Economic Assessment Report

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Falkirk Council

Grangemouth Flood Protection Scheme
27 November 2023

Economic Assessment Report

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Executive summary

This economic report records the economic assessment for the Grangemouth Flood Protection Scheme (FPS), which follow the approaches and guidance in the Scottish Government's 'Flood Protection Appraisals: Guidance for SEPA and Responsible Authorities', the HM Treasury's Green Book, Middlesex University's Multi Coloured Manual and Multi Coloured Handbook 2023.

This report has collated information and data from several sources including Falkirk Council, Jacobs, and their associated sub consultants and contractors.

Scheme benefits calculated include:

- Flood damages avoided because of reduced flood risk to existing properties
- Net carbon benefits associated with the above damages avoided
- Flood damages avoided to future development within the study area
- Benefits from avoiding a loss in economic activity due to flooding

Scheme whole life costs over the appraisal period have been estimated by Turner & Townsend, supplemented with assumed costs for future operation and maintenance.

A 100-year appraisal period has been assumed, starting in 2030, with all costs and benefits inflated using relevant GDP deflators.

A summary of benefits and costs calculated is shown below in Table ES-1.

Table ES-1. Summary of benefits and costs for Grangemouth FPS

	Grangemouth FPS
Total PV benefits	£2,390.2M
Total PV costs	£556.2M
Benefit - Cost Ratio (BCR)	4.3

Statement of limitations

The sole purpose of this report is to provide Jacobs' client, Falkirk Council, an economic assessment of the flood defence proposals for Grangemouth FPS. This document has been prepared on behalf of, and for the exclusive use of Falkirk Council, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Falkirk Council. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this document by any third party.

The data within this report is derived from multiple sources including: Falkirk Council, its Partners, Jacobs and its suppliers. The data sourced from Falkirk Council, its partners and Jacobs' suppliers, which the recommendations and conclusion within this report rely upon is used on the assumption that the data requested reflects all available data and is accurate.

Certain statements made within this report that are not historical facts may constitute estimate, projections or other forward-looking statements and though they are based upon reasonable and qualified assumptions at the date of reporting, such prediction has inherent risk and uncertainty that could culminate in material difference from the predicted outcome.

Where assessment of works or costs identified within this report are made, such assessment have their basis in the information available at the time. Where appropriate the assessment is subject to further investigations and refinement following relevant data or information being made available.

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Acronyms and abbreviations

£k	Thousand Pounds
£M	Million Pounds
AAD	Annual Average Damages
AEP	Annual Exceedance Probability
BCR	Benefit Cost Ratio
DQS	Data Quality Score
DTM	Digital Terrain Model
EFO	Economic and Fiscal Outlook
FCERM	Flood and Coastal Erosion Risk Management
FPS	Flood Protection Scheme
FRNS	Forth & Tay Navigation Service
GDP	Gross Domestic Product
GVA	Gross Value Added
HCA	Homes and Communities Agency
LIDAR	Light Detection and Ranging
mAOD	Metres Above Ordnance Datum
MCH	Multi Coloured Handbook
MCM	Multi Coloured Manual
NDR	Non-Domestic Rate
OBR	Office for Budget Responsibility
ONS	Office for National Statistics
PV	Present Value
PVD	Present Value Damages
SEPA	Scottish Environment Protection Agency
SoP	Standard of Protection
TEU	twenty-foot equivalent unit is an inexact unit of cargo capacity, often used for container ships and container ports
UKHPI	UK House Price Index

1. Introduction

1.1 Overview

The Grangemouth Flood Protection Scheme is the largest flood defence project in Scotland and one of the biggest in the United Kingdom, protecting communities in Grangemouth, Wholeflats, Glensburgh, Langlees, Carron, Carronshore and Stirling Road, Camelon.

The scheme was identified as the highest priority given the potentially significant costs if an extreme flood were to occur. Whilst other parts of Scotland have been significantly affected by flooding over the last 5 years, Grangemouth has fortunately avoided significant flooding.

Works are planned along the River Carron from Stirling Road to the Port, on the Grange Burn from Beancross to the Port and on the River Avon from Wholeflats Road to the Firth of Forth with coastal defences along the estuary frontage.

1.2 Purpose of this report

This report summarises the economic assessment undertaken by Jacobs for Grangemouth FPS.

This provides Falkirk Council with economic data for the baseline and with scheme scenarios for the project to demonstrate the economic justification for the project.

1.3 Guidance used

The economic analysis of the baseline and with scheme options was undertaken in adherence to the criteria and guidance as set out in these key documents:

- Scottish Government - 'Flood Protection Appraisals: Guidance for SEPA and Responsible Authorities'
- HM Treasury – Green Book
- Multi Coloured Manual (MCM).
- Multi Coloured Handbook 2023 (MCH 2023).

The full list of guidance used is detailed in Section 8.

1.4 Proportionate approach

The Scottish Government appraisal guidance identifies the importance of proportionality in the level of detail of each appraisal. A proportionate approach has been used in this economic assessment to allow enough information to be collected to make a robust and defensible decision but to avoid collecting more information that will not make a significant difference to the outcome. This approach has influenced the data used in this assessment and the approaches used to calculate flood damages. MCM also provides guidance on the proportionate approach to specific types of flood damages.

1.5 Appraisal period

An appraisal period of 100 years has been used for this assessment, with Year 0 assumed to be 2030. The 100-year appraisal period is the standard recommendation of the Scottish Government.

2. Option definition and costs

2.1 Baseline (Do Nothing)

The Grangemouth FPS uses the existing situation as the required Do Nothing baseline. This is considered reasonable and proportionate as there are no significant flood risk management assets in the area. Therefore, there would no deterioration of such assets (and potential increase in flood risk) when they are not maintained under a Do Nothing scenario. As no assets would be maintained under this scenario, there are no costs.

Consideration of alternative baseline scenarios (e.g., Do Minimum) is not required for this study.

2.2 With scheme (Do Something)

The proposed scheme includes works along the River Carron from Stirling Road to the Port, on the Grange Burn from Beancross to the Port and on the River Avon from Wholeflats Road to the Firth of Forth with coastal defences along the estuary frontage.

Turner & Townsend supplied a range of scheme costs shown in Table 2-1 at 2030 prices. The project development costs incurred prior to the current stage of the project (pre-2019) have been itemised separately. The future operation and maintenance costs (not included in the figures supplied by Turner & Townsend) are assumed as £800k/year for 92 years, starting following construction of the scheme in 2038 (Year 8 of the appraisal period) and continuing until the end of the appraisal period in 2129. Risk has not been itemised separately for the future costs.

For the economic assessment, the mean cost has been taken as shown in Table 2-2. In addition, sensitivity testing on upper and lower ranges are included in Section 7. Pre-2019 costs have been assumed to be sunk costs for the economic assessment.

Table 2-1. Range of costs supplied by Turner & Townsend (2030 prices)

Description	Lower range (£M)	Upper range (£M)	Mean (£M)
Pre-2019 project development costs	3.6	3.6	**3.6**
Project development costs	20.5	20.5	**20.5**
Risk (project development)	0.5	1	**0.8**
SUB-TOTAL – PROJECT DEVELOPMENT	**24.6**	**25.1**	**24.9**
Project costs	276.8	402.3	**339.6**
Inflation	77.3	154.7	**116.0**
Risk	79.6	103.6	**91.6**
SUB-TOTAL – PROJECT COSTS	**433.8**	**660.6**	**547.2**
TOTAL PROJECT COSTS	**458.4**	**685.7**	**572.1**
Future costs*	73.6	73.6	**73.6**
Risk*	0	0	**0**
SUB-TOTAL – FUTURE COSTS*	**73.6**	**73.6**	**73.6**
TOTAL WHOLE LIFE COSTS	**532.0**	**759.3**	**645.7**
* Future costs not estimated by Turner & Townsend and are instead based on assumed operation and maintenance costs.			

Table 2-2. Costs (Cash and PV) for the with scheme option (2030 prices)

Description	Economic costs (PV) (£M)	Whole life costs (cash) (£M)
Pre-2019 project development costs	Sunk	3.6
Project development costs	20.5	20.5
Risk (project development)	0.8	0.8
SUB-TOTAL – PROJECT DEVELOPMENT	**21.3**	**24.9**
Project costs	320.2	339.6
Inflation	109.1	116.0
Risk	87.6	91.6
SUB-TOTAL – PROJECT COSTS	**516.9**	**547.2**
TOTAL PROJECT COSTS	**538.0**	**572.1**
Future costs	18.2	73.6
Risk	0	0
SUB-TOTAL – FUTURE COSTS	**18.2**	**73.6**
TOTAL WHOLE LIFE COSTS	**556.4**	**645.7**

2.3 Risk

Risk allowances are shown in Table 2-1 and Table 2-2. These form 16% of the total project cost.

3. Information used for MCM damage calculation

3.1 Introduction

The purpose of this section is to explain the information which has been used in the economics calculation for Grangemouth FPS. Each subsection outlines the separate phases completed in collating and preparing information to calculate flood damages.

3.2 Flood levels

Flood levels have been derived from 1D-2D hydraulic modelling covering the study area. Model runs have been completed for both the baseline and with scheme options. The raw model results have been post-processed to provide a single set of grids for fluvial flooding scenarios and a separate set for tidal flooding scenarios. The flood level scenarios for each flood type are summarised in Table 3-1. It should be noted that the hydraulic modelling represents conditions in 2030, except for the 0.5% AEP flood which has been simulated for both 2030 and 2080.

Table 3-1. Level grids from hydraulic modelling used in economic analysis

	Flood AEP (%) in 2030									
Flood type	**50**	**20**	**10**	**5**	**3.3**	**2**	**1**	**0.5**	**0.5 +CC***	**0.1**
Fluvial	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tidal	✓	✓	✓	✓		✓	✓	✓	✓	✓

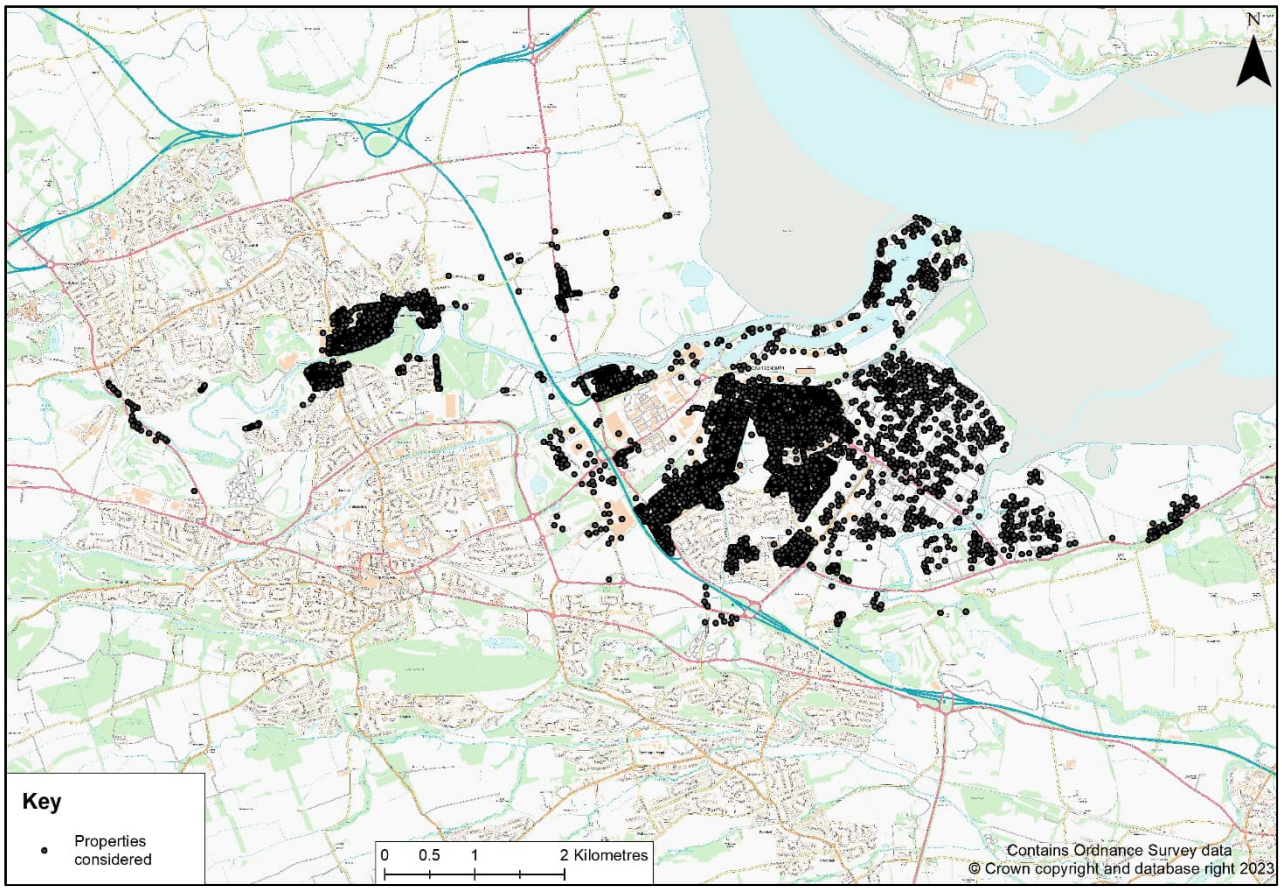
*Includes an allowance for climate change, representing flood risk in 2080. For fluvial scenarios an allowance of +40% has been applied to model inflows. For tidal scenarios, an uplift of 0.43m has been applied to the downstream boundary.

3.3 Input data

3.3.1 Property data

A property dataset giving the location (in national grid coordinates), floor area, property type (using the codes detailed in MCM) and threshold level (in mAOD) has been developed. In total 9,061 properties were considered (7,256 residential and 1,805 non-residential). The properties considered are shown in Figure 3-1.

Figure 3-1. Properties considered in assessment



3.3.2 Market values

Market values have been added to the property dataset, for use in capping and write-off calculations.

Residential properties were allocated capping values from the Land Registry UK House Price Index (https://landregistry.data.gov.uk/app/ukhpi) values for Scotland, obtained in February 2023. The values used are shown in Table 3-2.

Table 3-2. Average residential property price in Scotland (February 2023)

Property type	Average price by type of property in Scotland (UKHPI, February 2023)
All property types	£180,287
Detached houses	£324,742
Semi-detached houses	£192,197
Terraced houses	£152,401
Flats and maisonettes	£123,098

Non-residential properties were allocated capping values using the following formula:

$$Non\ residential\ market\ value = Rateable\ value \times multiplier\ from\ chapter\ 3\ of\ MCH$$

The rateable values were obtained from the NDR Valuation Roll for Scotland. The following assumptions have been made when assigning rateable values to non-residential properties:

- Where rateable values are available for properties with zero floor area in the property dataset, their rateable values have not been assigned to the zero-floor area property and have instead been added to the property point which includes the floor area associated with that point, based on inspection of mapping. This is because Flood Modeller Damage Calculator will not generate damages for properties with zero floor area.
- Where there are multiple rateable values associated with a single property point (or set of property points) the rateable values have been added together.
- Where a single rateable value (or set of rateable values) is associated with multiple property points the total rateable value have been pro-rated by floor area between the property points.

Comments have been included in the property dataset to note the rateable value record and, where relevant, the approach used.

3.4 Depth damage data

Depth-damage data used is taken from Flood Hazard Research Centre's MCH 2023.

3.5 Inflation

The damages are based on 2023 prices. Inflation has been applied to the final assessment of costs and benefits (see Section 6) to update them to 2030, which is Year 0 of the appraisal period. In the absence of Scotland-specific guidance, the GDP deflators used have been based on the Environment Agency's 'Allowing for inflation in FCERM projects guidance and the GDP deflators at GDP deflators at market prices, and money GDP - GOV.UK (www.gov.uk).

For the costs, inflation has already been applied to the cost estimates provided by Turner & Townsend.

3.6 Data Quality Score system

All data included in this assessment was reviewed using the Data Quality Score system according to the MCH 2023 (Chapter 3). Table 3-3 below shows the DQS scores for data listed above:

Table 3-3. MCH data quality scores

Data	DQS score (1-4)
Flood levels	1
Property data	2
Market values	2/3
Threshold levels	2/3
Depth-damage data	1

4. Economic assessment of MCM benefits

4.1 Approach

The various types of damage category considered are listed in Table 4-1, including the approach or reasoning behind their exclusion. Damage Calculator (part of the Flood Modeller software suite) was used to calculate the majority of economic damages for this study. Damage Calculator uses the information detailed in section 3 of this report to calculate Annual Average Damages (AAD) and Present Value Damages (PVD). Damages produced using Damage Calculator have been identified in the table.

Table 4-1. Damages considered in the Grangemouth economic assessment

MCH	Type	Sub-type	Included in this assessment	Approach or reason for not including	Health discount rate used
4	Residential	Building, content and clean up (Direct)	Yes	Included in Damage Calculator - uses MCH data and capping and write off applied based on 2023 market values	✖
		Health: Intangible	Yes	Included in Damage Calculator	✓
		Vehicle damages	Yes	Included in Damage Calculator – assumes 1.33 vehicles per property, £5,600 per vehicle, vehicle flooding threshold 0.39 m (set as 0.24m plus the property threshold level, assuming that property thresholds are approximately 0.15m above ground level).	✖
		Temporary and alternative accommodation	Yes	Included in Damage Calculator - uses MCH 2023 data.	✖
		Socio-economic equity	No		✖
5	Non-residential	Building, content and clean up (Direct)	Yes	Included in Damage Calculator - uses MCH data and capping and write off applied based on 2023 market values	✖
		Indirect	Yes	Included in Damage Calculator – using 3% of direct damages	✖
N/A	Risk to Life		Yes	Included in Damage Calculator	✓
	Mental health costs		Yes	Included in Damage Calculator	✓
6	Other flood losses	Electricity and gas	No		✖
		Water & wastewater	No		✖
		Telecommunications	No		✖
		Road	No		✖

		Rail	No		✖
		Schools	No (except as direct non-residential damage)	Direct damages to schools included in Damage Calculator as part of non-residential damages- uses MCH data. No separate loss of education damages calculated as school flooding only expected in extreme (infrequent) events.	✖
		Hospitals	No	No hospitals shown at risk of flooding.	✖
		Emergency response and recovery	Yes	Included in Damage Calculator - using 5.57% of Direct Damages	✓
8	Recreation		No		✖
9	Agricultural		No		✖
10	Environmental		No		✖
N/A	Holiday parks	Caravan Relocations	No		✖
		Park Homes	No		✖

4.2 Discount rates

Table 4-2 presents the two discount rates used in FCERM economic appraisals. The standard discount rate is used in all instances; except for the specific areas indicated in Table 4-1.

Table 4-2. Discount rates

	Years 0-30	Years 31-75	Years 75-125	Discount factor years 0-99
Standard discount rate	3.5%	3.0%	2.5%	29.813
Health discount rate	1.5%	1.286%	1.071%	54.356

4.3 Depth damage curves used

Within Damage Calculator, depth damage curves are selected from MCH 2023 for residential and non-residential properties based on the nature of floodwater (storm, saline or sewage), typical duration of storm and the current flood warning system in place. Table 4-3 summarises the damage curves used for the different scenarios.

Table 4-3. Damage curves used for Grangemouth

Option	Residential/Non-Residential	Storm Type and Duration	Flood Warning
Baseline fluvial	Residential	Storm water, short duration	None
	Non-Residential	Storm water, short duration	None
Baseline tidal	Residential	Saline water, short duration	None
	Non-Residential	Saline water, short duration	None

Option	Residential/Non-Residential	Storm Type and Duration	Flood Warning
With scheme fluvial	Residential	Storm water, short duration	None
	Non-Residential	Storm water, short duration	None
With scheme tidal	Residential	Saline water, short duration	None
	Non-Residential	Saline water, short duration	None

4.4 Approach to climate change

The proposed scheme is designed to provide a 0.5% AEP standard of protection in 2030. With climate change the flood levels for a given AEP are projected to increase, effectively increasing the frequency of flooding. This means that the standard of protection provided by the scheme will decrease year on year throughout the appraisal period.

To account for this, two epochs (2030 and 2080) have been considered in the damage calculation with linear interpolation applied for the intervening years and linear extrapolation for the years beyond 2080.

As described in Section 3.2, the majority of the model results available are for 2030 with only limited results available for the future epoch (2080). The assessment of damages for the future epoch has therefore been undertaken based on "return period switching" (i.e., for the 2080 scenario, reassigning the probabilities associated with the 2030 grids to reflect the increased likelihood of occurrence of a flood of the same magnitude in future). To supplement this, the results from the 0.5% AEP 2080 simulation have also been included and the 2030 probability for these have been back calculated using the same "return period switching" method. The probabilities calculated for each of the modelled scenarios is shown in Table 4-4.

Table 4-4. Flood probabilities calculated by "return period switching"

Fluvial scenario		Tidal scenario	
2030 AEP	2080 AEP	2030 AEP	2080 AEP
50.00*	Not used	**50.00***	Not used
20.00*	Not used	**20.00***	Not used
10.00*	33.33	**10.00***	Not used
5.00*	25.00	**5.00***	Not used
3.33*	16.67	**2.00***	50.00
2.00*	10.00	**1.00***	20.00
1.00*	5.00	**0.50***	9.09
0.50*	2.38	**0.10***	1.39
0.14	**0.50***	0.04	**0.50***
0.10*	0.48		
*** Indicates modelled scenario**			

4.5 Approach to fluvial and tidal damages

The damages for fluvial and tidal sources have been added together to give the overall damages for each of the baseline and with scheme scenarios. Whilst some properties are at risk from both sources, it is assumed that generally fluvial and tidal floods will occur independently of each other so their associated damages can be aggregated. A limitation of this method is that a property may be subject to damages exceeding the property market value when the sources are combined but will not be subject to capping in Damage Calculator if the total damages for each source do not exceed the market value. Furthermore, properties may be subject to write-off from one source at some point during the appraisal period, but this would not be allowed for in the damage calculation for the other source. Additional checks and post-processing of the damage calculations have therefore been undertaken to quantify the potential impacts of this.

4.6 Damage calculation results

This section presents the results of damage calculation and shows how the damages are split.

Present Value Damages calculation results for the baseline and with scheme scenarios are provided below in Table 4-5 for flooding from fluvial sources and in Table 4-6 for flooding from tidal sources. The damages have been calculated based on 2023 prices. See Appendix B for a comparison on capped and uncapped damages.

Table 4-5. Present Value Damages for fluvial flooding (2023 prices)

Damage Type	Baseline	With scheme
Residential	£27,616,428	£20,983,118
Non-Residential	£93,851,767	£36,640,827
Vehicle Damage	£3,571,065	£2,879,270
Indirect (non-res) damage	£2,872,545	£1,099,460
Emergency services costs	£14,807,082	£7,957,554
Evacuation/ re-housing costs	£4,567,653	£3,163,693
Mental Health costs	£11,939,500	£8,764,851
Risk to Life (Residential)	£10,921,349	£6,831,007
Risk to Life (Non-Residential)	£6,120,644	£2,930,009
Health Intangible Benefits	£4,340,626	£641,827
TOTAL	**£180,608,657**	**£91,891,616**

Table 4-6. Present Value Damages for tidal flooding (2023 prices)

Damage Type	Baseline	With scheme
Residential	£63,613,070	£8,083,615
Non-Residential	£254,499,257	£5,950,185
Vehicle Damage	£3,748,190	£950,699
Indirect (non-res) damage	£6,067,647	£180,024
Emergency services costs	£26,155,213	£1,828,230
Evacuation/ re-housing costs	£6,002,791	£1,192,134
Mental Health costs	£15,537,309	£3,022,554
Risk to Life (Residential)	£39,290,530	£3,152,394
Risk to Life (Non-Residential)	£16,163,103	£234,482
Health Intangible Benefits	£5,959,153	£1,271,282
TOTAL	**£437,036,264**	**£25,865,598**

Figure 4-1 and Figure 4-2 show the relative proportions of the baseline damages for the fluvial and tidal scenarios. This figure includes residential and non-residential property damages in addition to vehicle damage, indirect damage, emergency services costs, evacuation/ re-housing costs and risk to life, which are all outputs from Damage Calculator. The non-residential damages are relatively high, particularly for the tidal scenario, as some of the highest risk areas are located around the port, oil refinery and petrochemical works.

Figure 4-1. Damage breakdown for fluvial baseline

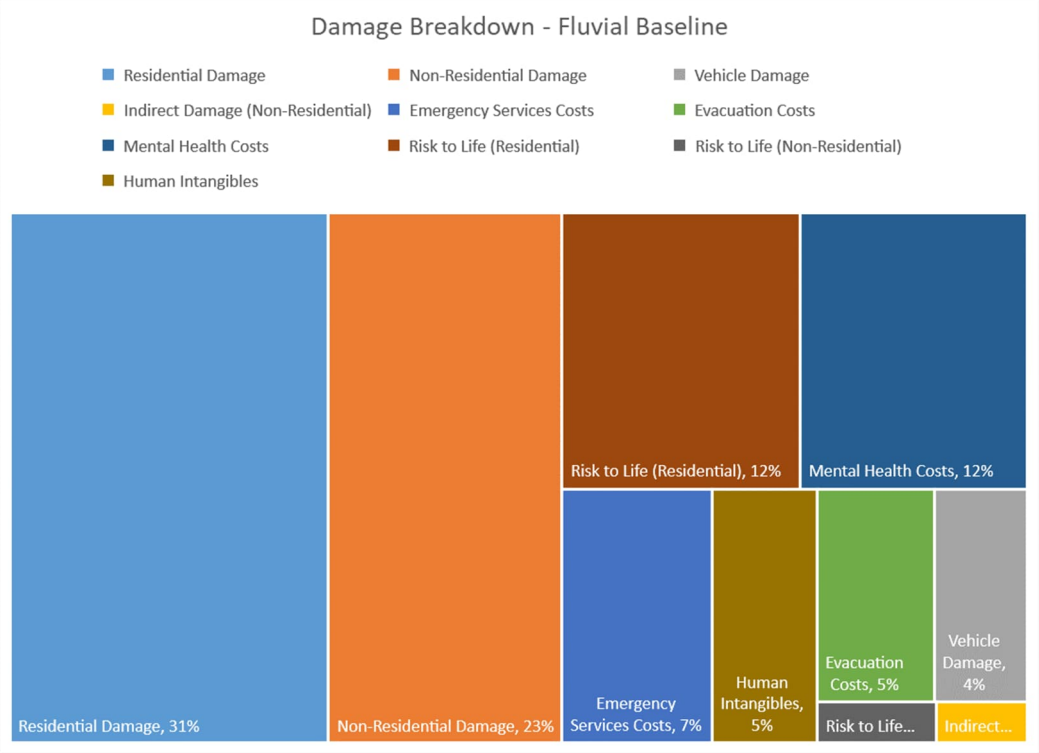


Figure 4-2. Damage breakdown for tidal baseline

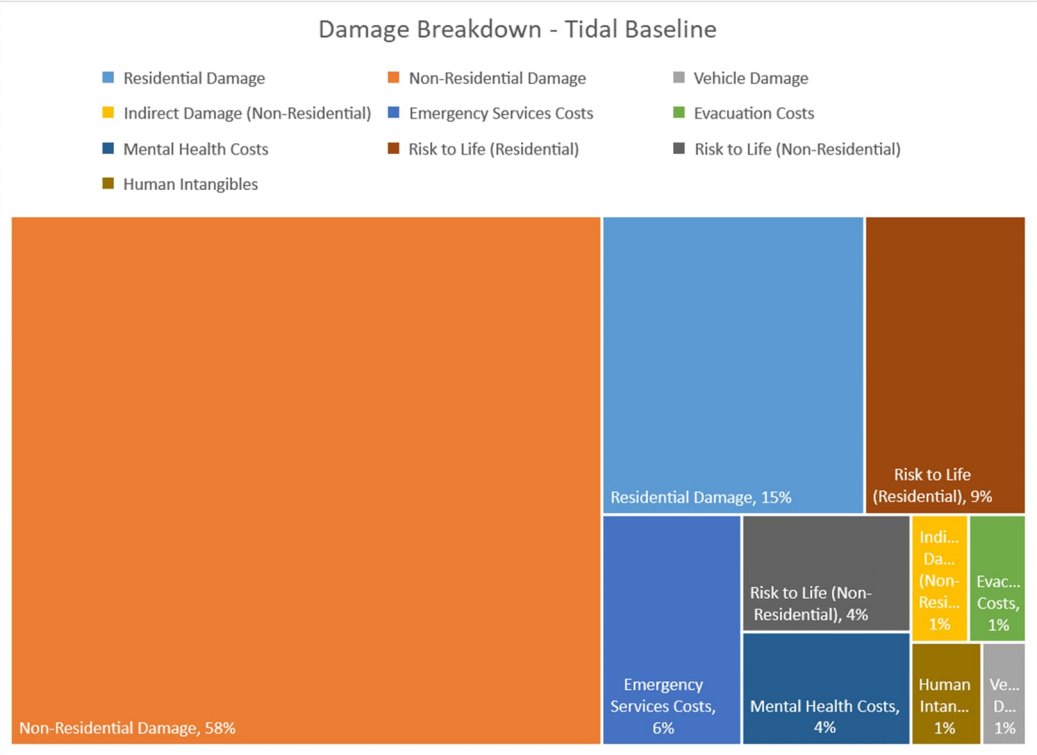


Figure 4-3 and Figure 4-4 show the geographic distribution of present value damages for the fluvial and tidal baseline scenarios.

Figure 4-3. Capped Present Value Damages per property, fluvial baseline scenario

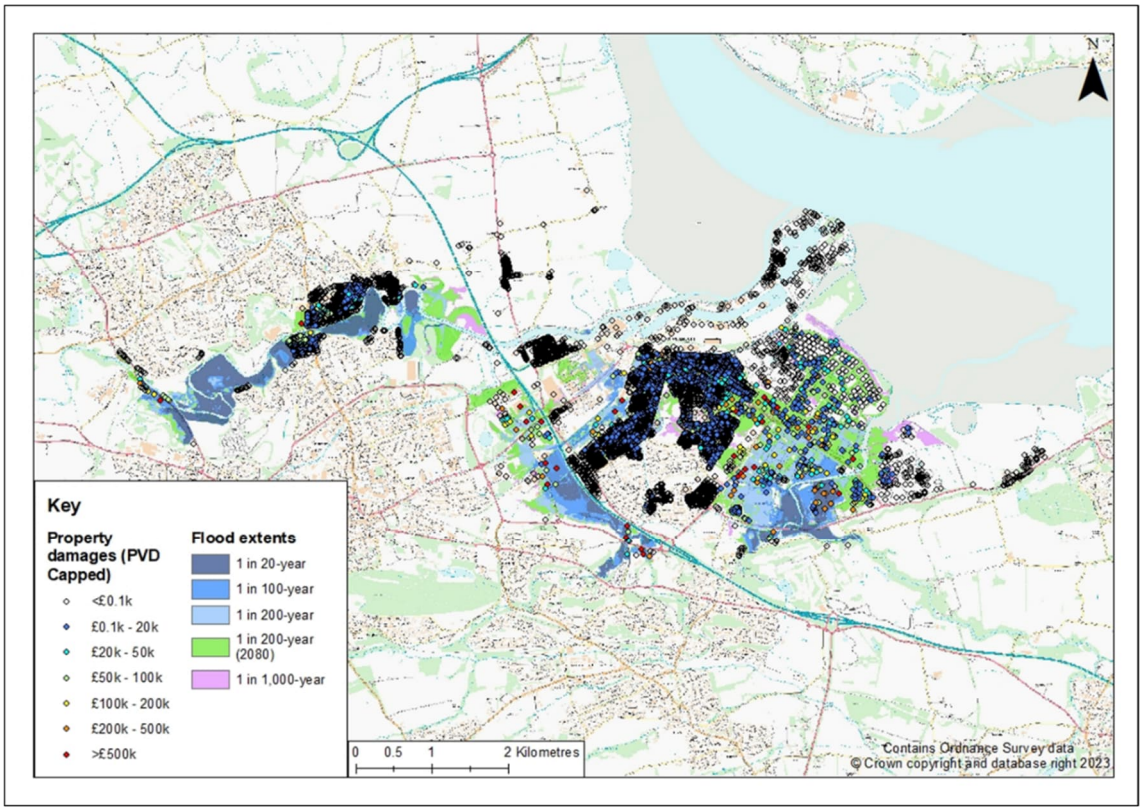
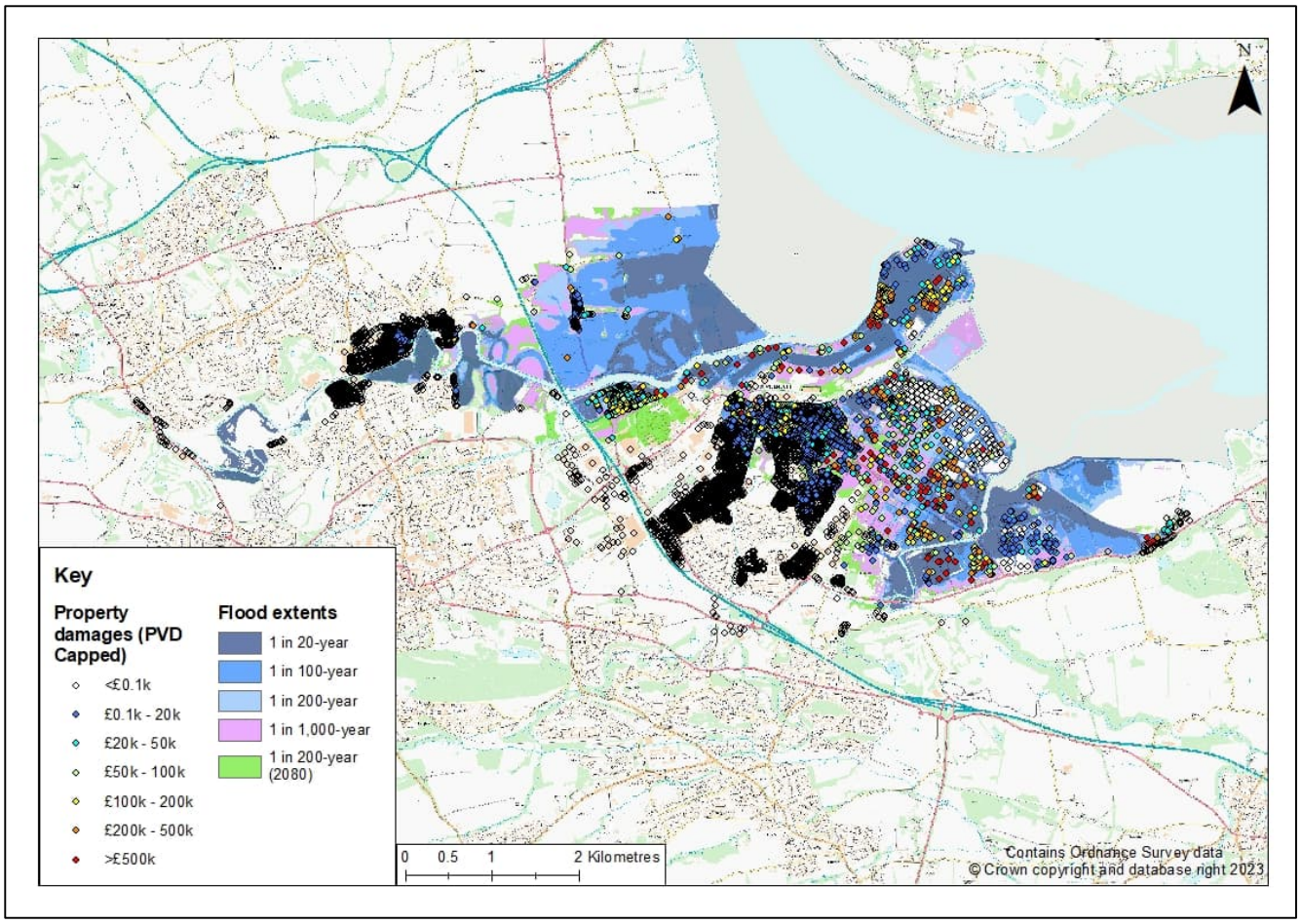


Figure 4-4. Capped Present Value Damages per property, tidal baseline scenario



The ten properties generating the largest capped present value damages for each scenario have been inspected and all found to be non-residential properties with large floor areas. These properties accounted for 56% of the total damages in the fluvial scenario and 14% of the total damages in the tidal scenario. For the tidal scenario all of the top ten properties have had their damages capped, indicating that the damages are potentially highly dependent on the assumptions made around market value. However, as the market values have been assigned based on the best available data and standard methods, they are considered appropriate.

The total capped present value damages generated for the fluvial and tidal baseline scenarios are £180.6M and £437.0M respectively. In comparison, the maximum theoretical damages, equal to the capping value of all properties within the study area, are £2,286.0M. The damages for the fluvial and tidal baseline scenarios are therefore 8% and 19% of the maximum theoretical damages respectively. The aggregated total damages across the two sources (£617.6M) are 27% of the maximum theoretical damages.

As described in Section 4.5, checks have been undertaken to determine the potential for overestimation of overall total damages arising from aggregating the tidal and fluvial damages. One potential issue is that the total damages across the two sources for a property may exceed its capping value. To determine the potential impact of this the tidal and fluvial present value damages for each property have been summed and compared to the property capping value. From this, the total overestimation across all properties is estimated as £20.1M (PV), with a total of 290 properties affected.

Another potential source of overestimation is where properties may be subject to write-off from one source but still generating damages from the other source due to the calculation method. Damage calculator results indicate that 142 properties are written off in 2030 in the tidal scenario (with 0 written off from fluvial sources)

and a further 532 are written off in 2080 (plus 1 from fluvial sources). For properties that are written off from one source the total calculated damages from the other source have been summed to determine the upper limit of overestimation. This gives a maximum value of potential overestimation of £15.3M (PV). The high number of properties written off at the start of the appraisal period in 2030 compared to observed flooding is considered to be due to increases in tidal flood risk in 2030 compared to present day resulting from the impacts of climate change. Many these properties are located within the port, oil refinery and petrochemical plant.

For some properties both sources of overestimation may be occurring and there is therefore some overlap in the £20.1M overestimation for capping and £15.3M overestimation for write-off. The maxima of the different sources of overestimation made for each property have been summed and total £23.4M (PV). This is approximately 4% of the total aggregated damages so is not considered significant.

4.7 Properties affected

Table 4-7 below shows the number of properties affected in each option, per return period, for the 2030 epoch. Refer to Table 4-4 to determine the equivalent AEP for the 2080 epoch. The property count is based on the properties where the flood level exceeds the property threshold, not all of the properties suffering damages. The latter number is larger as property damages start below threshold. The property count also excludes upper floor properties in flatted developments. All totals are cumulative.

The results show that a significant number of properties within the study area are protected by the scheme for up to a 0.5% AEP flood in 2030 from either source.

Table 4-7. Property counts

Source	Option	Property type	Flood probability in 2030 (AEP)								
			50%	20%	10%	5%	3.3%	2%	1%	0.5%	0.1%
Fluvial	Baseline	Residential	0	0	1	1	2	4	93	278	1,995
		Non-residential	0	0	0	22	23	29	59	183	684
		TOTAL	0	0	1	23	25	33	152	461	2,679
	With scheme	Residential	0	0	0	0	0	0	2	2	1,239
		Non-residential	0	0	0	0	0	0	0	0	574
		TOTAL	0	0	0	0	0	0	2	2	1,813
Tidal	Baseline	Residential	33	33	50	69	-	104	144	302	704
		Non-residential	109	131	176	268	-	428	516	678	930
		TOTAL	142	164	226	337	-	532	660	980	1,634
	With scheme	Residential	0	0	0	0	-	2	4	8	216
		Non-residential	0	0	1	1	-	2	2	4	17
		TOTAL	0	0	1	1	-	4	6	12	233

4.8 Additional damages

4.8.1 Carbon

The carbon benefits of the scheme, in terms of net carbon emissions avoided, have been calculated using the (England) Environment Agency's FCERM carbon impacts tool[1]. Whilst this tool was developed for flood schemes in England, the assumptions made in the tool are considered valid for Scotland and there is no Scottish equivalent to the tool.

The carbon impacts tool requires the input of carbon cost and benefit data to determine the net carbon emissions avoided and the associated economic benefit. The carbon costs for construction and operation have been extracted from the carbon calculator produced for the scheme. The carbon emissions avoided have been estimated using the "Flood Level 3" method in the tool, which generates an estimate based on the flood damages avoided for residential properties, non-residential properties, temporary accommodation (evacuation) and vehicles. This was calculated from the damage calculation results documented in Section 4.6 above.

For consistency with the other economic benefits calculations Year 0 in the tool has been set to 2030, with carbon costs before that date aggregated into Year 0. However, it should be noted that the carbon prices used in the tool use a 2020 base date and GDP deflators will therefore need to be applied to the final benefits to update them to 2030.

The total net carbon benefit of the scheme (based on 2020 prices) is estimated as -£3,750k (i.e., an overall net carbon disbenefit).

4.8.2 Flooding of schools and hospitals

The Multi Coloured Manual includes methods for the calculation of damages associated with disruption to critical services such as schools and hospitals. These are separate to the direct property damages for these property types, which are already included in the main damage calculation. An initial screening of the results from the main damage calculation was undertaken to determine whether disruption to schools and hospitals would be likely to be a source of significant additional damages for inclusion in the overall benefit cost assessment.

Three schools were found to be at potential risk of flooding: one from tidal sources and two from fluvial sources. The school at risk from tidal flooding was shown to be at risk in a 2030 0.1% AEP or rarer event. Whilst the likelihood of flooding would increase to around 1.4% AEP by 2080 the total present value damages from this are expected to be very small. The two schools shown within the flooded area from fluvial sources were both found to have flood levels below their threshold for all modelled scenarios. Whilst they may still be subject to disruption due to being surrounded by flood water, one in a 2030 1% AEP or rarer event and one in a 2030 0.1% AEP or rarer event, the duration of this disruption would be relatively short due to the lack of internal flooding. Given expected the low frequency and duration of disruption this was not considered to be a likely source of significant present value damages.

No hospitals at risk of flooding were identified within the study area. Four health centres/medical practices at risk of flooding were identified, two in a 2030 0.1% AEP or rarer tidal event and two in a 2030 0.1% AEP or rarer fluvial event. There are no specific methods to estimate disruption damages for non-hospital health settings included within the Multi Coloured Manual and the low frequency of flooding indicates that the present value damages from any such disruption are likely to be minimal.

[1] https://www.gov.uk/government/publications/fcerm-carbon-impacts-tool

Based on the above, no further assessment has been made of the potential damages associated with disruption to schools and hospitals.

4.8.3 Loss of economic activity

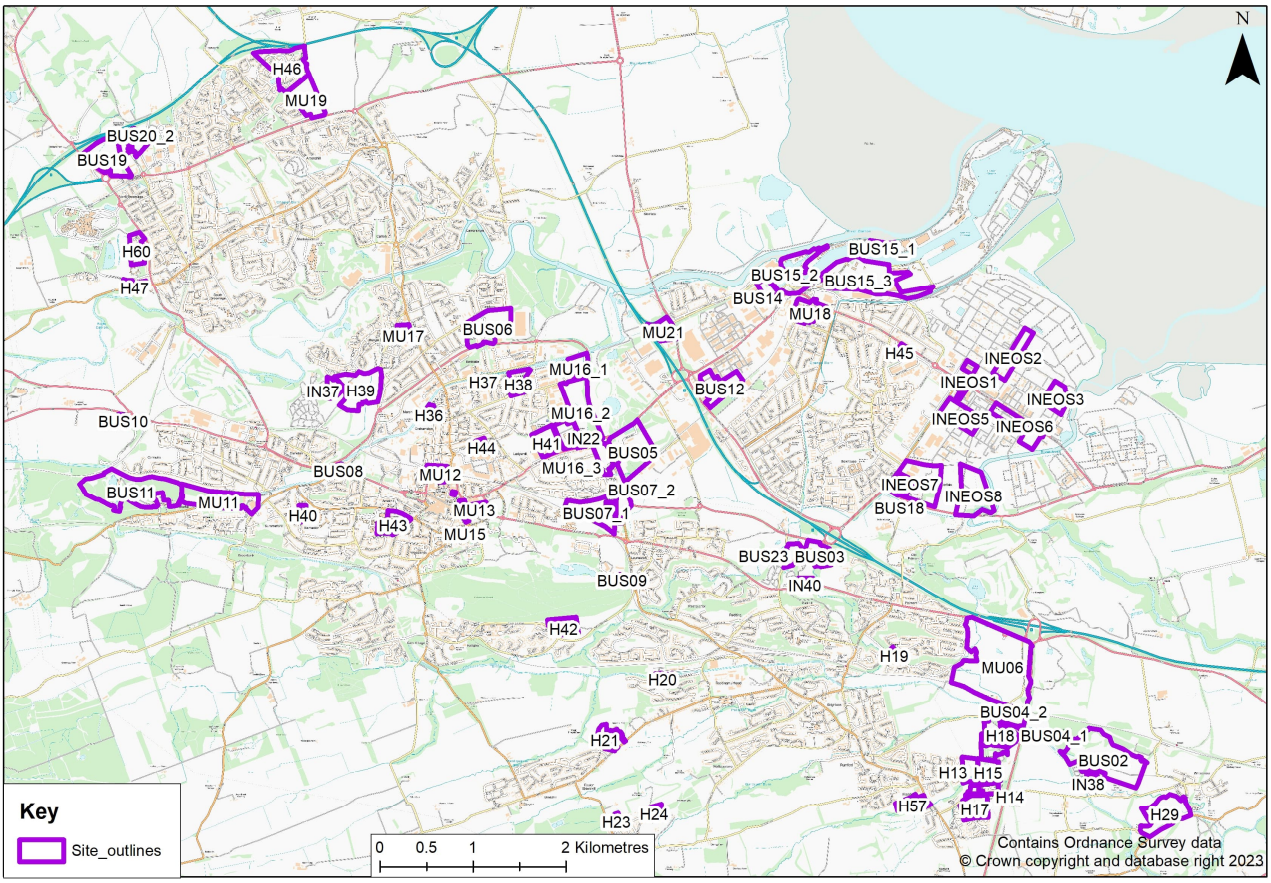
Wider damages associated with loss of economic activity (due to flooding of commercial properties) have been calculated. The methodology and results from this analysis are documented in Section 5.

4.8.4 Impacts on future development

In addition to the existing properties at risk in Grangemouth, there are also a number of proposed development sites which are located within the study area, and which are at risk of flooding. An additional damage calculation has been completed for future development, using Damage Calculator. This approach assumes that future development will occur regardless of whether the scheme is built and calculates the damages avoided to future development if the scheme is constructed. The following assumptions have been made in the calculation:

- All proposed development will be constructed prior to 2030 (Year 0 of the economic appraisal).
- Sites included are those identified in the Falkirk Local Development Plan 2 (https://www.falkirk.gov.uk/services/planning-building/planning-policy/local-development-plan/) plus future potential development sites within the INEOS oil refinery and petrochemical plant, as identified by the Falkirk Council (see Figure 4-5).
- Sites have been represented as a single point (as this is required by Damage Calculator).
- Thresholds have generally been assumed to be at the LIDAR DTM level plus 100mm except where the proposed development is in addition to the existing buildings on the site (rather than a redevelopment). Where this is the case, the threshold level has been assumed based on the existing buildings. Sensitivity testing has been undertaken on threshold levels, as documented in Section 7.
- The floor areas have been calculated by assuming that 25% of the site will be covered by buildings, which is consistent with existing development patterns in the area. The exception to this is where there are sites which are partially occupied by water (e.g., around the port), where a lower percentage coverage has been assumed.
- The relevant MCM code for each point has been identified based on the development description in the local development plan. Where development is mixed use, the lower vulnerability development type has been assumed as it is likely that this would be located on lower floors. For all INEOS sites, an MCM code of 8 (industrial) has been assumed.
- Rateable values for each site have been assumed as the average rateable value per m^2 for each MCM code from existing development in the study area, multiplied by the estimated floor area (see above). This has then been multiplied by the multipliers from Chapter 3 of the MCH.
- Where the proposed development represents a complete redevelopment of a site with existing properties, the total present value damages from existing development points on the site have been subtracted from the final total damages for future development, to avoid double counting.

Figure 4-5. Future development sites in the study area



The total damages for future development sites (with existing development damages subtracted) are shown in Table 4-5 and Table 4-6 for fluvial and tidal sources respectively. Negative values are shown where the damages of that type from existing properties exceed those from the proposed development.

Table 4-8. Future development Present Value Damages for fluvial flooding (2023 prices)

Damage Type	Baseline	With scheme
Residential	£0	£0
Non-Residential	£53,623,393	£48,730,741
Vehicle Damage	-£51,080	£0
Indirect (non-res) damage	£1,622,455	£1,466,595
Emergency services costs	£4,828,402	£4,044,104
Evacuation/ re-housing costs	-£29,388	£0
Mental Health costs	-£66,666	£0
Risk to Life (Residential)	£0	£0
Risk to Life (Non-Residential)	£9,518,540	£8,691,011
Health Intangible Benefits	-£60,248	£0
TOTAL	**£69,385,409**	**£62,932,451**

Table 4-9. Future development Present Value Damages for tidal flooding (2023 prices)

Damage Type	Baseline	With scheme
Residential	£0	£0
Non-Residential	£118,557,705	£46,374,987
Vehicle Damage	-£91,046	£0
Indirect (non-res) damage	£2,327,540	£122,191
Emergency services costs	£7,539,934	£306,839
Evacuation/ re-housing costs	-£49,113	£0
Mental Health costs	-£63,852	£0
Risk to Life (Residential)	£0	£0
Risk to Life (Non-Residential)	£10,685,262	£333,568
Health Intangible Benefits	-£29,361	£0
TOTAL	**£138,877,069**	**£47,137,585**

The total aggregated baseline damages across both sources are £208.3M. However, the same checks have been undertaken for double-counting of damages between sources as for the main damages' calculation (see Section 4.6). These indicate that up to £50.8M of the total baseline damages (c.25%) may be double-counted. However, a further check on the with scheme scenario indicates that £45.4M of damages are also potentially double-counted in the with scheme scenario so the overall impact of this on the estimation of total damages avoided is small.

5. Wider Economic Benefits

5.1 Introduction

In addition to the primary benefits of avoided property damages, this analysis also considers a wide range of economic benefits that could be created through the delivery of the flood defence scheme. The benefits stem from reducing the likelihood of a loss in economic output at key commercial sites as a direct result of flooding. For the purpose of this analysis, the following four[2] sites are considered:

- Grangemouth Oil Refinery;
- Grangemouth Petrochemical Plant;
- Forth Port Grangemouth; and
- All other commercial properties within the context area.

We recognise Scottish Government guidance that indirect losses are unlikely to arise from disruptions to commerce and retail, as multiple outlets usually offer comparable services. However, significant supply chain disruptions, such as those caused by flooding, may pose challenges for Scottish consumers and businesses in acquiring adequate oil, petrochemicals, and ports for export.

Given Grangemouth's status as Scotland's sole crude oil refinery and primary fuel producer, along with its large port, we expect consumers and business to face difficulties in accessing these goods, resulting in loss of GDP. To understand the extent of the impact on GDP and businesses, we have conducted an economic analysis.

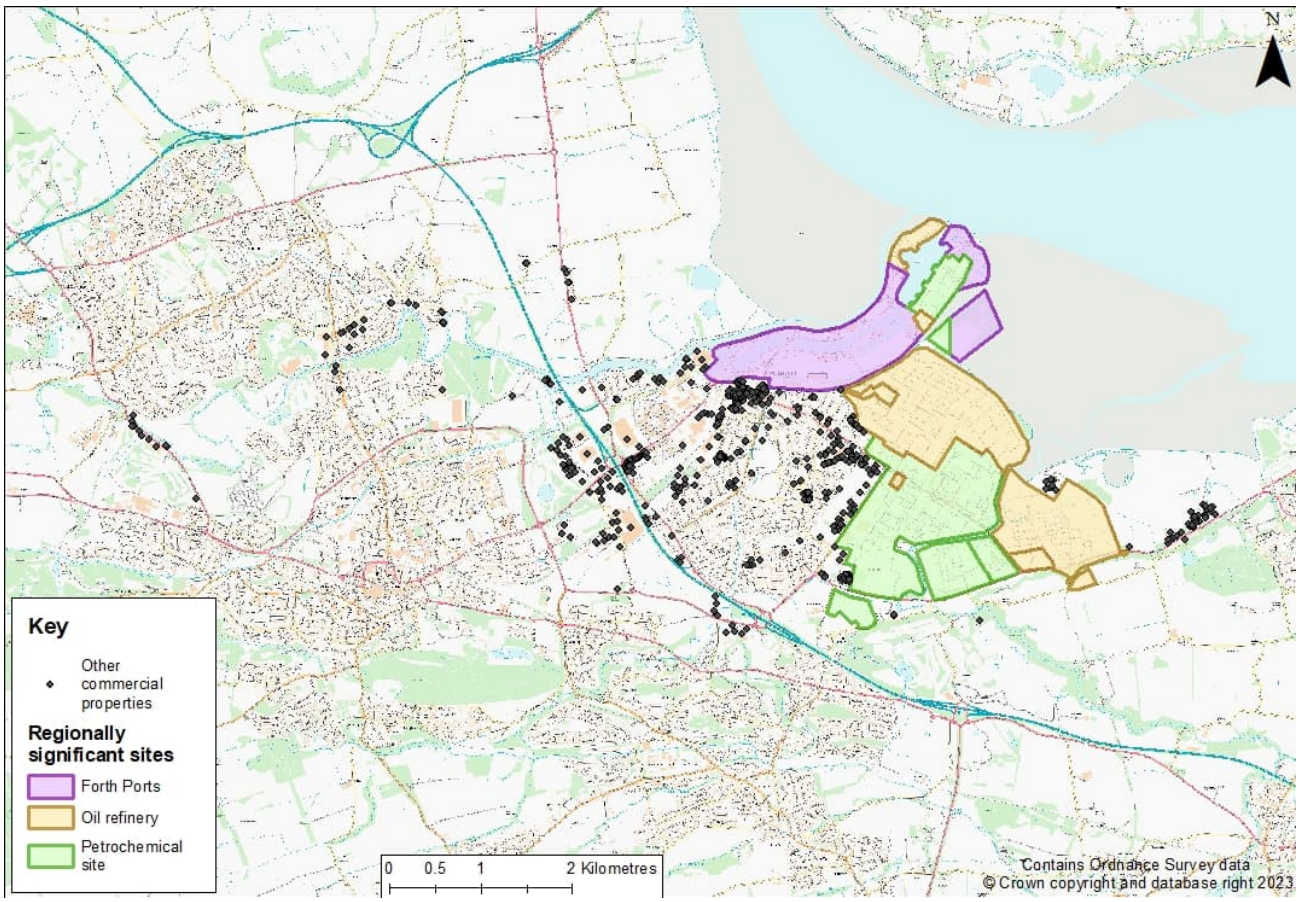
This section presents the overarching methodology adopted and resultant benefits from implementing the flood defence measures.

5.1.1 Context Area

The context area in Grangemouth demonstrates the geographical boundary that has been selected for the assessment of the wider economic benefits. Commercial properties that fall within this boundary only have been analysed as part of this wider economics assessment. The Grangemouth site area is a regional hub home to several different companies on site. Amongst these are regionally significant sites such as the Grangemouth Oil Refinery, Grangemouth Petrochemical Plant and Forth Port Grangemouth that are separately included in the cost-benefit analysis to describe the isolated economic impact of a flood disruption on these sites' economic activity contribution to the economy. Hence, direct economic output losses arising out of a flood are assessed for these regional sites assuming independent operations and no substitution/spill-over of inputs and/or outputs across these regional sites.

[2] Distinction has been for the first three receptor groups due to their national and strategic importance.

Figure 5-1. Grangemouth Context Area



5.1.1.1 Grangemouth Site

The oil refinery, a joint venture between INEOS and Petrochina, produces the bulk of fuels used in Scotland. Co-located on the same site is the INEOS Petrochemical plant, which produces the following four petrochemicals: ethanol, polyethylene, propylene, and polypropylene.

With an overall production capacity of around 7 million tonnes[3] of fuels and 1.4 million tonnes[4] of petrochemicals per annum according to INEOS, it has positioned itself as a key supplier of Scotland's fuel demand; supplies two-thirds of the petrol and diesel for forecourts and aviation fuel in Scotland as well as large volumes for the north of England and Northern Ireland.

The oil refinery holds strategic importance as it supports regional economic development in Scotland, accounting for 4% of Scotland's GDP and 8% of its manufacturing base[5]. Whereas the petrochemicals produced are used as intermediates in applications ranging from pharmaceuticals to non-drip paints, medical appliances to the lightweight plastics used in the automotive industry.

The oil production capacity at Grangemouth stood at 150,000 barrels per day in 2020 according to INEOS, a decline from 210,000 barrels per day in 2019. While it is acknowledged that 2020 was an outlier year, it is

[3] https://www.ineos.com/sites/grangemouth/about/

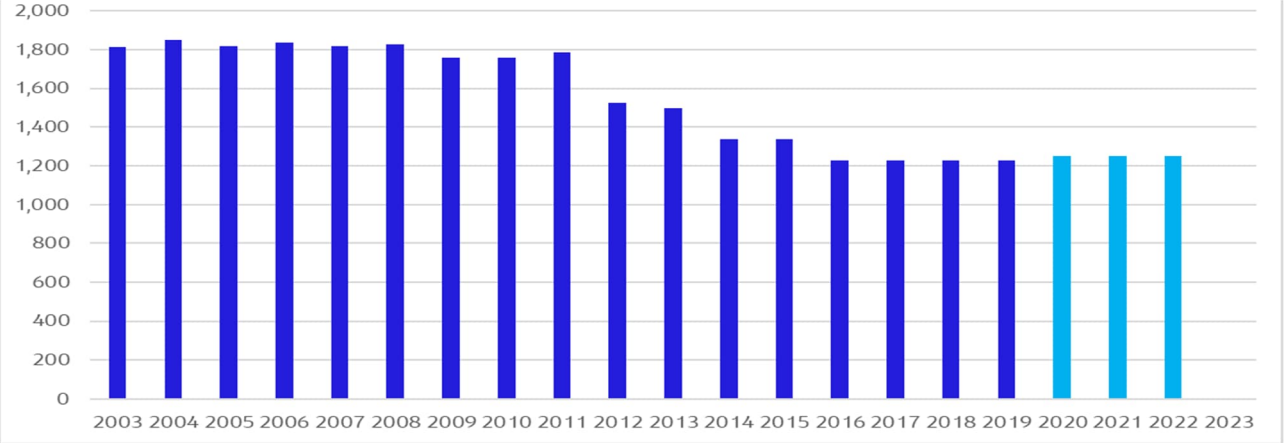
[4] Ibid

[5] https://www.ineos.com/sites/grangemouth/about/

important to note that the overall oil production across the UK has not yet recovered to pre-COVID levels (as depicted in **Figure 5-2. UK Oil Refining Capacity in Thousand Barrels from 2003 – 2022**

[6].

Figure 5-2. UK Oil Refining Capacity in Thousand Barrels from 2003 – 2022



5.1.1.2 Forth Ports Grangemouth

Besides being home to the largest oil refinery in Scotland, the largest port in Scotland is also situated within the flood impact zone. Forth Ports Grangemouth, with a handling capacity of 9[7] million tonnes of cargo per annum represents as much as 30% of GDP in Scotland, effectively an economic facilitator for Scotland. Situated midway between Scotland's main cities of Glasgow and Edinburgh, the port is the ideal logistics and distribution hub for Scotland with 70% of the population within a 1-hour radius to the port.

The port works with all major deep sea shipping lines, as well as European short sea, multimodal and tank operators. Forth Ports Scotland also provides a comprehensive range of facilities to ensure the safe movements of shipping for all of Scotland. These include a vessel traffic system (VTS), pilotage and navigational aids such as lighthouses, shore marks and buoys; hence playing an integral role is the Grangemouth-based Forth & Tay Navigation Service (FTNS).

5.2 Economic Benefits

To understand the economic impact of flooding on the four receptor groups, the first step is to establish the most appropriate metric to measure, quantify, and monetise economic activity for each receptor. Considering the type of data available at the impact sites, and scale of output at the sites, Gross Domestic Product (GDP), Revenue and Gross Value Added (GVA) have been adopted to proxy the economic activity. Comparison of the with-scheme and without scheme/baseline impacts estimates the economic activity that could be safeguarded through the delivery of the flood defence measures proposed. Table 5-1 below demonstrates the metric that has been adopted to measure output loss at a given site.

These wider economic impacts and benefits of the scheme have been quantified using the Scottish Government's *Flood protection appraisals: guidance for SEPA and responsible authorities* process for calculating average annual impact of loss of GDP in present values. In instances where data availability did not allow for appraisal against FCERM-AG alternative metrics were assessed, in particular to calculate the loss of revenue to the relevant impact sites.

[6] Source: Statista - Oil refinery capacity in the United Kingdom (UK) from 2003 to 2022.

[7] https://www.forthports.co.uk/our-ports/grangemouth/

Table 5-1. Wider Economic Benefits

Site	Wider Economic Benefit	Reason
Grangemouth Oil Refinery	Annual average impact Assessment of a loss in GDP Impact assessment of a Loss of Revenue	Assess the impact of varying degrees of flooding on the UK GDP. Revenue also monetised to demonstrate a wide range of impacts.
Grangemouth Petrochemical Refinery	Impact assessment of a Loss of Revenue	Assess the impact of varying degrees of flooding on the revenue of the site. GDP impact unable to be calculated due to insufficient data.
Forth Port Grangemouth	Annual average impact Assessment of a loss in GDP	Assess the impact of varying degrees of flooding on the UK GDP.
Remaining commercial properties within the flood zone	Annual average impact Assessment of a loss in GVA	Assess the impact of varying degrees of flooding on sub-regional GVA.

5.2.1 Grangemouth Oil Refinery – GDP Loss

This method involves identifying how much each tonne of oil contributes to UK's GDP known as oil intensity and what the potential impact on GDP would be as a direct result of flood disruption.

5.2.1.1 Assumptions

The following key assumptions have been adopted using secondary research to estimate the loss of GDP from flood disruptions at the oil refinery.

Table 5-2. Grangemouth Oil Refinery Assumptions

Assumption	Unit	Value	Source
Production of Refined Oil	Barrels per day	150,000	INEOS, UK Oil Refining Capacity
Disruption Period	Days	4	Estimated disruption period based on emergency oil storage capacity
Oil Storage Capacity	Days	22.5	UK Emergency Oil Stocks, Department of Energy & Climate Change
PV Factor	Years	30	Based on UK 2050 Net Zero Ambition

A flood at Grangemouth Oil Refinery is assumed to disrupt production for an estimated 15 days in an unconstrained scenario. However, UK Emergency Oil Stocks published by Department of Energy & Climate Change indicates that refineries are to maintain a strategic reserve of refined oil equivalent to 22.5 days'[8] worth

[8] UK Emergency Oil Stocks, Feb 2015, UK Government

of consumption, specifically for emergency situations to ensure uninterrupted supply to consumers. Therefore, we are assuming a constrained disruption period of 4 days. This accounts for the time needed to mobilise and re-align transportation routes to source from the strategic storage supplies rather than from the refinery itself.

The UK's commitment to achieving Net Zero emissions by 2050 entails a substantial reduction in fossil fuel consumption within the country. While Net Zero allows for some limited fossil fuel use, we are working under the assumption that the majority, if not all, oil refineries in the UK, including Grangemouth, will need to cease operations. This impacts the assumption on the appraisal period.

This analysis also assumes that the current production capacity remains consistent with the 2020 level.

5.2.1.2 Impact

The potential impact of flooding at Grangemouth oil refinery can be measured as a function of an oil production shortfall's impact on UK GDP. This can be inferred by measuring the relationship and linkages between oil production and GDP, known as GDP Intensity. Total impact can then be quantified by combining GDP intensity by daily production volume and number of days disruption to determine the scale of UK GDP affected by a flood disrupting activities at Grangemouth.

$$(GDP\ Intensity) * (Daily\ Production\ Volume) * (No.\ Days\ of\ Disruption)$$

The output of this equation provided the input for the AAD/PV tool to ultimately calculate average annual damage in present value. The resultant benefits in 2023 prices for a 30-year appraisal period are presented below. The analysis assumes that all four days of disruption would be avoided through the delivery of the scheme. The output of this appraisal is documented in the table below.

Table 5-3. Grangemouth Oil Refinery Benefit Summary

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Oil Refinery	Impact on GDP	30	4	1,190

5.2.2 Grangemouth Oil Refinery – Revenue Loss

This method involves calculating the daily production output and then multiplying it by the average price of the corresponding commodity to estimate the potential revenue lost due to flood-based disruptions.

5.2.2.1 Assumption

Similar assumptions to the GDP analysis have been adopted for the revenue loss analysis.

Table 5-4. Grangemouth Oil Refinery Assumptions

Assumption	Unit	Value	Source
Production of Refined Oil	Barrels per day	150,000	INEOS, UK Oil Refining Capacity
Disruption Period	Days	4	Estimated disruption period based on emergency oil storage capacity
Commodity Price	£ per barrel	382	Derived based on the total revenue achieved through oil production in 2022 and divided by the yearly production capacity.

5.2.2.2 Impact

The value depicted in **Table 5-5. Grangemouth Oil Refinery Benefit Summary**

has been derived using the methodology outlined in this section. This alternative method involves calculating the daily production output and then multiplying it by the average price of the corresponding commodity. The resulting figure serves as an estimate of the company's revenue loss, which serves as an initial indicator of potential reductions in VAT and national GDP. This estimate provides insight into the extent of the flooding impact.

$$(Daily\ Production\ Output) * (Average\ Price\ of\ Commodity) * (No.\ Days\ of\ Disruption)$$

The benefits in 2023 prices corresponding to an annual impact can be seen below. The analysis assumes that all four days of disruption would be avoided through the delivery of the scheme. Undisrupted supply and production of refined oil will mitigate any flood related increase in oil prices and thus benefit the population of Scotland.

Table 5-5. Grangemouth Oil Refinery Benefit Summary

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Oil Refinery	Commodity Price (Revenue)	Duration of disruption	4	235

5.2.3 Grangemouth Petrochemical Site – Revenue Loss

This method involves calculating the daily production output and then multiplying it by the average price of the corresponding commodity to estimate the potential revenue lost due to flood-based disruptions.

5.2.3.1 Assumptions

The key assumptions adopted for this analysis that are specific to the petrochemical plant are outlined in Table 5-6.

Table 5-6. Grangemouth Petrochemical Plant Assumptions

Assumption	Unit	Value	Source
Production of Petrochemicals	Tonnes per annum	1,400,000	INEOS
Production Output per product	%	25	Assumed equal production output between the four produced petrochemicals
Disruption Period	Days	15	Subject Matter Experience. Petrochemicals not part of the UK strategic reserve and thus full disruption period is assumed.
Polypropylene	£ per Metric Tonne	909	Statista
Polyethylene	£ per Metric Tonne	1,090	Chemanalyst
Propylene	£ per Metric Tonne	800	Statista
Ethylene	£ per Metric Tonne	851	Statista

The facility manufactures four significant petrochemicals: propylene, polypropylene, ethylene, and polyethylene, with an annual production output of 1.4 million tonnes. These substances find utility either as intermediary components within the supply chain or as finished products, serving a wide array of applications. Given the diverse derivatives produced, there isn't a fixed petrochemical price; therefore, we have determined an average price using the global pricing data for the four chemicals manufactured at the site. INEOS doesn't publish the production capacity per chemical, and we have thus assumed an equal split. Hence, combining 4 petrochemical prices with equal weights for the 4 petrochemicals results in a weighted average price calculated to quantify the revenue loss for Grangemouth Petrochemical plant. Like our approach for the oil refinery, we have chosen a 30-year present value (PV) factor estimation instead of a 100-year one.

5.2.3.2 Impact

The analysis adopts the following formula to estimate the revenue loss outlined in Table 5-7. Grangemouth Petrochemical Plant Benefit Summary:

$$(Daily\ Production\ Output) * (Average\ Price\ of\ Commodity) * (No.\ Days\ of\ Disruption)$$

The benefits in 2023 prices corresponding to an annual impact can be seen below. The analysis assumes that all 15 days of disruption would be avoided through the delivery of the scheme.

Table 5-7. Grangemouth Petrochemical Plant Benefit Summary

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Petrochemical	Commodity Price (Revenue)	Annual impact	15	52

5.2.4 Forth Port Grangemouth – GDP Loss

This method involves assessing identifying how much each container contributes to UK's GDP and what the potential impact on GDP would be as a direct result of flood disruption.

5.2.4.1 Assumption

The key assumptions adopted for this analysis that are specific to the port are outlined in Table 5-8.

Table 5-8. Forth Port Assumptions

Assumption	Unit	Value	Source
Flow of goods	£ billion per annum	6	Grangemouth Forth Ports Official Website
Days of Disruption	Days	6	Industry Standard Benchmark[9]
Container Throughput	TEUs	250,000	Grangemouth Forth Ports Official Website
Inward Container Volume	%	54%	UK Maritime Statistics
Outward Container Volume	%	46%	UK Maritime Statistics
PV Factor	Years	100	Standard Appraisal Period

The port has an annual container throughput of 250,000 TEUs that generate £6 billion pounds per year of economic output for the UK. The core scenario assumes that no container traffic would be diverted, and the port would cease operations for a 15-day period. Whilst in the constrained scenario we assume that inward traffic (54% of TEUs) would be diverted to a nearby and non-affected port, whilst only outward traffic would be impacted. Furthermore, in the constrained scenario we also assume a downtime of approximately 6 days. The inference is based on industry standard benchmarks based on industry/academic literature.

5.2.4.2 Impact

The outputs documented in Table 5-9. Forth Port Benefit Summary have been derived by using the formula below.

$$(GDP\ Intensity) * (Daily\ Production\ Volume) * (No.\ Days\ of\ Disruption)$$

[9] https://www.sciencedirect.com/science/article/pii/S1361920920305800?fr=RR-2&ref=pdf_download&rr=814e165c6c2e6532

The benefits in 2023 prices corresponding to an annual impact can be seen below. The analysis assumes that all six days of disruption would be avoided through the delivery of the scheme.

Table 5-9. Forth Port Benefit Summary

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Forth Port Grangemouth	(GDP)	100	6	27

5.2.5 Economic Impact Summary

The economic impact of the three identified sites that are located within the flood risk zone are captured in Table 5-10. The robust analysis undertaken in the section above provide additional benefits that are considered in the overall BCR calculation. The values that have been taken forward for BCR calculation are highlighted in light blue.

Table 5-10. Economic impact of output disruption of oil refinery and petrochemical plant at Grangemouth site

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Oil Refinery	(GDP)	30	4	1,190
Oil Refinery	Commodity Price (Revenue)	Duration of disruption	4	235
Petrochemical	Commodity Price (Revenue)	Annual impact	15	52
Forth Port Grangemouth	(GDP)	100	6	27

The analysis indicates that a single disruption scenario involving both the oil refinery and the port would result in damages totalling approximately 1.2 million GBP. This represents a substantial economic impact on the UK, but the flood protection scheme offers a viable solution to mitigate these consequences, thereby providing the region with a crucial safeguard against future natural disasters.

5.2.6 Sensitivity and Risk Profile

A number of sensitivities have been undertaken to evaluate the robustness of our outputs. Sensitivities have only been performed for the GDP based approach because its values are included within the overall BCR calculation and thus we assessed a constrained and unconstrained scenario that considers external factors that mitigate the disruption period. This is further discussed below.

The following sensitivity have been considered as part of the appraisal:

1. Unconstrained impact on GDP. Unconstrained refers to standard AAD calculation with no consideration of external factors such as storage systems that could mitigate the impact to economy in the event of a flood,

whilst constrained considers these external factors. UK refineries are legally mandated to maintain storage capacities for providing refined oil for a period of 22.5 days and crude oil for 44.5 days[10]. This requirement implies that in the event of a flooding incident causing production disruptions, oil can still be sourced from their storage facilities, mitigating the impact on consumers. Consequently, we conducted sensitivity analyses to accommodate for these emergency contingency measures. This impacts the assumption of the disruption period of four days as employed in the analysis so far accounting for these unconstrained aspects of storage capacity requirements for oil refineries. Hence, in the absence of these external mitigating mechanisms, a disruption period of 15 days is employed. The core scenario is based on a constrained position.

2. The core scenario for the Grangemouth oil refinery and petrochemical production facility is assuming an appraisal period of 30 years because the UK is aiming to achieve Net Zero by 2050 and thus will significantly reduce its fossil fuel consumption. However, a sensitivity has also been run using the standard appraisal period of 100 years.

The impact of these sensitivity tests on GDP is presented in the table below:

Table 5-11. Sensitivities

Type of Output Loss	Approach	Appraisal Period (Years)	Disruption Period (Days)	Impact (Millions GBP) 2023 Price Base
Oil Refinery	Unconstrained (GDP)	30	15	4,461
Oil Refinery	Unconstrained (GDP)	100	15	6,987
Forth Port Grangemouth	Unconstrained (GDP)	100	15	147

5.2.7 All Other Commercial Properties Within the Context Area

Grangemouth is host to a number of key businesses that are currently at risk from fluvial and tidal flooding as per flood modelling undertaken. Under the current flood measures, a significant quantum of floorspace is impacted by floods of varying degrees. As a result, "businesses that are affected by floods face periods of temporary close, or in instances of substantial damages, the possibility of a permanent closures. This can lead to business downtime and resulting lost economic output. The analysis undertaken however is predicated in the event of a temporary closure only due to flooding.

Through the provision of enhanced flood defences up to a 0.5% AEP SoP, businesses within scheme context area will face a lower risk being flooded. Thus, the scale of temporary business closure, associated business downtime and lost economic output within Grangemouth will be reduced through the scheme delivery.

It should be noted that the GVA benefits calculated do not feature as part of the BCR which is in line with SEPA guidance.

5.2.7.1 Methodology

To estimate the impact of the flood defence scheme on existing economic activity, an approach was adopted that is aligned to the 'Flood Protection Appraisals: Guidance for SEPA and Responsible Authorities'. This

[10] UK Emergency Oil Stocks, Feb 2015, UK Government

approach monetises the loss in output because of temporary closure of businesses through the economic measure of Gross Value Added.

The approach to assessing the value of existing economic activity safeguarded can be summarised as follows:

- Existing commercial properties inundated by different floods were identified using the property data set developed by the project overlain on flood extent mapping.
- The commercial floorspace associated with affected properties was obtained from the property data set, split by broad economic sectors using MCM codes.
- Floorspace data was converted to employment by industry sector using employment density benchmarks sourced from the Homes and Communities Agency's (HCA) 'Employment Densities Guide' (2015).
- Employment estimates were converted to annual GVA values using GVA per employee benchmarks. The benchmarks were derived from the ONS Regional gross value added (balanced) by industry: all International Territorial Level (ITL) regions (2023), coupled with Business Register and Employment Survey data by broad industry group (2021).
- The scale of GVA lost as a result of a specific floods as estimated for the baseline and with-scheme scenarios, based on the number of businesses (and subsequently floorspace, employment and GVA) affected by each flood.
- The resulting GVA impacts were converted to annual average values before being extrapolated over the appraisal period and discounted to determine present values.
- The difference in 'lost' GVA associated with business downtime across the scenarios represents the safeguarded GVA resulting from following a particular flood defense solution.

5.2.7.2 Economic Impacts on Existing Commercial Properties

Floorspace Affected

Based on the approach described above, Table 5-12demonstrates that flood defence measures will result in significantly less inundated commercial floorspace than the baseline scenario, across multiple floods. It should be noted that whilst there are multiple flood probabilities, the analysis presented below relates to a specific flood for illustrative purposes. The information presented below for a tidal flood is for a 1 in 200 year tidal flood.

As per Table 5-12, in 2080, around 100,000 m^2 of commercial floorspace will be at risk of inundation based in a 0.5% AEP tidal flood without the scheme. Under the with-scheme scenario, the quantum of floorspace inundated falls to around 25,000 m^2 in the year 2080.

Table 5-12. Commercial Floor Area (m^2) Inundated in a Tidal Flood

Tidal Flood	
Flood AEP	0.5%
Baseline Scenario - Present Day	34,886
With -Scheme Scenario - Present Day	744
Flood Return Period	200
Baseline Scenario - 2080	96,816
With -Scheme Scenario - 2080	24,153

For the fluvial scheme, for comparator purposes a 0.5% AEP flood has been presented for illustrative purpose for the year scenario 2080 only. The scenario "Present day" has not been presented as the flood return period 0.5% AEP doesn't feature within the with scheme scenario in the "Present Day".

Analysis undertaken for a fluvial flood demonstrates that nearly 250,000 m^2 of floor space is at risk of being flooded under a 1 in 200. Following the scheme delivery, it is estimated that this could reduce to nearly 73,000 in 2080 for fluvial flood. This information is presented in the table below.

Table 5-13. Commercial Floor (m^2) Area Inundated in a Fluvial Flood

Fluvial Flood	
Flood AEP	0.5%
Baseline Scenario - 2080	246,494
With -Scheme Scenario - 2080	72,766

Employment Affected

The quantum of floorspace listed in Table 5-12 and Table 5-13 are translated into employment estimates presented in Table 5-14 and Table 5-15. This is done through the HCA employment density benchmarks to the relevant commercial floorspace by industry. The analysis demonstrates that based on a 1 in 200-year flood in 2080, the quantum of employment affected is an estimated 4,000 under baseline tidal flood conditions. This figure reduces to nearly 800 under the with-scheme scenario in 2080. This is summarised in Table 5-14.

Table 5-14. Employment Affected in a Tidal Flood

Tidal flood	
Flood Return Period	200
Baseline Scenario - Present Day	1,398
With -Scheme Scenario - Present Day	42
Flood Return Period	200
Baseline Scenario - 2080	3,944
With -Scheme Scenario - 2080	773

Similarly, in the 2080 for a fluvial flood, employment impacts are an estimated 7,300 in the baseline scenario for a 0.5% AEP flood in 2080. This reduces to around 2,500 under the with-scheme scenario.

Table 5-15. Employment Affected in a Fluvial Flood

Fluvial Flood	
Flood Return Period	200
Baseline Scenario - 2080	7,288
With -Scheme Scenario - 2080	2,552

The affected employment estimates outlined in the table above are translated into estimates for lost GVA per event through the application of GVA per employee benchmarks. These benchmarks are specific to the industry groups.

The analysis demonstrates that for following a 0.5% AEP event in 2080, the scale of GVA lost because of flood could amount to around £265m. Whilst in in the baseline scenario present day, this figure could be an estimated £97m. These values reduce to £54m and £1.2m with the scheme respectively.

Table 5-16. GVA Affected in a Tidal Flood

Tidal Flood	
Flood AEP	0.5%
Baseline Scenario - Present Day	£ 97,385,511
With -Scheme Scenario - Present Day	£ 1,230,047
Flood AEP	0.5%
Baseline Scenario - 2080	£ 265,231,331
With -Scheme Scenario - 2080	£ 54,321,543

Under the fluvial scenario, in a 0.5% AEP flood in the year 2080 an estimated £481m in GVA could be lost. This value reduces to £189m with the scheme in place.

Table 5-17. GVA Affected in a Fluvial Flood

Fluvial Flood	
Flood AEP	0.5%
Baseline Scenario - 2080	£ 481,439,914
With -Scheme Scenario - 2080	£ 189,754,484

The GVA per flood is then weighted down to take into account the average duration a business is likely to be temporary closed for. This is done through the application of business downtime benchmarks [11]. The resultant GVA lost is then annualised by taking into account the flood probabilities.

Average Annual Impact & Present Value Impacts (PV)

From the annualised GVA it is converted into average annual impacts by adopting the AAD to PV calculator. These average annual impacts are then discounted to arrive at present value impacts for tidal and fluvial floods. The total PV for both tidal and fluvial floods is significantly lower with the flood protection scheme in place. Similarly, the PV total demonstrates a significant reduction in damages after the scheme in place in case of aggregation of tidal and fluvial floods. The values are in the table below.

Table 5-18. Present Value of Impacts

Annual Average Damages - Present Value	Baseline	With-Scheme	Savings
PVD Tidal	£3,336,920	£311,573	£3,025,347
PVD Fluvial	£1,494,903	£68,002	£1,426,901
PVD TOTAL	**£4,831,823**	**£379,575**	**£4,452,248**

[11] Based on a range of case study evidence.

6. Overall economic benefits

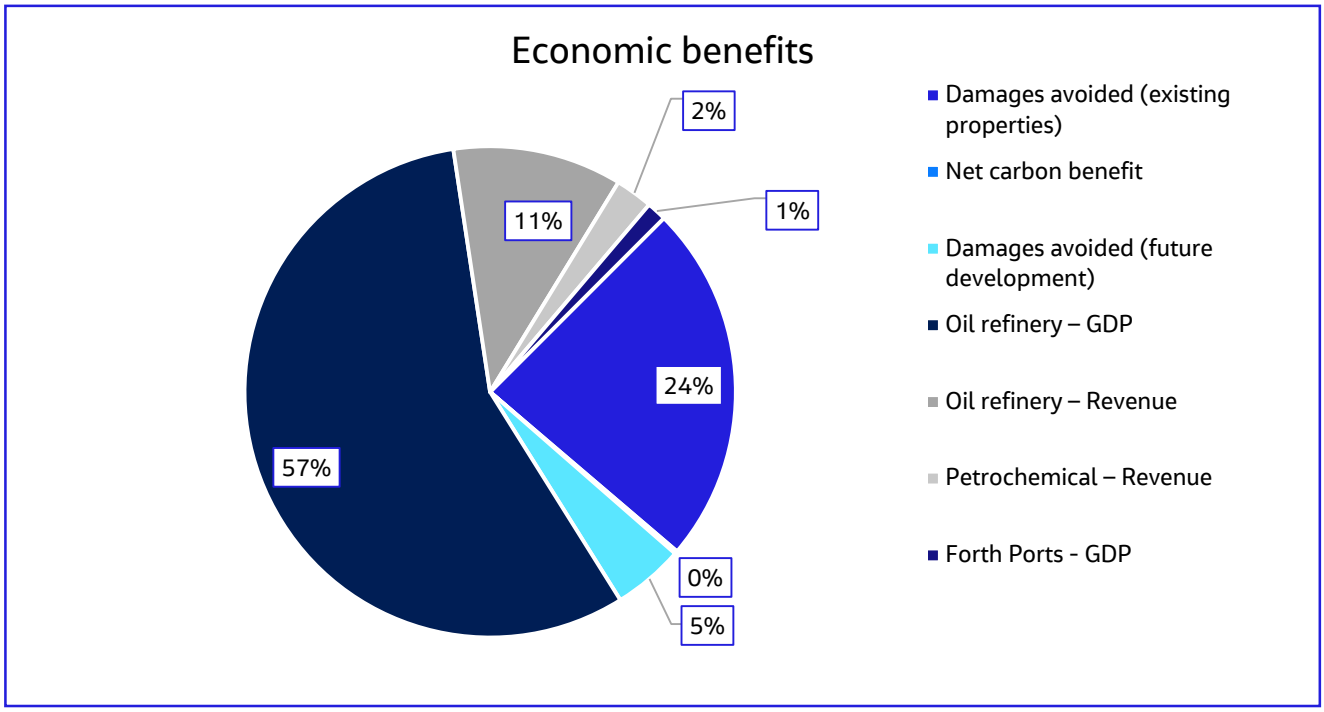
6.1 Summary of benefits

The national benefits identified for Grangemouth FPS have been collated from Table 4-5, Table 4-6, Table 4-8, Table 4-9 and Table 5-10. Economic impact of output disruption of oil refinery and petrochemical plant at Grangemouth site and their associated report sections are summarised in Table 6-1 and Figure 6-1. All benefits have been updated to 2030 using GDP deflators (see Appendix A). For the years beyond the current published deflators (after 2028) an inflation rate of 2% has been assumed, based on the UK government's target for inflation.

Table 6-1. Summary of national economic benefits for Grangemouth FPS

Benefit type	Report section	PV benefit at base price year	Base year for benefit	PV benefit (2030 prices)
Damages avoided (existing properties)	4.6	£500M	2023	£570M
Net carbon benefit	4.8.1	-£4M	2020	-£5M
Damages avoided (future development)	4.8.4	£98M	2023	£112M
Oil refinery – GDP	5.2.1	£1,190M	2023	£1,356M
Oil refinery – Revenue	5.2.2	£235M	2023	£268M
Petrochemical – Revenue	5.2.3	£52M	2023	£59M
Forth Ports - GDP	5.2.4	£27M	2023	£31M
TOTAL BENEFIT				**£2,390M**

Figure 6-1. Economic benefits



Local benefits from Table 5-18 are summarised in Table 6-2. These are not included in the overall cost benefit assessment.

Table 6-2. Summary of local benefits for Grangemouth FPS

Benefit type	Report section	Economic PV benefit at base price year	Base price year for economic benefit	Economic PV benefit inflated to 2030
Economic activity - GVA	5.2.7	£4,452k	2023	£5,072k
			TOTAL BENEFIT	£5,072k

6.2 Comparison of costs and benefits

Table 6-3 compares the benefits and costs and shows the Benefit: Cost Ratio (BCR) for the scheme.

Table 6-3. Comparison of Costs and Benefits (2030 prices)

	Grangemouth FPS
Total PV benefits	£2,390.2M
Total PV costs	£556.2M
Benefit - Cost Ratio (BCR)	4.3

7. Sensitivity testing

7.1 Costs

As described in Section 2, Turner & Townsend have supplied a range of costs for the scheme. Table 7-1 compares the BCR for the different scheme costs provided, assuming no change in PV benefits.

Table 7-1. Comparison of BCR for different scheme costs (2030 prices)

	Mean cost (used in appraisal)	Lower range	Upper range
Total PV benefits	£2,390.2M		
Total PV costs	£556.2M	£449.3M	£663.1M
BCR	4.3	5.3	3.6

7.2 Benefits

7.2.1 Damages avoided

Sensitivity testing has been undertaken on the damage calculations for existing properties to determine the potential impacts of thresholds being higher or lower than those assumed in the property dataset. Table 7-2 compares the BCR for the different sensitivity scenarios, assuming no change in PV costs.

Table 7-2. Comparison of BCR for different existing property threshold levels (2030 prices)

	Thresholds as in property dataset	Threshold levels +100mm	Threshold levels -100mm
PV benefits from damages avoided (existing properties)	£569.6M	£521.0M	£624.6M
Total PV benefits	£2,390.2M	£2,341.6M	£2,445.2
Total PV costs	£556.2M		
BCR	4.3	4.2	4.4

7.2.2 Future development

Sensitivity testing has been undertaken on the damage calculations for future development to determine the potential impacts of thresholds being higher or lower than those assumed in the property dataset. Table 7-2 compares the BCR for the different sensitivity scenarios, assuming no change in PV costs.

Table 7-3. Comparison of BCR for different future development property threshold levels (2030 prices)

	Thresholds as in property dataset	Threshold levels +100mm	Threshold levels -100mm
PV benefits from damages avoided (future development)	£111.9M	£86.3M	£120.4M
Total PV benefits	£2,390.2M	£2,364.6M	£2,398.7M
Total PV costs	£556.2M		
BCR	4.3	4.3	4.3

8. References & guidance used

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Appendix A. Inflation -GDP deflators

Inflation – GDP deflators

In line with Environment Agency guidance GDP deflators have been used where appropriate to calculate the impact of inflation.

Background information: https://www.gov.uk/government/collections/gdp-deflators-at-market-prices-and-money-gdp

Dataset used: https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-november-2023-autumn-statement

Published: 23 November 2023

Data used:

- Outturn data are as at the Quarterly National Accounts from ONS - last updated 29 September 2023.
- Forecast data are consistent with OBR Autumn Statement EFO data as of 22 November 2023.

Calendar year	GDP deflator at market prices	
	2022 = 100	per cent change on previous year
2010	77.568	1.58
2011	79.267	2.19
2012	80.486	1.54
2013	82.188	2.12
2014	83.271	1.32
2015	83.823	0.66
2016	85.468	1.96
2017	87.056	1.86
2018	88.730	1.92
2019	90.606	2.11
2020	95.411	5.30
2021	95.107	-0.32
2022	100.000	5.14
2023	*107.030*	7.03
2024	*109.438*	2.25
2025	*111.288*	1.69
2026	*113.102*	1.63
2027	*115.070*	1.74
2028	*117.210*	1.86

Figures in red italic are not supplied in the original figures but have been calculated from the percentages in the third column.

Appendix B. Capped vs uncapped damages

Fluvial scenario:

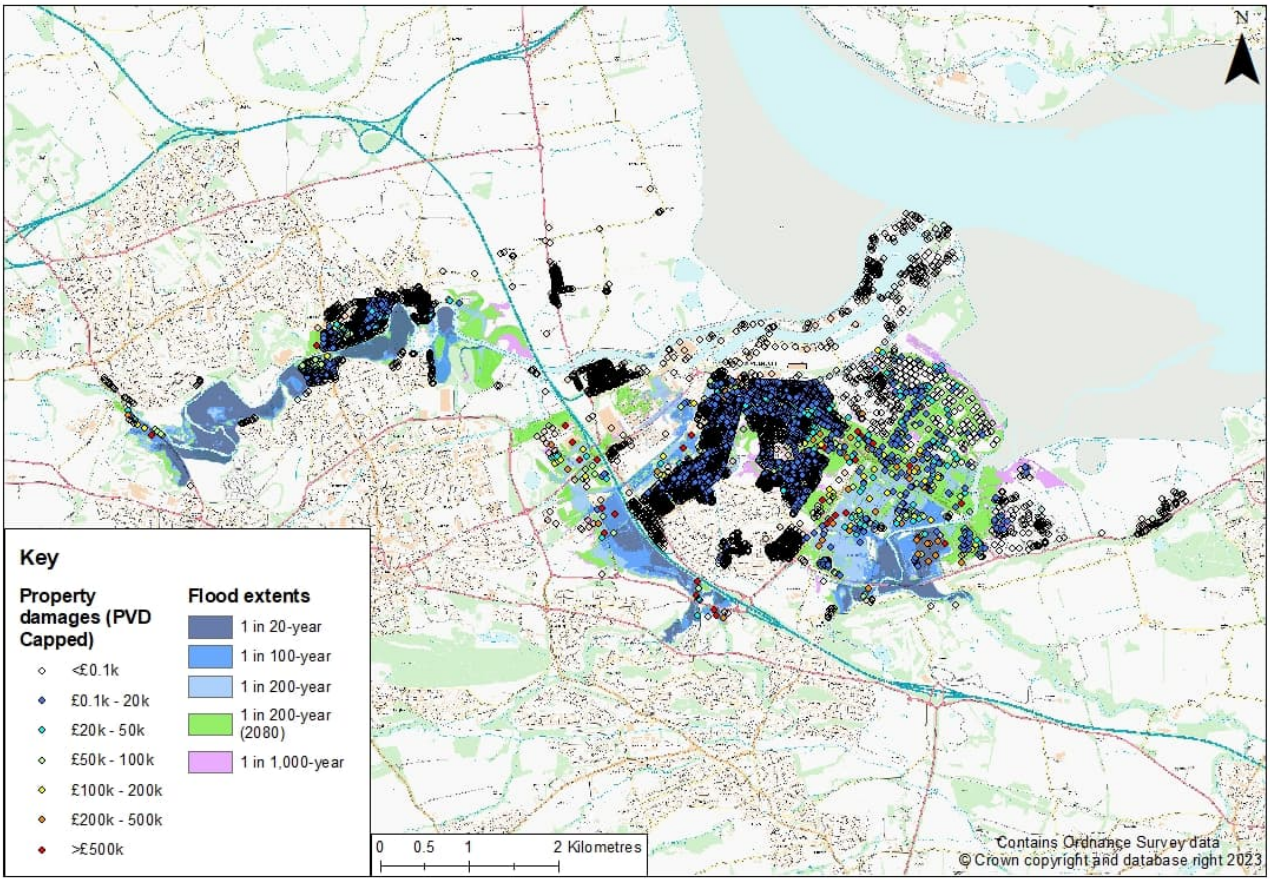
Damage Type	Baseline uncapped	Baseline capped	With scheme capped	With scheme uncapped
Residential	£27,640,579	£27,616,428	£20,983,118	£20,983,118
Non-Residential	£240,197,787	£93,851,767	£36,902,220	£36,640,827
Vehicle Damage	£3,574,824	£3,571,065	£2,879,270	£2,879,270
Indirect (non-res) damage	£7,205,934	£2,872,545	£1,107,067	£1,099,460
Emergency services costs	£35,737,273	£14,807,082	£8,011,963	£7,957,554
Evacuation/ re-housing costs	£4,574,753	£4,567,653	£3,163,693	£3,163,693
Mental Health costs	£11,977,871	£11,939,500	£8,764,851	£8,764,851
Risk to Life (Residential)	£10,931,997	£10,921,349	£6,831,007	£6,831,007
Risk to Life (Non-Residential)	£8,130,871	£6,120,644	£2,952,452	£2,930,009
Health Intangible Benefits	£4,344,679	£4,340,626	£641,827	£641,827
TOTAL	£354,316,568	£180,608,657	£92,237,467	£91,891,616

Tidal scenario:

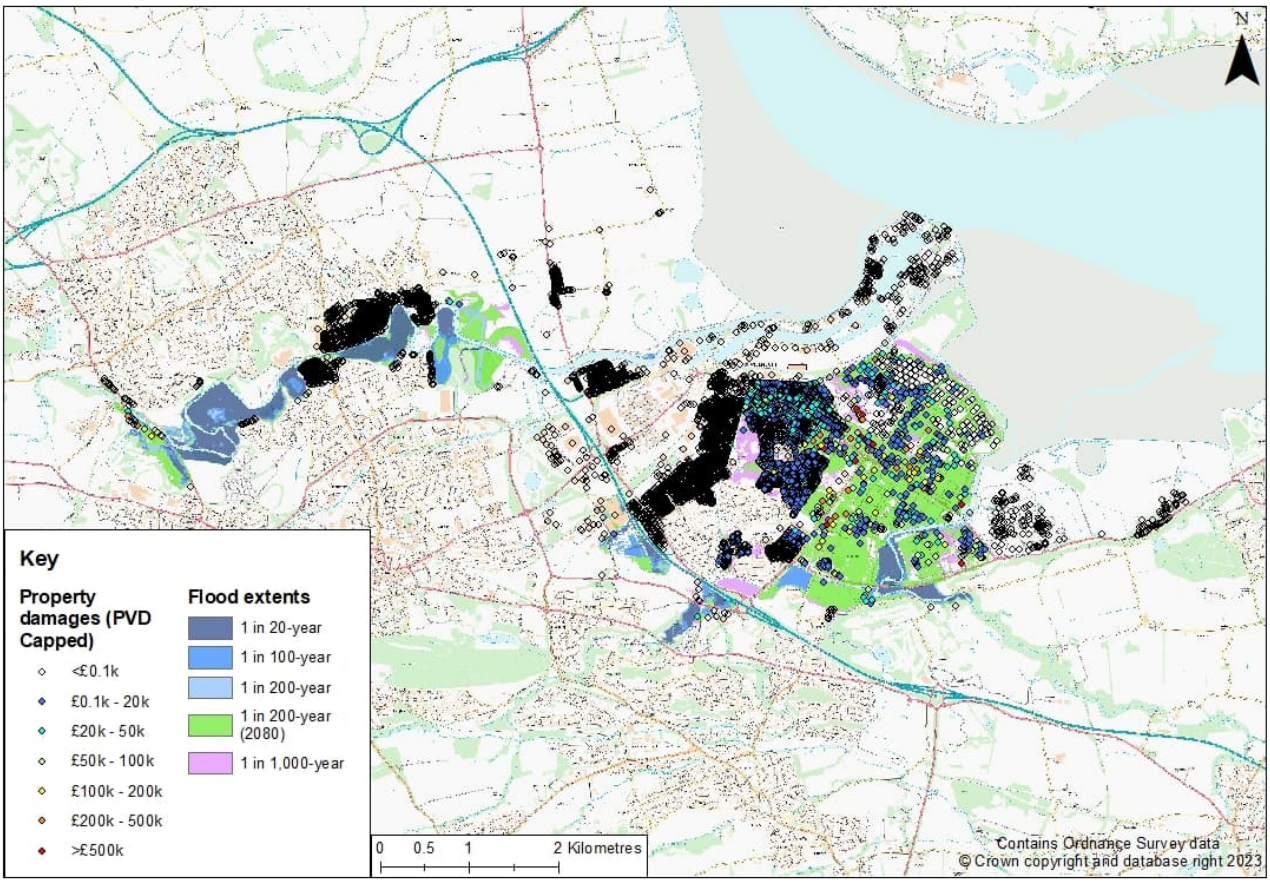
Damage Type	Baseline uncapped	Baseline capped	With scheme capped	With scheme uncapped
Residential	£77,303,214	£63,613,070	£9,754,236	£8,083,615
Non-Residential	£833,891,139	£254,499,257	£13,469,111	£5,950,185
Vehicle Damage	£7,970,256	£3,748,190	£1,045,107	£950,699
Indirect (non-res) damage	£25,016,734	£6,067,647	£404,073	£180,024
Emergency services costs	£121,399,308	£26,155,213	£3,286,463	£1,828,230
Evacuation/ re-housing costs	£9,461,241	£6,002,791	£1,293,398	£1,192,134
Mental Health costs	£25,098,268	£15,537,309	£3,360,054	£3,022,554
Risk to Life (Residential)	£49,562,467	£39,290,530	£3,267,323	£3,152,394
Risk to Life (Non-Residential)	£54,818,190	£16,163,103	£450,437	£234,482
Health Intangible Benefits	£7,002,309	£5,959,153	£1,305,680	£1,271,282
TOTAL	£1,211,523,127	£437,036,264	£37,635,882	£25,865,598

Appendix C. PVD capped damages by location

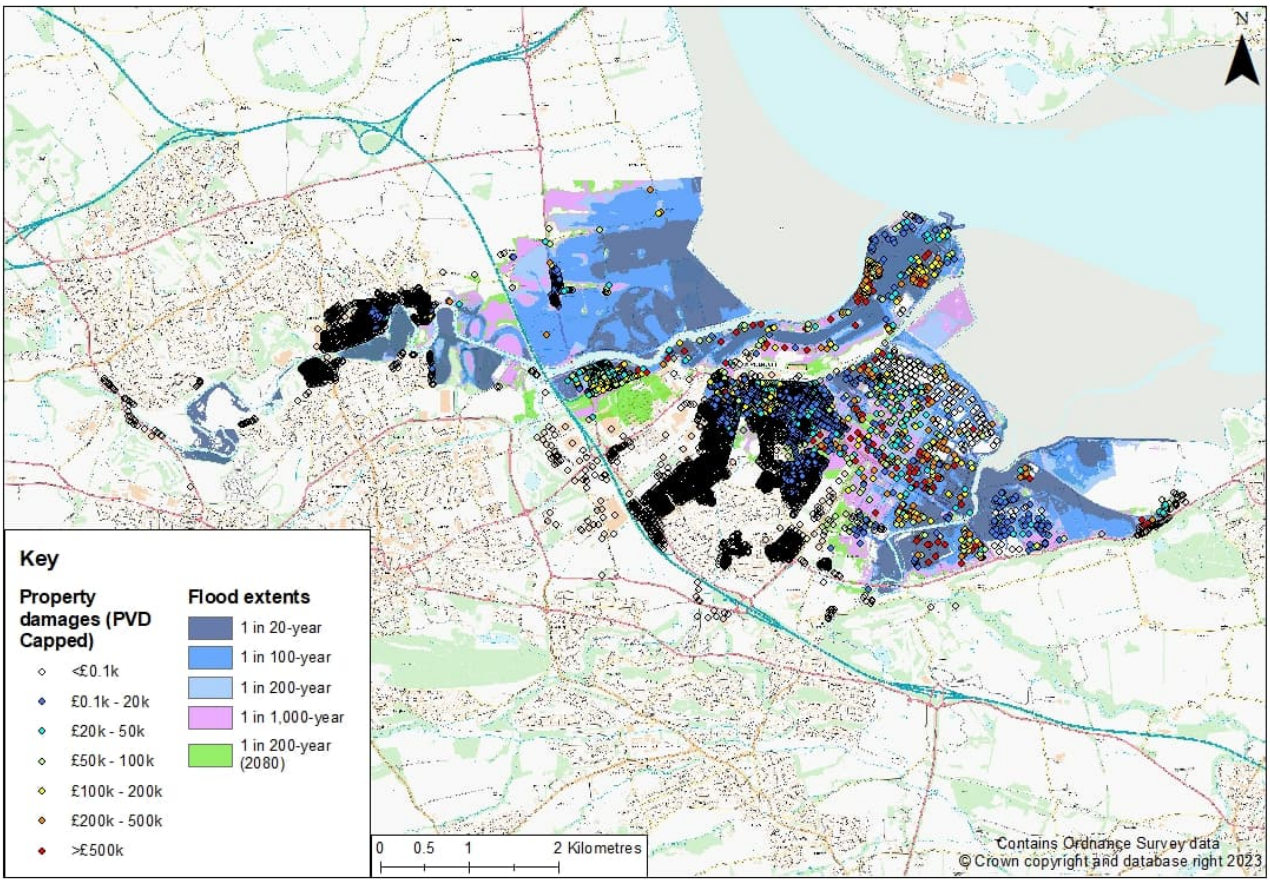
Fluvial baseline:



Fluvial with scheme:



Tidal baseline:



Tidal with scheme: