed flood protection scheme to exceed the value of the properties it protects.

The FCERM-AG guidance manual states: "Care should be exercised where the total present value of losses exceeds the risk-free market value of the asset. In the case of residential or commercial property, you should assume that the long-term economic loss cannot exceed the current capital value of the property and to cap the damages."

The guidance further notes that properties should be capped when *"the damages of repeated or occasional flooding mean that the total damages over the whole appraisal period exceed the market value of the asset"*. Capping values were therefore determined so that the present value of damages accrued at each property did not exceed the present market value of the property.

To calculate depth/damage related losses to residential properties, CH2M's own suite of in-house software, Damage Calculator, was used which is compliant with the MCM Methodology. The software calculates damages for properties for multiple return periods using depth/damage curves as per the data supplied with the MCM manual. The steps followed during the assessment are outline below along with the assumptions made.

5.3.3.1 Baseline data

The baseline date of the assessment to which all damages are referenced is Q2 2017.

The depth damage curves used for this assessment were the long duration, fluvial curves. The tidal depth damage curves were not used as defining the fluvial and tidal boundary would be difficult and using the fluvial curves gives a slightly conservative figure as damages from tidal flooding would result in higher damages.

As outlined in the DEFRA Supplementary Guidance note for operating authorities '*Revisions to Economic Appraisal Procedures Arising from the New HM Treasury 'Green Book'* (and adopted by the Scottish Government) an appraisal period of 100 years should be used for a conventional FPS. Annual Average Damages (AAD) and the Present Value of Damages (PVD) were therefore calculated over this period.

5.3.3.2 Petrochemical Plant and Port Area

A technical note on the cost benefit review for the petrochemical plant and port area is included in Appendix H of this report.

Estimating the damages to the petrochemical plant and port area is a complex process, due to the bespoke nature of work undertaken at petrochemical plants and the potential indirect impact of the facility being off-line.

Table 26, summarizes the direct and indirect 50 Year Present Value of Damages:

	Sensitivity Parameter	Indirect Damages	Sensitivity Parameter	Direct Damages
Estimate	**Days of Disruption**	**Present Value of Damages (50 Year)**	**Depth Damage Curve**	**Present Value of Damages (50 Year)**
Lower	10	£ 4,476,043,997	Industrial (MCM)	£ 366,485,728
Middle	15	£ 6,714,065,996	Petro-Chemical (Tebodin 1998)	£ 500,591,633
Higher	20	£ 8,952,087,995	Non-Residential Average (MCM)	£ 2,103,389,635

Table 26: Damages for the petrochemical plant

The depth damage curves from the MCM were used to estimate the damage factor for the petrochemical plant and port area, using the industrial curves and an average of the non-residential curves. Alternatively, the Tebodin (1998) approach (which estimates the Total Economic Value per m^2), was used with a depth damage curves to estimate the damages. All three methods use a 50-year appraisal period.

The indirect damage estimates for the petrochemical plant in table 24 are based on Oil Intensity method. An assumption has been made on the length of disruption period, 10, 15 & 20 days. These figures do not include damages to the port area, as it is anticipated that during a flood event goods would be rerouted, it should be noted that approx. 30% of Scotland's GDP goes through the port of Grangemouth, this equates to £130M of goods per day but is not included in the indirect damage estimate.

Having reviewed the figures above, the 'lower' figure (10-day disruption) of estimated damages has been used in calculating the benefit cost ratio.

5.3.3.3 Assumptions and Exclusions

In calculating the flood damages for Grangemouth, the following assumptions have been made:

- Agricultural damages have not been included within this assessment as the study predominantly covers an urban environment. No economic consideration of agricultural land being flooded upstream of the study area has been made.
- Road traffic disruption has not been quantified within this analysis, depending on which combination of options are selected to form the preferred scheme will potentially have an impact on road traffic, but this will be hard to quantify due to the complexity of assessing alternative routes and journey times.
- Except for the petrochemical plant and port area, for non-residential properties the damage assessment undertaken does not consider the financial loss of business or sales, the cost associated with business re-launch, or the cost of moving to an alternative location. The financial loss of revenue can be considered a transfer payment – in general where one business may decline / cease trading due to a flood event, another nearby business picks up the trade (transferred trade). There is financial loss to individual businesses, however, the overall economic losses to the area are generally cancelled out (transferred).
- Damages to local roads infrastructure have been omitted; recent Flood Hazard Research Centre guidance for England and Wales suggests that damages caused by flooding to roads maintained by local authorities can be high and roads maintained by Transport Scotland tend to be low in comparison. The responsibility for Scotland's truck road network lies with Transport Scotland. None of the proposed defences are thought to be directly affected the truck road network, however there maybe indirect impacts.
- Damages to residential vehicles have been calculated by assuming 1.15 vehicles per house, each having a value of £3,600.
- The potential flood risk from the Forth – Clyde Canal has been excluded from this damage assessment.
- Intangible losses, such as stress and bad health, are subjective and difficult to quantify. These are dependent on a comparison of the existing level of protection and what will be afforded by the scheme (once complete).

- No economic assessment has been made for any external contributions that may be sought from any major beneficiaries of the scheme, i.e. utilities or development sites. This is complex and difficult to assess and can be hypothetical. Discussions with Falkirk Council are ongoing to determine if sites identified with the Local Development Plan should be included in the damage assessment.
- The loss / risk to life have not been included in this assessment as it is generally considered that the risk to loss of life due to flooding from the Rivers Carron, Avon, Grange Burn and the Forth Estuary in the Grangemouth area is low due to the presence of a SEPA flood warning system, relatively slow rate of water rise in channel and at the estuary, would allow sufficient time to evacuate.
- Flood damage from the Skinflats area has not been included in this assessment
- Existing Falkirk Council flood protection measures have not been included in this assessment.
- The higher cost estimate has been used for the BCR in this report.

5.3.3.4 Intangible Benefits

In July 2004 DEFRA issued guidance for the estimation of intangible impacts of fluvial and coastal flooding and erosion. The guidance document (entitled *"Flood and Coastal Defence Project Appraisal Guidance – Supplementary Note to Operating Authorities"*) concluded that flooding caused physical effects in the short term and psychological effects in the short and longer terms, including the memory of stress associated with a flood event as well as the damage and the stress of recovering from a flood event, through settling claims with insurers and dealing with builders and repairers. Provision has been made within this assessment for these intangible damages via the method published in the *MCM* 2013. For example, the benefit to each household every year from a 200- year standard of protection is £289. Applying this to all residential properties, Table 27 lists the values used in this calculation:

Standard of Protection	Annual benefit per Residential Property	Number of Residential Properties Protected	Scheme-wide Intangible Annual Benefit
100 Year	£ 265	2,121	£ 562, 341
200 Year	£ 289	3,2651	£ 1,055,139

Table 27: Cost estimate for the options

The present Value of Benefits was derived by multiplying the number of properties that would be protected every year (for each standard of protection). By the intangible benefits per property per year as determined by DEFRA. The Annual Benefits of Defences were converted to a Present Value benefits by assuming these benefits occur every year over the 100-year appraisal period, applying a suitable discount factor for every year of this period.

The FCERM Appraisal Guidance also allows for the 'Risk to Life' caused by flooding to be valued. This has not been included within the present assessment due to the high awareness of flooding in the area and the subjective nature of the calculation.

5.3.3.5 Flood Levels

Predicted flood levels for the 2, 5, 10, 20, 50, 100 and 200-year return period events were extracted for each property (except the petrochemical plant) from the flood level grids generated during the hydraulic modelling.

Each property in the property database was given the maximum flood level within a 4m buffer around its footprint. This level was compared to the threshold level within each property to determine the depth of flooding.

5.3.3.6 Additional Losses

Included within the present-day damages, are the cost of damages associated with sports grounds within the Grangemouth area, these includes the sports pitches at Glensburgh and Grangemouth Athletics Stadium.

5.3.4 Damage Assessment Results

The damage assessment was carried out using CH2M's in-house spreadsheets developed for this purpose. Damages were calculated for the whole study extent, and also summarised by cell within the area of proposed defences.

In total 2,388 properties, have been identified through the hydraulic modelling as being within (at risk) the 100-year return period event envelope from flooding from the Rivers Carron, Avon, Grange Burn and the Forth Estuary in the Grangemouth area. The table below summarises the number of properties at risk per watercourse(s) and estuary. When using the 200-year extent the number of properties at risk rises to 3,551. It should be noted that there are sections of the Grange Burn and River Avon which experience tidal flooding from around the 5-year events, with wide spread flooding occurring on the River Carron and Grange Burn around the 10-year event. Table 28 identifies the number of properties at flood risk, are a range of return periods, for each of the cells, excluding cells 3,5 & 6 which cover the petrochemical plant.

Cells	Description	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year	200 Year
1 – Upper Carron	Residential	1	2	2	9	196	424	578
	Non-Residential	1	5	6	8	14	21	26
	Total	2	7	8	17	210	445	604
2 – Lower Carron	Residential	0	0	12	38	111	168	199
	Non-Residential	1	3	6	6	12	14	15
	Total	1	3	18	44	123	182	214

Cells	Description	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year	200 Year
4 - Grangeburn	Residential	0	6	170	371	1016	1529	2463
	Non-Residential	0	12	82	110	163	232	270
	Total	0	18	252	481	1179	1761	2733
1,2,4 – Residential	Residential	1	8	184	418	1323	2121	3240
	Non-Residential	2	20	94	124	189	267	311
	Total	3	28	278	542	1512	2388	3551

Table 28: Breakdown of flood damages

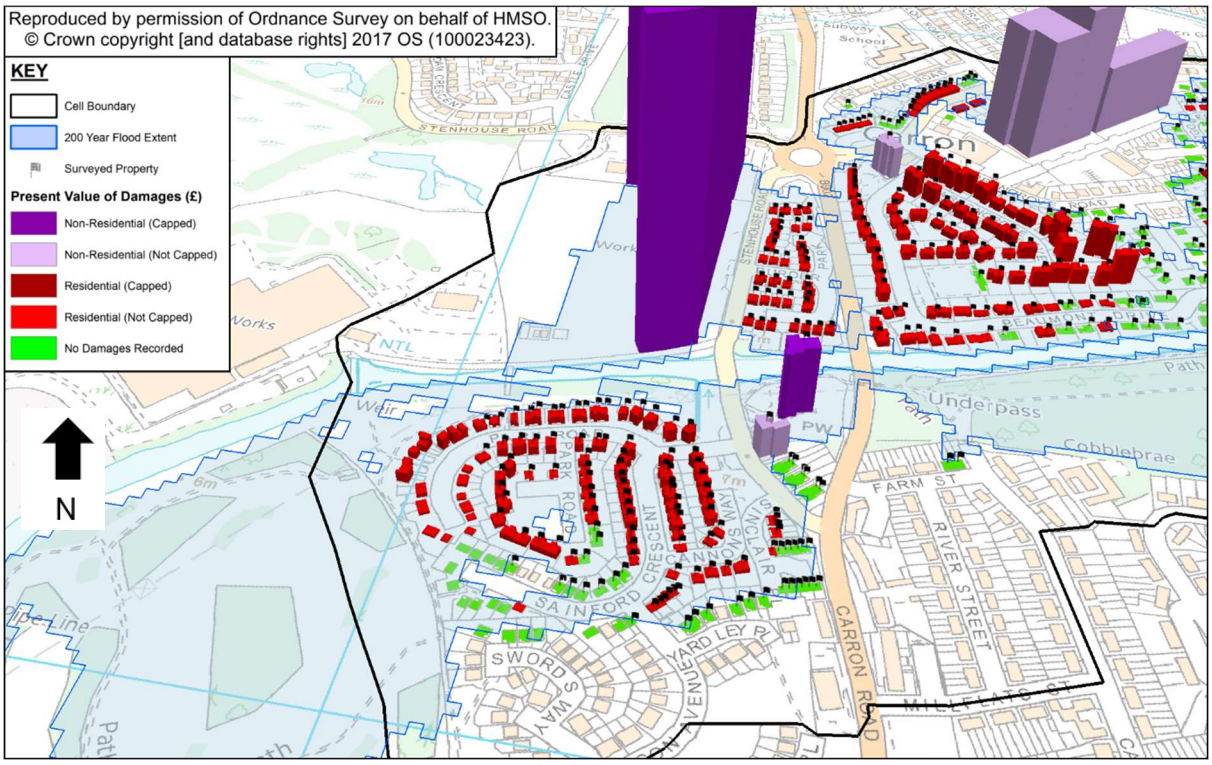

Figure 31: *Graphic of damage values for a part of Cell 1 (Carron Bridges)*

The two largest contributors on the right bank of the Upper Carron are a Church and an Inn, located very close to the River Carron. Most of the properties here were included in the threshold survey. There are a few residential properties on the periphery for which the threshold was estimated, and the damages calculated for them correlate to the damages for the surveyed properties.

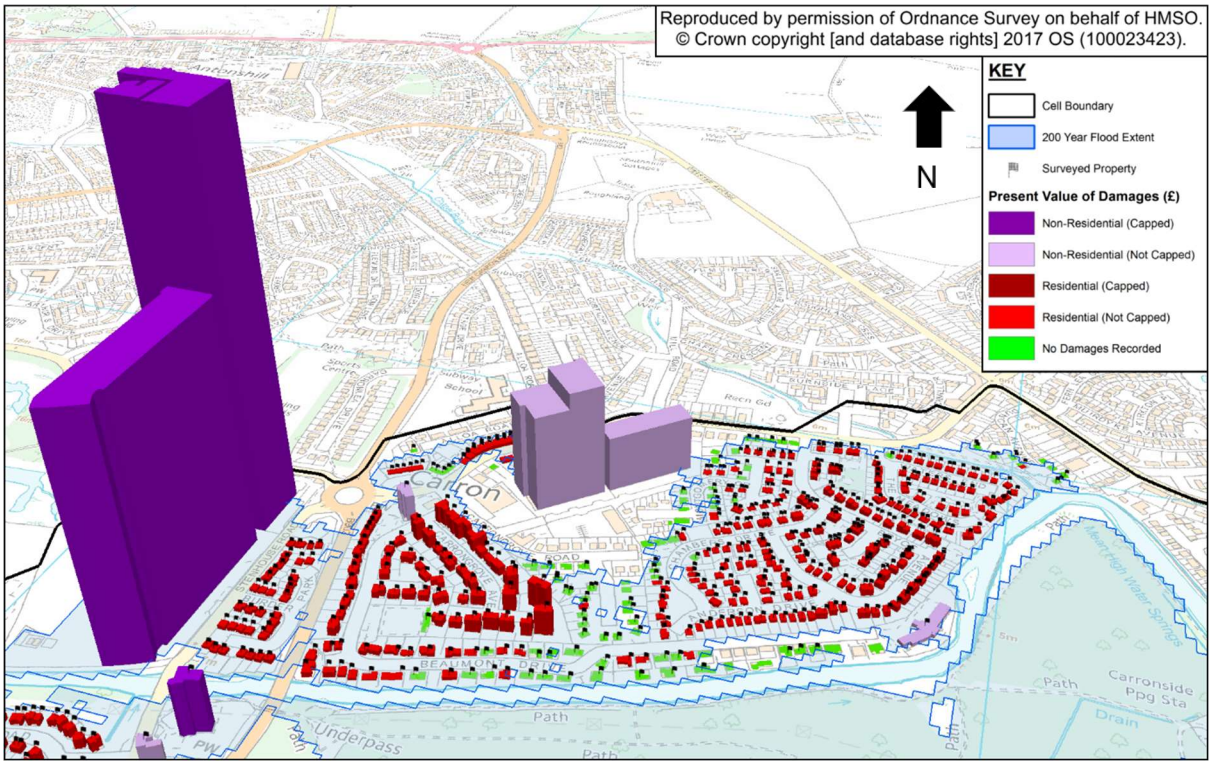

Figure 32: *Graphic of damage values for a part of Cell 1 (Beaumont Drive/ Chapel Burn)*

On the left bank, the residential properties on Carrongrove Avenue have significantly higher damages, because of a dip in topography in that area, resulting in higher depths of flooding. However, the largest contributors to damages are warehouses, which were not included in the threshold survey and have therefore been estimated.

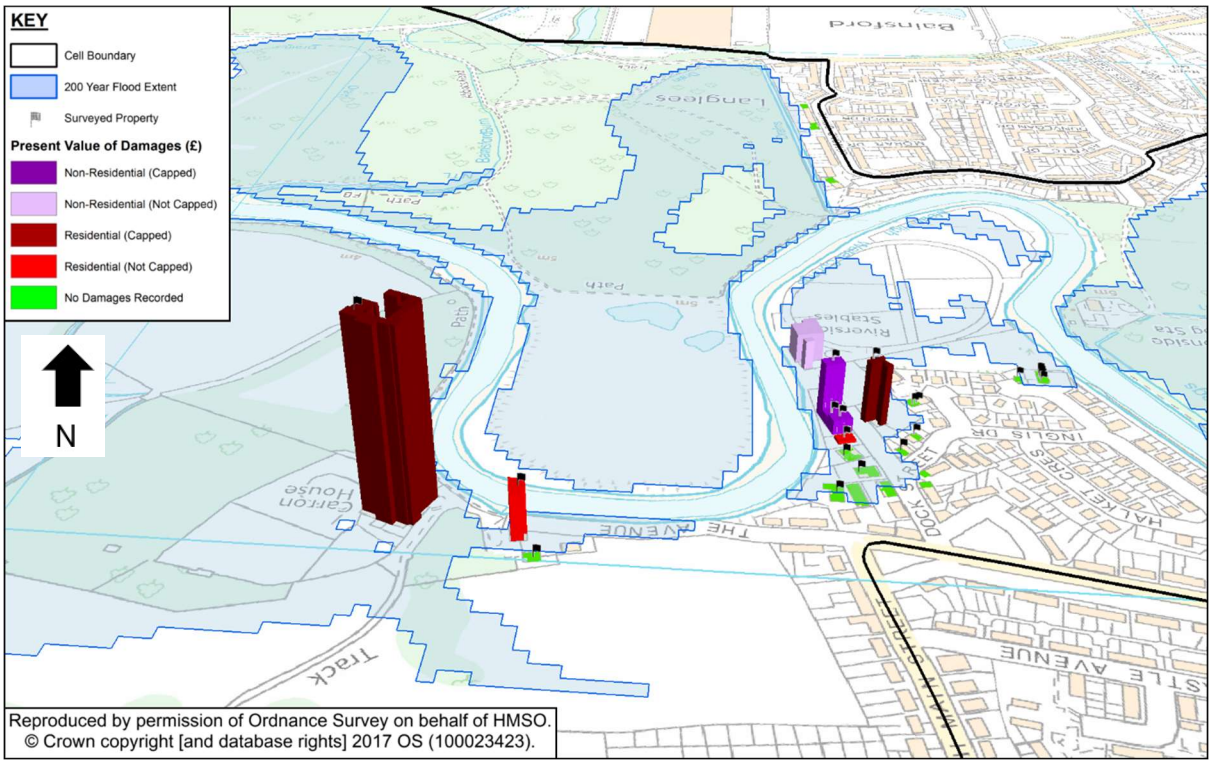

Figure 33: *Graphic of damage values for a part of Cell 1 (Dock Street)*

The highest source of damages for this area is the Carron House, which is a listed building. The capping value for this property has been set at 3 times the value of detached house, to reflect the additional value of such a building. On Dock Street, there are also some capped Residential and Non-Residential properties at risk of flooding.

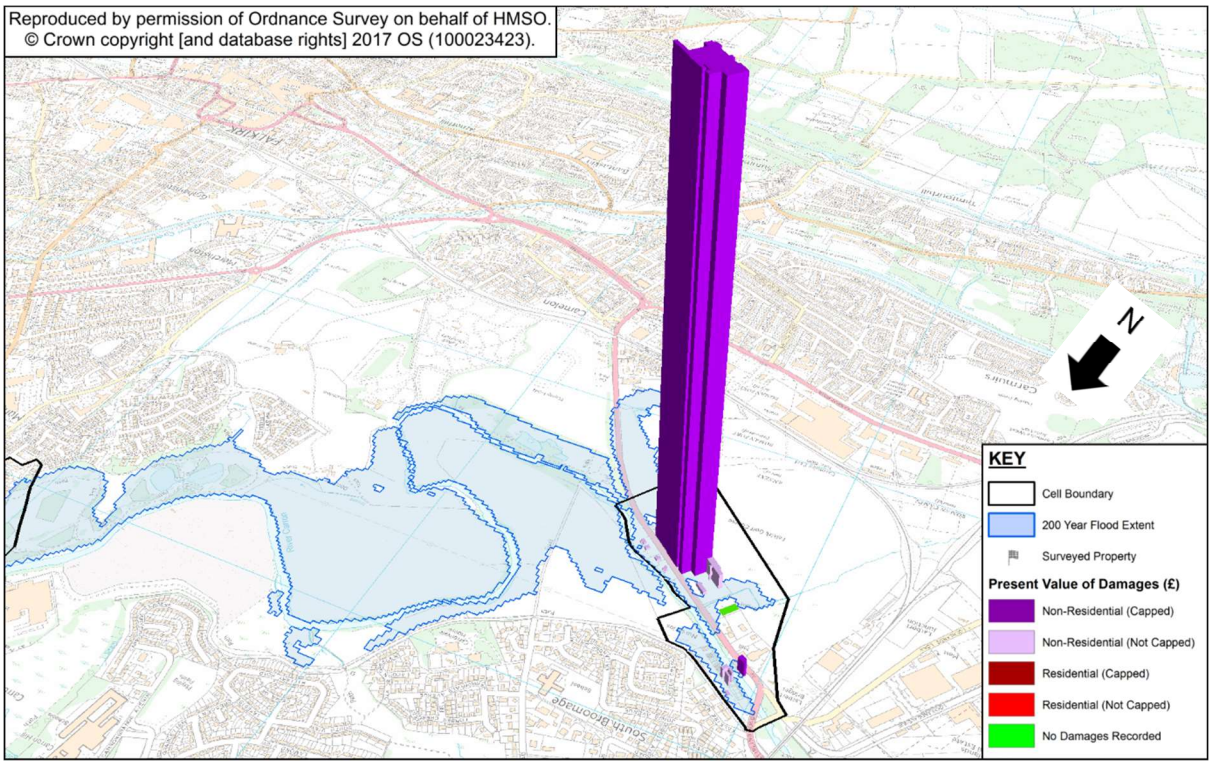

Figure 34: *Graphic of damage values for a part of Cell 1 (Stirling Road)*

All the properties on Stirling Road use LiDAR + 0.3m as the threshold level. Furthermore, there was no address point data, so the number of properties was assumed to be the same as the number of building footprints. However, given the scale of damages attributed to the bus depot, the biggest uncertainty is the capping value set for it.

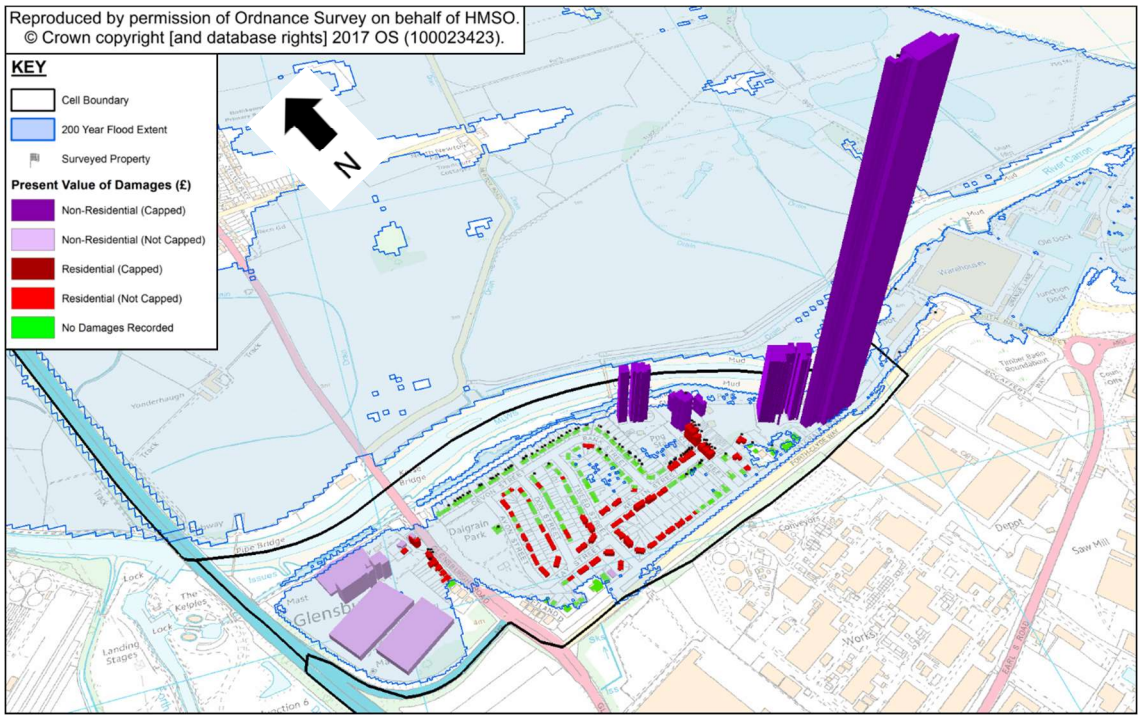

Figure 35: *Graphic of damage values for Cell 2*

The most significant source of damages in this area is the industrial launderette on the Forth-Clyde Way. The 'Retail' classification was chosen as opposed to 'Industrial', because damages to launderettes are included in the retail section. This is why the damages are higher than in the industrial buildings around it. Most of the properties surveyed on Devon Street indicate that they are not at risk of incurring flood damages. About half of the residential damages come from surveyed properties, and half from non-surveyed properties. The rugby pitches shown here have been included in the assessment.

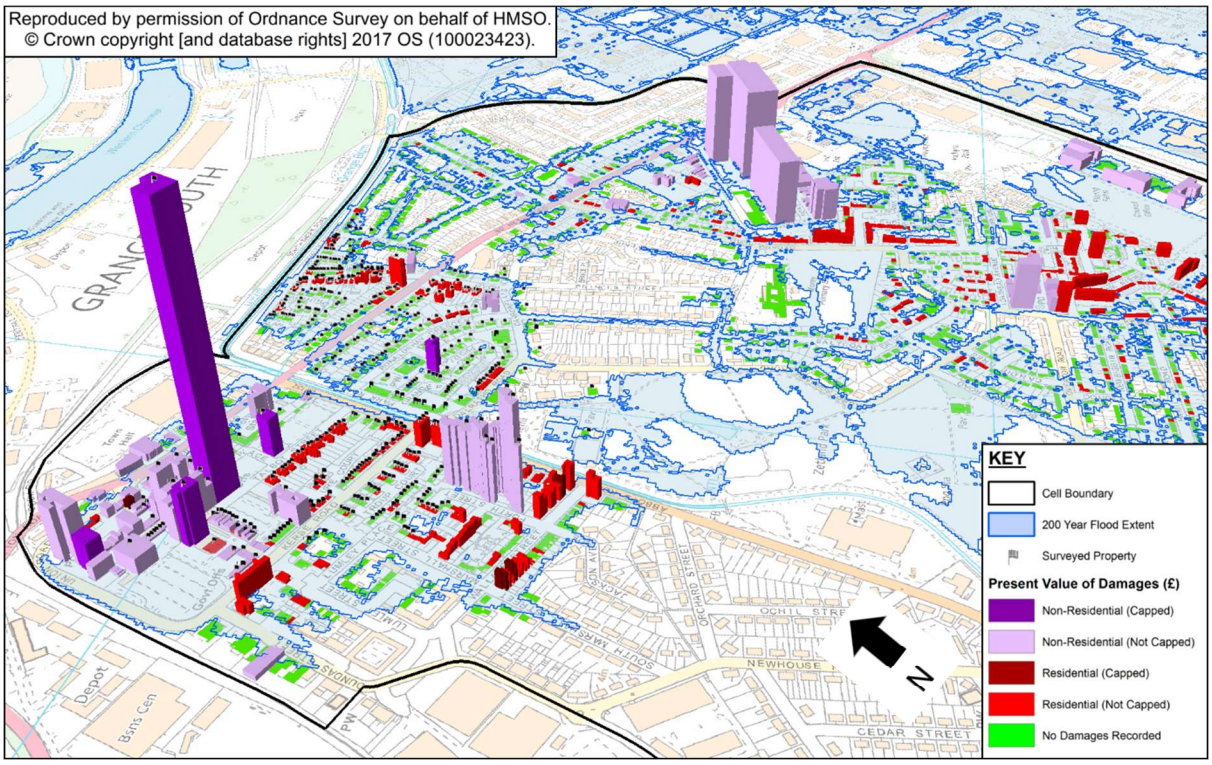

Figure 36: *Graphic of damage values for a part of Cell 4 (Grangemouth)*

The single biggest contributor to flood damages on the left side of the lower Grangeburn area is a B & M store. This is followed by the nursing homes on Forth Street. The damages here are higher than normal residential buildings. This reflects the vulnerability of the residents, who would find the experience of flooding particularly difficult, from onset up until post-flood recovery.

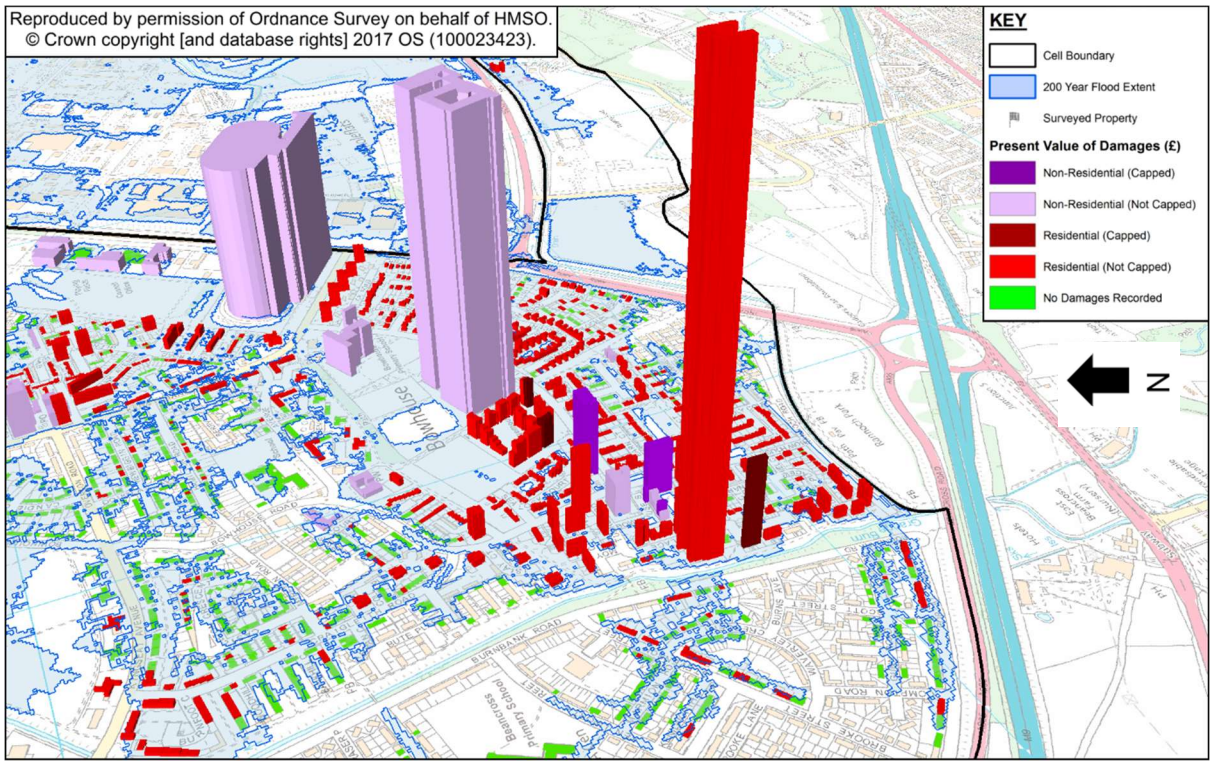

Figure 37: *Graphic of damage values for a part of Cell 4 (Rannoch)*

On the left bank of the upper Grangeburn, the damages are lower than on the right. This is due to flooding commencing on the left bank for the 100 year event, while on the right flooding commences from the 5 year event.

On the left bank of the upper Grangeburn, the highest contributor to damages is the flats at Morar Court. The reason for the high damages is because firstly it experiences flooding at the lower return period, which naturally gives it higher damages. However, unlike the buildings around it, it has 34 flats, and therefore the capping value for Annual Average Damages has been set at 34 times the price of a flat in Scotland. The next highest contributors to damages are non-residential buildings, namely Grangemouth High School and Grangemouth Stadium.

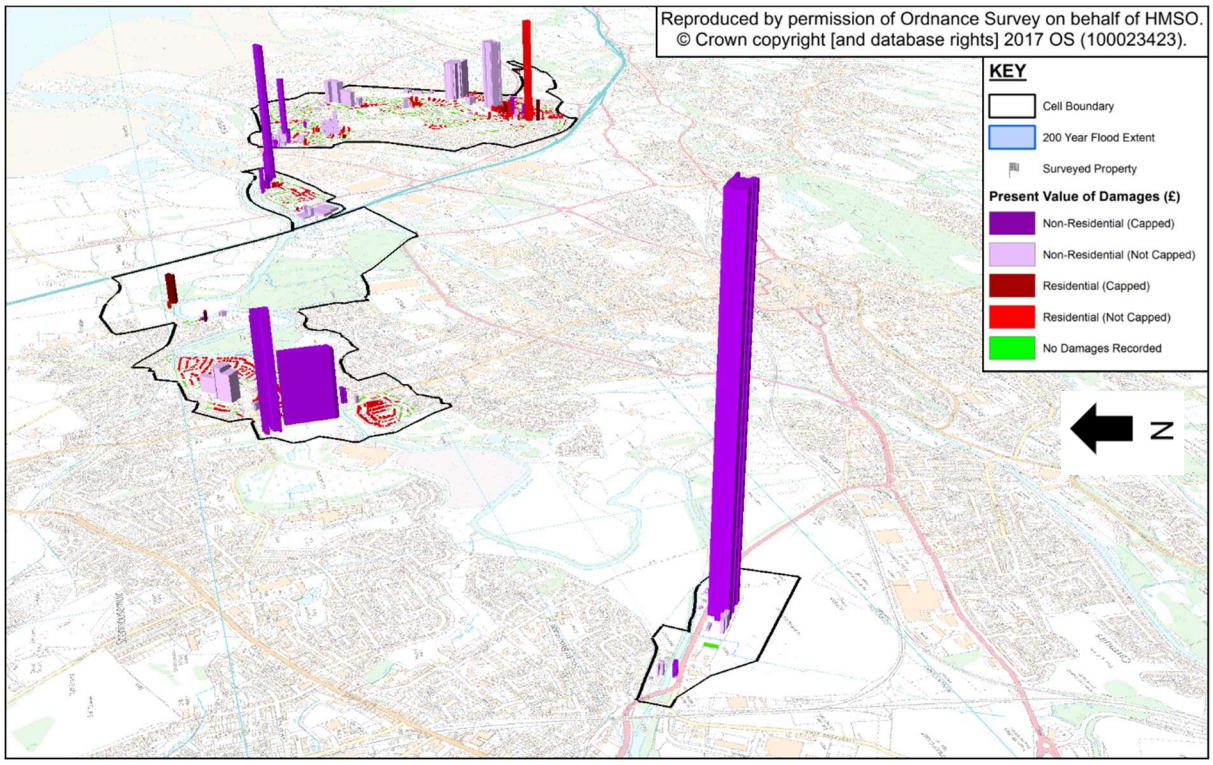

Figure 38: *Overview of the graphic of damage values for non-petrochemical plant areas*

On a scheme-wide basis, the highest contribution comes from the bus depot on Stirling Road. This is followed by the launderette on the lower Carron. Multiple properties on the Grangeburn make up a large proportion of the highest contributors. Finally, the warehouses on the Upper Carron make the highest damage contributions from that cell. Table 28 lists the ten highest damage contributors on a scheme-wide basis:

Annual Average Damages	Object ID	Description	Area (m^2)	MCM Code	Cell	Threshold Source	Capped/ Uncapped	Maximum Depth of Flooding (m)
£ 239,924	**990009**	Stirling Road Bus Depot	9,015	Miscellaneous	1	LiDAR and fixed value	Capped	1.05
£ 142,003	**5169**	Berendsen Launderette	2,756	Retail	2	Threshold Survey	Capped	0.99

Annual Average Damages	Object ID	Description	Area (m^2)	MCM Code	Cell	Threshold Source	Capped/ Uncapped	Maximum Depth of Flooding (m)
£ 123,771	**72850**	Morar Court Flats	1,267	Flats	4	LiDAR and fixed value	Uncapped	0.35
£ 85,677	**643440**	North Carron Works	6,787	Warehouse	1	LiDAR and survey estimate	Capped	1.11
£ 85,012	**483600**	Grangemouth High School	8,457	Public Building	4	LiDAR and fixed value	Uncapped	0.35
£ 73,282	**5130**	B & M Bargains Store	1,422	Retail	4	Threshold Survey	Capped	0.57
£ 53,105	**215740**	Carron Works 1	4,207	Warehouse	1	LiDAR and survey estimate	Capped	1.32
£ 53,105	**359490**	Carron Works 2	4,207	Warehouse	1	LiDAR and survey estimate	Capped	1.35
£ 53,105	**771420**	Carron Works 3	4,207	Warehouse	1	LiDAR and survey estimate	Capped	1.23
£ 47,200	**717190**	Grangemouth Sports Stadium	21,382	Sports Stadium	4	LiDAR and fixed value	Uncapped	0.61

Table 29: Ten highest damage contributors from non-petrochemical plant stakeholders

5.3.5 Damage reduction due to flood warning system

Falkirk Council are included within SEPA's Flood Warning system for the Forth Estuary.

5.3.6 Capping of damages

Damages to all properties within the study area are capped at market value, to ensure that damages are not accrued beyond the economic value of any given property. The impact of capping to residential properties can be seen in the table below.

5.3.7 Sensitivity Study

To assess the robustness of the damage risk assessment a sensitivity study was undertaken to determine the significance of certain variables. Sensitivity to property threshold levels was deemed to be worthwhile since there is uncertainty in the threshold level for properties that were not included in the threshold survey. As discussed in section 5.3.2.1.3, there are 3-types of threshold levels in this assessment:

- Obtained from threshold survey
- Estimated using LiDAR and threshold survey
- Estimated using LiDAR and a fixed value

There is uncertainty for using LiDAR and a fixed value, and therefore a range of values was tested to determine how much the damages could vary if an accurate threshold survey showed that this value was not the correct assumption. Table 29 lists how the Present Value of Damages varies for each fixed value added to the LiDAR level:

		Properties Flooded (Return Period)						
Fixed Value added to LiDAR (m)	**Present Value of Damages**	**2 Year**	**5 Year**	**10 Year**	**20 Year**	**50 Year**	**100 Year**	**200 Year**
0.10	£ 207,222,496	3	70	402	883	2230	3568	5127
0.15	£ 187,938,239	3	36	365	828	2085	3334	4849
0.20	£ 169,470,396	3	34	323	725	1913	2987	4527
0.30	£ 137,638,215	3	28	278	542	1512	2388	3551
0.40	£ 115,240,671	3	22	240	437	1074	1941	2749

		Properties Flooded (Return Period)						
Fixed Value added to LiDAR (m)	**Present Value of Damages**	**2 Year**	**5 Year**	**10 Year**	**20 Year**	**50 Year**	**100 Year**	**200 Year**
0.50	£ 102,535,519	3	22	221	384	859	1496	2268
0.75	£ 90,204,299	3	22	180	334	708	1119	1548
1.00	£ 85,344,309	3	22	179	333	699	1072	1473
2.00	£ 83,738,653	3	22	179	333	698	1070	1471

Table 30: Present value damages for fix value added to the LiDAR

Once a fixed value of higher than 0.5m is used, nearly all non-surveyed threshold properties would appear to be safe from flood damages, which would not be the case in reality. This indicates that in a scenario where using LiDAR and a fixed value for threshold levels has systematically overestimated the flood depths in properties, the Present Value of Damages would be upwards of £ 90,000,000 if an accurate threshold survey was carried out.

The other significant uncertainty in the assessment is the direct and indirect damages to the Industrial cells.

	Sensitivity Parameter	**Indirect Damages**	**Sensitivity Parameter**	**Direct Damages**
Estimate	**Days of Disruption**	**Present Value of Damages (50 Year)**	**Depth Damage Curve**	**Present Value of Damages (50 Year)**
Lower	10	£ 4,476,043,997	Industrial (MCM)	£ 366,485,728
Middle	15	£ 6,714,065,996	Petro-Chemical (Tebodin 1998)	£ 500,591,633
Higher	20	£ 8,952,087,995	Non-Residential Average (MCM)	£ 2,103,389,635

Table 31: Direct and indirect damage calculations for the petrochemical plant

To be conservative, the lower estimates were used to calculate the benefits for different standards of protection.

5.3.8 Summary of Damages

This damage assessment has calculated flood damages from the Rivers Carron, Avon, Grange Burn and the Forth Estuary into six discrete cells that are all at risk of flooding within the Grangemouth area. For ease of use the damage assessment has been split into the residential and light industrial areas (Flood Cells 1,2 and 4) and the Petrochemical Plant (Flood Cells 3, 5 and 6). The damages calculated for options 4gi and 4gii (cell 4 model extension) were determined using Global Flood Modeller which has a built-in damage calculation tool, which uses the principals of the MCM.

Cell	Average Annual Damages	Present Value of Damages	100 Year Stand of Protection Benefits	200 Year Stand of Protection Benefits
1 – Carron Upper	£ 1,319,810	£ 39,347,503	£ 23,375,688	£ 30,128,159
2 – Carron Lower	£ 710,332	£ 21,177,128	£ 19,137,123	£ 20,420,241
4 – Grangeburn	£ 2,586,576	£ 77,113,584	£ 68,740,686	£ 84,006,744
1,2,4 – Residential	£ 4,616,718	£ 137,638,215	£ 111,253,497	£ 134,555,145
3,5,6 – Industrial – Direct	£ 14,961,655	£ 366,485,728	£ 343,301,414	£ 350,621,487
3,5,6 - Industrial – Indirect	£ 182,732,966	£ 4,476,043,997	-	£ 3,468,934,098

Table 32: Overview of scheme damages, present value and benefit

5.4 Calculation of Benefits

Section 5.3 of this report summarises the damage assessment that have been carried out in to order to determine the economic value of benefits (in terms of damages avoided) that can be accrued through a flood protection scheme. The economic value of avoided damages forms the basis of the benefits associated with the implementation of a flood protection scheme. It should be noted that additional factors such as social and environmental benefits can also be considers within the benefit-cost analysis where appropriate. This is evidenced in section ** of this report which identifies social and environmental as criteria used in the option scoring matrix. In calculating the benefits, it is hard to quantify the social and environmental benefits in a monetary value.

In line with the guidance and following current best practice the scheme benefits have been assessed using "The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques" (Flood Hazard Research Centre, 2010) the MCM.

5.4.1 Benefit Cost Ratio

The benefit cost ratio has been calculated for all the options outlined in section ** of this report, using the Environment Agency 'Economic Appraisal Supporting Spreadsheets'.

The benefit cost ratio for each option was based on the following:

$$Benefit\ Cost\ Ratio = \frac{Benefits\ as\ summerised\ in\ section\ 5.3.4}{Costs\ as\ summarised\ in\ section\ 5.2}$$

For each option, it was assumed that the existing value of flood protection assets were written off by the construction of a replacement flood protection scheme. It was assumed the value of the flood protection scheme assets at the end of the 100-year appraisal period would be zero, this ties-in well the 100-year design life of the proposed structures.

For some cells the 1 in 100-year and 1 in 200-year events were assessed. The 1 in 200-year level of protection has been deemed by the project team and Falkirk Council as the minimum level of protection afforded by the scheme.

Climate change has not been considered when calculating the flood damages as the effects of potential increased flows are predictions and not certain to occur. Climate change is occurring, however there is significant uncertainty regarding the rate and impact of these changes. The cost estimate of damages does not account for climate change, based on the general approach taken with flood protection schemes in Scotland. The project team and Falkirk Council have accounted for climate change in the construction cost estimate for cells that cover the petrochemical plant, this is based on the following justification:

- Important national critical infrastructure is at flood risk,
- Difficulty in access the petrochemical plant, and
- Length process of obtaining statutory consent,

It is acknowledged that the benefit cost ratio for cells that contain the petrochemical plant (including the port) will have a significantly higher BCR than other cells, however, as the BCR's are ranked against other options within that cell only, it will not affect the identification of the preferred options from other cells.

Due to the complex nature of the petrochemical plant, Cells 3, 5 & 6 have been merged to create a single BRC, refer to section below for information relating to present-day benefits.

5.4.2 Summary of Benefits

Table 33 summaries the benefits that are accrued for both level of protection for each of the cells and totaled for the scheme.

Cell	Present Value Benefits	
	1 in 100-year	1 in 200-years
1	24,377,613	30,485,621
2	90,686,638	92,047,817
3, 5 & 6		
4	51,154,924	62,239,542
Total	**166,219,174**	**187,129,469**

Table 33: Summarises the benefits for cell and return period

5.4.3 Benefit Cost Analysis

The benefit cost analysis undertaken for the range of options consider within this appraisal has been undertaken on a cell by cell basis, with the exception of cells 3 ,5 & 6 which have been merged to the location of the Petrochemical Plant. For some of the cells, only one option has been considered (deemed feasible from an engineering point of view) in the option scoring matrix, see Table 34.

Cell	Option	Present Day Value Costs (construction cost)		Present Day Value Benefits (damages avoided)		BCR	
		100-year Return Period	200-year Return Period	100-year Return Period (£)	200-year Return Period (£)	100-year Return Period	200-year Return Period
1	1a		20,911,301		30,128,159		1.4
	1b	12,883,655		23,375,688		1.8	
	1c		21,869,709		30,128,159		1.4
	1d	13,834,253		23,375,688		1.7	
2	2a		6,494,124		20,420,241		3.1
3, 5 & 6	3,5 & 6a		102,081,797		3,819,555,585		37.4
4	4a*		48,832,473		84,006,744		1.7
	4b*	42,280,674		68,740,686		1.6	
	4c*		35,917,413		84,006,744		2.3
	4d*	31,089,664		68,740,686		2.2	
	4e*		45,040,025		84,006,744		1.9

	4f*	37,335,914		68,740,686		1.8	
	4g*		37,472,563		84,006,744		2.2
	4h*		45,251,875		84,006,744		1.9
	4i*		30,652,729		84,006,744		2.7
	4gi		49,657,086		62,239,542		1.3
	4gii		49,307,188		62,239,542		1.3

Table 34: Outlines the benefit cost ratio for the options

*calculated prior to the model extension in Cell 4. The present-day value benefits (damages avoided) is different for options 4gi and 4gii as this accounts for the model extension ad different flood flow paths.

Option 4a to 4i were all initially appraised and found to be unacceptable to take forward to the next stage, as outlined in section 4.4.5 of this report.

The BCR is one of the components that forms part of the option appraisal multi-criteria matrix. The BCR for each option will be ranked against the other options contained within that cell. BCR for each option will not be ranked against other options within their own cell.

All BCR's are based on the cost of constructing a concrete wall with sheet piled foundations as the flood defence; at this stage of the option appraisal it is not known what type of flood defences will be installed so a conservation approach has been made. At the outline design stage a better understanding of the type of direct defence will be gained. It should be noted that due to limited space on the existing banks, may result in a wall structure being the likely type of direct defence.

6. Conclusion

6.1 Economics

The Economic appraisal forms part of the Option Scoring Matrix and provides robust evidence that a flood protection scheme for Grangemouth is economically viable and justifiable. The BCR's for each option were ranked against other options within that cell.

When reviewing the BCR's, (which historically, has been the principal driver for selecting the need for a scheme and the options), the preferred options have the following BCR's (based on maintaining a 200-year level of protection for each cell.

	BCR										
Flood Cell	**200-year level of protection (option no.)**								**100-year level of protection (option no.)**		
1	1.4 (1a)		1.4 (1c)						1.8 (1b)	1.7 (1d)	
2	3.1 (2a)										
3,5 & 6	39.5 (3a, 5a & 6a)										
4	1.7 (4a)	2.3 (4c)	1.9 (4e)	2.2 (4g)	1.9 (4h)	2.7 (4i)	1.3 (4gi)	1.3 (4gii)	1.6(4b)	2.2 (4d)	1.8 (4f)

Table 35: Identifies the Scheme BCR; for comparison of Options in Cells 1 & 4, Options 1b, 1d, 4b, 4d & 4f have been included.

Table 35 identifies option 1a and 1c has having the same BCR, however, when considering the multi-criteria matrix option 1a has a better total overall ranked score of 11 compared to 14. Option 4i has the highest BCR in Cell 4 and has a positive correlation with the overall option scoring matrix. However, as outlined in section 4.4.5, options 4a, 4c, 4e, 4g, 4h and 4i have been discounted from the option appraisal on technical and operational risk grounds, leaving options 4gi and 4gii as the only feasible options for this cell. Options 4gi and 4gii have the same BCR of 1.3.

The BCR for the overall Scheme has been calculated excluding the Petrochemical Plant and including it.

Flood Cell	Option no.	Benefits of 200-Year Level of Protection – Damages avoided	Cost of providing 200-year level of Protection – Construction cost	Scheme BCR
1	1a	£30,128,159	£20,911,301	

Flood Cell	Option no.	Benefits of 200-Year Level of Protection – Damages avoided	Cost of providing 200-year level of Protection – Construction cost	Scheme BCR
2	2a	£20,420,241	£6,494,124	
4	4gii	£62,239,542	£49,307,188	
Total		£112,787,942	£76,712,613	**1.5**

Table 36: Identifies the BCR for the Scheme excluding the Petrochemical Plant

Flood Cell	Option no.	Benefits of 200-Year Level of Protection – Damages avoided	Cost of providing 200-year level of Protection – Construction cost	Scheme BCR
1	1a	£30,128,159	£20,911,301	
2	2a	£20,420,241	£6,494,124	
3, 5 & 6	3a, 5a & 6a	£3,819,555,585	£102,081,797	
4	4gii	£62,239,542	£49,307,188	
Total		£3,932,343,527	£178,794,410	**22**

Table 37: Identifies the BCR for the Scheme including the Petrochemical Plant

The overall Scheme BCR (including and excluding the Petrochemical Plant) is considerably favourable compared to other flood protection schemes in Scotland; table 38 compares the BCR for Grangemouth with other recently promoted / constructed flood protection schemes in Scotland.

Flood Protection Scheme	Benefit Cost Ratio
Grangemouth	22

Flood Protection Scheme	Benefit Cost Ratio
Grangemouth (excluding Petrochemical Plant)	1.5
Hawick	2.7
Selkirk	2.2
White Cart	2.2
Elgin	1.4
Broxburn	1.2

Table 38: BCR comparison with other recent Scottish Flood Prevention / Protection Schemes

6.1.1 Summary

The overall economic analysis from the option appraisal showed:

- there is no difference between BCR for Options 1a and 1c, (both provide a 1 in 200-year level of protection), there is an increase in the BCR if the 1 in 100-year level of protection is used in Cell 1;
- Including the petrochemical plant in the scheme BCR does significantly increase the overall Scheme BCR, however, when excluding the petrochemical plant, the scheme BCR is still positive at 1.5;
- the preferred options identified through the option scoring matrix correlate positively with BCR;
- Option 4gii has been identified as the preferred option having the joint highest BCR;

6.2 Recommendations

The economic appraisal will be updated within Stage 4 - Outline Design, when the cost of the scheme can be more accurately estimated as the project tram have more confidence in the type / structure (wall / embankment) and alignment of flood defences. Within Stage 4, the optimism bias (included within the cost estimate) will be reviewed and reduced to account for increased confidence in the design of the scheme. It should be noted that due to the high overall scheme BCR, limited time should be spent reviewing the economic viability of the scheme as any changes to the figures will have a negligible effect on the overall Scheme BCR.

6.3 Environmental

Each option has been assessed against environmental criteria / scheme objectives and assigned a score, which has been subsequently ranked against other options within that Cell. The Option Scoring Matrix identifies option 1c and 1d as the top ranked options for Cell 1; 2a for Cell 2; 3a 5a & 6a for Cells 3, 5 & 6 and 4c to 4g and 4gi / 4gii - for Cell 4. If we exclude options that do not provide the 1 in 200-year level of protection and the discounted options for Cell 4, the top ranked environmental options would be options 1c, 2a, 3a 5a & 6a and

4gi/4gii. With the exception of Cell 1, the overall environmental scores / rankings positively correlate with the overall top ranked options.

Flood Cell	Option	Level of Protection	Environmental Score	Environmental Ranking	Carbon Emissions Ranking
1	1a	200	2	3	2
	1b,	100	2	3	1
	1c	200	3	1	4
	1d	100	3	1	3
2	2a	200	3	1	1
3, 5 & 6	3a, 5a, & 6a	200	1	1	1
4	4a	200	1	6	9
	4b	100	2	5	8
	4c	200	4	1	2
	4d	100	4	1	1
	4e	200	4	1	7
	4f	100	4	1	6
	4g	200	4	1	4
	4h	200	4	1	5
	4i	200	4	1	3
	4gi	200	4	1	(2781) 1*
	4gii	200	4	1	(2931) 2*

**Options ranked for Carbon emissions after remaining options in Cell 4 were discounted on technical grounds.*

Table 39: Environmental scores and rankings from the Option Scoring Matrix

6.3.1 Carbon Emissions

A review of the Carbon emission rankings identifies options 1a, 2a, 3a 5a & 6a and 4c as the best ranked options when maintaining the 1 in 200-year level of protection. However, when omitting option 4c (based on technical grounds) from the option matrix, option 4gi is identified as the top ranked option.

6.4 Social

Each option has been assessed against criteria linked to the Scheme Objectives and assigned a score. The score has been subsequently ranked against other options within that Cell. The Option Scoring Matrix identifies all the options in Cells 1, 2, 3, 5 & 6 as having the top score and ranking. Within Cell 4 options 4c /d / e / f / I / gi and gii were all identified as having the top score and ranking. When discounting all the options from cell 4, except 4gi and 4gii, the overall social scores and rankings from the Option Scoring Matrix shows a positive correlation to the identified preferred scheme. It should be noted that the social scores were very consistent with a limited range of scores / rankings recorded.

Flood Cell	Option	Level of Protection	Social Score	Social Ranking
1	1a	200	2	1
	1b,	100	2	1
	1c	200	2	1
	1d	100	2	1
2	2a	200	4	1
3, 5 & 6	3a, 5a, & 6a	200	4	1
4	4a	200	2	5
	4b	100	2	5
	4c	200	4	1
	4d	100	4	1
	4e	200	4	1
	4f	100	4	1
	4g	200	3	4
	4h	200	3	4
	4i	200	4	1
	4gi	200	4	1*
	4gii	200	4	1*

**Options ranked after remaining options in Cell 4 were discounted on technical grounds.*

Table 40: Identifies scores and ranking from the Option Scoring Matrix

6.5 Utilities

Each option has been assessed against utility criteria and assigned a score, which has been subsequently ranked against other options within that Cell. The Option Scoring Matrix identifies all the options in Cells 1, 2, 3, 5 & 6 as having the same score and ranking. Within Cell 4 options 4i was identified as having the top score and ranking; which positively correlates to the overall option scoring matrix.

Flood Cell	Option	Level of Protection	Utility Score	Utility Ranking
1	1a	200	2	1
	1b,	100	2	1
	1c	200	2	1
	1d	100	2	1
2	2a	200	4	1
3, 5 & 6	3a, 5a, & 6a	200	4	1
4	4a	200	1	9
	4b	100	2	4
	4c	200	3	2
	4d	100	3	2
	4e	200	2	4
	4f	100	2	4
	4g	200	2	4
	4h	200	2	4
	4i	200	5	1
	4gi	200	3	2*
	4gii	200	4	1*

**Options ranked for Carbon emissions after remaining options in Cell 4 were discounted on technical grounds.*

Table 41: Utility scores and rankings from the Option Scoring Matrix.

6.6 Operational Risk

Although operational risk was not a category within the option matrix, it was considered when selecting a preferred scheme. As outlined in section 3.4 of this report, options that had an operation risk score of 3, were discounted from the operation appraisal as Falkirk Council deemed the operation risk too high for the option to be taken forward.

With reference to Cell 4, the operational risk reflects a positive correlation to the identified preferred scheme. Options 4gi and 4gii have the same overall ranked score, however, option 4gi has a higher operational risk score than compared to option 4gii.

6.7 General Summary

From analysing the option scoring matrix, the Environmental, Social, BCR, Utilities and operational risk scores and subsequent rankings reflect a very positive correlation with the overall top ranked option for each Cell. The estimated Carbon Emissions scores and subsequent ranking do not positively correlate with the overall top ranked option for Cell 4. This can be partly explained as the estimated Carbon footprint emissions is only based on a length of flood defence, there is no accounting for height of flood defences or number of bespoke structures.

Overall, the option scoring matrix reflects a generally positive correlation between the five aspects used to evaluate options.

6.8 Selecting the Preferred Scheme

6.8.1 Overview

This section of the report examines the advantages and disadvantages associated with the remaining options and decisions that are required to be made to select a preferred Scheme for Grangemouth.

6.8.1.1 Level of Protection

As outlined in section 3 of this report, the option scoring matrix identified a mixture of 100 and 200-year level of protection as the preferred option. To maintain the same level of protection throughout the Scheme, the options with a 1 in 100-year level of protection were not considered. The table below outlines the options that provide a 1 in 200-year level of protection, with a breakdown of their option scores and ranks.

Option	No.	1a	1c	2a	3a, 5a & 6a	4a	4c	4e	4g	4h	4i	4gi	4gii
Standard of Protection Years		200	200	200	200	200	200	200	200	200	200	200	200
Flood Cell		1		2	3, 5 & 6	4							
Benefit Cost Ratio	**Actual Score**	1.4	1.4	3.1	37.4	1.7	2.3	1.9	2.2	1.9	2.7	1.3	1.3
	Rank compared to other options in cell	1	1	1	2	6	2	4	3	4	1	1	1
Utilities	**Actual Score**	3	1	3	1	1	3	2	2	2	5	3	4
	Rank compared to other options in cell	1	2	1	1	6	2	3	3	3	1	2	1
Environmental	**Actual Score**	2	3	3	1	1	4	3	4	4	4	4	4
	Rank compared to other options in cell	2	1	1	1	6	1	5	1	1	1	1	1
Carbon emissions (CO^2e)	**Amount (Tonnes)**	1028	22,199	495	1,210	3,070	1,191	2,865	2,019	2,065	1,252	2781	2931
	Rank compared to other options in cell	1	2	1	2	6	1	5	3	4	2	1	2
Social	**Actual Score**	2	2	4	4	2	4	3	3	3	4	4	4

	Rank compared to other options in cell	1	1	1	1	6	1	3	3	3	1	1	1
Overall totaled rankings (Lowest figure = top rank)		**6**	**7**	**5**	**7**	**30**	**7**	**20**	**13**	**15**	**6**	**6**	**6**
Operational Risk		**1**	**1**	**1**	**2**	**1**	**3**	**1**	**2**	**3**	**3**	**2**	**1**

Table 42: Overview of Option Scoring Matrix, that provide a 1 in 200-year level of protection

Through the Option Scoring Matrix, the following options have been identified as a preferred Scheme to provide a 1 in 200-year level of protection:

- 1a,
- 2a,
- 3a, 5a & 6a, and
- 4gii

Having a variable level of protection for the scheme is likely to cause a negative social and political reaction (the FCERM-AG refers to this situation and advises that extreme caution should be taken if considering a variable level of protection of Schemes). Through project team meetings with Falkirk Council a variable level of protection was not deemed appropriate, therefore a uniform minimum level of protection across flood cells was selected as the preferred choice. The scheme will provide a minimum 1 in 200-year level of protection, to account for residual uncertainty (freeboard), the design level for flood defences may use a lower return period event with an allowance factored into the design level to account for residual uncertainty, with the overall design level at least equal to the 1 in 200-year design level. Climate change will be accounted for in the design of flood defences for Cells 3, 5 & 6.

From initial flood modelling the project team were able to determine the proposed defence heights; very few defences heights are greater than 2.5m above existing ground level, except for defences along the estuary frontage which are up to 3.5m above existing ground level. In general, a defence height of less than 2.5m (above existing ground level) is deemed acceptable; it would be possible for the ground to the rear of the defences to be raised locally to suit the required visibility requirements of Falkirk Council. As this stage, no maximum defence height has been stated by Falkirk Council or maximum acceptable visible defence height.

The identified preferred options have been modelled against the baseline 200-year flood event, to ensure the scheme will not materially increase flood risk to other properties through the delivery of the Scheme.

6.8.1.2 Environment Impact

The Scheme Objectives that relate to the level of protection, are to ensure the scheme is environmentally acceptable and achieves a neutral impact on the environment, whilst maximising the environmental benefits.

The ecological and environmental impacts associated with construction of flood defences are generally not dependent on the level of protection. The impact of constructing defences regardless of height is generally the same, whether the defence is 2m or 3m above ground level. The spatial extent of defences is very similar between the 100 and 200-year levels of protection and will have no significant influence on this.

6.8.1.3 Social Impact

Apart from the economic impact of the BRC, which has potentially the most influence on the choice of the level of protection, the social impact should be considered particularly relevant. Defences should not act a physical barrier to communities, rather provide communities with the opportunity to enhance the environment through improving wellbeing, sustainability and increase the appeal of the environment in which people want to live in.

The impact on cultural heritage, will be assessed through the social impact. It should be noted that the impact of difference level of protection will have little impact on cultural heritage.

6.8.1.4 Utilities Impact

Very limited impact on the different levels of protection.

6.8.1.5 Interaction with other projects

Some options will have an interaction with the upgrade work to Junction 5 of the M9, A9/Grandsable Road Junction improvements and any associated work on Inchyra Road. Details of these projects are not currently available from Falkirk Council, however the design of flood defences associated with scheme works will need to consider these projects. The A9/Grandsable Road junction improvement works are closely aligned to the proposed flood defences.

Details of proposed work within the petrochemical plant are limited at present. Early engagement with industrial stakeholders is seen as a critical method of managing this risk. The Industrial Stakeholder do not need apply for statutory planning consent, having deemed planning due to the specialist nature of their work, therefore the project team need to be made aware of any proposed developments within the petrochemical plant and port areas which may impact the proposed flood defences.

6.8.1.6 Access and Flood Gates

Several flood gates are required to ensure access is maintained along the river bank, for commercial and recreational purposes.

6.8.1.7 Public and Stakeholder Reaction

The identified preferred scheme was developed on feedback received from the public consultation events. The principals of options 4gi and 4gii are not dissimilar to option 4g, which was included as an option at the public consultation events.

6.8.1.8 Operational Risk

The operational risks associated with each of the options has been reviewed by the project team and scored according to criteria set out in the options matrix. Falkirk Council will have responsibility for operating and maintaining the flood defences. Some options pose significant operational risks to Falkirk Council who will ultimately be responsible for them. Options that have been scored as 3 – pose significant operational risks and have not been progressed to the outline design stage on the grounds that the operational risk is too high for Falkirk Council, regardless of where the option ranked in comparison to other options within that cell.

6.8.1.9 Summary and Conclusion

Apart from Cell 4 there are a limited number of options to appraise in each cell, to maintain the 1 in 200-year level of protection. Various factors are likely to influence the identification of the preferred option for Cell 4, factors that are likely to influence the decision are:

- Disruption caused to Grangemouth during construction;
- Interaction with World Heritage Site - Antonine Wall;
- Spatial extent and height of defences;
- Impact on utilities;
- Impact of physical barrier between communities; and
- Permeant changes to flow regime in the Grange Burn.

7. Summary of Preferred Scheme

7.1 Preferred Combination of Options

Following extensive investigation, design and consultation, table 43 summaries the preferred combination of options which form the proposed Grangemouth Flood Protection Scheme, which shall have a 1 in 200-year level of protection.

The preferred Scheme represents the combination of options which makes best use of existing infrastructure;

- locks at the entrance to the port,
- embankments next to the Forth - Clyde canal, by the A905,
- embankment parallel to North Shore Road,
- embankment along the estuary frontage next to the Grange Burn, and
- embankment to the east of the Kinneil Waste Water Treatment Works.
- Embankment on the River Avon around the (KG plant).

It is recognised investigation work will be required for each of the items identified above, to determine their structural integrity as a flood protection structure.

Option no.	Defence Type	Flood Cell	Water Course	Description
1a	Mixture of walls and embankments, set-back and at channel edge	1 – Upper Carron	River Carron	• 2,749m of direct defences along both banks from Stirling Road to Carronshore. • Direct defences will be a mixture of walls and embankments; alignment of defences is likely to be within the gardens of residential property on Beaumont Drive. • Some opportunity for defences to be set-back from the channel. • Majority of defences are 0.5 - 1m high, maximum height 2.5m above existing ground level.

Option no.	Defence Type	Flood Cell	Water Course	Description
				• Multiple utilities clash with the proposed alignment of direct defences, limited space to divert utilities.
2a	Mixture of walls and embankment, set-back from channel and at channel edge	2 – Lower Carron	River Carron	• 1,043m of direct defences along the right bank from Clyde Street to the Sea Cadets building on North Shore Road. • Direct defences will be a mixture of walls and embankment. • Limited opportunity for defences to be aligned back from the channel edge, due to commercial land-use. • Majority of defences are 0.5 - 1m high, maximum height 1.5m above existing ground levels. • Some utilities clash with defence alignment, but nothing significant.
3a, 5a & 6a	Mixture of wall and embankment, set-back from the channel and at channel edge, some with rock armour revetment in front.	3- Harbour 5 – River Avon 6 - Estuary Frontage	Estuary and River Avon	• 13,112m of direct defences along the harbour and estuary frontage. • Direct defences will be a mixture of walls and embankments. • Direct impact with the SPA. • Limited opportunity for defences to be aligned back from the channel. • Rock amour revetment required in front of direct defences to dissipate wave energy. • Some utilities clash with defence alignment, limited opportunity to move defence alignment. • Raise / replace existing lock-gates at the entrance to the port – potential for significant disruption during this work.

Option no.	Defence Type	Flood Cell	Water Course	Description
4gii	Direct defences construction on the banks of the Westquarter and Polmont Burns. A flow control structure on the Grangeburn to limit flow to 10.5m^3, direct majority of flows down the FRC. Mixture of walls and embankments set back from the channel where possible but in Grangemouth likely to be a wall structure near the channel edge.	4 – Grange Burn	Grange Burn	• 7,787m of direct defences. • Direct defences are likely to be walls rather than embankments due to limited space on the existing bank. • Majority of defences are 0.5m – 1m high on the FRC and Grange Burn; maximum height 2m on FRC and 1m on the Grange Burn. • Requires a flow control structure on the Grange Burn to limit the maximum flow to 10.5m^3, the majority of flow will be directed down the FRC. • Some utility clashes, particularly with the dam and along the FRC. Significant reduction in the potential for utility clashes along the Grange Burn.

Table 43: Identifies the preferred options from the Option Scoring Matrix which provide the Scheme with a 1 in 200-year Level of Protection

Provision of seepage and ground conditions has not been assessed at the option appraisal stage. It should be noted that the rate for the coastal revetment has been determined on the following parameters:

- Revetment height – 3m
- Revetment width – 7m
- Revetment length - ~7,000m
- Density of stone – 2.6

The rates for headwalls has been determined by their size and passed experience of constructing similar structures. The rates for the port lock gates is based on previous experiences of installing similar sized gates.

All existing outfalls will need to be fitted with non-return valves to stop water backing up the pipe, depending on the condition / size of the pipe, a NRV maybe retrofitted to the pipe, or if required a new section of pipe will need to be installed.

7.2 Key Facts and Figures

Table 44 provides a series of pertinent facts and figures relating to the provision of the preferred Scheme:

Parameter		Value
Level of Protection		1 in 200-year for all cells
Total number of properties protected (excluding the Petrochemical Plant)		>3,000
Overall length of direct defences		24,639m
Length of flood defences, per flood cell	Flood Cell	
	1	2,749m
	2	1,043m
	3, 5 & 6	13,112m
	4	7,787m
Maximum height of flood defences, above existing ground level, per flood cell	Flood Cell	
	1	3m
	2	2m
	3, 5 & 6	3m
	4	2m
Number of Flow Control Gates		1
Number of new lock gates		2
Total number of flood gates across road / footbridges		>20

Table 44: Grangemouth FPS Key facts and figures

7.3 Preferred Scheme Scoring Matrix

The preferred Scheme contains elements which will require further investigation during Stage 4 to confirm they are feasible and refine the scheme design.

For ease of use, the four components of the Option Scoring Matrix have been broken down for each of the preferred scheme options.

7.3.1 Costs and Benefits

Table 45 summarises the estimated capital and maintenance costs (including WLC), benefits and benefit cost ratio, along with the ranked score for the preferred scheme option.

Option	Capital and Maintenance Costs (£M)	Benefits (£M)	BCR	Ranked Score	Ranked Score for 1 in 200-year options only
1a	20.9	30.1	1.4	4	1
2a	6.4	20.4	3.1	1	1
3a, 5a & 6b	96.7	3,819	39.5	1	1
4gii	47.8	62.2	1.3	1	1

Table 45: Summary of the economic justification for the preferred scheme option

7.3.2 Utilities

Table 46 Summarises the assigned Utility Score from the option scoring matrix for the identified preferred scheme option.

Option	Utility Score from Option Scoring Matrix	Ranked Score	Ranked Score for 1 in 200-year options only
1a	3	1	1
2a	3	1	1
3a, 5a & 6b	1	1	1
4gii	4	1	1

Table 46: Summary of the utility option scoring matrix for the preferred scheme option

7.3.3 Environment

Table 47 summarises the assigned Environmental Score from the option scoring matrix for the identified preferred scheme option.

Option	Environmental Score from Option Scoring Matrix	Ranked Score	Ranked Score for 1 in 200-year options only
1a	2	3	1
2a	3	1	1
3a, 5a & 6b	1	1	1
4gii	4	1	1

Table 47: Summary of the environmental option scoring matrix for the preferred scheme option

7.3.4 Social

Table 48 summarises the assigned Social Score from the option scoring matrix for the identified preferred scheme option.

Option	Social Score from Option Scoring Matrix	Ranked Score	Ranked Score for 1 in 200-year options only
1a	2	1	1
2a	4	1	1
3a, 5a & 6b	4	1	1
4gii	4	1	1

Table 48: Summaries the social scoring matrix for the preferred scheme option

7.4 Opportunities for Multiple Benefits within the Scheme

Opportunities for multiple benefits within the Scheme include:

- Potential for new play facilities to be integrated into some of the flood embankments;
- Enhance biodiversity of existing revetment along estuary frontage and around the harbour;
- Create feature of the Antonine Wall, interpretation board, viewing area;

- Create new habitat to mitigation encroachment of construction work into the SPA;
- Improvements to the local path network;
- Improvements to the hydro-geomorphic classification of the Grange Burn
- Improvements to the bank stability of the FRC;
- Creation of new wetland habitat on the Westquarter Burn, within the Flood Storage Area;
- Upgrade the Leisure Harbour on the River Carron;
- Up-size the lock-gates at the entrance to the port;
- Improve the bank stability of the River Carron;

7.5 Residual Major Risks

7.5.1 Seepage

The scope limitations at this stage of the scheme meant that investigation into the seepage risk was based on limited ground investigation data. The seepage risk and consequence has been identified at various locations, but a critical parameter which is required to fully evaluate the seepage risk remains to be calculated. This parameter is the volume of seepage flow which can be expected, and this flow rate will determine whether the preferred scheme (which is to use existing infrastructure and floodproof existing buildings) is feasible.

The best way to determine this value is to ensure that the ground investigation works which are currently ongoing contain the correct permeability tests at each borehole and the piezometers are installed to determine the lag time between river / tidal rise in ground water level.

7.5.2 Secondary Drainage

A basic assessment of pluvial flood risk has been undertaken, to determine if the proposed flood defences would increase flood risk to properties. A more detailed assessment of pluvial flood risk needs to be undertaken once Scottish Water Integrated Catchment Model is linked to the flood protection schemes model. In conjunction with this, a surface water management plan has been identified through the flood risk management strategies as needing to be conducted.

7.5.3 Utilities and Services

There are several locations where the alignment of direct defences (from the identified preferred scheme) are likely to clash with existing utilities and services, the following areas have been identified as particularly critical:

- Upper Carron - Right bank near Stenhouse and New Carron Road Bridges,
- Upper Carron – Left bank from Carrondale Nursing Home to the Chapel Burn,
- Lower Carron – Bank around the Leisure Harbour,

- Estuary Frontage – Between the Grange Burn and River Avon proximity to above ground pipelines; pipelines on existing bank next to South Shore Road and
- FRC – left bank – Nitrogen Pipe line in existing bank and proximity to pressurised industrial pipelines,
- River Avon – Both banks, multiple pipes / ducts; proximity to above ground pipelines and multiple pipe bridges,

The areas above only highlight some of the significant utility clashes and is not a full list of utility clashes.

When assessing the impact of utility clashes with the proposed scheme, several potential risks need to be managed, principally these are:

- length of time required to programme diversion,
- length of time required to carry out diversions and associated enabling / traffic management works,
- who is undertaking the diversion works,
- feasibility of diversion is it possible / practical, and
- financial implications, the overall cost of the diversion works.

No direct capital costs have been allocated for utility / service diversions; however, utilities were considered in the option scoring matrix with options scored against criteria and the scores ranked compared to other options. The capital cost estimate for the scheme includes a 60% optimum bias to account for uncertainties (difficult access and utilities) at the option appraisal stage. Additionally, the capital cost estimate uses the average (50th percentile) and the 80th percentile (for industrial areas) rate for constructing a flood defence wall based on a sheet pile foundation for the entire scheme. This is a conservative approach as some defences will be embankments which have a lower capital cost, however, the conservative approach was deemed appropriate to account for uncertainties relating to utilities and access to the industrial area.

The Utility and Service Stakeholder Group has been consulted on the Scheme options, with no significant issues raised, however it is recommended that investigations / discussions take place with service providers and Industrial Stakeholders to determine if a diversion is required or what protection will be required. Further to these initial discussions a '*outline cost estimate*' will be requested from service provides. This exercise will mitigate some of the uncertainty over the cost and programme implications relating to service diversions.

During initial discussions with service provides, the project team will request information (programme / plans) from utility companies relating to future upgrade works in the area. It is important for the scheme works to be coordinated with other utility works to minimise disruption the public and make best use of potential road closures.

It should be noted that there is likely to be direct clashes with several above ground pipelines within the petrochemical plant. These pipelines are unlikely to be able to be moved (due to criticality of pipeline and wider impact on productivity at Grangemouth) and potentially classified as *'major accidence hazard pipelines'*, mean

the alignment of flood defences will need to be amended or incorporate the pipeline within the flood defence structure.

7.5.4 Existing Structures

7.5.4.1 Embankments

The option appraisal process has highlighted the potential to utilise some of the existing embankments / walls on the River Carron, River Avon and Estuary Frontage. A structural survey of the existing embankments / walls will be undertaken during the outline design stage (Stage-4), if any of the existing embankments / walls are not structural capable of satisfying the requirements for a 100-year design life or able to with-stand the forces associated with the 200-year flood event, a new direct defence will be proposed, depending on the footprint of the structure and land available.

7.5.4.2 Port Lock-Gates

Critical to the integrity of the flood defences around the Port is the need to maintain the height of flood defences across the lock at the entrance to the Port. This lock is the only access point for ships to enter / leave the Port. The top level of the current lock-gates is 3.4m AOD; the design level of the flood defences either side of the lock is 5.7m AOD, this requires the lock-gates to be raised by 2.3m to maintain the 1 in 200-year level of protection. From initial dialogue with Forth Ports, closure of the lock and entrance to the port is something that takes a significant amount of programming and is likely to have financial implications. Therefore, at the outline design stage, all possible methods of raising the height of the lock-gates should be investigated.

7.5.4.3 Flood Relief Channel

Option 4gii requires a flow control structure on the Grange Burn to limit the flow on the Grange Burn to 10.5m^3. This will increase the flows down the FRC, during high flow events. The increased flows on FRC, will result in higher velocities within the FRC channel, a consequence of this may require further investigation during Stage-4 to determine if remedial works would be required to the FRC to accommodate the increased flows and velocities.

7.5.5 Existing Tributaries

Multiple watercourses join the three main rivers within the proposed Scheme area.

7.5.5.1 River Carron

Historically, there was a canal parallel to Beaumont Drive on the River Carron, it has been assumed that the canal was back-filled when the housing estate was constructed, however investigatory work would be required to confirm the canal outfall into the River Carron has been sealed up.

The Chapel, Mungal, How, Ladys Mill, Skinflats, Glenburgh, Grange Lane and Brainsford Burns are all tributaries of the River Carron, new headwall structures will be required at the confluence of each water course with non-return / flap valves installed on the outfall structures. The invert level of each outfall will be determined during

Stage-4. A more detailed investigation of the interaction between the River Carron and the Chapel Burn will take place during Stage-4.

The entrances of the Forth-Clyde Canal need to be assessed to determine the height of the lock-gates and impact of flooding on the canal.

7.5.5.2 Grange Burn

The Grange Burn is formed at the confluence of the Polmont and Westquarter Burns, an existing weir structure controls flow between the Grange Burn and the Flood Relief Channel. Option 4gii requires engineering works to take place at the Grange Burn / FRC confluence and is likely to involve work on the existing weir between the Grange Burn and the FRC.

7.5.5.3 Avon

The Flood Relief Channel outfalls into the River Avon. Additionally, the Millhall Burn outfalls into the lower reaches of the Flood Relief Channel, just before it flows into the River Avon. The Kinneil Kerse Burn flows into the River Avon and will require a headwall structure with non-return valve.

7.5.6 Industrial Stakeholders

Dialogue with the petrochemical plant has been ongoing for many years, with the Industrial Stakeholder Group initiated to coordinate the design of the Scheme. Early engagement with the petrochemical plant stakeholders is a key method of managing issues relating to the petrochemical plant.

7.5.7 Bridges

Hydraulic analysis has shown that flood levels for a given flood event will be higher at locations where defences are proposed on the banks of the watercourse. This means that many of the bridges which cross the River Avon are at risk of increased lateral forces during flood events, this may affect the structural integrity of the bridges which will be assessed during Stage-4. The options identified in the preferred scheme for the River Carron and Grange Burn have intermittent defences on the banks, which reduce the potential for high lateral forces on bridges.

The hydraulic capacity of bridge structures was assessed during the option appraisal, with consideration given to bridge raising at bridges which increased the water level directly upstream of the structure by more than 0.3m. From this assessment, engineering judgement was used to determine the practicalities of bridge raising; due to the urban environment, bridge raising was not deemed practical or effective in reducing water levels and defence heights upstream. The identified preferred scheme has been modelled with existing bridge structures in place to ensure the proposed defences are not increasing water level in the channel which could have an impact on existing bridge structures.

7.5.8 Ground Conditions

From initial desk studies, it is assumed the depth of bed-rock increases considerably as you move down the water courses, with bed-rock estimated to be more than 100m below existing ground level along the estuary frontage. The current Ground Investigation Contract will provide more accurate information on the depth of bed-rock and make-up of ground conditions.

7.5.9 Port Area

Due to restricted access to the port area, several uncertainties exist:

- Location of services and pipelines, plans have been requested;
- New developments / buildings / pipelines that have been constructed through deemed planning process (no need to seek statutory consents), and
- Condition of existing structures

7.5.10 Railway Line

A spur from the main line in Falkirk runs down to the port of Grangemouth, parallel to South Shore Road before crossing the Grange Burn and entering the petrochemical plant. There will be some interface between the railway and direct defences on the right bank of the Grangemouth, particularly where the railway line crosses the Grange Burn. Raising the railway line is not practical here due to limited space, therefore flood gates will be required at the location where the railway line traverses through the flood defence.

It should be noted that some of the proposed defences along the estuary frontage are close to railway line, but do not directly clash with them.

7.5.11 Downstream flood risk

Through hydraulic analysis, each water course was assessed to determine if the preferred scheme design would increase fluvial or tidal flooding elsewhere in the Grangemouth area. Usually, it is the areas downstream of flood protection schemes which sometimes reflect an increased flood risk as water in the channel can be constrained by defences on the banks overtop the banks where defences are not located. The location of Grangemouth on the banks of the Forth Estuary, principally negate the downstream flood risk as the tidal influence (reach) of the Forth Estuary reaches up the three main water courses.

Through hydraulic analysis of each water course, the project team were able to determine if fluvial or tidal flows are the principal source of flooding. Through this analysis part of the Upper Carron was identified as being at increased flood risk, where proposed defences stopped. The area of land which showed an increase in flood risk is owned by Falkirk Council, agricultural land and not identified in the Local Development Plan as a development site; no buildings are at increased flood risk. It should be noted, increases in flood risk because of the scheme can pose significant risks to the scheme during the statutory approval / consultation process. Close consultation with all landowners downstream of the defended areas is required during Stage-4 to gauge reaction to the flood risk increase. Fundamentally, the only way to offset the increase in flood risk would be to provide some form of

upstream storage (expensive) or provide local defences to protect against the increase (expensive and impractical).

Through consultation with Falkirk Council, the Skinflats area (on the Lower Carron) has not been identified as requiring flood protection as part of the scheme, therefore no defences have been modelled for this area. The principal source of flooding in the Skinflats area is tidal, through hydraulic modelling of the proposed defences (on one bank of the River Carron) there is a negligible (approx. 0.01m) increase in flood depths to the Skinflats area. Consultation with Falkirk Council and communities in the Skinflats area will be undertaken during Stage-4 to gauge reaction and determine if measures are required to reduce / manage flood risk. It should be noted that the Skinflats area does offer the potential opportunity for habitat creation (compensatory habitat) or managed realignment of the coast line.

Due to the spatial extent of the scheme, it is highly likely that construction work will be phased over 5-10-year period. Phasing construction works will need to be reviewed and checked to ensure that flood risk does not increase because of one phase being complete.

7.5.12 Environmental Sensitivity

The alignment of proposed flood defences along the Estuary Frontage may have a significant adverse impact directly on the SPA and the qualifying habitat / species. During the option appraisal process, initial discussions have taken place with SNH; who have advised that a '*worst case scenario*' should be assumed '*significant adverse impact on the SPA*' with no alternative option possible, the 'Imperative Reasons of Overriding Public Interest (IROPI) route may need to be pursued. During Stage-4, more discussion and consultation with SNH will be required to identify the most appropriate method of dealing with the encroachment into the SPA and identify appropriate mitigation / compensating for construction works. This will be assessed through the HRA and Appropriate Assessment process.

It is likely that some construction work will be required within the channel due to the limited space on the existing bank. During Stage-4 the design team will have a better understanding of the type and alignment of defences which is likely to determine if permeant construction work is required in the channel, or if temporary (enabling) works are required in the channel.

7.5.12.1 Tree Felling

A significant number of trees may be required to be felled as part of the preferred Scheme. To mitigate the risk of negative reaction to this, the project team proposes planting 3 new trees for every tree (or agreed alternative species) that is felled (subject to confirmation by Falkirk Council) if avoidance is not possible.

7.5.13 Consents

Several environmental consents will be required, through Stage-4 the project team will be liaising with regulatory bodies on the proposed alignment of defences and potential impact of the preferred scheme design.

7.5.13.1 CAR Licence

A Controlled Activities Regulation Licence will be applied for work taking place within the fluvial reaches of the watercourses.

7.5.13.2 Marine Scotland Licence

A Marine Scotland Licence will be applied for, for work taking place below the Mean High Water Mark (including the tidal reaches of the watercourses).

7.5.13.3 Scheduled Monument Consent

Schedule monument consent will be applied for from Historic Environment Scotland for work that will directly impact Scheduled Monuments. World Heritage Site or is within the buffer zones.

7.6 Overall Comparison with the Scheme Objectives

Table 49 provides a summary / commentary of how the preferred Scheme compares with the Scheme Objectives set the Project Team at the commencement of the option appraisal process.

Scheme Objective	Comply	Evidence
To develop a flood protection Scheme in accordance with the measures set out in the Forth Estuary Flood Risk Management Strategy and Local Flood Risk Management Plan to reduce flood risk at Grangemouth.	Yes	The Scheme has been developed in accordance with the Forth Estuary Flood Risk Management Strategy and the Local Flood Risk Management Plans and provides a minimum 1 in 200-year level of protection.
The Scheme will be promoted under the Flood Risk Manager (Scotland) Act 2009.	Yes	The option appraisal stage is a crucial part of the overall process in identifying a preferred scheme and selecting a scheme that complies with the requirements of the Act and relevant Regulations – The Scottish Governments guidance for Appraising Flood Protection Schemes has been followed.
The scheme will consider all possible practical options for reducing flood risk.	Yes	A long-list of options was initially used to scope-out unpractical options, with a range of options considered on the short-list including online flood storage, flow conveyance, direct defences and mechanical barriers.
The scheme will provide multiple benefits to the local community	Yes	The identified preferred scheme provides multiple opportunities for local community benefits to be incorporated into the design of the scheme, by improving local path networks, enhance access,

Scheme Objective	Comply	Evidence
		environmental improvements, increase commercial confidence in Grangemouth, provide security and safety from flood events.
The scheme meets the goals and values of Falkirk Council, namely by: • Further developing a thriving sustainable and vibrant economy; • Continuing to improve the health, safety and wellbeing of citizens and communities; • Increasing effects to tackle disadvantage and discrimination; • Enhancing and sustaining an environment in which people want to live and visit, and • Promoting public service, performance and partnership.	Partially	The scheme provides flood protection to the Grangemouth area, which improves health, safety and wellbeing to communities in Grangemouth. Enhances the development of Grangemouth, through improved commercial confidence to invest in Grangemouth with the knock-on effect of providing local employment. Limited opportunity to directly tackle discrimination and disadvantage, however, the identified preferred scheme does have less direct defence through Grangemouth than compared to other options. Opportunities for environmental enhancements with the identified preferred option.
The scheme is aligned with Falkirk Councils Corporate Plan, Development Services – Service Performance Plan and the Strategic Outcome and Local Delivery Plan.	Partially	The preferred scheme provides opportunities for enhancing the local path network, improving the commercial and residential appeal of Grangemouth.
Community Benefits will be incorporated into the Scheme.	Yes	Multiple opportunities for community benefits to be incorporated into the preferred scheme, more detail on this will be provided during Stage - 4.
The scheme has a Benefit Cost Ratio greater than one.	Yes	The preferred scheme has a BCR of 22, excluding the Petrochemical Plant the BCR is 1.5.
An Economic Assessment is undertaken to evidence the economic benefit and cost associated with the scheme, this assessment is produced prior to the outline design stage.	Yes	The preferred scheme has the optimum BCR, social, environmental and utility aspects were including in the option scoring matrix which has been used to identify the preferred scheme.
The preferred scheme represents the best value for money for the Council.	Yes	The option scoring matrix was used to identify the preferred scheme, which representation the best value combination of options by maintaining the

Scheme Objective	Comply	Evidence
		same minimum level of protection throughout the scheme.
The scheme is delivered in line with the National Planning Framework Action Programme for the Grangemouth Investment Zone.	Yes	In line with National Planning Framework 3, the scheme provides flood protection to Grangemouth, which is commercially beneficial to Grangemouth and the wider Planning Framework.
The scheme aims to increase development activity in the Falkirk / Grangemouth corridor.	Yes	The scheme will provide flood protection which will have the knock-on effect of increasing business confidence and attract new businesses to the area.
The scheme provides a platform for the regenerations of Grangemouth.	Yes	The identified preferred scheme has the potential to incorporate wider projects relating to the regeneration of Grangemouth.
The scheme achieves a neutral impact on the environment.	To be determined	The identified preferred scheme has been designed with the preference for set-back defences where possible. It is not possible to state whether the scheme will have neutral / positive / negative impact until the EIA is completed during Stage-4. The benefit of providing flood protection should be positively evidenced where assessing the potential negative environmental impact of major construction work.
The scheme incorporates appropriate natural flood management measure.	No	The identified preferred scheme does not contain specific standalone NFM measures, although it is recommended that NFM measures should be considered for some of the tributaries where appropriate and small scale NFM on short reaches of the water courses, even on reaches where defences are not proposed.
The scheme maximises environmental benefits.	Partially	The option scoring matrix considered the environmental benefits of each option. During Stage-4 further opportunities will be identified to maximise environmental benefits of specific options.
The scheme is delivered sustainable with the following aims: • Minimise construction waste,	As far as reasonably practical	The preferred scheme makes use of as much existing infrastructure as possible and minimises the consumption of raw material. Recycling and re-use of materials will be considered during the

Scheme Objective	Comply	Evidence
• Maximise reuse of materials, • Adopt low Carbon construction strategies, and • Minimise Carbon Footprint of the scheme		detailed design stage of the project. During Stage-4 the Carbon Footprint of the preferred scheme will be calculated and used as a baseline to identify opportunities of reducing the Carbon Footprint of the scheme.
The scheme reduced overall flood risk.	Yes	It is not possible to completely remove the danger of flooding, but the 1 in 200-year level of protection does provide a significant increase in the level of protection that is currently offered to the residents of Grangemouth (and industrial areas).
The scheme delivers the required level of protection.	Yes	The 1 in 200-year level of protection has been deemed by Falkirk Council as the minimum level of protection that the scheme should provide.
The scheme will not materially increase flood risk to residential and non-residential properties in the Grangemouth area.	Partially	The preferred scheme does not materially increase flood risk to commercial land or residential properties. These is some minor increase (~0.01m) in flood risk to agricultural and Council owned land, where defences are not proposed on the lower section of the Upper Carron and Skinflats area. Discussions with land owners where flood risk increases, will take place during Stage-4.
The scheme is technically viable	Yes	The preferred scheme is based on tried and tested techniques from similar projects – integrity of existing structures needs to be determined. Installing new flood gates at the entrance to the port, will require careful consideration of vessel movements through the lock.
Residual flood risk will be documented and identified to Falkirk Council	Yes	A Surface Water Management Plan will be developed for the Falkirk area (including Grangemouth), alongside Scottish Waters - Integrated Catchment Study which will help identify residual flood risk.

Table 49 Grangemouth FPS preferred Scheme - comparison with original Scheme objectives

8. Recommendations for Stage-4

8.1 Ground Investigation

To mitigate the risks associated with seepage, depth of bed-rock and potential contaminated ground, further ground investigation is required to be undertaken. The investigation should concentrate on detailing the stratification, the depth of bed-rock, proving permeability of various strata through appropriate testing and testing material for contamination at various locations.

Numerous ground investigation contracts are proposed over the coming months / year which will provide crucial information to the design of flood defences during Stage – 4 and beyond.

Consultation with Falkirk Council's Environmental Team (Contaminated Land specialist) will be required regarding contamination risks at various locations, particularly at locations where known historical industrial activity has taken place on the River Carron and the lower section of the Grange Burn.

8.2 Topographic Surveys

The existing topographic survey contains spot levels and local feature information for most of the banks, however, there are areas which will require further topographic survey, particularly on the Westquarter Burn. An overall review of the current topographic information should be undertaken at the beginning of Stage-4 to identify any areas where extra topographic information is required in relation to the proposed alignment of defences for the preferred scheme.

8.3 Structural Investigation / Condition Survey

The preferred scheme does incorporate existing infrastructure into the design (in the form of existing walls / embankments). It is critical that the integrity of existing walls / embankments is assessed through a combination of intrusive and non-intrusive tests.

The condition of the banks on the Flood Relief Channel will need to be assessed against the predicted 1 in 200-year flows / velocities (for the preferred options) to determine if remedial work is required on part /or all of the Flood Relief Channel.

The structural condition of existing revetments and quay walls (at the Leisure harbour) will need to be assessed to determine their condition, structural integrity and life expectancy.

A condition survey of existing bridges will need to be undertaken, to assess the impact of the predicted flows / velocities and lateral forces from the preferred scheme. The outcome from this assessment may require additional bridge strengthening works to be included within the Scheme design.

8.4 Technical

Further investigation work is required on the port lock-gates at the entrance to the port, to ascertain dimensions, condition of the structure and structural loading of the quay wall. Investigative work will be required, to determine the condition and technical viability of utilising some of the existing lock components, e.g. lock coyness and pintles.

8.5 Environmental / Ecological Surveys

To inform the SEA and EIA, a range of environmental and ecological surveys will be required. It is recommended that the surveys are undertaken in advance of the EIA screening and scoping exercise, to ensure seasonal survey windows are not missed.

The scope of surveys shall therefore be determined based on existing environmental / ecological information and experience from previous flood protection schemes. It should be noted that through the HRA process it is likely that additional information (to support the IROPI process) relating to no practical alternatives are possible may be required.

8.5.1 Environmental Impact Assessment

An Environmental Impact Assessment will be required, to determine the environmental impact of the scheme and assist with the development of the project Environmental Statement

8.5.2 Habitat Regulation Appraisal

An HRA will be required to assess the impact of the scheme on the SPA and conclude if an appropriate assessment is required.

8.6 Surface Water Management Plan

As identified in the Flood Risk Management Strategies, a Surface Water Management Plan should be developed for the Falkirk / Grangemouth area. To ensure pluvial flood risk and surcharge from Scottish Water's networks is managed regarding the scheme's flood defences, a Surface Water Management Plan should be developed.

8.7 Stakeholder Consultation

During Stage-4, the impact of those directly and indirectly affected by the scheme will become clearer. Consultation to date has generally been in relation to the overall general concept and principal of the scheme options rather not focusing on issues. Consultation during Stage-4 will focus on the issues relating to the implementation of the specific flood risk management measures container with the preferred Scheme. As such it is recommended that the following consultation exercises are carried out:

- Discuss scheme with Scottish Government, spend profiles, cost estimate of the scheme

- Discuss impact of the scheme road network and structures, with Falkirk Council
- Discuss the aesthetic requirements of the visible flood defences, with Falkirk Council
- Discuss the integration with other projects (Falkirk Council and others)
- Carry out a screening and scoping exercise for the EIA
- Identify opportunities for environmental and community benefits with local groups
- Public exhibition on the preferred scheme
- Discussions with environmental stakeholders relating to proposed works on the SPA
- Discuss scheme with Network Rail

8.7.1 Environmental

Through the EIA, consultation with multiple statutory and non-statutory stakeholders. Early and detailed consultation with SNH will be crucial to the success of the EIA and HRA, along with statutory environmental regulators.

Discussions with Historic Environment Scotland and Falkirk Community Trust will continue regarding the impact of the scheme on the Antonine Wall. As more details are developed further discussion with HES may be required.

8.7.2 Industrial Stakeholders

During the option appraisal process the Industrial Stakeholder Group was initiated and One-2-One meetings were arranged with individual industrial stakeholders. Following on from the One-2-One meetings further meetings with individual industrial stakeholders will take place during Stage-4. It is increasingly likely that during Stage-4 more frequent meetings with industrial stakeholders will be required to discuss in more detail the alignment of the defences and the impact / constraints which may be are imposed by the stakeholders. It is important that the alignment of defences is agreed with industrial stakeholders to allow sufficient time for the design of the structure to be agreed, particularly where pipelines will be crossing over / under the alignment of the defences.

8.7.3 Utility Companies

Individual discussions with utility provide / pipeline owners will take place, with C2 – Budget Estimate inquires submitted. The cost and time implications of utility diversions is something that needs to be confirmed but has the potential to significantly impact the delivery and budget estimate of the project.

8.7.4 Core Stakeholders

Further discussions with Core stakeholders will been undertaken during Stage-4 to ensure the scheme is being is developed in-line with the scheme objectives and maximises the overall benefits to the wider community of Grangemouth.

8.8 Landowner Consultation

Determine the landowners who are affected by preferred Scheme and commence dialogue with community groups. The level of engagement during Stage-4 should reflect the extent and impact the proposed flood defences could have on various community groups.

8.9 Land Searches

Identifying affected parties under the Flood Risk Management (Scotland) Act 2009, should be undertaken. This is likely to require land conveyancing to determine who is the owner / occupier of land and those other parties, as defined in the Part 4 Guidance, who might have an interest including those with a heritable interest or servitude right.

Appendix A. – PVA datasheet 10/11

Appendix B. – Westquarter FSA Design Development

Appendix C. – Core Stakeholder Plans

Appendix D. – Utility Stake Holder Plans

Appendix E. – Falkirk Council Workshop Plans

Appendix F. – Flood Cells

Appendix G. – Costing

Appendix H. – Petrochemical Plant Damages