Moniaive Flood Study

Final Report

August 2016

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V2.0 / 12 August 2016	Updates following Council comments and a review of the 2015 flood incorporated.	Ross Gibson Brian Templeton

Contract

This report describes work commissioned by James McLeod, on behalf of Dumfries and Galloway Council, by a letter dated 9 June 2015. Dumfries and Galloway's representative for the contract was James Mcleod of Dumfries and Galloway Council. David Cameron, Robert Hooper, Jonathan Garrett, Barney Bedford and Angus Pettit of JBA Consulting carried out this work.

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Purpose

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Acknowledgements

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Executive Summary

Reason for works

Moniaive flooded in December 2013 and December 2015 causing flooding to properties predominantly along Dunreggan (2013) and the High Street (2015). The principal source of historic flood risk is from the Dalwhat Water. A Flood Prevention Scheme for the village was constructed in 1963. Between 1963 and 2013 there are no records of flooding within Moniaive.

In 2015, as part of the Flood Risk Management (Scotland) Act 2009, SEPA has completed a review of flood risk in the Nith catchment area as part of the Solway Local Plan District. Within this it identified three Potentially Vulnerable Area (PVA) and two candidate PVAs. Moniaive sits within the '4/25c' candidate PVA of 'Moniaive, Benbuie, Craigdarroch'.

Hydrology and review of 2013 and 2015 floods

An estimate of the event rarity for the December 2013 and December 2015 event is difficult to ascertain without gauging of flows. However, analysis of rainfall and flows on adjacent catchments would suggest that the event may have been in the region of a 25 to 50 year flood event. However, comparison between modelled flood levels against observed flood levels and surveyed defence elevations/bridges suggests that the two floods, whilst similar in magnitude could have been much higher (around the estimated 100 year flood).

Whilst the flow estimates have been carried out using standard methodologies, without any gauging of the watercourses the design flow estimates and associated probabilities should be treated with caution. Any flood defence improvements or significant capital spent would benefit from some flow gauging over a period of time to improve the flow estimates. This would also benefit any flood warning developments that should be considered by SEPA.

Flood mitigation options

A baseline option was assessed to determine the flood risk and to update flood maps and derive the current flood damages for the community. A number of flood mitigation options have been considered and refined further into three main options:

- Quick wins (short term measures)
- Option 1 - Property Level Protection
- Option 2 - Raised defences
- Option 3 - Breached defences
- Option 4 - Raised defences with breached embankments in the downstream reach
- Option 5 - Flood storage

Only Options 1, 2, and 4 are deemed to be technically viable. Option 1 and 2 could provide a 1 in 200 year standard of protection with an allowance for climate change, whereas Option 4 only has the ability to provide a 1 in 200 year standard.

Expected benefits

There are 24 properties at risk from flooding in Moniaive. Based on the flood hydrology and modelling undertaken the annual average flood damages are estimated to be £21,800 with a Present Value damage in the region of £650,000.

Costs

The estimated costs for each option are variable depending on the standard of protection assessed but can be summarised as follows:

- Option 1, PLP – costs of £0.6m – 0.9m depending on whether climate change is included in the design or not
- Option 2, Raised defences –cost of £0.8m - £1.4m depending on whether climate change is included in the design or not
- Option 4, Raise defences and breach embankment – cost of £0.6m.

The preferred aim for any upgrade to the flood defences in Moniaive is to provide a 1 in 200 year flood with an allowance for climate change. The only viable long term structural option to achieve this is via raised defences.

In addition to the above a low cost option to upgrade the flood defences in the upper reach upstream of the A702 road bridge has also been assessed. This could provide a 1 in 200 year standard of protection for the majority of the town but with a reduced freeboard for certain existing assets.

Investment appraisal

An economic appraisal has been undertaken to consider the economic viability of the options identified. The inclusion of optimism bias of 60% to the construction costs is standard for economic appraisals at this early scoping stage of analysis. The economic appraisal suggests that with this risk allowance, the only scheme option to be cost effective in the long term is the low cost option to upgrade the defences in the reach upstream of the A702 road bridge. This option could provide a 1 in 200 year standard of protection (without climate change and with limited freeboard on certain assets) and potentially protect flooding to 24 properties.

Table 1: Benefit cost ratios for options without inclusion of climate change

	Do Minimum	Option 1	Option 2	Option 4	Defences U/S only
Total PV costs (£k)	-	643	820	518	198
Total PV costs + Optimism bias (£k)	-	1,029	1,312	829	317
PV damage (£k)	650	122	238	238	238
PV damage avoided (£k)	-	528	412	412	412
Benefit-cost ratio	-	0.5	0.3	0.5	1.3

Recommendations

A number of recommendations and additional quick wins have been made. Key recommendations include:

- Provision of gauging in the catchment to improve flood estimation in the future and to provide input to flood warning for the community.
- Procurement of LiDAR data for the town and wider area to improve future flood mapping studies.
- Post flood monitoring to collect calibration data.
- Maintenance of the flood defence assets.

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Abbreviations

1D	One Dimensional (modelling)
2D	Two Dimensional (modelling)
ALTBAR	Mean catchment altitude (m above sea level)
AMAX	Annual Maximum
AOD	Above Ordnance Datum
BAP	Biodiversity Action Plan
BFI	Base Flow Index
BFIHOST	Base Flow Index estimated from soil type
C1	Benchmarking system using GPS
CEH	Centre for Ecology and Hydrology
DPLBAR	Index describing catchment size and drainage path configuration
DTM	Digital Terrain Model
EC	European Community
FARL	FEH index of flood attenuation due to reservoirs and lakes
FCERM	Flood and Coastal Erosion Risk Management (R&D programme)
FEH	Flood Estimation Handbook
FPEXT	FEH index describing floodplain extent
FPS	Flood Protection Scheme
FRM	Flood Risk Mapping
GIS	Geographical Information System
GL	General Logistic Distribution
ISIS	Hydrology and hydraulic modelling software
LiDAR	Light Detection And Ranging
mAOD	metres Above Ordnance Datum
NGR	National Grid Reference
OS	Ordnance Survey
OS NGR	Ordnance Survey National Grid Reference
PDM	Probability Distributed Model
POL	Proudman Oceanographic Laboratory
PVc	Present Value Cost
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SEPA	Scottish Environment Protection Agency
SFRA	Strategic Flood Risk Assessment
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff estimated from soil type
TUFLOW	Two-dimensional Unsteady FLOW (a hydraulic model)

1 Introduction and site description

1.1 Background

This flood study was commissioned by Dumfries and Galloway Council in June 2015 in order to gain a greater understanding of the flood mechanisms and improve upon SEPA's Flood Risk Management maps in Moniaive and provide an appraisal of options to reduce flood risk.

The Council commissioned a Strategic Flood Risk Assessment (SFRA) for Dumfries and Galloway in 2007. This study ranked Moniaive 18th in a list of priority areas for further investigation into flood risk based on the number of properties potentially at risk of flooding. The assessment was based on 5 categories; economics, social, environmental, planning and frequency of flood risk for all towns within the council area. In total 49 properties were identified to lie within the 1 in 200 year flood outline (based on SEPA's second generation flood maps; now superseded).

In 2015, as part of the Flood Risk Management (Scotland) Act 2009, SEPA has completed a review of flood risk in the Nith catchment area as part of the Solway Local Plan District. Within this it identified three Potentially Vulnerable Area (PVA) and two candidate PVAs. Moniaive sits within the '4/25c' candidate PVA of 'Moniaive, Benbuie, Craigdarroch' with an estimated 10 residential properties at risk and an estimated £150,000 of Annual Average Damages (AAD).

In response to the above findings and to investigate a large flood event that occurred in Moniaive in December 2013 and 2015 this flood study was commissioned.

1.2 Report objectives and approach

The aim of the study will enable Dumfries and Galloway Council to make an informed decision with regard to the current and future level of flood risk from the Dalwhat Water and Craigdarroch Water in Moniaive. The study will produce flood maps for different return periods, outline flood mitigation options and assess the economic viability of the preferred flood mitigation option.

Hydraulic analysis and inundation mapping has been carried out both with and without hydraulic structures for the following return periods, and annual probabilities (AP):

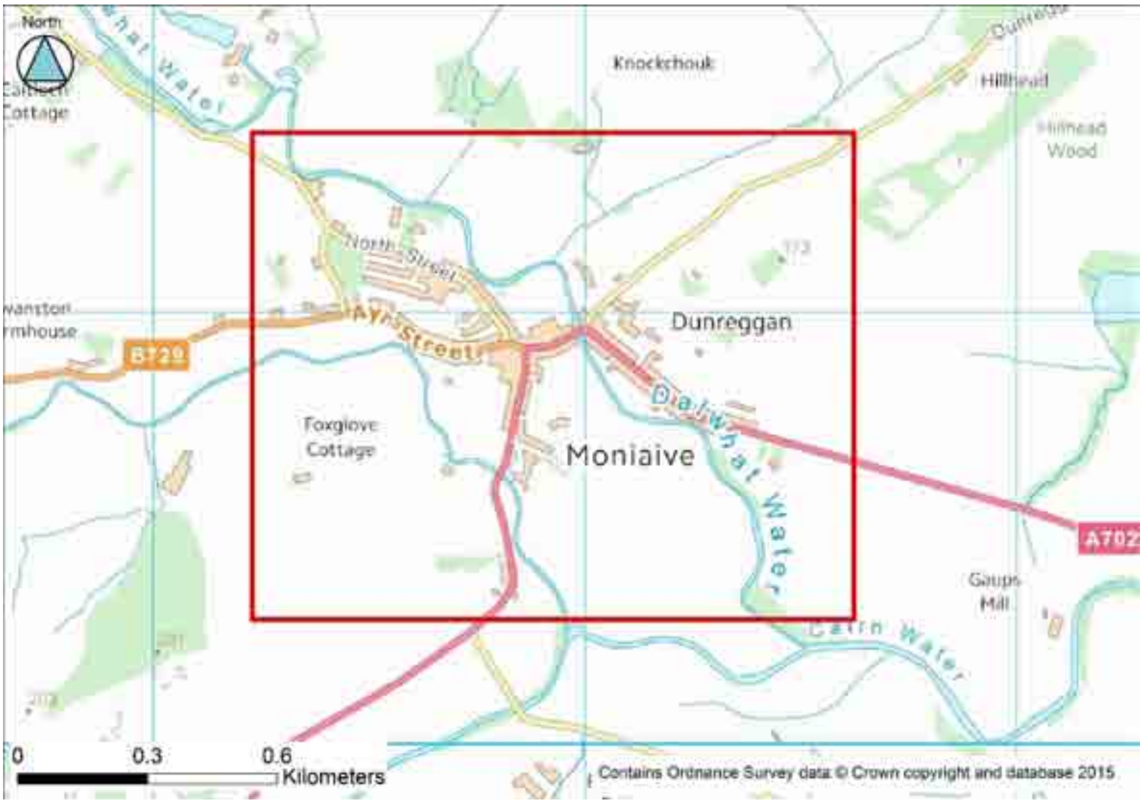
- 1:2 (50% AP)
- 1:5 (20% AP)
- 1:10 (10% AP)
- 1:25 (4% AP)
- 1:50 (2% AP)
- 1:100 (1% AP)
- 1:200 (0.5% AP)
- 1:200 + Climate Change (0.5% AP considering climate change)
- 1:1000 (0.1% AP)

Outline options have been tested to achieve a 200 year (0.5% AP) with an allowance for climate change level of protection. Other quick wins to alleviate flooding have been discussed.

1.3 Extent of study area and description

Moniaive is located approximately 30km to the north west of Dumfries. The town is located on the north and south side of the Dalwhat Water and to the north of the Craigdarroch Water. Figure 1-1 shows the study area in relation to its position in Scotland.

Figure 1-1: Location Map and study area



The study area for flood mapping extends along both banks of the Dalwhat Water and Craigdarroch Water through the town of Moniaive. The red square shown in Figure 1-1 frames the main area of interest.

1.4 Catchment description

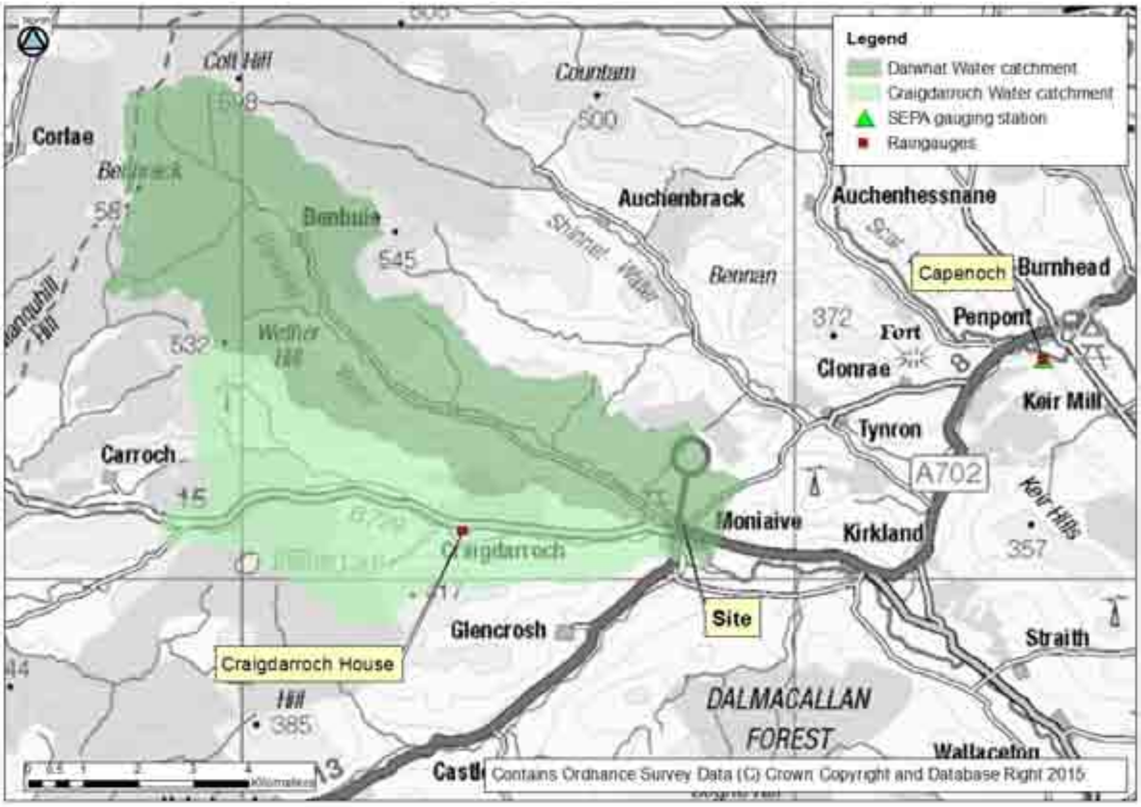
Two watercourses flow through Moniaive: the Dalwhat Water and the Craigdarroch Water. The Dalwhat Water flows in an approximately south easterly direction and has a catchment area of 33.76 km^2 at Moniaive. The Craigdarroch Water flows in an easterly direction and has a catchment area of 21.08 km^2 at Moniaive. The catchment land use is typically hill grazing with some forestry. The area of the catchment at Moniaive is underlain by sedimentary bedrock with superficial deposits of alluvium and till[1]. Both watercourses, together with the Castlefairn Water, are tributaries of the Cairn Water, the confluence of which is located approximately 1 km downstream of Moniaive. The Cairn Water ultimately flows into the River Nith north of Dumfries where it discharges into the Solway Firth.

The Dalwhat Water and the Craigdarroch Water are both ungauged. The nearest SEPA gauging station (number 79004) is located at Capenoch on the Scar Water catchment (Figure 1-2), about 7 km north east of Moniaive. This gauging station has been in operation since 1963 and is included within the HiFlows-UK dataset and is listed as being suitable for both QMED estimation and inclusion in pooling groups[2] and was used in the flood estimation approach described in subsequent sections.

[1] http://mapapps.bgs.ac.uk/geologyofbritain/home.html

[2] http://nrfa.ceh.ac.uk/data/station/peakflow/79004

Figure 1-2: Dalwhat Water and Craigdarroch Water catchments and the nearest gauging station



1.5 Return Period and Probability

For flood frequency analysis, the probability of an event occurring is expressed as a return period. The return period on the annual maximum scale, T, is defined as the average interval between years containing one or more floods exceeding a flow Q(T). In the Flood Estimation Handbook (FEH), the flood with return period T is referred to as the T-year flood.

A useful term closely linked to return period is the annual probability, AP, which is the probability of a flood greater than Q(T) occurring in any year. This is simply the inverse of T:

$$AP = 1/T$$

For example, there is a 1 in 100 (or 1%) chance of a flood exceeding the 100-year flood in any one year. Return periods are used throughout this report for readability, however, for reference a full list of typical return periods and APs used for flood management is shown in the table below.

Table 1-1: Return period and equivalent annual probability

Return Period	Annual Probability [AP] (%)
2 year	50
5 year	20
10 year	10
25 year	4
30 year	3.33
50 year	2
75 year	1.33
100 year	1
200 year	0.5
500 year	0.2
1000 year	0.1

It is very important to realise that a flood with a return period of T years has a finite probability of occurring during any period of duration less than T years. The probability p that a T year flood will occur at least once in an N year period is given by the "risk equation":

$$P = 1 - (1 - 1/T)^N$$

This equation indicates that over a ten year period (for example), the probability of a 100 year flood occurring is 10%. This increases to 34% for a 25 year flood occurring in a 10 year period.

2 Flood review and flood estimation

2.1 Introduction

The village of Moniaive has flooded historically, most recently in 2013 and 2015. The principal source of historic flood risk is from the Dalwhat Water. Prior to 2013 flood records of the town precede the construction of the flood defences. A complete record of available flood records for the town is provided below.

Table 2-1: Historic flood events/evidence

Comment	Year of flood	Source
Comparable to the 1815 flood.	February 1780	The Times (London, England),Thursday, Oct 05, 1815; pg. 4; Issue 9644
Extensive flood but on a lesser scale to the 1815 flood.	15-16 November 1807	The Times (London, England),Thursday, Oct 05, 1815; pg. 4; Issue 9644
Three days of torrential rain and high winds caused flooding across Dumfries. The area between the River Nith to New Abbey to New Galloway was the worst affected. The River Nith was said to be out of bank for 20 miles along its length. At New Abbey a bridge which had "stood the buffetings of winter storms for centuries" was washed away. A newly constructed bridge in New Galloway was also washed away as well as several bridges in Moffat area.	September 1815	The Times (London, England),Thursday, Oct 05, 1815; pg. 4; Issue 9644
Stories of flooding in the area but no specific information.	1930's	Public Meeting, Moniaive, 16 November 2015
Reports of river flooding to Dunreggan despite lack of formal records.	Post-1963	Public Meeting, Moniaive, 16 November 2015
Moniaive and Penpont area; very heavy intense rain; several instances of flooding of roads and houses at Brairbush, Penpont, Tyron and Moniaive; sandbags provided.	28 Nov 2002	D&G 4th Biennial Report (2001-2003)
Moniaive Woodside Cottage, Dunreggan; Dalwhat Water; Garden flooded (B729).	17 Nov 2006	D&G 6th Biennial Report (2005-2007)
Moniaive A702; 2 Miles West Of Moniaive; Road Drainage flooding; 8" Of Water Across Road at Bend.	25 Nov 2006	D&G 6th Biennial Report (2005-2007)
Moniaive in Dumfriesshire which has been flooded 3 times this year - Miss Tessy Woods an employee of McCulloch and Searing points out height of flood water on wall of car lockup.	Not stated	www.scran.ac.uk
Flooding was also a problem for the houses on Dunreggan, the river would quite often break its banks and flood the whole street. I recall that my grandparents' house had guides built into the door frames, back and front, that 'Flood Boards'	Not stated	Growing Up In Moniaive 1954 1969: A Memory of Moniaive[3]

[3] http://www.francisfrith.com/moniaive/growing-up-in-moniaive-1954-1969_memory-43831

slotted in to try to limit the damage, these would be backed up with sandbags against the outside. And many a time we went down there to 'Board and Bag' when a flood was expected.		
Stories of flooding to hotel cellars in the past across Moniaive.	Not stated	Public Meeting, Moniaive, 16 November 2015
Small drains and culverts on the A702 access road into the village thought to have contributed to village flooding.	Not stated	Public Meeting, Moniaive, 16 November 2015

2.1.1 Adjacent catchment information

Analysis of the annual maximum flood flows on the adjacent catchment of the Scar Water (gauged at Capenoch since 1963) indicate that particularly high flows occurred on the 30 October 1977 (178 m^3/s) and the 19 December 1982 (193m^3/s). The December 2013 flood was the third largest on record with a peak flow of 190m^3/s. The December 2015 event is the largest on record (198 m^3/s).

2.2 Historical context

A full photographic review of past flooding is provided in Appendix A. This evidence along with the flood record above suggests the following key points:

- In the 1950's-1960's flooding of some parts of Moniaive (particularly Dunreggan) from the Dalwhat Water was relatively frequent, sufficiently so for some low lying property owners to install 'flood boards' on their door frames. This suggests that the owners had flooded in the past and had adapted to the flood risk.
- Since the construction of the flood defences in 1963, no reports of flooding behind the defences (until December 2013) are recorded or available).

Without flow gauging on the river, the standard of protection of the defences is difficult to establish definitively. Some may assume that as there has been a period of nearly 50 years without a flood that it has similar standard of protection however this would be incorrect and could over or under estimate the return period.

2.3 2013 and 2015 flood mechanisms

2.3.1 December 2013 flood

Torrential rain at the end of December 2013 across the south west Scotland caused severe flooding in Moniaive which was documented by various news articles.

- The flooding mechanism experienced on 30 December 2013 involved water overtopping the flood defences and then flowing down the main road at "Dunreggan", reaching considerable depths and velocities.[4]
- Police Scotland said "the village of Moniaive in Dumfries and Galloway was almost cut off at one point due to flooding on the A702, and a family had to be evacuated from a bungalow which was cut off by flood water".[5]
- "Tractors with pumps are now pumping water away from the village and the river level has dropped slightly. Things improving for the moment. Talking to people who have been in the village more than 20 years, they haven't ever seen anything like this".[6]
- "Moniaive and Kirkconnel in Nithsdale were badly hit and several houses were left sitting in up to two feet of water."[7]

[4] Dumfries & Galloway Council tender clarification

[5] http://news.stv.tv/scotland/258661-persistent-rain-and-strong-winds-to-batter-scotland-as-2014-begins/

[6] https://www.facebook.com/DGWGO/posts/602911556448309

[7] Dumfries & Galloway Standard, page 19, Jan 7, 2015

A full photographic review of the flooding is provided in Appendix A. This review provides the following evidence of the flood mechanisms during the December 2013 event, which can be summarised in Table 2-2.

Table 2-2: Summary of flood mechanisms

Description	Photograph
Flooding to the right bank upstream of the A702 occurred via the fields to the rear of the garage and bypassing of the sheet pile wall along the river. It is unclear if the flood waters crossed the A702 or drained away using surface water drains.	
The embankment upstream of the A702 on the left bank overtopped as water levels rose. The timing of this is unclear.	
Flood water ponded in the car park to the rear of the Bridgend property.	
Flood waters flowed towards the A702 and ponded on the road at the junction of the A702 and Dunreggan.	

Via a low point in the road, flood waters flowed down Dunreggan in a south westerly direction.	
A number of properties flooded as a result of the flood water flowing down Dunreggan and ponding in low points and behind the flood embankment. It is unclear if flooding overtopped the embankment. Anecdotal evidence suggests that overtopping at the upstream end did not occur with flood levels in the region of 200-300mm below the embankment crest.	

2.3.2 December 2015 flood

Torrential rain at the end of December 2015 across the south west Scotland caused severe flooding in Moniaive which was documented by the local community.

- The flooding mechanism experienced on 30 December 2015 was very similar to that witnessed in December 2013 with water overtopping the flood defences and then flowing down the main road at Dunreggan.
- Flooding along Dunreggan was less severe than in December 2013. However, more water appeared to flow onto the right bank and along the High Street than in December 2013. Anecdotal evidence provided by local residents at the public meeting held in April 2016 suggested that works in the field on the right bank during December 2013 may have diverted flows to the north (left) bank and away from the high Street.

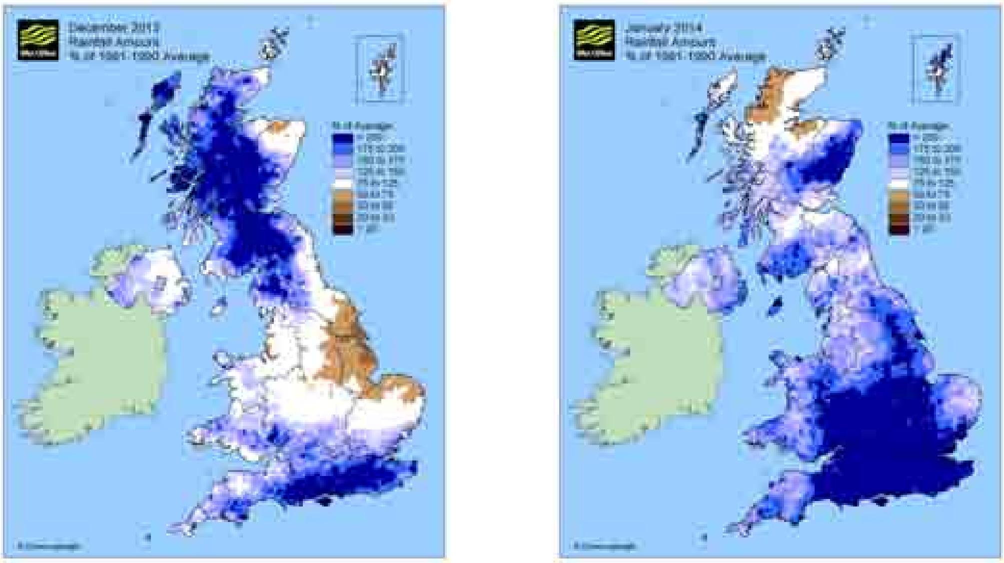
A full photographic review of the flooding is provided in Appendix A. This review provides the following evidence of the flood mechanisms during the December 2013 event, which can be summarised in Table 2-2.

2.4 Analysis of rainfall

2.4.1 Analysis of December 2013 rainfall

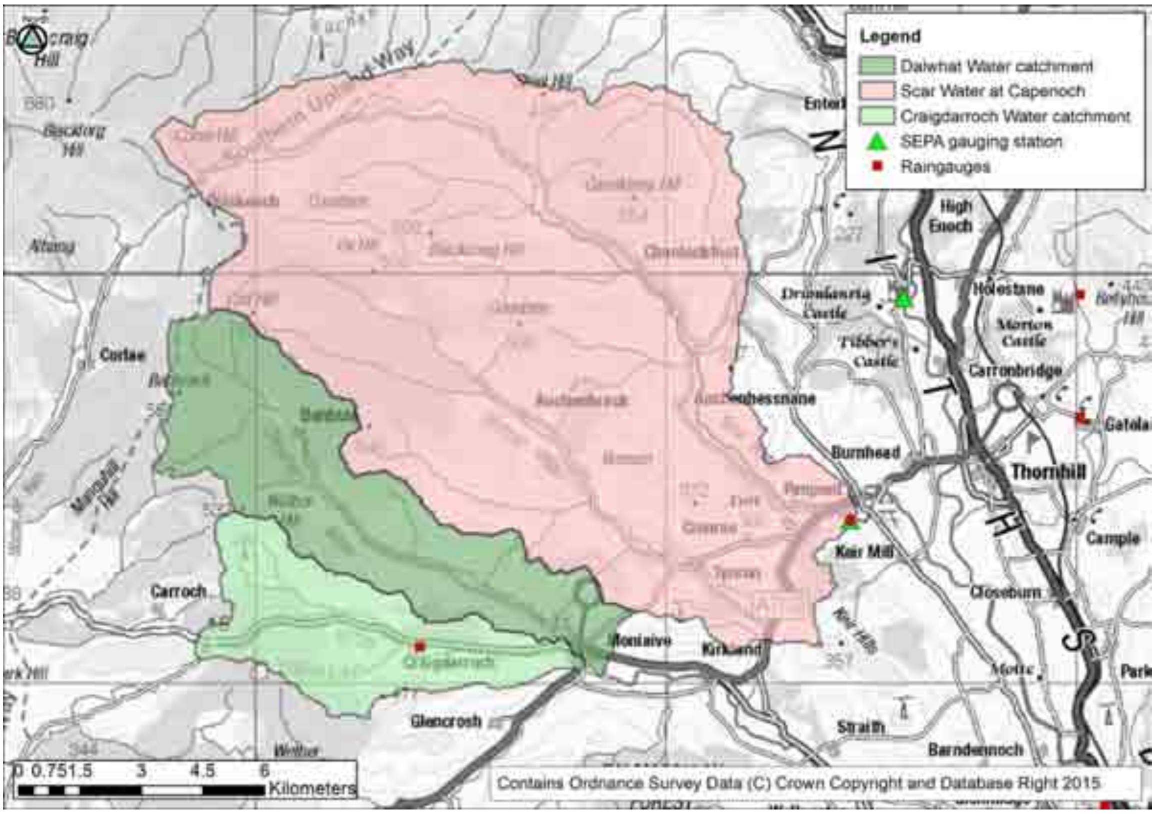
Met Office information (Figure 2-1) shows that average rainfall was above average in both December 2013 and January 2014. The rainfall is consistently above average throughout Dumfries and Galloway, although there is some spatial variation which should be considered when assessing recorded rain data.

Figure 2-1: UK Monthly rainfall as a percent of average. (December 2013, left and January 2014, Right)



The closest raingauges to Moniaive are at Craigdarroch House (in the Craigdarroch Water catchment) and at Capenoch (in the Scar Water catchment), Figure 2-2.

Figure 2-2: Location of the rain gauges in relation to the Dalwhat Water and adjacent catchments



An assessment of cumulative rainfall totals was carried out at these two raingauges for the December 2013 event (Figure 2-3). Although the storm duration and general shape of the rainfall event are similar at the two gauges, the Craigdarroch gauge consistently recorded a higher total rainfall amount. This difference between the two gauges is consistent with information from other sources, namely the Met Office monthly average data, and radar observations. Radar observation data, which can be viewed on a spatial grid, showed widespread rainfall across Dumfries and

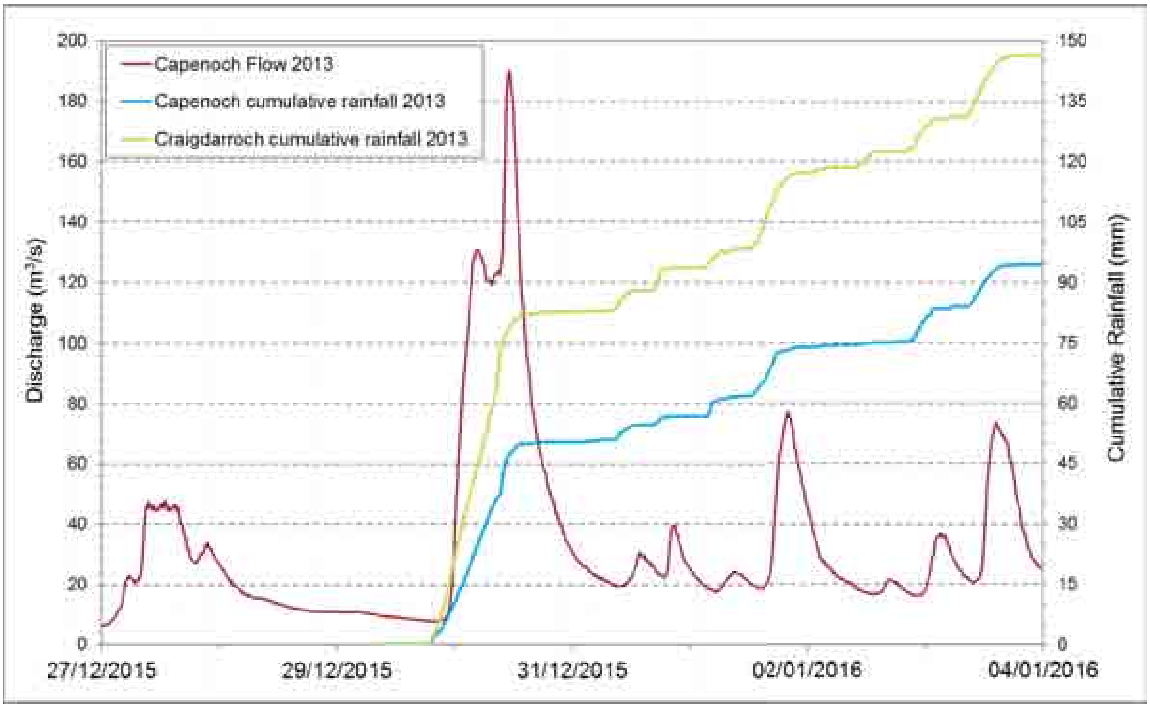
Galloway at the time of peak rainfall intensity during the event, and also showed variations in intensity across this area, consistent with the rain gauge records.

FEH Depth Duration Frequency Analysis (DDF) was carried out for the 30 December 2013 event at both the Craigdarroch and Capenoch raingauges (Table 2-2) for durations of 6 h, 12 h and 24 h. From this analysis, the rarest event was estimated to be the 12 h total at Craigdarroch with a depth of 66.8 mm and an estimated return period of 18 years.

Table 2-2: FEH analysis of the 30 December 2013 event at Craigdarroch and Capenoch Raingauges

Duration (h)	Craigdarroch Rainfall depth (mm)	Craigdarroch Return Period (Years)	Capenoch Rainfall depth (mm)	Capenoch Return Period (Years)
6	36.0	5	22.8	2
12	66.8	18	40	4
24	83.0	15	50.8	4

Figure 2-3: Cumulative rainfall at each rain gauge during the 30 December 2013 event

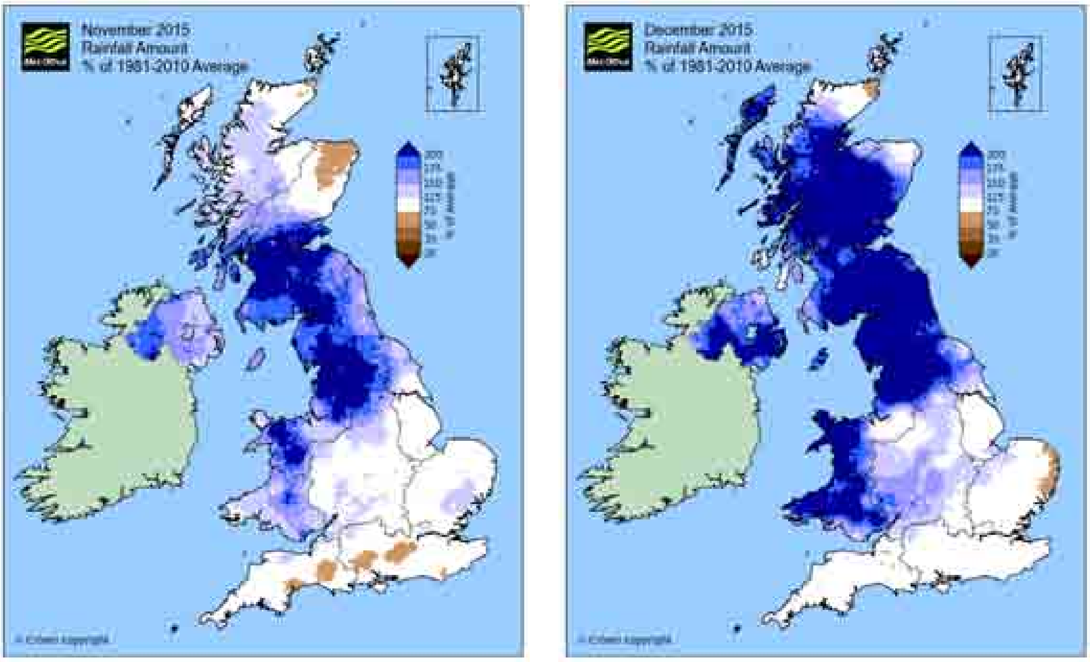


2.4.2 Analysis of December 2015 rainfall

Met Office information (Figure 2-4) shows that average rainfall was above average in both November 2015 and December 2015. The rainfall is consistently above average throughout Dumfries and Galloway, although there is some spatial variation which should be considered when assessing recorded rain data.

An assessment of cumulative rainfall totals was carried out for the Craigdarroch and Capenoch raingauges for the December 2015 event. As in 2013, the Craigdarroch gauge recorded a higher total rainfall amount.

Figure 2-4: UK Monthly rainfall as a percent of average. (November 2015, left and December 2015, Right)

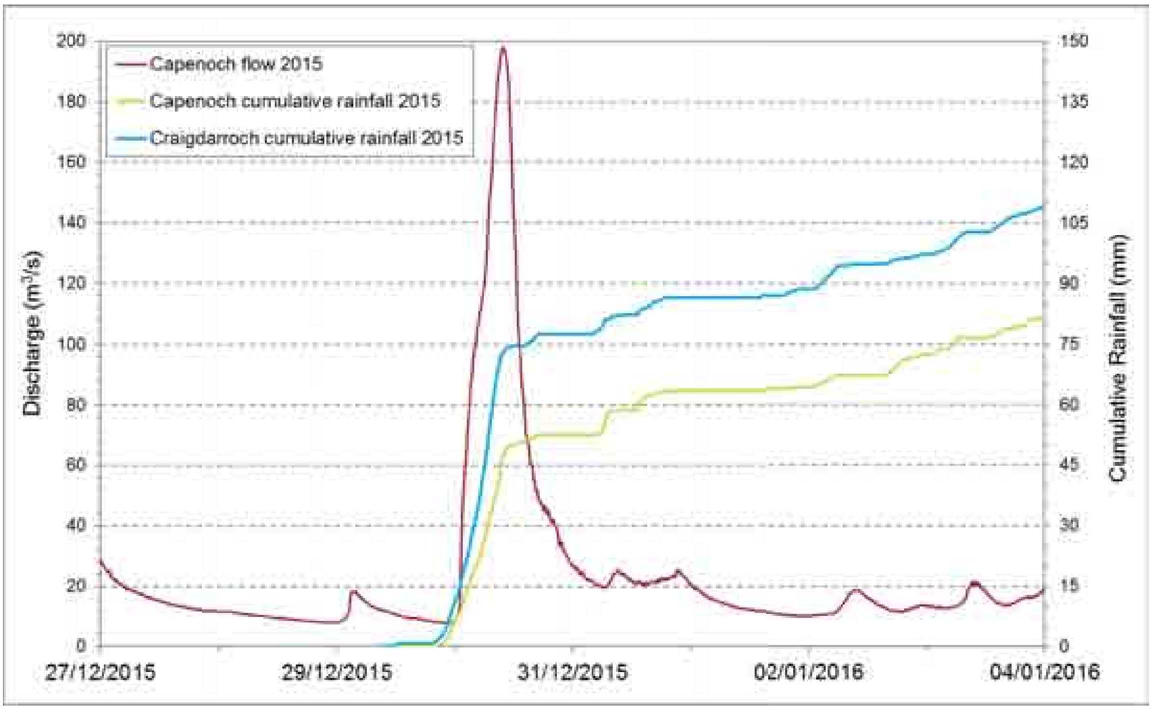


FEH Depth Duration Frequency Analysis (DDF) was carried out for the 30 December 2015 event at both the Craigdarroch and Capenoch raingauges (Table 2-3) for durations of 6 h and 12 h. From this analysis, the rarest event was estimated to be the 12 h total at Craigdarroch with a depth of 70 mm and an estimated return period of 23 years.

Table 2-3: FEH analysis of the 30 December 2013 event at Craigdarroch and Capenoch Raingauges

Duration (h)	Craigdarroch Rainfall depth (mm)	Craigdarroch Return Period (Years)	Capenoch Rainfall depth (mm)	Capenoch Return Period (Years)
6	47	13.4	30	4.2
12	70	22.5	48	9.0

Figure 2-5: Cumulative rainfall at each rain gauge during the 30 December 2015 event



2.4.3 Comparison with rainfall-runoff analysis for the catchment

The recorded rainfall series from the Craigdarroch gauge was used to assess the flow in each of the catchments, using a unit hydrograph derived from FEH catchment descriptors. This gauge was chosen due to its proximity to the catchments.

Peak flows from these events were compared with peak flows from the FEH Statistical analyses already carried out for these catchments. For the Dalwhat Water the peak flow from the FEH unit hydrograph assessment matches the 25-year peak flow.

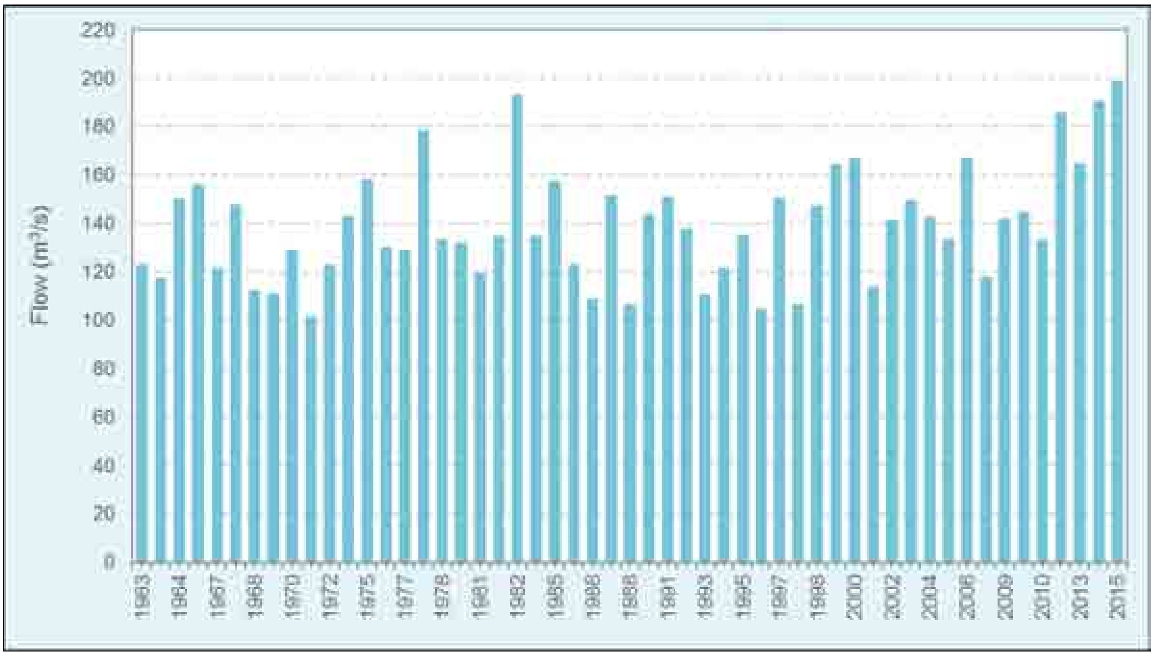
Whilst this is an estimate only, it is consistent with the flood history of Moniaive, given that the Flood Protection Scheme was built in the late 1960s after a flood event, with no sizeable events until further flooding during the 2013 event.

2.4.4 Comparison with locally gauged watercourses

With respect to flows, the Dalwhat Water and Craigdarroch Water are ungauged. However, AMAX flow data for the Capenoch gauging station on the Scar Water for the water year period 1963 to 2015 were obtained from SEPA (Figure 2-6). For this period, the December 2015 event is the largest on record (198 m^3/s). The December 2013 event is the third largest flood (190 m^3/s) after the December 1982 event (slightly larger at 193 m^3/s).

A preliminary flood frequency estimate for the December 2013 event at Capenoch is about 2.5% AP (40 years) using single site analysis.

Figure 2-6: Annual maximum flows on the adjacent gauged catchment (1963-2015)



2.5 Flood frequency estimation using FEH

Flow estimates were required for the Dalwhat Water and Craigdarroch Water in order to provide a comprehensive input to the hydraulic model. Important inputs into a flood risk assessment are the analysis of historic floods (where data are available), and estimation of flood flows for a range of annual probabilities or 'design' events. Flood estimates for catchments of this size and type are undertaken using the Flood Estimation Handbook (FEH).

The FEH offers three methods for analysing design flood flows:

- the Statistical,
- the Rainfall Runoff, and
- hybrid methods.

The Statistical method combines estimation of the median annual maximum flood (QMED) at the subject site with a growth curve, derived from one of three methods; (a) a pooling group of gauged catchments that are considered hydrologically similar to the subject site, (b) through single site analysis of a nearby gauge, or (c) a combination of the two through the use of enhanced single site. The Rainfall Runoff method combines design rainfall with a unit hydrograph derived for the subject site (the Rainfall Runoff method has recently been updated as ReFH2[8]). Hybrid methods involve a combination of the two. Both the Statistical and Rainfall Runoff procedures require the derivation of catchment descriptors. For this study these were abstracted digitally using the FEH CD ROM v3 (Table 2-4).

Adjustments were then made to catchment area (using OS background mapping) and URBEXT (using the national growth model through the year of study, 2015, per FEH Volume 5). The FEH CD-ROM BFIHOST values appeared reasonable in comparison to the available geological information[9]. Tests were undertaken on the BFI value used and are further discussed in Appendix B and Section 3.6.

With respect to choice of approach for estimating flood flows, the catchments are largely rural with a minimum influence of attenuating features such as lochs. Given the availability of the Scar water at Capenoch as a potential donor site from a similar nearby catchment, the Statistical method was therefore assumed to be the most reasonable approach for estimating flood flows for the watercourses near the site (Table 2-5). A 20% climate change allowance upon the 0.5% AP (200

[8] Wallingford Hydro Solutions (WHS) The Revitalised Flood Hydrograph, ReFH2: Technical Guidance. 2015

[9] http://mapapps.bgs.ac.uk/geologyofbritain/home.html

year) event was applied, per SEPA guidance[10]. A full comparison of the Statistical, FEH Rainfall Runoff and ReFH2 flow estimates is included in Appendix C.

Table 2-4: Catchment descriptors for the Dalwhat Water, Craigdarroch Water and the Scar Water at Capenoch Gauging Station

Catchment Descriptor	Dalwhat Water	Craigdarroch Water	Scar Water at Capenoch Gauging Station (79004)
AREA (km^2)	33.76 adjusted (33.64 default FEH CD-ROM)	21.08 adjusted (21.20 default FEH CD-ROM)	142.76
ALTBAR (m above sea level)	315	282	318
BFIHOST	0.464	0.456	0.446
DPLBAR (km)	9.88	7.40	13.67
FARL	0.998	1.00	0.999
FPEXT	0.0447	0.0463	0.0319
SAAR (mm)	1618	1519	1627
SAAR4170 (mm)	1776	1624	1729
SPRHOST (%)	39.85	38.14	41.96
URBEXT1990	0.0015 adjusted (0.0014 default FEH CD-ROM)	0.0005 adjusted and default FEH CD-ROM	0.0001
URBEXT2000	0.0026 adjusted (0.0025 default F)EH CD -ROM	0.0014 adjusted and default FEH CD-ROM	0.0007

Table 2-5: Design peak flows from the FEH Statistical Method for use in the hydraulic model

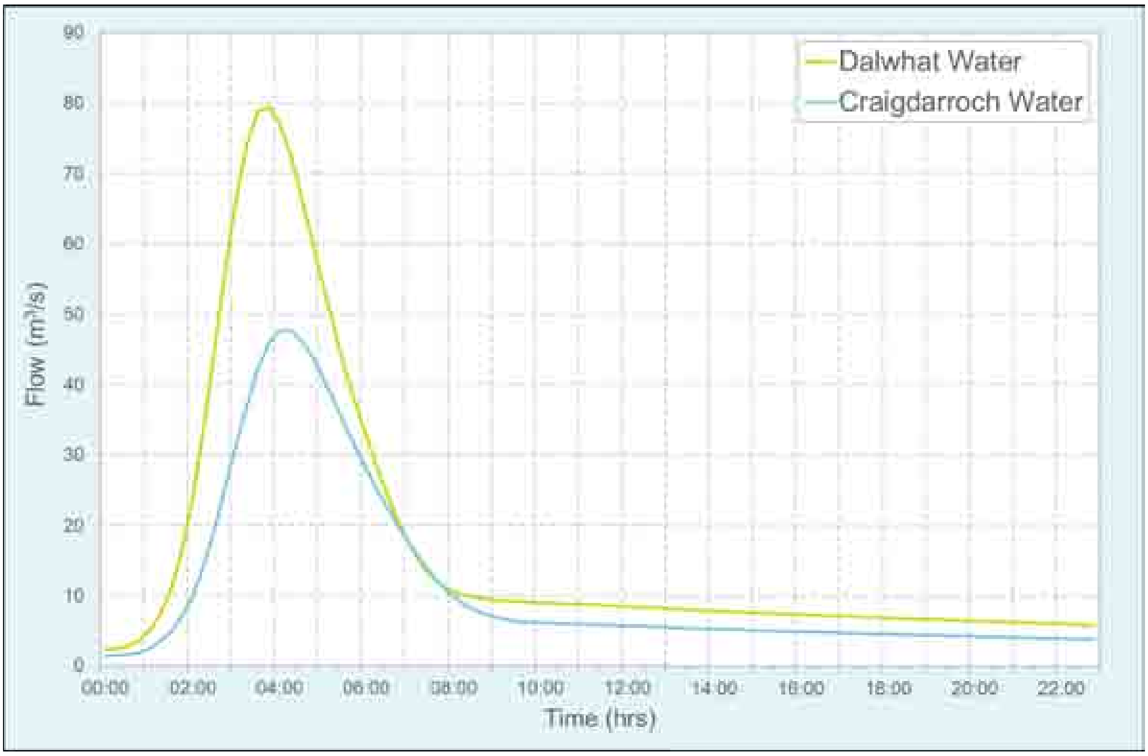
Annual Probability (AP)	Return period (years)	Dalwhat Water (m^3/s)	Craigdarroch Water (m^3/s)
50	2	31	20
20	5	39	26
10	10	46	29
4	25	54	35
3.33	30	56	36
2	50	62	40
1.33	75	67	42
1	100	71	45
0.5	200	81	50
0.5 + 20% CC	200 + 20% CC	97	60
0.2	500	96	59
0.1	1000	109	66

[10] SEPA – Technical Flood Risk Guidance for Stakeholders, Version 9.1, June 2015

2.6 Design hydrograph

Design hydrographs for the Dalwhat Water and the Craigdarroch Water were required for input to the hydraulic model. As both watercourses are ungauged, ReFH2 was used to generate design hydrographs. The magnitudes of the hydrographs were then scaled using peak flow to match the FEH Statistical estimates.

Figure 2-7: Example scaled ReFH2 hydrograph for the Dalwhat Water and Craigdarroch Water (200 year, event)



2.7 Summary of hydrology

The above chapter can be summarised as follows:

- An estimate of the event rarity for the December 2013 and 2015 events is difficult to ascertain without gauging of flows. However, analysis of rainfall and flows on adjacent catchments would suggest that the event may have been in the region of a 25 to 50 year flood event.
- Flood flow estimates for design purposes have been undertaken using standard FEH methodologies.
- A range of design flows have been provided using the preferred FEH Statistical Method.
- Whilst the flow estimates are carried out using standard methodologies, without any gauging of the watercourses the design flow estimates should be treated with caution.
- Tests have been undertaken on the BFI value used. An adjustment of this parameter is not deemed necessary but could increase flood flows significantly. The impact of this on flood mapping is discussed.
- Any flood defence improvements or significant capital spent would benefit from some flow gauging over a period of time to improve the flow estimates.
- A standard 20 % for climate change has been used in the assessment.

3 Hydraulic Model

3.1 Introduction

This section of the report presents the model used in this study, along with justification of the decisions made during development of the model. Further details of the model and modelling approach can be found in the Model Check File, which is included in Appendix I.

Each reach in Moniaive is modelled as a separate model. The Dalwhat Water model and Craigdarroch model are two separate models, which share many similar features in the 2D domain.

3.2 Model method

The Dalwhat Water through Moniaive (as well as the Cragdarroch Water) has been modelled using a linked 1D-2D model. This modelling approach is the most suitable for this study, in terms of;

- floodplain and channel flow
- ease of modelling defence options

A linked 1D-2D model is the most valid and the most efficient approach for this study, as explained in the following paragraphs.

In order to assess the standard of protection of the FPS, overland flow behind the defences must be assessed and the modelling of river channel levels must take account of interaction with floodplain flows, meaning linked modelling is the most suitable approach.

There is a requirement to produce a model which is capable of assessing the impact of changes to the arrangement of defences through Moniaive, and the 2D portion of the model can be easily edited to model such scenarios.

3.2.1 Software choice

There are several software packages available to produce linked 1D-2D models. The Moniaive models are constructed using ISIS-TUFLOW since the computational methods used in this model are tried and tested, such that this approach is industry standard.

An additional benefit of this approach is the range of model outputs, which can be used to produce mapped deliverables which suit the project brief.

ISIS-TUFLOW was chosen in order to produce a high quality model and deliverables, while bearing in mind the efficiency benefits of using this standard modelling approach to meet the client's brief.

3.3 Topographic datasets

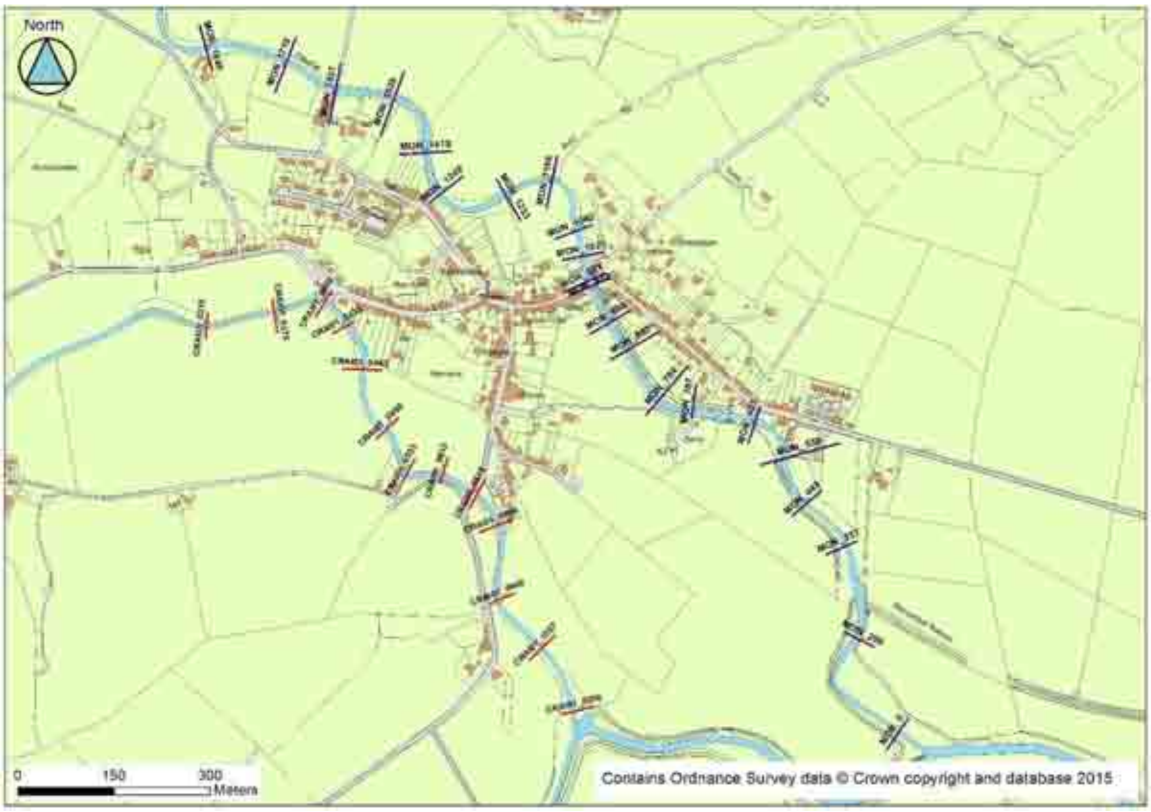
The Moniave models are built using topographic data from a variety of sources, as presented below. Where survey data were used, these were gathered by JBA Consulting as part of this study.

3.3.1 JBA cross section survey

JBA Consulting carried out a cross section survey on 14 July 2015, which forms the basis of the Dalwhat Water ISIS model.

Further survey took place on 1 September 2015 on the Craigdarroch Water, gathering cross section data for this reach.

Figure 3-1: Cross sections surveyed on the Dalwhat Water and Craigdarroch Water



3.3.2 JBA structure surveys

All structures in the model reaches were surveyed as part of the river cross section surveys. Details of these structures and their representation in the models are included in the model check file. All structures within the modelled reaches are provided in Table 3-1. Further details on the modelling undertaken for each is provided in Appendix B.

Table 3-1: Hydraulic structures on the Dalwhat Water and Craigdarroch Water

Structure	Photograph	Location
Access bridge at Hall Bridge		Looking to right bank from left. Location: Hastings Hall OS NGR: 277588 591253
Low weir upstream of Moniaive		Looking to right bank from left bank Location: Upstream of A702 Road Bridge OS NGR: 277956 591076

Footbridge over the Dalwhat Water upstream of the A702 Bridge		Looking downstream from right bank Location: A702 Moniaive OS NGR: 277982 590957
A702 Road Bridge		Downstream face - looking to left bank from right bank Location: A702 Moniaive OS NGR: 277985 590952
Footbridge		Upstream face from right bank Location: Moniaive, behind bowling green OS NGR: 278288 590679
Waulkmill Bridge (Craigdarroch Water)		Upstream face from right bank Location: Waulkmill Bridge, south of Moniaive OS NGR: 277803 590624

3.3.3 JBA top of bank survey

JBA Consulting also carried out a top of bank survey, to find the crest level of all embankments within the study reach on Dalwhat Water.

3.3.4 Topographical point data and building thresholds

Point data were surveyed along the A702 to ensure that the road elevation is correctly represented in the model. These data were collected by JBA Consulting in order to overcome limitations in the model grid which arose due to using a 5m resolution DTM dataset. JBA Consulting also collected building threshold data in order to carry out a damage assessment.

3.3.5 Grid elevation data

Filtered DTM data are used to create the model grid. The DTM dataset, which was procured from getmapping, is on a 5m grid. LiDAR data is becoming a standard topographic dataset for this level of flood mapping in the UK. Unfortunately this dataset is not currently available for Moniaive. As a result the detail and accuracy of the 2D element of the modelling and mapping is reduced due to the need to rely on a more coarse DTM.

3.3.6 OS Mastermap

Ordnance Survey Mastermap was used to apply the Manning's 'n' roughness values to the 2D grid according to land use type.

3.4 Model boundaries

Flow boundaries to the model consist of a single inflow in the 1D domain, and Normal Depth boundaries at the downstream extent in the 1D and 2D domains. This section of the report presents the boundaries applied in each domain, and discusses the hydrology which is applied to each model.

3.4.1 1D domain boundaries

Inflow to the ISIS models is via a flow-time boundary at the upstream extent of each model. The design hydrograph from ReFH2 is applied through these boundaries, adjusted to the FEH statistical peak.

At the downstream limit, the model calculates water depth using the flow input and river bed slope. In hydraulic modelling this type of boundary is known as a Normal Depth boundary. A normal depth boundary is applied on each reach.

3.4.2 2D domain boundaries

Boundary conditions are applied at the downstream extent of the floodplain in the 2D domain. These are Normal Depth boundaries, as used in the ISIS model. There is one each of these boundaries on the left and right banks in each model.

3.5 Model setup

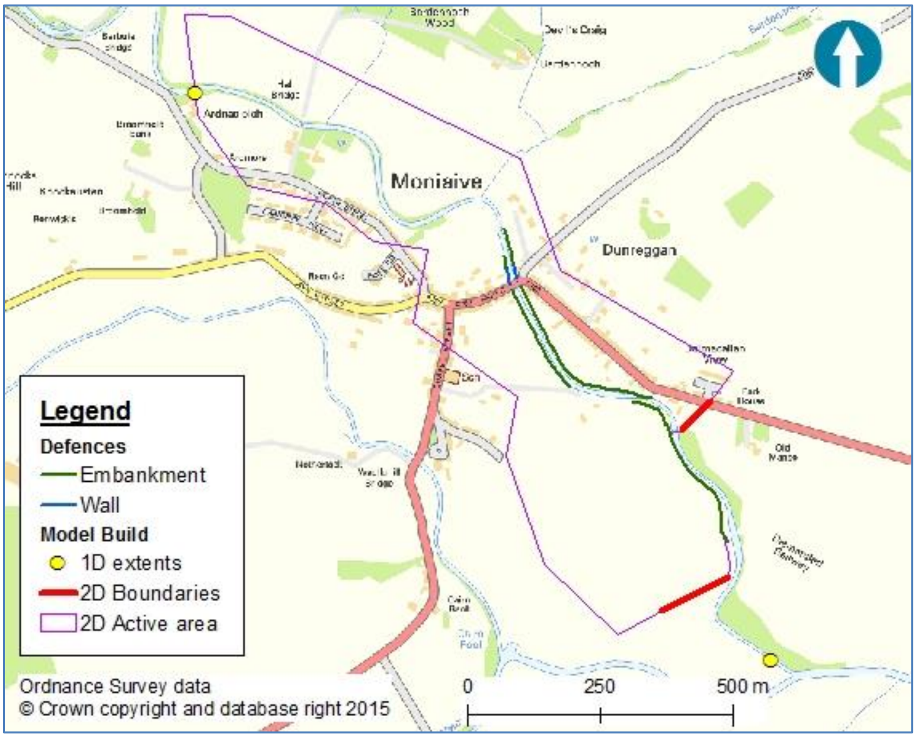
This section of the report presents the methods used to produce each component of the two models. Further discussion of these modelling methods can be found in the model check file, which accompanies this report as an appendix.

3.5.1 Dalwhat Water model extent

The model consists of a 1D reach on the Dalwhat Water through Moniaive, and a single 2D domain which covers the floodplain in the study area (Figure 3-2). The study area consists of the built-up area of Moniaive, including the area behind the flood defences. However the downstream part of the left bank floodplain is not represented in the model as it is outside the scope of this study - it is outside the built up area and there would be no benefit in modelling this area, where there are complicated flowpaths in the floodplain.

The 1D portion of the model runs from NGR 277387, 591315 to NGR 278465, 590251. The 2D grid of cell size 4m, has its origin at NGR 277052, 591380.

Figure 3-2: Model schematic

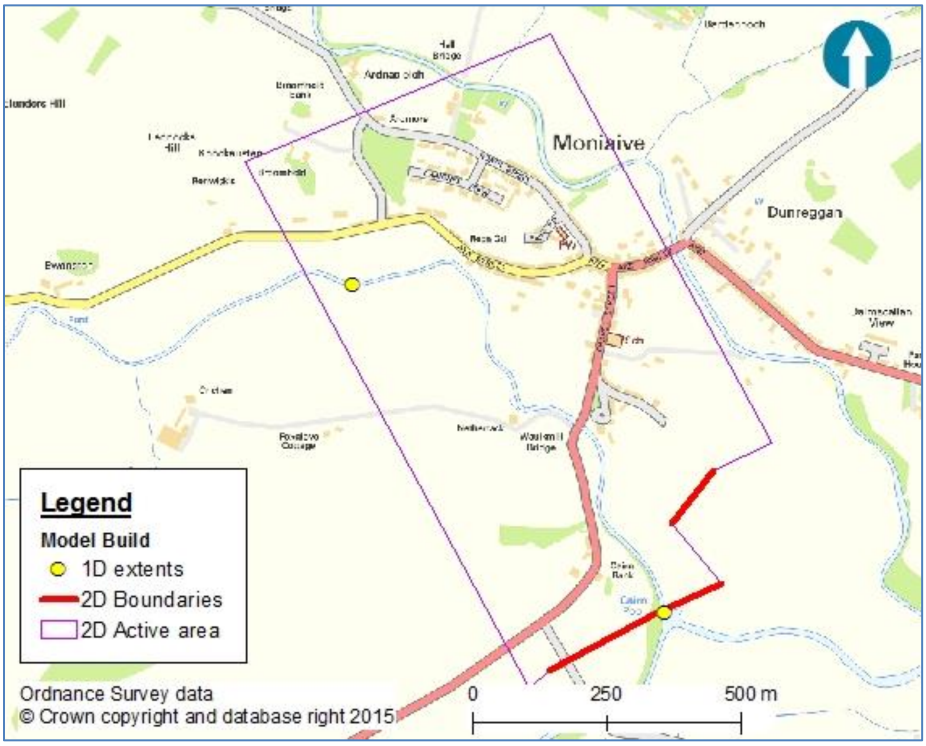


3.5.2 Craigdarroch Water model extent

The Craigdarroch Water model also consists of a single 1D reach, in a single 2D domain which covers the floodplain through the modelled reach. The active area of this model is shown in the schematic (Figure 3-3).

The upstream limit of this model is at NGR 277385, 590885, and the downstream limit is situated at NGR 277960 , 590280.

Figure 3-3: Craigdarroch Water model schematic



3.5.3 1D roughness

Roughness values in the 1D model are uniform throughout both models. A Manning's 'n' value of 0.035 is applied in the channel, and 0.040 is applied for the overbank portions. A typical section of the riverbed is presented in Figure 3-4.

Figure 3-4: River channel at a typical cross section on the Dalwhat Water (MON_1528)

3.5.4 Dalwhat Water 2D domain

The TUFLOW portion of the model consists of a single domain, of cell size 4m (see schematic, Section 3.5.1). Base elevation data in the model grid are interpolated from the Getmapping DTM, which has a resolution of 5m.

3.5.5 Craigdarroch Water 2D domain

The 2D portion of the Draigdarroch Water is based on the Dalwhat Water model, and has many of the same features. There is a single domain of cell size 4m, and the elevation data are interpolated from the same DTM, which was sourced from getmapping and has a horizontal resolution of 5m.

3.5.6 Linking the channel (1D part) and the floodplain (2D part)

A uniform approach was used to link the 1D reach to the 2D domain. TUFLOW 'HX' links were used to create a dynamic link based on modelled water levels. Elevations are enforced along these links, using Z lines to ensure that the model grid represents the bank levels in the 1D-2D interface cell. This was done using top of bank survey where available. Outside the surveyed area, levels are interpolated between ISIS cross sections.

3.5.7 Building representation

Buildings are modelled in the active domain of the model, using a high roughness level rather than excluding from the modelled domain. Building footprints were taken from OS Mastermap. All buildings have a Manning's n roughness value of 0.3 applied to the grid cells within their footprint.

3.5.8 Floodplain roughness

Floodplain areas were divided into polygons according to landuse and surface, based on Ordnance Survey Mastermap dataset. Manning's 'n' roughness values were then applied to these polygons in the model. The Manning's n values are presented in the following table, along with a description and the TUFLOW material code which was used to apply each value.

Table 3.2: Manning's roughness values used for 2D modelling

Material Code	Manning's n	Description
1	0.02	Manmade surfaces, roads, manmade paths
2	0.04	Natural surfaces, grass/rough grass
3	0.03	Gardens
4	0.30	Buildings
5	0.03	Glasshouses and other structures (sewage works)
6	0.06	Inland water
7	0.07	Non-coniferous woodland
8	0.10	Coniferous woodland
9	0.08	Mixed trees and vegetation
10	0.05	Scrub and marsh

3.5.9 2D features - Dalwhat Water model

Elevations in the 2D model domain have been reinforced where necessary, using TUFLOW Z lines to apply elevation values. This is a more direct method than interpolating grid values from the DTM, and is therefore more accurate.

In the Dalwhat Water model, the bank elevations were applied in this way along the entire modelled reach, using elevation data from the top of bank survey and river cross section survey.

Elevation data were also applied direct to the model grid along the A702 road, on Dunreggan and Moniaive High Street, in order to reinforce ground elevations on this key flow path.

The crest of the disused railway embankment at the southern end of the right bank floodplain is also applied directly to the model, to ensure that spilling over this feature is modelled correctly - this controls flood depths on the floodplain in this area. The elevation data on this crest are from the DSM (unfiltered) terrain data rather than the DTM since the filtering process lowered this crest in the DTM dataset.

3.5.10 2D features - Craigdarroch Water model

As in the Dalwhat Water model, elevations in the 2D domain have been applied using TUFLOW Z lines to ensure the grid cells have the correct elevation value at critical points.

In the Craigdarroch model, these lines have been applied along the banks, as well as on the A702 where the road embankment at the bridge approaches impedes flow in the floodplain.

3.5.11 Data issues

The 2D grid uses elevations from a Digital Terrain Model (DTM) procured from Getmapping Ltd. This dataset is on a 5m grid, and the low level of accuracy of this dataset meant that some edits had to be carried out to the models, to improve both accuracy and stability. The vertical accuracy of the DTM is stated as "less than 60cm RMSE". Our checks showed that the dataset, when compared against the corresponding Digital Surface Model (DSM), was seen to have an error margin of ±0.30m.

Shortcomings in the DTM resulted in model edits being made at two locations in the Dalwhat Water model, as described below.

At the High Street Bridge, an edit was made to the model topography in the triangle between Dunreggan and the river. Levels were edited here for the first five properties along Dunreggan, using building threshold levels to lower grid elevations to a more realistic level.

The crest elevation of the disused railway embankment in the southern floodplain was applied to the model using elevation data from the DSM, since this had been lowered in the DTM. This area is not vegetated and the filtering of this feature seems to be based on an incorrect assumption that vegetation was present.

3.5.12 Modelled scenarios

As well as the baseline modelling, the Dalwhat Water model has been run in a 'No Freeboard' scenario. The purpose of this scenario is to assess the Standard of Protection without an allowance for freeboard.

In the 'No Freeboard' scenario, surveyed defence crest levels have been lowered at all defences, by 0.30m.

3.5.13 Robustness

The representation of the model structures and the 2D domain are valid up to the 1,000 year flow.

The Dalwhat Water model has been constrained on the left bank, downstream of the built-up area. This area is not modelled in the 2D domain, since there are complicated flowpaths in this area which would have required an extension in the model domain. These overland flow paths are not the focus of the study so the active area (see schematic, Figure 3-2) was set up so that the overland flow stops upstream of the point where these flow paths develop.

3.6 Model calibration and validation

The model check file which accompanies this report as an appendix contains more information on the model calibration that was undertaken.

3.6.1 Dalwhat Water

There are very little data available in the Dalwhat Water catchment to carry out model proving. Lack of recorded river and rainfall data means that it is difficult to estimate a return period for the observed flood event of December 2013 and December 2015. Therefore, the approach to model proving was to carry out sensitivity testing to understand the sensitivity in the model.

While the model is sensitive to roughness in the 1D domain, the calibration data is such that the initial roughness estimate has not been changed.

Furthermore, the model is sensitive to the inflow rate applied to the model, hence the results of the standard of protection investigation are reliant on the estimated return periods from the ReFH analysis. Future work to record river levels and rainfall within the catchment are likely to reduce the uncertainty of the hydrological estimates used in this study.

Tests on the hydrology were undertaken on the BFI values used in the flood hydrology. Both sets of hydrology were modelled and used as a validation of the hydrology undertaken. The current standard of protection for the upstream left bank embankment is the 50 year flood. This would seem to match the historical record. However, if the adjusted BFI hydrology is assumed, the standard of protection would reduce to the 5-10 year flood, which is not necessarily supported by the historical flood analysis.

3.6.2 Craigdarroch Water

Model proving of this model is limited to sensitivity testing, since there are no recorded data relating to historic flood events on this reach. The model check file documents the sensitivity testing which was carried out.

4 Model results

4.1 Introduction

Flood mapping has been undertaken and is based on the 1D-2D modelling. It should be noted that the quality of the mapping provided is only as good as the underlying topographical data. Whilst it is becoming standard for appraisal studies to use LiDAR data, unfortunately this key dataset does not currently cover the area of Moniaive. As a result, the mapping is of a lower standard than other similar studies carried out by Dumfries and Galloway Council.

Despite this, every effort has been made to improve the underlying topographical data using selected topographical survey data along the roads and at structures surveyed to improve the 2D modelling element and the resultant flood flow pathways.

Model results are provided in a number of formats (Refer to Figure 3-1 for the cross section locations):

- The flood levels in mAOD at each cross section for each return period are contained in Appendix G.
- The model results have been displayed graphically as flood maps in Appendix F.

Discussion on the performance of the flood defences is provided in Section 5.

4.2 Validation of mapping against recent flood events

A number of flood photos are available against which to calibrate the flood events modelled (see Appendix A). A selection of these that can be validated against surveyed levels (e.g. bridges and defence elevations) are shown in the Table below. The purpose of this assessment is to gauge the return period and peak flow that was witnessed within Moniaive for the two recent flood events.

Table 4.1: Flood model validation

	December 2015 Low point of embankment along car park = 105.33mAOD Cross Section Ref: 1062 50 year flood level at 1062 = 105.28mAOD 100 year flood level at 1062 = 105.59mAOD
	December 2013 Top of wall level = 105.7mAOD Cross Section Ref: 1021 200 year flood level at 1021 = 105.54mAOD

	December 2015 Flooding of field on right bank downstream of A702. Flood Extent similar to 50yr to 100 yr modelled flood map (Appendix F)
	December 2015 Deck of bridge = 103.88mAOD Soffit of bridge = 103.19mAOD Water level estimated to be 102.5 - 102.6mAOD Cross Section Ref: 529 100 year flood level at 529 = 102.46mAOD 200 year flood level at 529 = 102.59mAOD

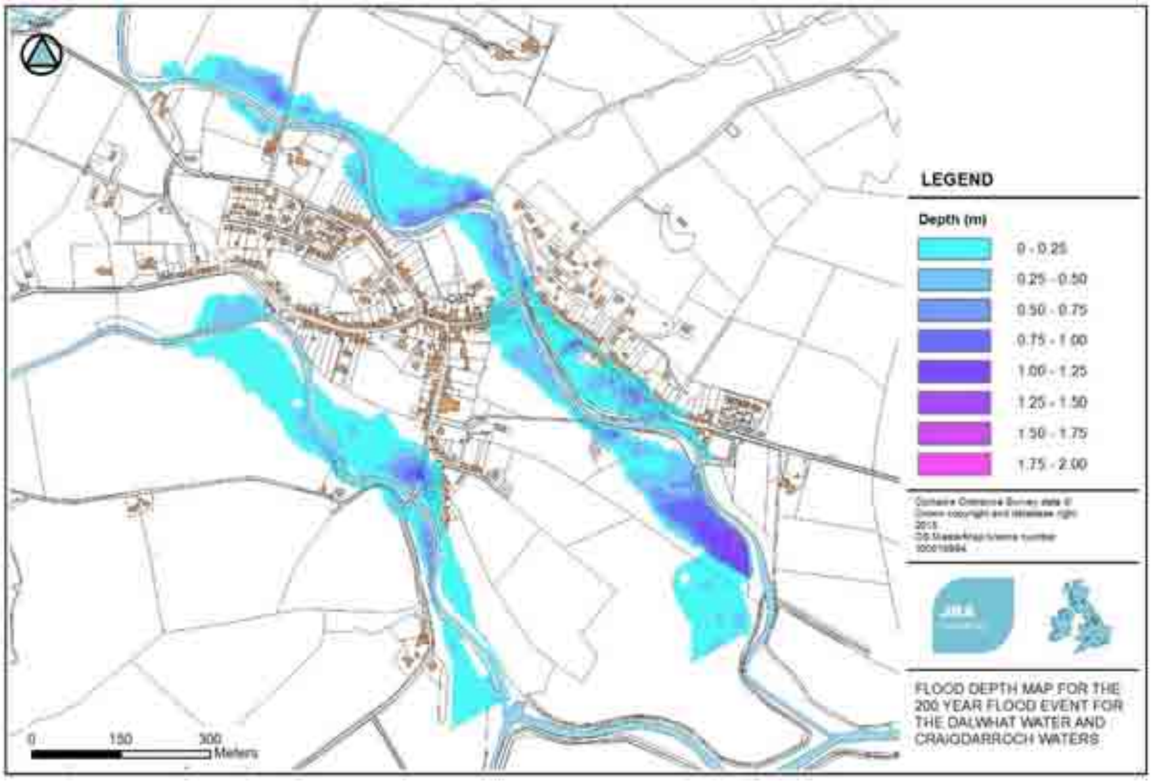
The above results suggest that the two most recent flood events generated a flood event in the region of a 100-200 year return period (estimated to be in the region of 70-80 m^3/s). This assessment should be treated with caution in the absence of any gauging station and records of flow for the watercourse.

This assessment also suggests a higher flow than that suggested by the rainfall analysis. This discrepancy is difficult to resolve in the absence of flow gauging, but may reflect that the rain gauges assessed are located at the downstream end of the catchment and may not have been recording greater rainfall depths falling in the upper catchment (that would be anticipated to be greater).

4.3 Flood map results

Flood maps were produced by combining the 1D and 2D results. The 2D maximum flood depths were produced in TUFLOW however as the channel and adjacent banks were modelled as 1D the results do not show any water in the watercourse channel. The 0.5% AP (200 year) flood map is provided for both modelled burns in Figure 4-1 below. These maps have also been created as 0.25m flood depth contours.

Figure 4-1: 0.5% AP (200 year) flood depth map for Moniaive



The modelled flood extents are believed to slightly under estimate the extent of flooding observed during the December 2013/2015 flood events. This is particularly the case for the lower return period flood events where the overland flow path down Dunreggan is not as extensive as observed during the December 2013 flood. This is primarily due to the poor quality of topographic data available for 2D modelling. It is recommended that the modelling is updated if and when LiDAR becomes available for the region.

4.3.1 Flood mapping deliverables

The following flood maps listed and described in Table 3-7 have been produced and are contained in Appendix F. These have been supplied digitally to Dumfries and Galloway Council in MapInfo and AutoCAD format.

Table 4-2: Summary of model results

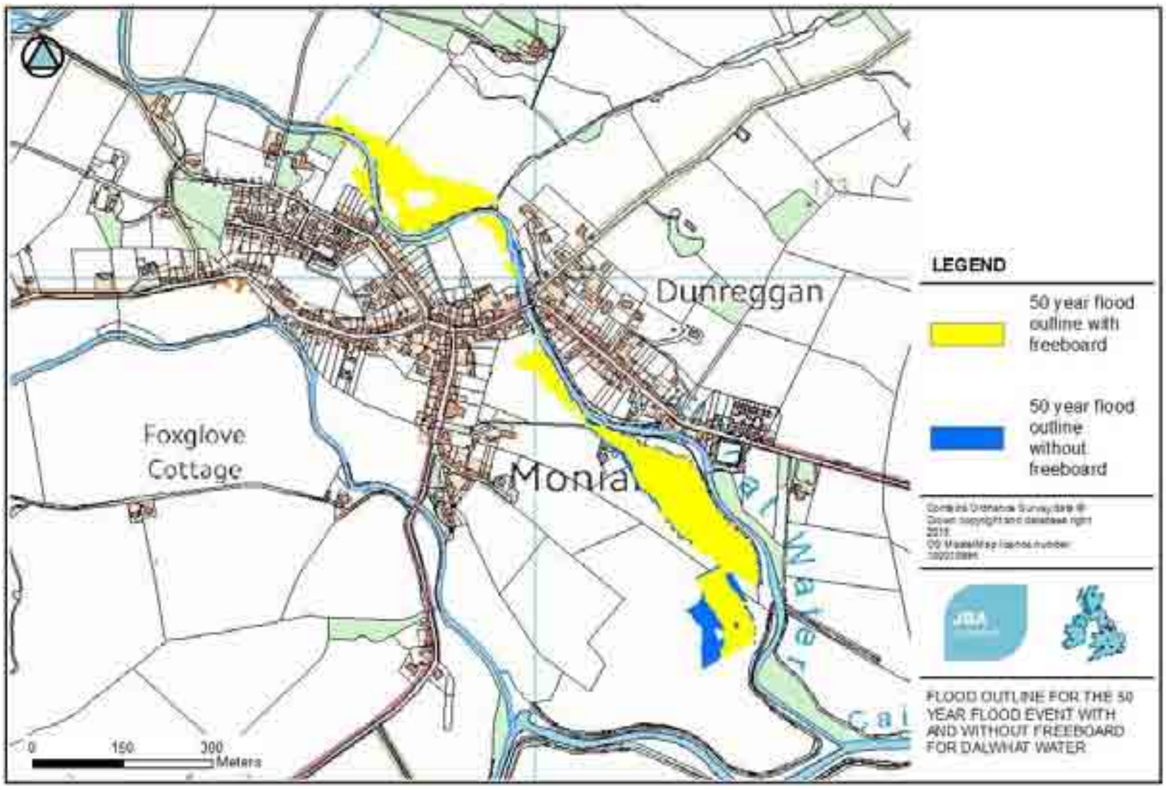
Name	Description
2 Year Event.pdf	2 year flow on the Dalwhat Water and Craigdarroch Water
10 Year Event.pdf	10 year flow on the Dalwhat Water and Craigdarroch Water
25 Year Event.pdf	25 year flow on the Dalwhat Water and Craigdarroch Water
50 Year Event.pdf	50 year flow on the Dalwhat Water and Craigdarroch Water
100 Year Event.pdf	100 year flow on the Dalwhat Water and Craigdarroch Water
200 Year Event.pdf	200 year flow on the Dalwhat Water and Craigdarroch Water
200CC Year Event.pdf	200 year flow plus an allowance for climate change on the Dalwhat Water and Craigdarroch Water
1000 Year Event.pdf	1000 year flow on the Dalwhat Water and Craigdarroch Water
BFI Comparison_v1.pdf	200 year flow on the Dalwhat Water and Craigdarroch Water with BFI adjustment

4.4 Freeboard modelling

The modelling undertaken has been repeated with the flood defences lowered by 300mm. This is to adjust the defence crest levels to the original design levels and to consider uncertainties in the original design.

The flood maps results do not show a significant difference between the with and without freeboard runs once overtopping of the defences occurs. There are minor differences in flood outlines for the lower return period events (see Figure 4-2 for the 50 year flood).

Figure 4-2: Impact of lower crest levels for the 50 year flood



Further analysis of the impact of the freeboard adjustment is shown in Figures 4-3 (left bank and 4-4 (right bank) below. These plans compare the 200 year flood (baseline) against the existing and adjusted flood defence and top of bank levels through Moniaive on the left and right banks.

Figure 4-3: Left bank crest levels, asset locations and the 200 year floods levels

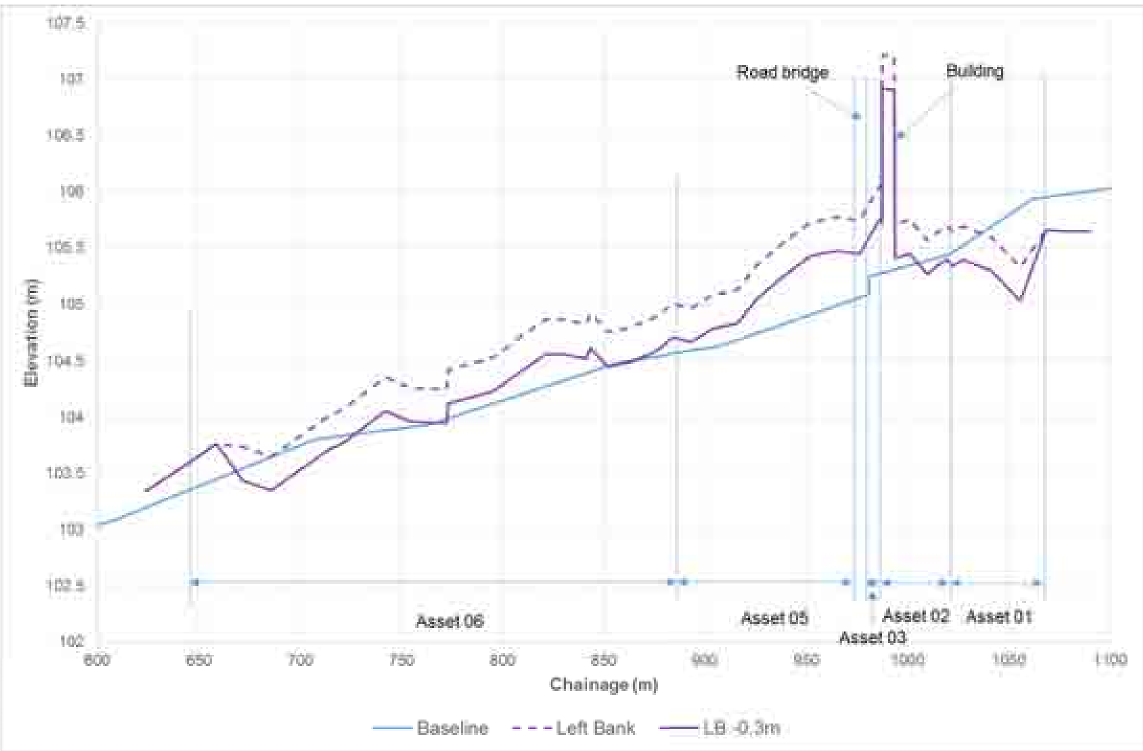
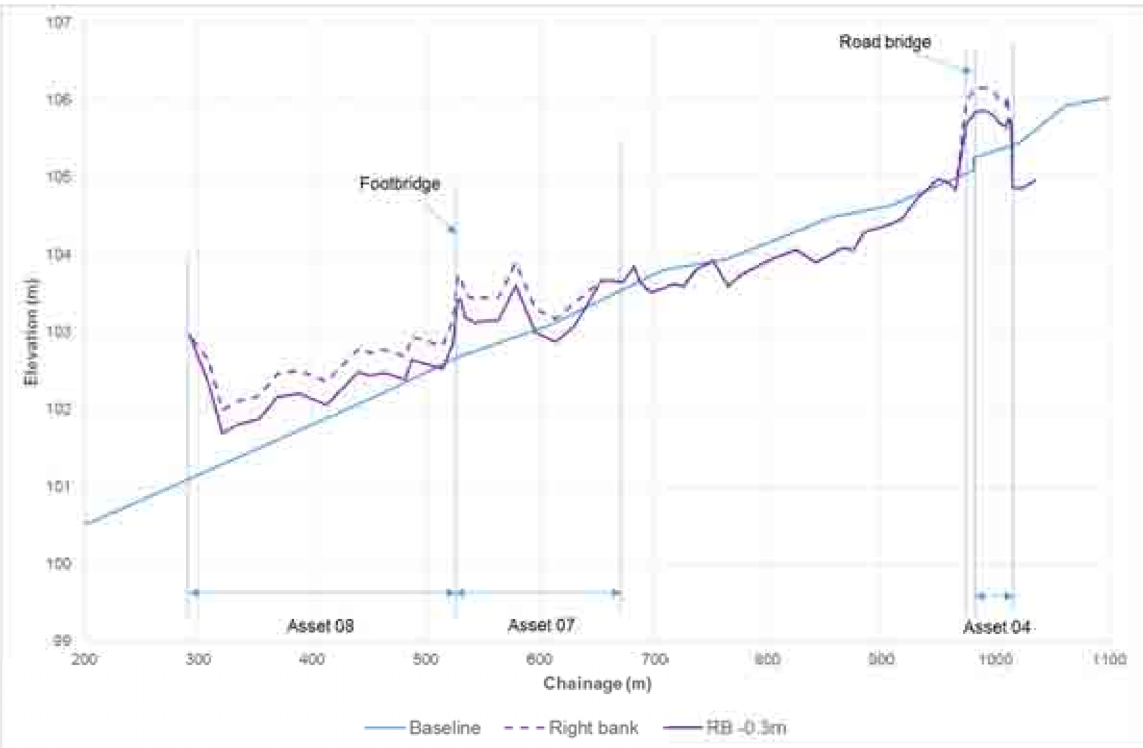


Figure 4-4: Right bank crest levels, asset locations and the 200 year floods levels



The results show that the defence line has a variable crest gradient and localised raising would improve the SOP of the scheme. This could be undertaken as part of any maintenance works.

These results show that the impact of taking into account a standard 300mm freeboard, and show that many of the flood defences do not have sufficient spare capacity. This is particularly important given the lack of gauging within the catchment, inherent uncertainties in the hydrology and the aging flood defences.

4.5 Bridge capacity review

Hydraulic structures are important considerations in flood modelling as their presence generally constricts the cross section of the watercourse. They are often liable to get blocked by large debris carried by the flood flows and hence are often the point where the watercourse exists the channel.

The structures in this reach generally have a good standard of protection, able to convey the 200 year flow without water levels surcharging the bridge soffits (as shown in Table 4-2).

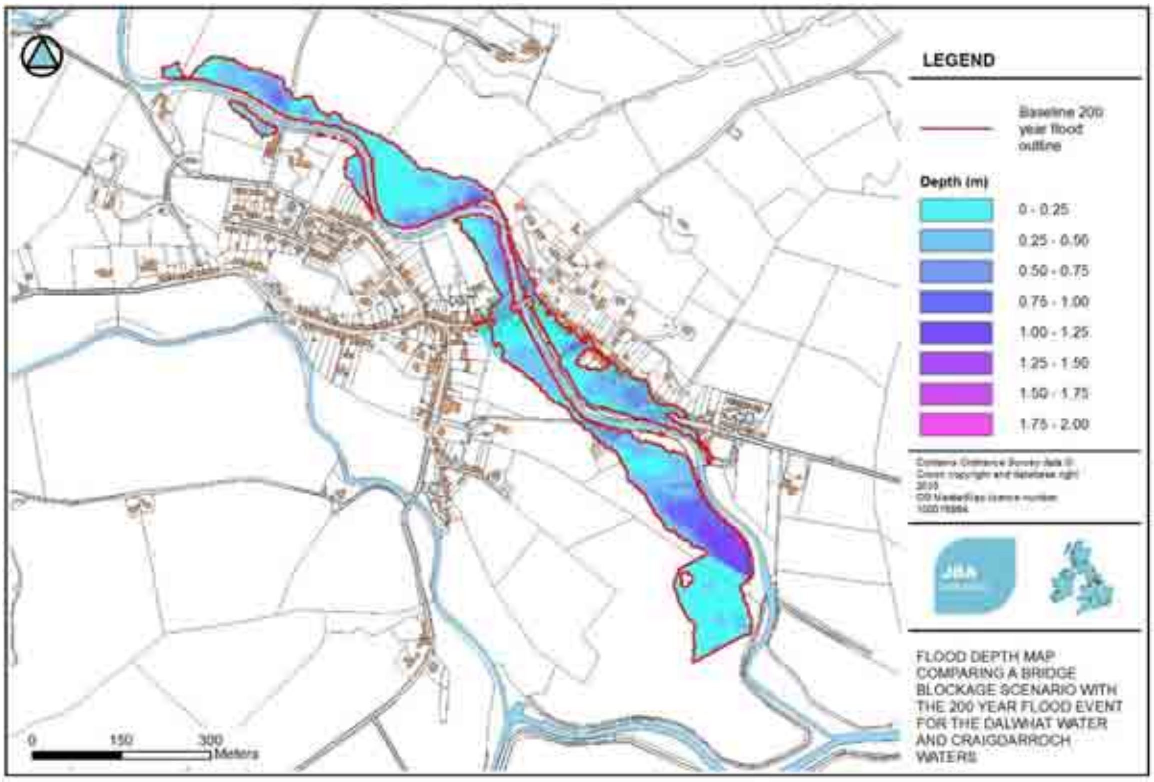
Table 4-3: Bridge capacity

Bridge	Watercourse	Lowest soffit level	Return period at which soffit is reached
Hall Bridge	Dalwhat	109.52	1000 yr
Footbridge U/S of A702	Dalwhat	105.47	200 yr + CC
A702 Road Bridge	Dalwhat	105.78	N/A - 1000 yr conveyed
Footbridge	Dalwhat	103.19	N/A - 1000 yr conveyed
Waulkmill Bridge	Craigdarroch	105.29	N/A - 1000 yr conveyed

4.5.1 Bridge blockage analysis

As blockage of bridges during floods can significantly reduce the opening area of the structures and increase the afflux across the bridge, a test in the modelling was undertaken to block the structures. As all structures in the reach are single span open structures, the probability of blockage is limited, however there is still a risk of a tree, for example, blocking on the upstream face of the bridges. As such, the soffit of each bridge was lowered to reduce the opening area of the bridge by 20%. The results in terms of the modelled flood extent is shown in Figure 4-5.

Figure 4-5: Impact of blockage on flood depths/outlines

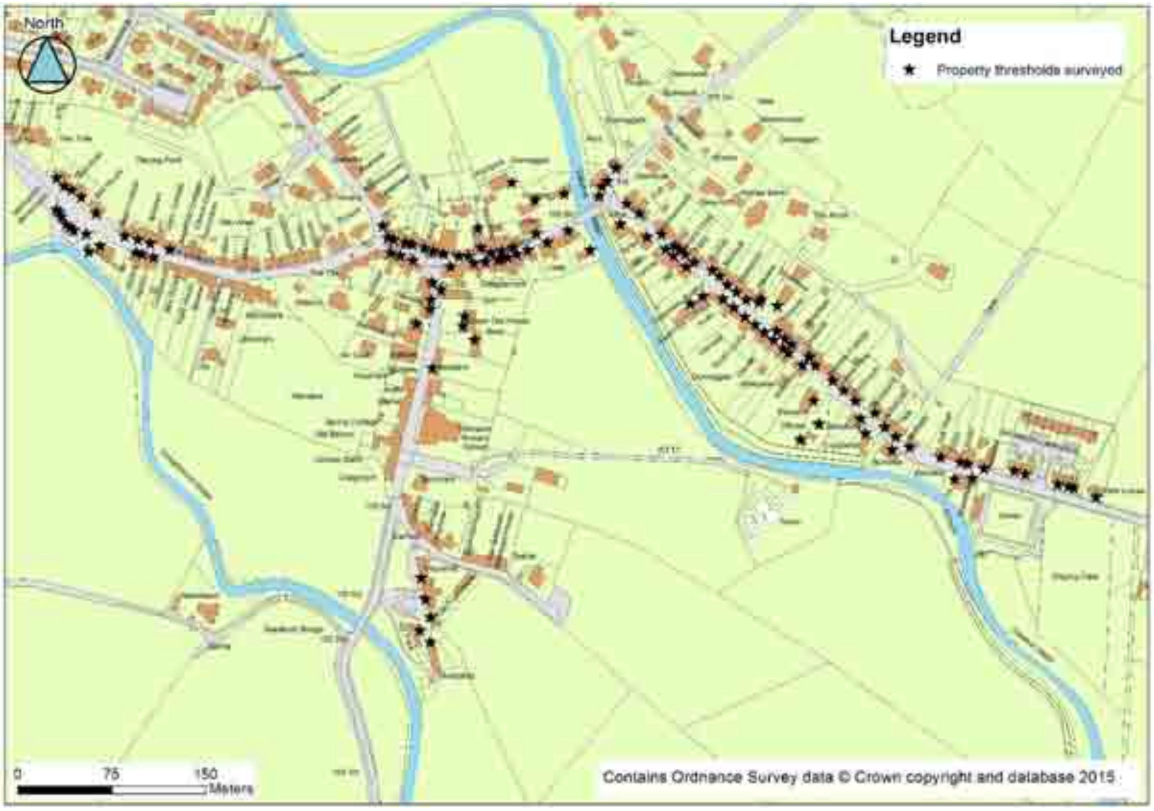


This test suggests that the impact of blockage on flood extents could marginally increase the flood extent around the A702 Bridge due to increased water levels upstream. The impact of blockage on the footbridge is more marginal.

4.6 Properties at risk

All properties potentially at risk were identified and threshold surveys were undertaken to determine the flood risk to each property. Modelled flood levels were compared against these property threshold levels to determine the number of properties at risk from flooding from the Dalwhat Water. The properties where threshold level surveys were undertaken are shown on Figure 4-6.

Figure 4-6: Surveyed threshold levels in Moniaive



4.6.1 Properties at risk from the Dalwhat Water

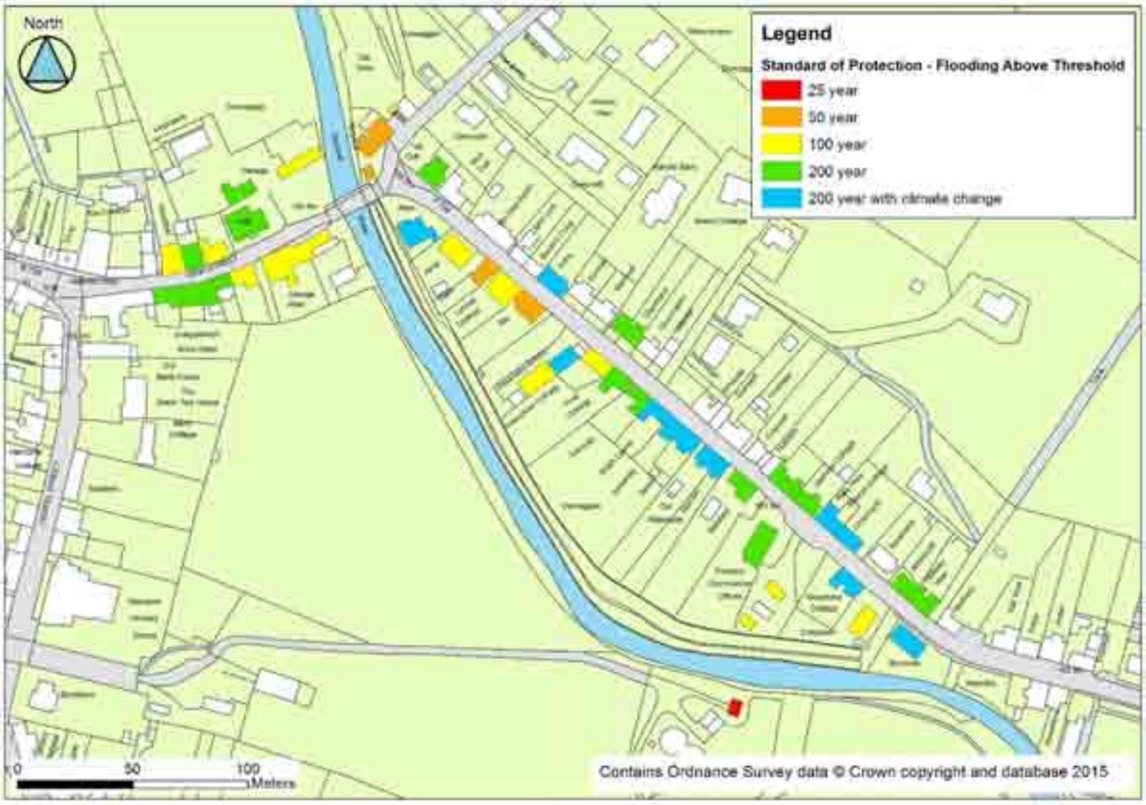
A summary of the properties flooded is provided in Table 4-3, and a plan of the standard of protection for each property is shown in Figure 4-7. A full database of properties at risk and the modelled depth of flooding is provided in Appendix H.

Table 4-4: Summary of properties at risk from the Dalwhat Water

	10	25	50	100	200	200cc	1000
Properties flooded above TL	0	0	1	6	19	36	59
Properties flooded (includes below floor level to -0.3m)	0	0	1	9	36	54	71
Average flood depth	0.00	0.00	0.01	0.29	0.29	0.33	0.44
Maximum flood depth	0.00	0.00	0.01	0.70	0.92	1.04	1.36

Analysis of properties flooded in the table above are given for those above the property threshold and those below the threshold (in the solum between ground and floor level). Not all property types will flood below the floor level (as this depends on construction type and age), but it is useful to include as it will still cause flood damages (drying and clean-up costs). Furthermore, the use of PLP measures can minimise these type of flooding relatively easily.

Figure 4-7: Properties at risk and standard of protection



Note. A 100 year SOP suggests that the properties would not flood at the 100 year flood, but would be at risk from a 200 year flood.

4.6.2 Properties at risk from the Craigdarroch Water

A summary of the properties flooded is provided in Table 4-4, and a plan of the standard of protection for each property is shown in Figure 4-8. A full database of properties at risk and the modelled depth of flooding is provided in Appendix H.

Table 4-5: Summary of properties at risk from the Craigdarroch Water

	10	25	50	100	200	200cc	1000
Properties flooded above TL	0	0	0	0	0	2	6
Properties flooded (includes below floor level to -0.3m)	0	0	1	1	1	3	9
Average flood depth	0.00	0.00	0.00	0.00	0.00	0.06	0.18
Maximum flood depth	0.00	0.00	-0.23	-0.11	-0.03	0.09	0.31

Very few properties are at risk from the Craigdarroch Water. There are some garages in the upstream reach (off Ann Street) that are potentially at risk and some outbuildings in the lower reach (off Chapel Street). Overall the risk is very low.

Figure 4-8: Properties at risk from the Craigdarroch Water and standard of protection

5 Existing flood defence measures

5.1 Background

In 1963 a Flood Protection Scheme (FPS) was installed in Moniaive which aim was to protect properties and infrastructure in the Dunreggan and High Street area. The aim of the scheme was to mitigate river flooding of Dunreggan from the Dalwhat Water.

The following work was carried out in the Dalwhat Water:

- Realignment and regrading of the Dalwhat Water and widening of the bed width to thirty feet for a distance of 1,200 feet upstream of the bridge carrying part of the High Street over the Dalwhat Water and forty feet for a distance of 1,300 feet downstream of the High Street Bridge.
- Construction of a steel sheet pile wall along the right bank of the Dalwhat Water for a distance of 120 feet upstream of the High Street Bridge and of an earthen flood bank from the northmost end of said wall to a point 100 feet south-west. The top of the flood bank was designed to a level of 347.00 feet above ordnance datum.
- Construction of a masonry wall to an elevation of 347.00 feet above ordnance datum along the left bank of the Dalwhat Water for a distance of 66 feet upstream of the High Street Bridge. Raising and strengthening of the existing flood bank from the northmost end of the masonry wall for a distacne of 240 feet upstream.
- Laying of a 9 inch diameter pipe from the Dalwhat Water along the northwest side of the public road leading to Tynron for a distance of 210 feet to connect with two existing road gullies.
- Laying of an 18 inch diameter pipe from a point on the left bank of the Dalwhat Water approximately 1,100 feet downstream of the High Street Bridge for a distance of 42 feet along the line of an existing ditch.

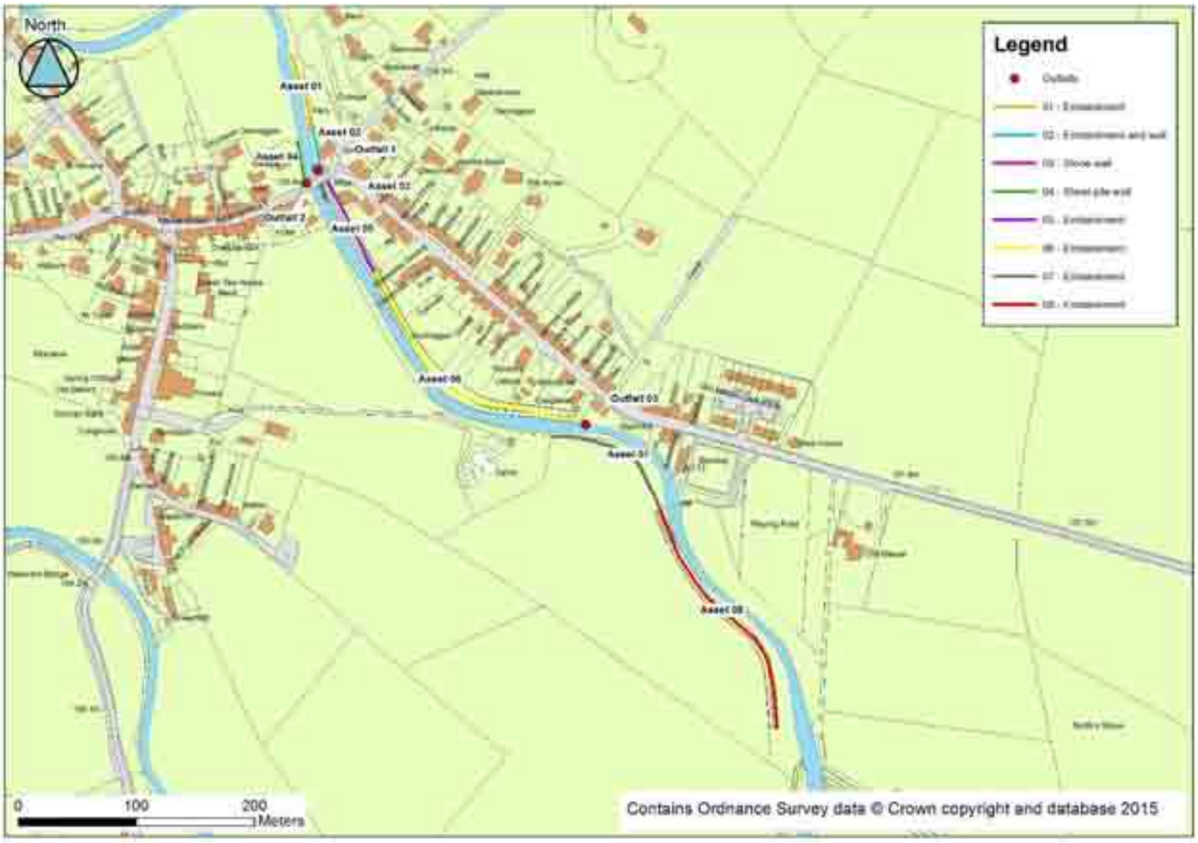
5.2 Current condition

Dumfries and Galloway Council's requested JBA to carry out a condition assessment of the existing flood defences which form the 1963 FPS in terms of structural condition, overall effectiveness and suggested improvements. This condition assessment included inspection of the culverts which form part of the FPS.

Angus Pettit (Principal Flood Analyst) of JBA Consulting carried out the assessment of FPS infrastructure during a walk over on the 22 July 2015 based on visual observations. No testing of the infrastructure took place.

A detailed condition assessment of the defences is provided in Appendix D. Figure 5-1 displays the assessment classification and location. The condition assessment included flood defence structures as part of the FPS as well as other walls, which although not part of the FPS, may influence flood flows.

Figure 5-1 Location map of Dalwhat Water existing defences



5.2.1 Review of channel dimensions against design

The defence crest survey indicated that the defence line has a variable crest gradient and localised raising would improve the SOP of the scheme.

A comparison of original design to relative to present-day channel dimensions was carried out to assess the scale of any changes since the defences were installed and channel modifications undertaken. Although the exact dimensions of original cross sections is difficult to assess, overall there is a good level of consistency between the 1963 sections (and the description of works) and those surveyed in 2015. Channel widths in those areas that were widened are similar to the widths surveyed in 2015.

The long profile, split into an upstream and downstream section by the main bridge, shows greater deviation, suggesting some greater changes over time. The upstream section has changed from a designed 1 in 120 slope to a 1 in 163 slope, suggesting that there may have been some deposition in parts of the channel. Downstream of the bridge the channel slope has changed to a lesser extent, from a 1 in 200 slope to a 1 in 209 slope.

In both cases the uniform values given in the original design drawings may suggest some level of inaccuracy, making this comparison less accurate. The changes in long profile may be a result of the channel widening carried out at the time of the initial scheme or could be a re-adjustment of the channel following artificial adjustment to the long profile made during the scheme.

5.2.2 Current standard of defences

The current condition grade of each flood defence asset was determined using the Environment Agency Condition Assessment Manual. Results for each asset are provided in Table 5-1. The condition of the assets is variable, with some graded 4 (poor). Further structural inspection and maintenance of these assets is recommended to ensure that they are fit for purpose.

Despite the rating of poor for some assets, the defences withstood the overtopping of the flood waters during the December 2013 and December 2015 floods, with no reports of breaching or failure of defences.

Table 5-1: Asset condition summary

Asset reference	Asset location	Asset Type	Condition grade
01	Left bank U/S of A702 Bridge	Embankment	4 - Poor
02	Left bank U/S of A702 Bridge	Embankment with wall on rear side	4 - Poor
03	Left bank U/S of A702 Bridge	Short wall between building and bridge	2 - Good
04	Right bank U/S of A702 Bridge	Sheet piling	4 - Poor
05	Left bank D/S of A702 Bridge	Embankment	3 - Fair
06	Left bank D/S of A702 Bridge	Embankment	4 - Poor
07	Right bank D/S of STW	Embankment	2 - Good
08	Right bank D/S of footbridge	Embankment	3 - Fair

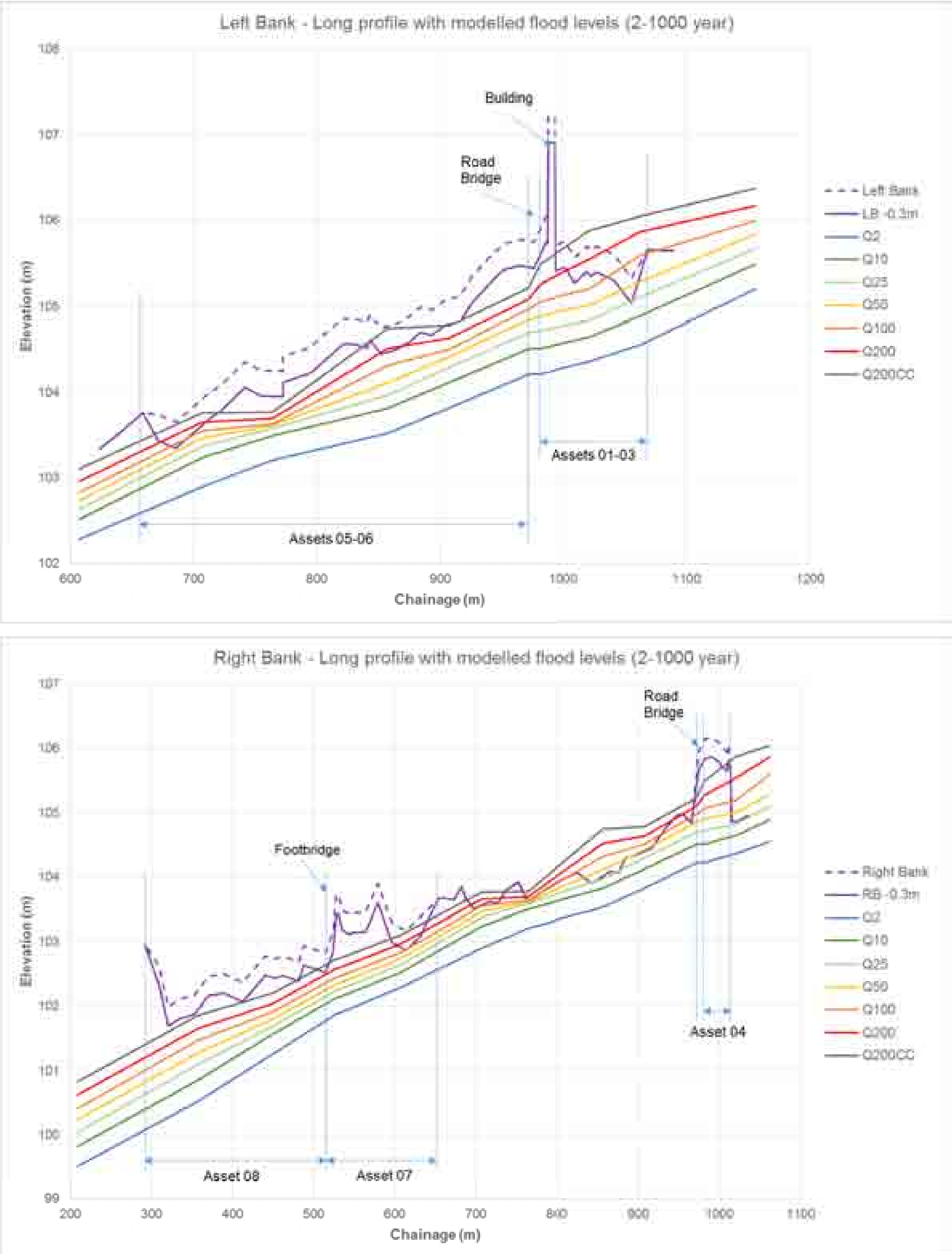
Based on the Environment Agency/Defra guidance on asset deterioration[11] a narrow turf embankment in a fluvial environment would deteriorate from a Grade 3 to a Grade 4 in 19 years with no maintenance, and in 15 years from a Grade 4 to a Grade 5. However, with maintenance this deterioration can be reduced and the life of the defence lengthened.

5.2.3 Effectiveness of FPS

The defence elevations have been compared against the modelled water levels to determine the current standard of protection for those defences along the Dalwhat Water. This analysis is shown in Figure 5-2.

[11] Environment Agency, 2013. Practical guidance on determining asset deterioration and the use of condition grade deterioration curves: Revision 1. Report – SC060078/R1.

Figure 5-2: Defence height vs. water surface elevation on the Dalwhat Water



The analysis of the modelled water levels against the surveyed defence crest levels suggests that the right bank flood defences have a good standard of protection in the region of a 200 year standard of protection with an allowance for climate change. The section downstream of the A702 road bridge has a lower standard of protection in the region of a 25 year flood (as anticipated as this is not protected by flood defences).

The results for the left bank suggest that the embankment upstream of the A702 road bridge has a 50 year standard of protection (matching the flood mapping analysis). The embankment downstream of the A702 road bridge has a 200 year standard of protection with an allowance for climate change. This matches the flood mapping undertaken that shows flood waters overtopping into the car park on the right bank upstream of the A702 bridge at the 100 year flood, but not the 50 year flood.

5.2.4 Impact of freeboard

A freeboard is usually added on to flood water levels to determine the flood defence elevations to account for uncertainties in the design criteria (e.g. hydrological and hydraulic) as well as post construction unknowns (e.g. settlement for example). A standard 300mm freeboard has been used to assess the variation in standard of protection.

Figure 5-2 shows the impact of reducing the defence elevations by this nominal freeboard value of 300mm. On the left bank the standard of protection reduces to the 10 year flood upstream of the A702 road bridge and 50 year flood at a low point in the downstream reach.

For the right bank, the sheet pile wall has a 200 year standard of protection (notwithstanding the drainage holes through the wall) and the embankment in the downstream reach is reduced to a 100 year standard of protection.

5.3 Current condition of FPS culverts

The culverts were inspected internally via a CCTV survey carried out by Underground Inspection Services 27 August 2015. A full survey report has been supplied to Dumfries and Galloway Council, with a summary of the condition of the culverts and the outlets provided below.

A full condition survey report for the culverts is provided in Appendix E. Table 4-1 provides a summary of the culvert outfall condition grades for these assets. Culverts 1-3 are currently graded as 4 (poor) due to the fact that they are partially or completely blocked and the flap valves are stuck open and poorly maintained (and difficult to access). The culvert 4 outfall is in better condition and the culvert is clear.

Table 5-2: Asset condition summary

Asset reference	Asset location	Condition grade
1	Left bank upstream of A702 bridge*	4 - Poor. Culvert blocked and flap valve open at outlet.
2	Left bank upstream of A702 bridge*	4 - Poor. Culvert clear but cracks and joint displacement present. Flap valve open at outlet.
3	Right bank beneath A702 bridge	4 - Poor. Culvert blocked and flap valve open at outlet.
4	Left bank adjacent to Burnside	2 - Good. Culvert clear.
* Note that Culvert 1 and 2 share the same outfall.		

5.3.1 Impact of condition on fluvial flood risk

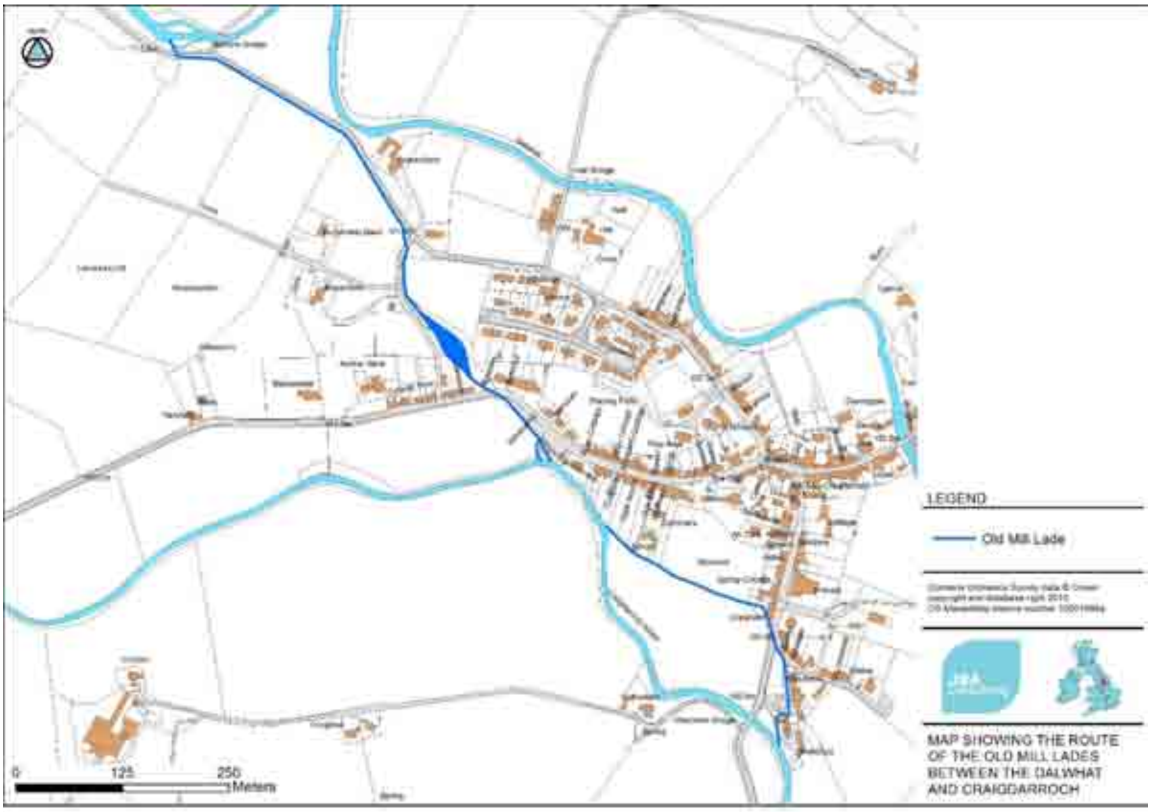
Culverts play in an important role in conveying surface water from street level to the nearest suitable watercourse. When the culverts become choked with debris, such as culvert 1 and 3, they can no longer carry out their intended purpose. Likewise where flap valves are stuck open flood flows in the channel can back up the culvert and surcharge at street level.

The culvert outlet inverts are positioned close to normal water elevations in the channel. By maintaining correctly operating flap valves it will also help to keep the culvert free of debris that may get washed into the culvert during higher than normal flows.

5.4 Discussion of Mill Lade through village

Following a public meeting with the community on 16 November, members of the public highlighted the presence of an old mill lade through the village. A review of historic flood maps suggests that two lades existed as shown in Figure 5-3. Evidence collected by the Council would suggest that any old connections to the Mill Lade have been closed off and much of the lade has been buried or filled in.

Figure 5-3: Location of old mill lades



There are also two manholes present to the south of Craignee Drive (see Figure 5-4). It is not known whether these connect to additional old lades (since buried) or other drainage within the village. Historic mapping does not suggest that any lade was present along the line of these two manholes. Recent inspection by the local authority suggest that any drainage in this area is not actively in use.

Figure 5-4: Manholes to the south of Craignee Drive

5.4.1 Historic lade recommendations

Whilst the mill lade channel is less pronounced to the northeast of the town, the subsurface mill lade could be an additional flow route through the town, posing a risk to nearby properties if no formal blockage has been carried out. It is recommended that an assessment is carried out to ensure that inlets are sufficiently blocked to avoid the entry of water in the event of high flows.

5.5 Surface water flood risk

SEPA's Flood Risk Management Maps show limited surface water flood risks in Moniaive. This surface water mapping was carried out using SEPA's national surface water mapping that has not been carried out to the same methodology or detail as the regional mapping undertaken by JBA Consulting. As a result surface water mapping has been re-assessed for this study using the available DTM and the SEPA regional mapping methodology.

SEPA's surface water flood maps were developed by JBA Consulting using JFlow, JBA's in-house 2D modelling software package. JBA has undertaken the same methodology to assess the surface water flood risk to Moniaive to help inform flood risk and risk under defended scenarios.

5.5.1 Methodology

JFlow for surface water mapping works on the basis of applying a rainfall event across the entire study area. The chosen rainfall event was the 200 year, 1 hour storm duration. The rainfall event was calculated based on the FEH CD v3 using a point located in Moniaive to give appropriate catchment descriptors and rainfall rate. To be conservative the summer profile was chosen as this has a shorter time to peak. A summer profile may not be appropriate for the essentially rural upstream catchment leading to Moniave, but represents a conservative assumption for this site.

The model was run on a 5m resolution to match the available DTM data. Maximum flood depth and velocities were derived automatically from the 2D modelling. As this type of surface water modelling applies rainfall to every cell, the flood depths derived from the 2D modelling are clipped at a predefined depth (otherwise all cells would be shown as being flooded). The depth typically used is 0.05m.

The mapping is useful to review the flow paths and ponding areas, however it will not necessarily correctly identify all flow paths due to the lack of more accurate LiDAR data and as the resolution will not pick up key features such as walls, buildings, surface water drainage and kerbs.

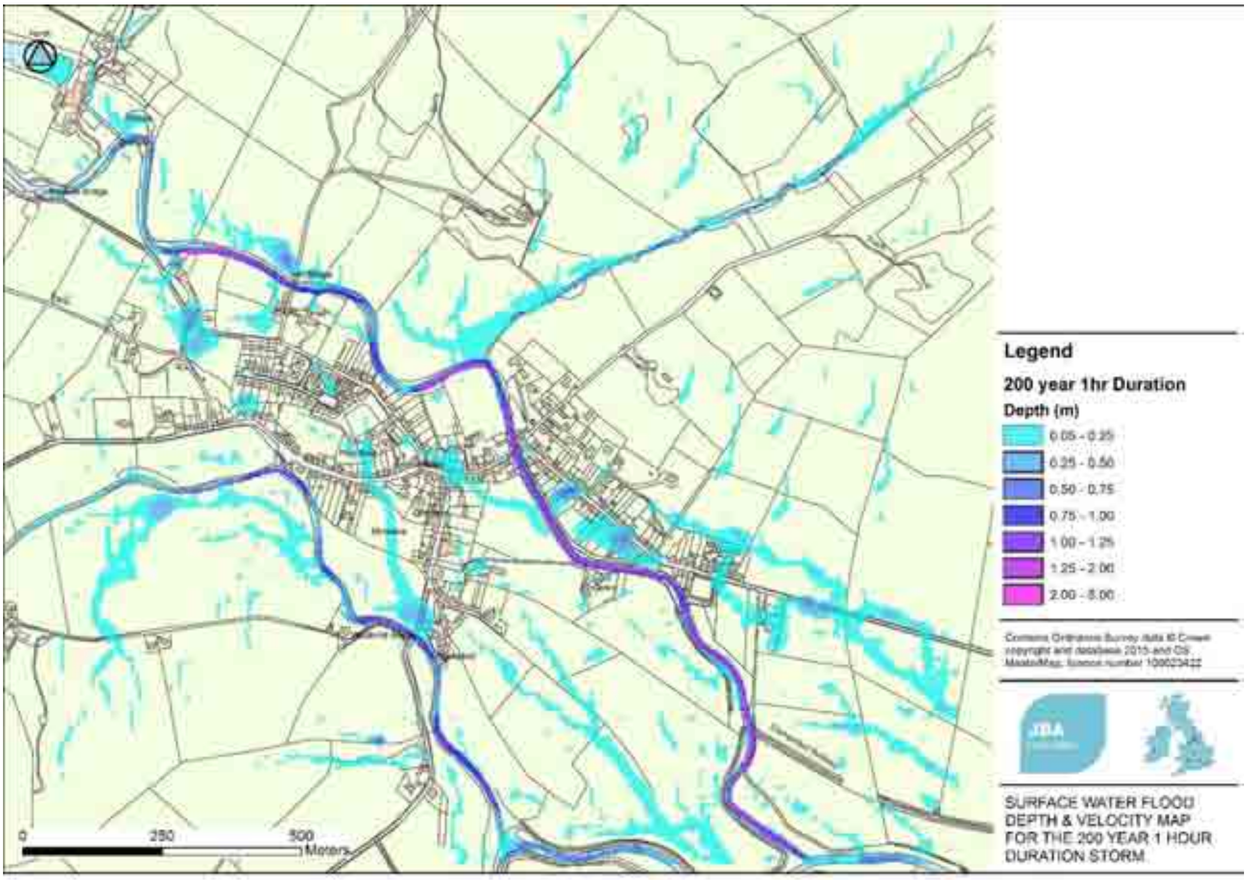
5.5.2 Results

The surface water flood map results are shown in Figure 5-6. The results suggest that there is localised ponding in Moniaive to depths that could cause a flood risk to properties. The location of culverts correspond to the location of low points and ponding shown in Figure 5-6. In addition, there are a number of flow paths within the town itself and outside the fluvial flood outlines that could cause additional flood risk to the town.

The flow paths down the steep road to Dunreggan and leading to Culverts 1/2 (see photograph below, Figure 5-5) is not picked up by the analysis, possibly due to the resolution of the DTM used. It is recommended that this analysis is repeated if and when LiDAR is available for the catchment to improve the quality and resolution of the analysis undertaken.

Figure 5-5: Surface water flow path to Dunreggan

Figure 5-6: 200 year surface water flood risk for Moniaive



6 Options for flood mitigation

6.1 Relevant legislation

Local Authorities are responsible for flood management under the Flood Risk Management (Scotland) Act 2009. Under this legislation, Local Authorities have discretionary powers to undertake activities to mitigate against flooding.

6.1.1 Relevant Guidance

Guidance for flood risk management in Scotland is provided within the following documents:

- Flood Risk Management (Scotland) Act 2009: Sustainable Flood Risk Management - Principles of Appraisal: A Policy Statement
- Flood Risk Management (Scotland) Act 2009: Delivering Sustainable Flood Risk Management

Specific guidance on project appraisal is provided in the Scottish Government Flood Protection Scheme - Guidance for Local Authorities document. Only Chapters 5 and 6 of this document are currently available. Chapter 5 which covers the project appraisal guidance (assessment of economic, environmental and social impacts) was updated in February 2012. Further guidance is available in the Flood Risk Management (Scotland) Act 2009 - Local Authority Functions Under Part 4 Guidance document[12].

6.2 Guideline standard of protection

The Scottish Government do not specify design standards for flood protection schemes. However, the standard of protection against flooding typically used in Scotland is the 0.5% AP flood (1 in 200 year). This standard is the level of protection required for most types of residential and commercial/industrial development as defined by SPP.

Whilst design standards are a useful tool in terms of engineering goals and useful benchmarks, as well as in clear communication to stakeholders and the public, there is a general move in Scotland away from design standards to a risk based approach. Restricting options to desired standards of protection can limit consideration of factors that influence defence effectiveness and can limit future responses to external factors.

It is expected that a variety of protection levels are considered during the design process including the 0.5%, 1% annual probability and if appropriate a lesser level. The guidance also states that options should be tested against a “1% exceedance probability plus allowances for climate change to be included in all appraisals”.

Based on the above guidance the aim of the scheme will be to assess options up to the 0.5% AP (200 year) flood if possible, but to test lower return period events if required. Each option has been assessed to achieve a:

1. 0.5% AP with an allowance for climate change level of protection
2. 0.5% AP level of protection

6.3 Freeboard Allowance

For the flood defences considered, a standard freeboard allowance of 0.3 m has been applied for all defences. These values are fairly typical at an initial stage of appraisal, but would need to be refined at the detailed design stage of a flood protection scheme to take into account local conditions/risks.

6.4 Exclusions

It should be noted that the works do not include mitigation of flood risk from the Craigdarroch Water as this is outside the scope of this assessment.

[12] The Scottish Government, Flood Risk Management (Scotland) Act 2009 - Local Authority Functions Under Part 4 Guidance, July 2015: http://www.gov.scot/publications/2015/07/7909/0

6.5 Long list of options

The following table provides an overview of potential flood alleviation options that could benefit Moniaive. Those that are considered to be most viable have been assessed further in Section 6.

Table 6-1: Available flood alleviation options

Category	Measure / Action	Discussion
Avoid	Relocation	Relocation is not a widely used method of flood mitigation in the UK partly due to the fact that the HM Treasury's economic appraisal methodology limits flood damages to the market value of the property. *Decision: Unlikely to be economically or socially viable at this stage. Option not progressed further.*
Prepare	Flood warning	Flood warning is currently not available for Moniaive other than as a regional flood alert from SEPA. Provision of flood forecasting in this catchment with sufficient lead time would be challenging due to the short time to peak and rapid response. Such an option would require upstream PDM modelling linked to rain gauges, rainfall RADAR and Nowcast data feeds. Discussions with SEPA suggest that they are planning to extend coverage of flood warning on the Nith catchment. In the short term however, this will be provided for parts of the catchment with currently available gauge data. In the longer term, we therefore would recommend that discussions are held with SEPA to install river flow gauges on the catchments and rivers of interest to start collecting the necessary information to support future flood warning and forecasting. This will also have secondary benefits of improving the long term hydrology estimates and any property level protection offered by the Council. *Decision: Viable option that should be assessed further through discussions between SEPA and D&G Council*
	Resistance	Flood resistance measures help mitigate floodwater from entering a building using a variety of techniques and products. Resistance measures such as airbrick covers and door guards are provided by the Dumfries and Galloway subsidy scheme. This is discussed further in the section below. *Decision: Viable option that should be assessed further.*
	Resilience (retrofit)	Flood resilience measures reduce the consequence of flooding and accept that flooding into a property can occur, but can be managed and cleaned rapidly after a flood with minimal disruption and temporary accommodation. These measures are usually only viable if they are undertaken after a flood event and as part of the repair process. *Decision: Unlikely to be economically viable at this stage. Option not progressed further.*
Protect	Natural Flood Management	Natural flood management options are being progressed by SEPA separately as part of the Flood Risk Management Strategies and through river basin planning and flood risk management pilot catchments[13]. Natural flood management options should focus on the catchment rather than single sites such as Moniaive. *Decision: Not assessed as part of this project.*

[13] http://www.sepa.org.uk/water/river_basin_planning/implementing_rbmp/pilot_catchment_project.aspx

Category	Measure / Action	Discussion
	Demountable defences	Demountable defences are linked to the availability of adequate flood warning and are typically used where direct defences are impractical, uneconomic or environmentally / aesthetically unacceptable. Temporary or demountable defences in Moniaive will unlikely to be technically or practically suitable due to the long length of defences required, the short lead time and large staff numbers required to install. *Decision: Unlikely to be a practical option. Option not progressed further.*
	Direct defences	Flood defences already exist in Moniaive. The analysis undertaken so far has highlighted that these defences are in variable condition and standard. Raising or the provision of new flood defences in Moniaive is a technically viable option that should be considered further. *Decision: Viable option that should be assessed further.*
	Upstream storage	Upstream storage would have multiple benefits for flood risk throughout the catchment. However, there are many technical, environmental and economic constraints associated with damming the watercourse. The volume of flood water between the 50 year and 200 year return period floods is in the region of 165,000m^3. This rises to 280,000 m^3 for the 200 year with an allowance for climate change. *Decision: Unlikely to be a practical or cost effective option for Moniaive. Option reviewed as part of this report.*
	Channel modification	Channel modification as an independent option is unlikely to provide the benefits of flood protection. The options for channel widening are limited and constrained by existing bridge crossings, existing defences and riparian ownership boundaries. *Decision: Unlikely to be a practical option. Option not progressed further.*
	Diversion	There is no scope for channel diversion around the town of Moniaive. Any diversion from the Dalwhat Water would be into the Craigdarroch Water that has its own flood risk. There may be scope for breaching the embankment downstream of the town onto the agricultural land to the south of the Dalwhat Water. This could reduce levels through the town, although additional modelling is required to test this. *Decision: Option that may reduce flood levels, but unlikely to solve the problem. Option considered further.*
	Bridge adjustments	The current standard of protection for the bridges on the two rivers is good, thus any adjustment to these is unlikely to reduce the flood risk further. This was evident in the December 2013 and 2015 floods as the flooding came out of bank before any bridges were surcharged. A minor improvement could be made by raising the footbridge on the upstream side of the A702 bridge so that it is at least as high as the road bridge. This is discussed in Section 6.5. *Decision: Unlikely to be an option in its own right. Unlikely to significantly reduce flood risk. Option not progressed further.*

6.6 Options in relation to SEPA Flood Risk Management Strategies

The Act places responsibilities on various authorities including SEPA, Scottish Water and Local Authorities to work collaboratively to responsibly and sustainably seek to reduce flood risk from all sources. The Scottish Environment Protection Agency (SEPA) and 14 lead local authorities are jointly consulting on the future direction and delivery of flood risk management in Scotland. Together, they are focusing on where the flooding impacts are greatest and where the benefits of investment can be maximised.

SEPA are currently developing Flood Risk Management Strategies (FRMS) in association with local authorities. These will provide prioritised actions for flood mitigation in each PVA to allow the careful reduction of risk in a holistic way at a catchment level. The plans are due to be drafted by the end of 2015. As this area is covered by a candidate PVA, this report will provide a more detailed assessment of the risks and options for mitigation than the SEPA strategy. The recommendations of this report will need to be fed into the wider SEPA Strategy for the Solway Local Plan District and Local Flood Risk Management Plan.

6.7 Recommendations and quick wins

Overall the FPS defence is in good to fair condition but is showing signs of localised deterioration and a lack of regular maintenance. The average condition is 3, however when this declines to 4 or 5 the assets may not be recoverable through maintenance alone and more costly refurbishment may be required.

There may be a number of short term or small scale measures that could benefit the village of Moniaive from future flooding. A number of different types of measures or short term 'quick wins' have been identified that cover a range of aspects from maintenance to small scale works. These are summarised in Table 6-2 and referenced geographically in Figure 6-1.

Figure 6-1: Location reference plan for recommendations and quick wins identified in Table 6-2.

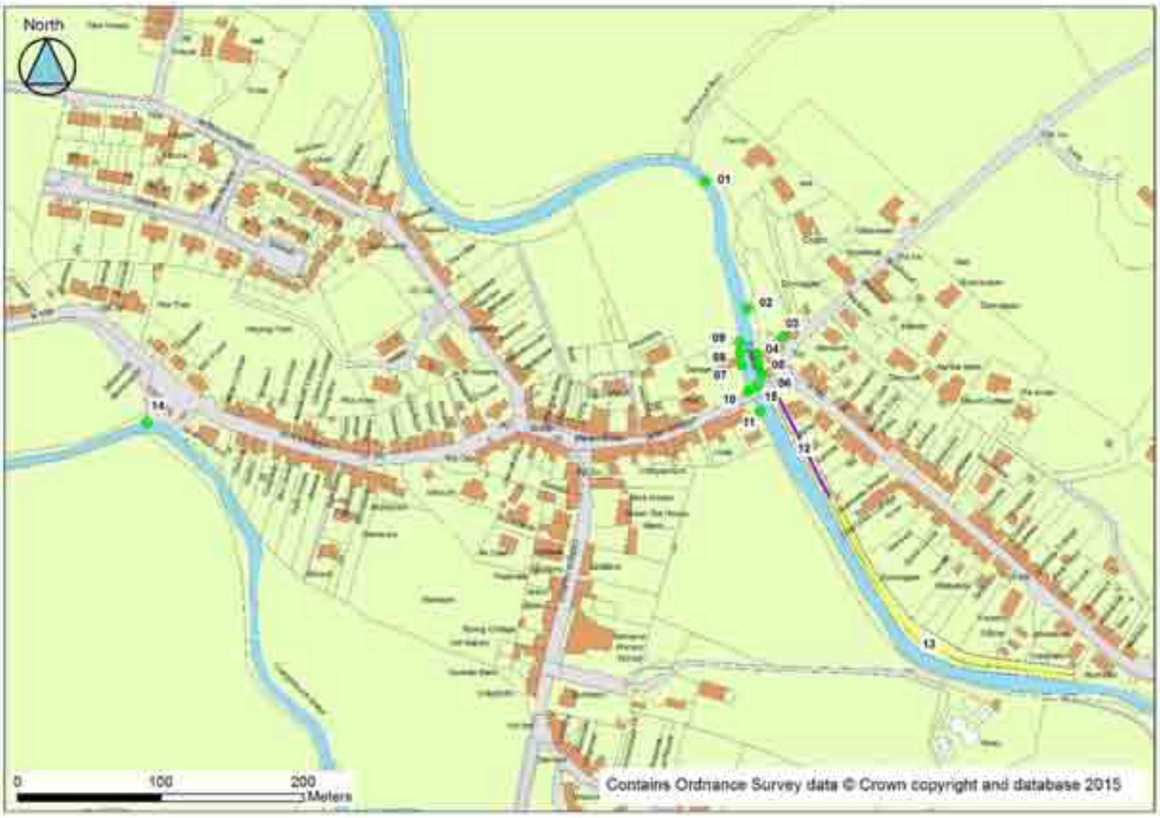


Table 6-2: Short term recommendations and quick wins

Ref	Problem	Action	Evidence
01	Tree in river causing obstruction and blockage risk downstream.	Remove tree.	
02	Embankment overgrown. Difficult to inspect.	Set up maintenance plan for embankment as a minimum. Annual cut and removal of arisings, plus inspection for piping and maintenance of level. Inspect embankment once initial maintenance complete.	
03	Flow path from car park to road.	Consider flood gate to mitigate flow path.	
04	Unflapped outfall.	Fit flap valve and appropriate headwall. Investigate outfall, CCTV to confirm responsibilities and flow paths.	
05	Erosion of stone armoured bank.	Monitor erosion and any further deterioration, particularly after flood events. Respond if necessary.	
06	Outfall flap valve stuck open.	Maintain flap valve and remove obstructions.	
07	Hole through sheet piling.	Fill hole or fit flap valve.	

Ref	Problem	Action	Evidence
08	Hole through sheet piling.	Fill hole or fit flap valve.	
09	Hole through sheet piling.	Fill hole or fit flap valve.	
10	Outfall flap valve stuck open.	Maintain flap valve and remove obstructions.	
11	Erosion of bank.	Monitor condition of bank. Repair if necessary.	
12	Encroachment of gardens onto rear side of embankment.	As a minimum undertake annual cut and removal of arisings and inspection for piping and maintenance of level. Monitor condition of embankment and encroachment by gardens.	
13	Embankment overgrown. Difficult to inspect.	As a minimum undertake annual cut and removal of arisings and inspection for piping and maintenance of level. Inspect embankment once initial maintenance complete.	

Ref	Problem	Action	Evidence
14	Deformation of gabion wall (Craigdarroch Water)	Monitor gabions and any further deterioration.	
15	Low footbridge	Raise footbridge.	

6.7.1 Alternative option to limit flow path down Dunreggan

A key flow path of flood risk to the properties on Dunreggan is from the car park upstream via the low point in the road (see photograph below).

Limiting this flow path would significantly reduce the flood risk to properties on Dunreggan. This could be achieved through the following options:

- Temporary barriers
- Flood gates
- Road raising

The use of temporary barriers and flood gates would need good flood warning on the catchment which is not currently available. Flood defences may also be required around the adjacent properties and the electricity sub-station. There would also be the risk of bypassing of flood waters through the riparian property itself. Therefore, this option is unlikely to provide a significant benefit.

The option to raise the road would be difficult to achieve whilst also maintaining access to the local properties.

6.8 Culvert recommendations

It is clear from the CCTV footage that the culverts are in need of regular maintenance. Major blockages should be removed as a priority. Where culverts are silted, damaged or cracked regular inspections should be carried out to monitor crack progression and ingress of material from the breaks. If it is deemed necessary the damaged culverts should be repaired or replaced. Pipe sliplining or pipe bursting technique could be considered as rebuild methods. Each of the outlets have flap valves which are seized in place which prevents them from closing when needed. These should be repaired and replaced with a maintenance schedule implemented to ensure that the hinge does seize in the future. Culvert recommendations can be summarised:

- Reduce silt entry through regular gully cleaning and upstream silt traps.
- Remove blockages.
- Repair or replace flap valves.
- Establish regular inspection and cleaning maintenance schedule.

7 Short list of options

The selected short list of options have been assessed in more detail and included within the economic appraisal. Further details on each are provided below.

7.1 Do Nothing

The Do Nothing represents the 'walk away' scenario, cease all maintenance and repairs to existing defence and watercourse activities. This represents a scenario with no intervention in the natural processes. The 'Do Nothing' option is used within the appraisal as a baseline and a means of calculating the whole scheme benefits of the 'Do Something' option.

The Do Nothing option is not technically a viable option in Moniaive due to the presence of existing defence assets that the Council has a duty to maintain. Furthermore, the Council also has a duty to maintain the watercourse under the Flood Risk Management (Scotland) Act 2009.

One could argue however that little maintenance has been carried out on the flood defence assets and a Do Nothing scenario is a more realistic reflection of the previous management of the defences.

7.2 Do Minimum

The 'Do Minimum' option represents the situation with ongoing maintenance of the watercourse, channel banks and defence assets. This assumes that no blockage (other than permanent fixtures) are present on any structure. The inspection shows limited maintenance to date and this has been confirmed with the council. It is assumed that as a result of the recent flooding and the instigation of this assessment that this forms an applicable Do Minimum case, however further maintenance of the defences would be required to ensure that this is representative.

7.3 Option 1 - property level protection

Property Level Protection (PLP) is flood resistance and resilience measures however it generally takes the form of demountable door guards and air brick covers. Dumfries and Galloway employs a subsidy scheme that would be used to implement this option. Under this scheme, residents can purchase PLP products from the Council at a subsidised rate.

Figure 7-1: Examples of PLP (automatic airbrick and door guard)

PLP products generally only work or are reliable up to a depth of 0.6m. Therefore, to assess the feasibility of PLP the number of properties at risk from direct flooding and those that could benefits from installation of PLP products are displayed in Table 7-1. The table below shows that for the 200 year flood, 33 properties could benefit from PLP, although three have flood depths that exceed the standard 0.6m depth. For these properties, alternative approaches or specialist products may be required to provide flood mitigation. In the very least a survey of the property would be required.

Table 7-1 suggests that most properties (92%) at risk from a 200 year flood would be inundated to a depth less than 0.6m and would therefore benefit from PLP. For more extreme floods greater than the 200 year flood, the impact of PLP reduces with 72% benefitting at the 1000 year flood (due to greater flood depths).

As the standard of protection to residential properties is high (50 year SOP), the implementation of PLP would need to be combined with education for homeowners, regular trial runs and exercises to ensure that the community can manage and respond adequately to flood events. This would be a challenge over the long term for this site where flood risk is relatively low.

Table 7-1: Number of properties at risk and protected

Scenario	25 year	50 year	100 year	200 year	200 year CC	1000 year
Properties at risk	0	1	9	36	54	71
No. properties at risk with PLP assuming a 0.6m limit	0	1	8	33	48	51
The property counts represent both residential and commercial properties and include all properties flooded above the surveyed floor level and to a depth 300mm below the floor level (sub floor or solum flooding).						

Furthermore, specific flood warning and forecasting would be required on the catchment to provide the necessary lead time for the community to react to flood warnings. If this cannot be implemented (indeed, there are challenges to providing adequate lead times on a small catchment), an automatic approach to PLP may be preferable. Automatic PLP products aim to be passive and do not require homeowner intervention prior to a flood. The downside of these products is that they are more expensive and may not be available via the Dumfries and Galloway subsidy scheme.

Outcome: Until flood forecasting can be provided an automatic PLP approach is preferred. Benefits and costs of this option to be assessed.

7.3.1 Lower cost PLP option

The above approach is the preferred recommendation for implementation of PLP in Scotland based on Scottish Government guidance. However it does not take into account the Council's current subsidy scheme for PLP products. The use of this scheme could achieve many of the flood benefits stated above at a lower cost. However, the approaches provided are generally manual approaches that require installation prior to a flood. Such an approach therefore would require some form of flood warning, although this could be provided by the Council in the absence of any SEPA gauging and catchment flood warnings.

7.4 Option 2 - Raised flood defences

Direct defences generally take the form of earth embankments with a sheet pile wall protecting the garage on the left bank upstream of the A702. A raised flood defence option would need to raise defences that have a low standard of protection and to raise others that do not currently provide a sufficient freeboard.

There is little room for raising the flood defences without either encroachment into the river or onto the gardens of riparian properties. As a result, the most likely approach to defence raising would be to add low flood walls on top of the existing defence. Whilst the sheet pile wall has a good standard of protection, this asset is in poor condition and would benefit from being replaced or upgraded. A summary of the works required is provided below (and in Figure 7-2) and a summary of defence lengths and the increase in elevation is provided in Table 7-2.

- Raise Asset 1/2 (embankment on left bank upstream of A702 bridge)
- Raise Asset 3 (short wall upstream of A702 bridge)
- New embankment (right bank upstream of garage)
- Replacement of Asset 4 (sheet pile wall on right bank upstream of A702 bridge)
- Raise Assets 5/6 (embankment on right bank downstream of A702 bridge)

In order to achieve a 200 year plus climate change standard, additional new defences would be required on the left and right bank as shown in Figure 7-3.

Figure 7-2: Flood defence assets to be raised or new assets required for a 200 year standard with 300mm freeboard

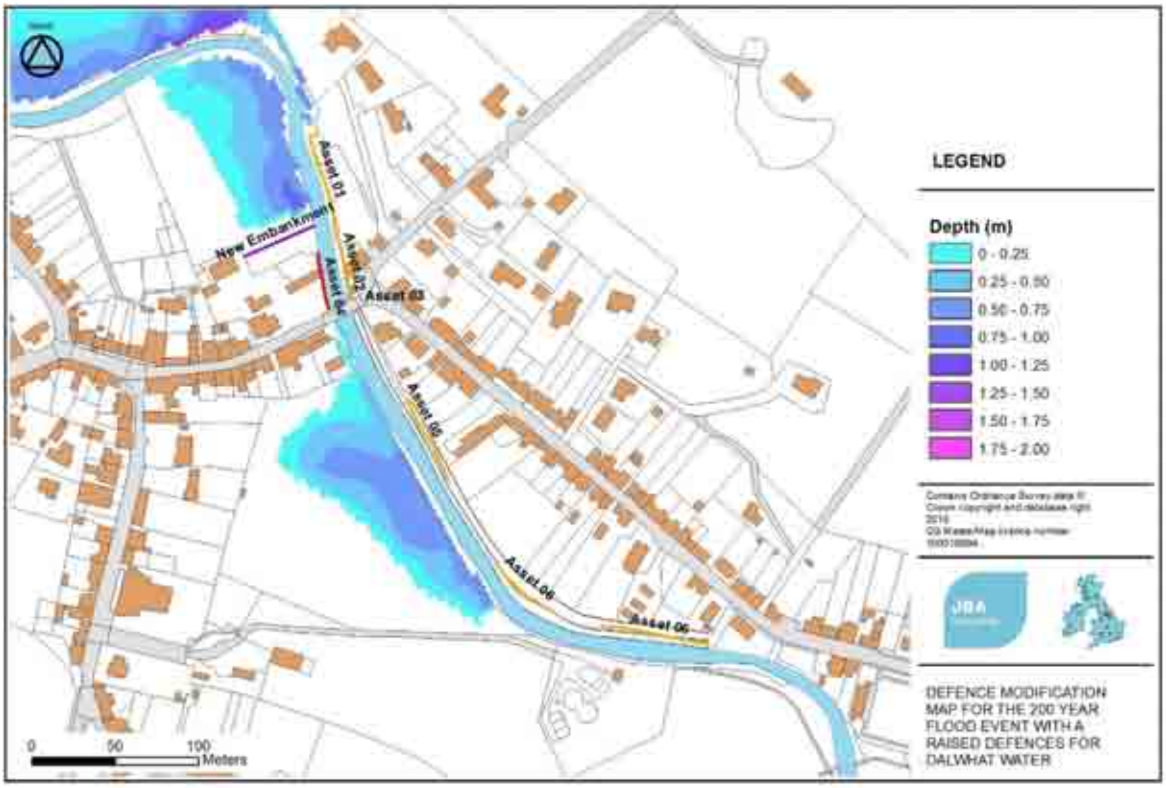


Figure 7-3: Flood defence assets to be raised or new assets required for a 200 year plus climate change flood with 300mm freeboard (plan shows additional flood routes with climate change)

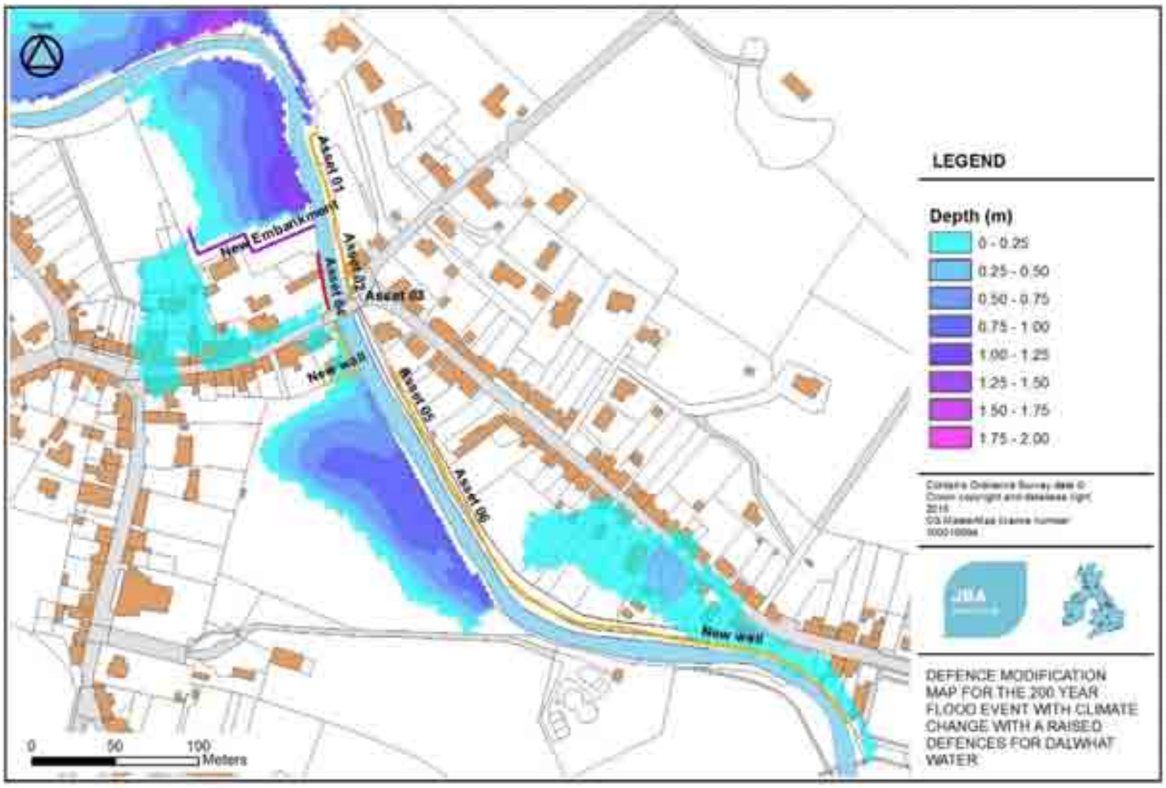
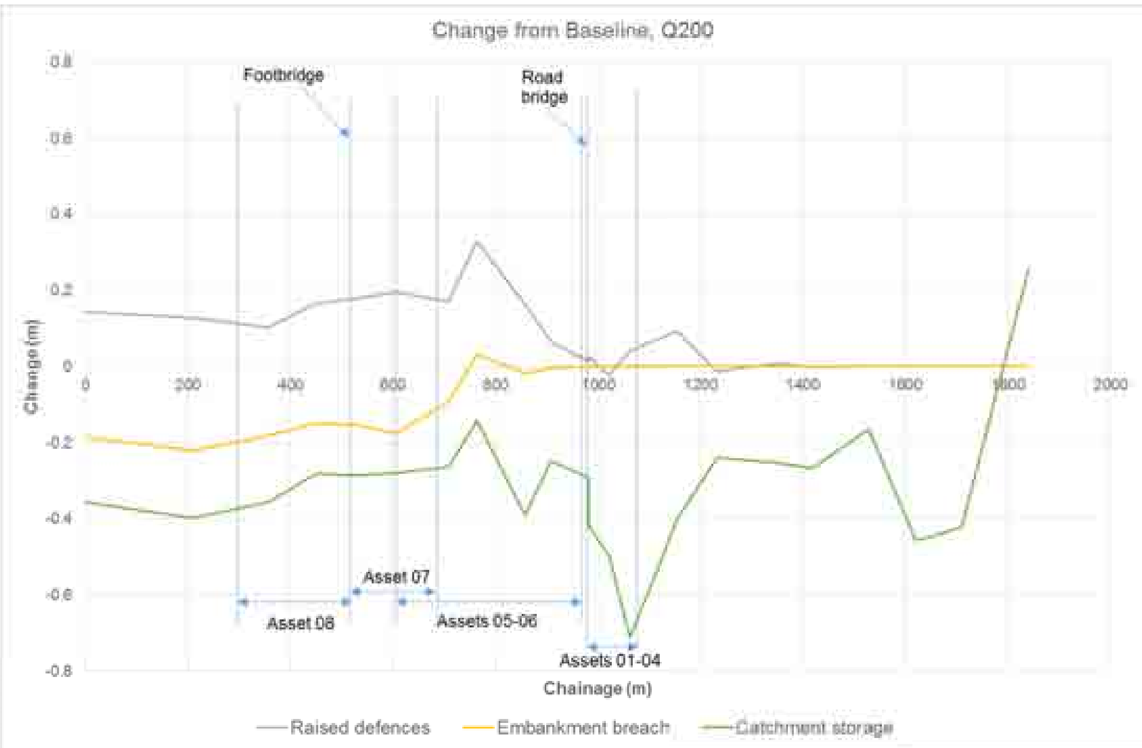


Table 7-2: Estimated defence length and height in metres (includes a 300mm freeboard)

Asset	200 year length (m)	200+CC year length (m)	200 year average increase in height (m)	200+CC year average increase in height (m)
Asset 1	57	57	0.45	0.64
Asset 2	26	26	0.11	0.31
Asset 3	1.4	1.4	0.11	0.31
New embankment	43	99	1.2	1.2
Asset 4	34	34	N/A	N/A
Asset 5	23	45	0.15	0.26
Asset 6	135	225	0.11	0.27

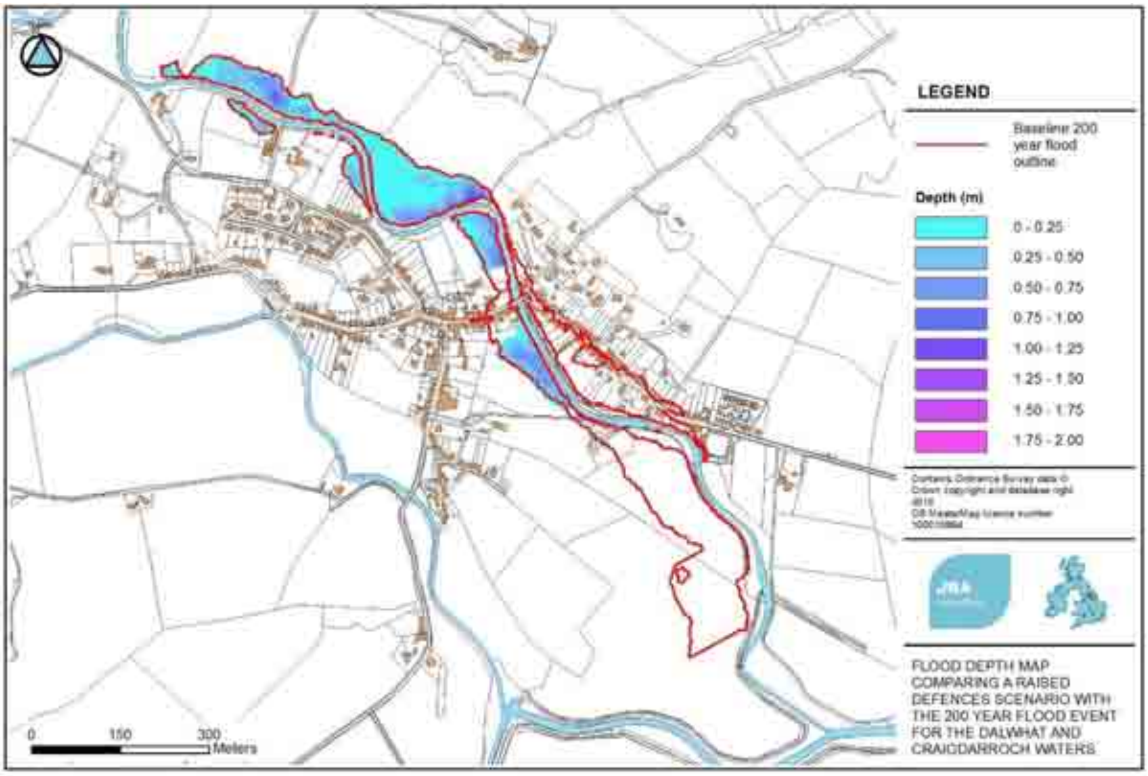
This option has been modelled by raising the flood defences either side of the river to generate a defended flood outline and to estimate the design levels and the impact on flood levels. The change in water surface for this option is shown in Figure 7-5 indicating that this option would increase flood levels by 200-300mm. This has been incorporated into the raised defence levels in Table 7-4.

Figure 7-4: Water surface comparison for the 200 year event (all options)



The resultant flood depth map and a comparison with the undefended flood outline is shown in Figure 7-5.

Figure 7-5: Flood map comparison between Do Minimum and Raised Defence Option



Outcome: This option would mitigate flood risk to Moniave from the Dalwhat Water up to a 200 year or 200 year plus climate change flood. Benefits and costs of this option to be assessed.

7.5 Option 3 - Breaching of embankment

The embankment that represents Assets 7 and 8 (see Figure 4.1) protects agricultural land only. There is no urban flood risk function to this embankment, however it is an important footpath for the community as it provides a link between the school and the playing fields that avoids the main road which has no pavement.

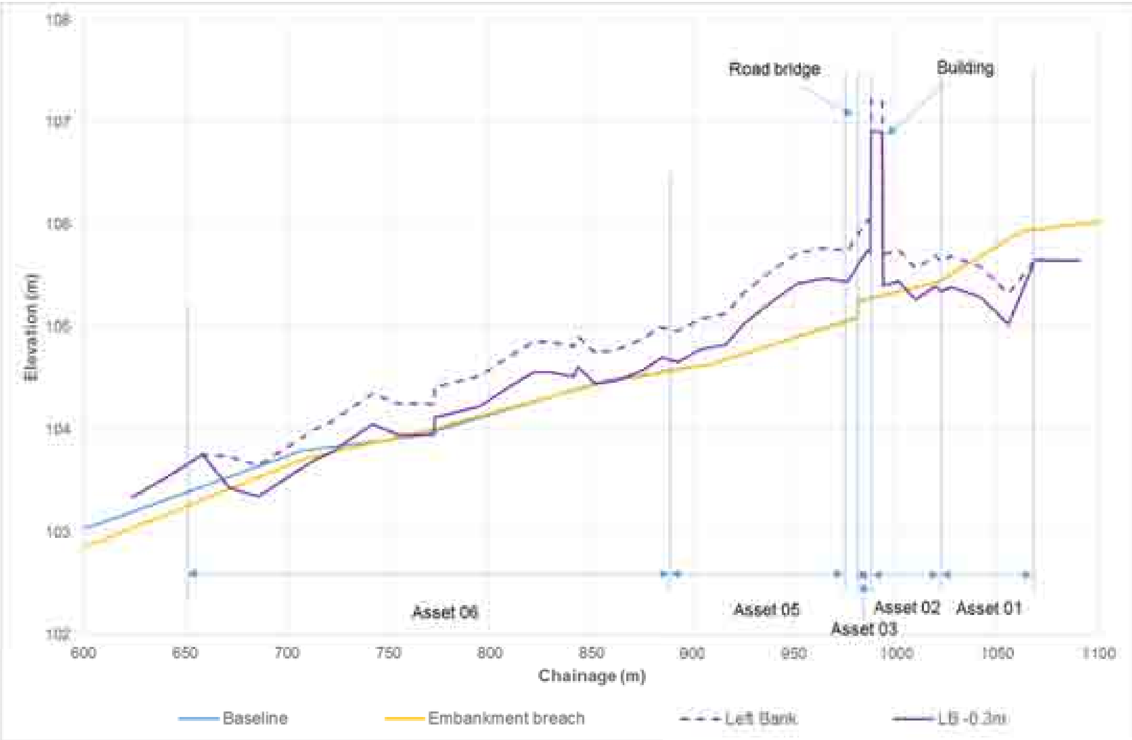
Figure 7-6: Embankment in downstream reach (Assets 7 & 8)

The embankment, whilst providing flood free access across the river, artificially raises water levels within the defended reach upstream. The breaching of the embankment (combined with bridging to retain access) could lower water levels within this reach. Modelling tests have been undertaken to test the impact of this. 2 breaches were modelled to test the impact. The impact on flood levels is shown in Figure 7-4.

The modelling results suggest that this option in isolation will not substantially reduce flood risk in Moniaive. However, the option, as modelled, suggests that flood levels could be lowered by approximately 200mm locally. This impact is however constrained to the lower reach and does not extend as far upstream as the A702 road bridge. The limited impact on the flood outline is constrained as the option does not lower flood levels upstream of the A702 road bridge which is the main flood route on the left bank through the village.

The option does reduce levels sufficiently to achieve a 300mm freeboard to the defence crest for Assets 5 and 6 for much of the defence length (apart from the downstream end of Asset 6). This is shown in Figure 7-9 but is a marginal benefit.

Figure 7-7: Impact of breaching the embankment on flood levels



Outcome: This option has marginal benefits on its own and does not significantly improve the standard of protection. This option is not assessed further, but a combined option may be more appropriate.

7.6 Option 4 - Breached embankment and raised defences upstream

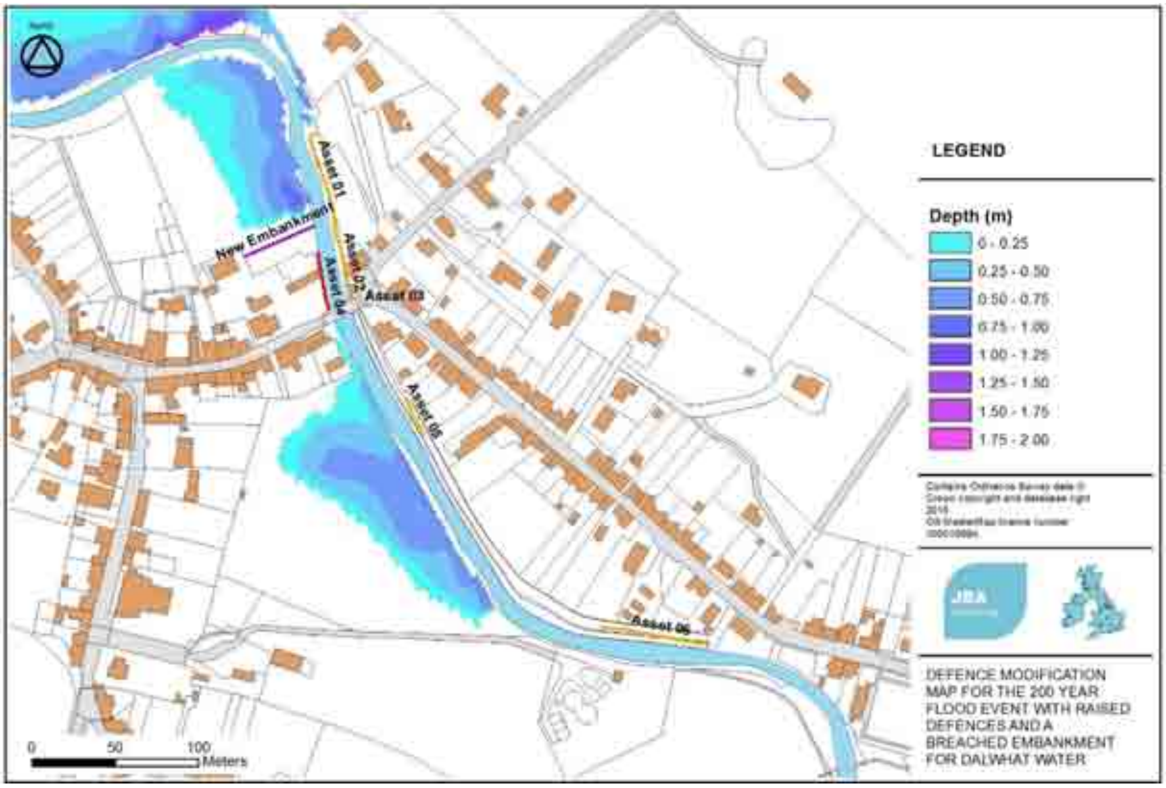
For the 200 year standard, Assets 5/6 only need to be raised to provide the necessary freeboard. They are currently high enough to protect against a 200 year flood, but without any freeboard between flood levels and the crest elevation. The breaching of the embankment has the potential to reduce the 200 year flood levels associated with these assets to the point that raising of the defences is not required. Furthermore, the breaching of the embankment is anticipated to be less disruptive and more cost effective than raising the defences.

For this option to work however, additional works would be required to raise the flood defences on the left bank upstream of the A702 road bridge (Assets 1, 2 and 3) and a new flood embankment on the right bank to limit the flow path to the garage.

This option is only viable up to the 200 year standard. The inclusion of increased flows for climate change is not viable as the necessary freeboard to the top of bank for Assets 5 and 6 cannot be achieved (meaning that the defence would need to be raised anyway).

This option has not been specifically modelled, but would achieve the same flood outline as shown in the direct defence option and would be a cheaper option as it should remove the need for any works to the left bank embankment downstream of the A702 road bridge.

Figure 7-8: Flood defence assets to be raised or new assets required for a 200 year standard with 300mm freeboard



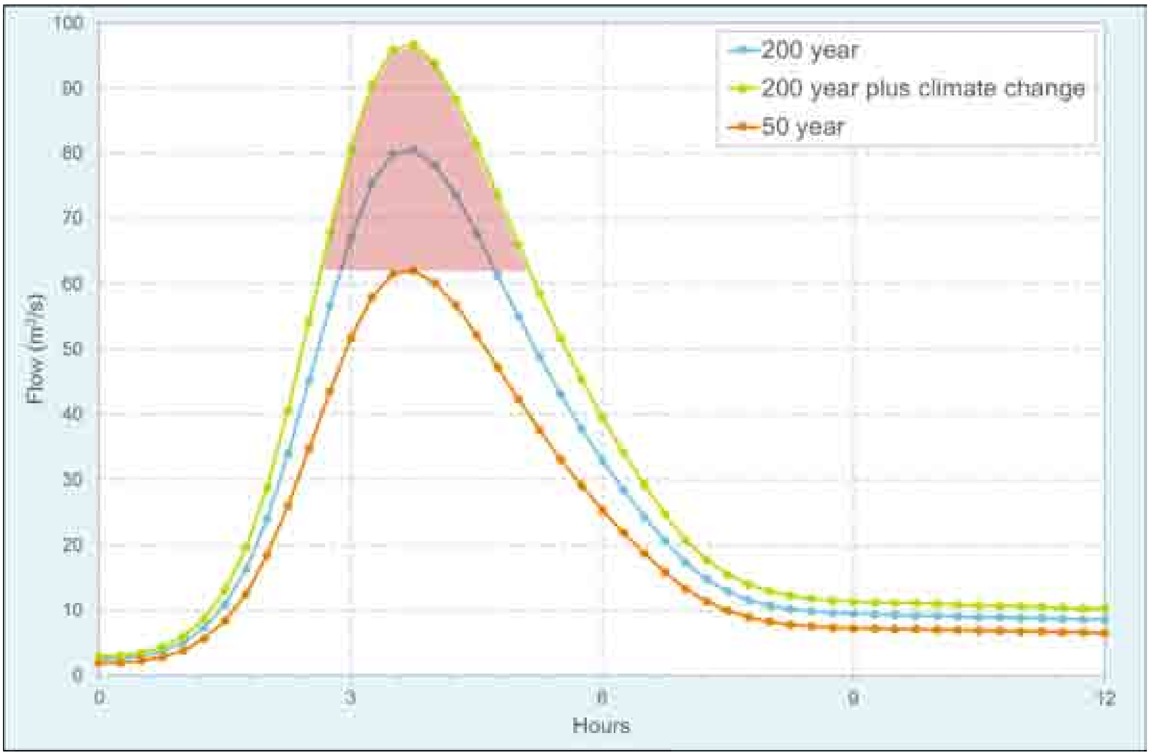
Outcome: This option would mitigate flood risk to Moniaive from the Dalwhat Water up to a 200 year flood. Benefits and costs of this option to be assessed.

7.7 Option 5 - Flood Storage

Flood attenuation via a storage basin or dam upstream of Moniaive would need to attenuate the 200 year flood (or the 200 year plus climate change flood) flow to the current standard of protection (the 50 year flood). This equates to the following reductions in flood flows:

- 200 year peak flow of 81m^3/s to a 50 year peak flow of 62m^3/s (19m^3/s reduction or 25% in peak flow)
- 200 year plus climate change peak flow of 97m^3/s to a 50 year peak flow of 62m^3/s (35m^3/s reduction or 37% in peak flow)

The volume of flood water between the 50 year and 200 year return period floods is in the region of 165,000m^3. This rises to 280,000m^3 for the 200 year with an allowance for climate change.



The actual storage required will be greater than the estimated volumes quoted above due to the presence of a flow control, the need to assess critical durations and the attenuation required to reduce the 200 year event to the 50 year event. Based on experience from previous studies, a factor of 2 to 3 may need to be applied to the estimated storage volumes to estimate the actual volume required. Thus, the volume to be stored may need to be in the region of 400,000m^3 - 700,000m^3 for the 200 year and 200 year plus climate change designs respectively.

Assuming that the total volume would need to be stored behind a dam and that the recent White Cart scheme storage reservoirs are a similar size and cost approximately £10/m^3 of stored water, the total cost of storage on the Dalwhat Water could be in the region of £4-7million.

There is little urban development upstream constraining options for flood attenuation, however areas for storage are limited due to the fact that

- Areas on the valley bottom may already be used by river flow in an event, and
- Steep channels mean that storage length behind any dam would be limited, and
- The minor road along the valley bottom would constrain any dam location.

Flood attenuation is unlikely to be a viable option due to the lack of suitable locations for attenuation, the large costs and the limited benefits. Smaller storage options as part of a catchment natural flood management approach may be more applicable in the long term.

Outcome: This option could significantly improve the standard of protection assuming a suitable site could be found to provide the flood storage. However, the benefits of flood attenuation are limited and the costs are unlikely to make this a viable option. This option is not assessed further.

7.8 Summary of options assessed

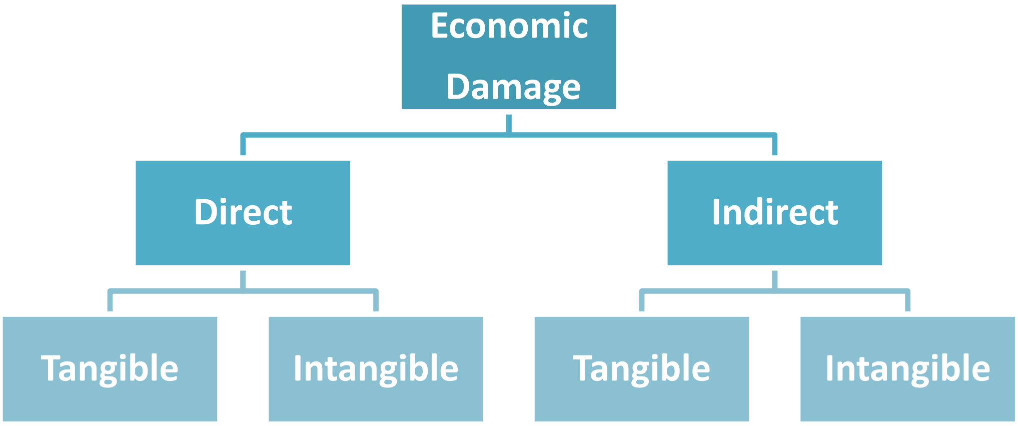
Based on the long list and short list appraisal of options assessed above we recommend that the following options are considered further in the economic appraisal:

- Do Minimum
- Option 1 - Property Level Protection
- Option 2 - Raised Defences
- Option 4 - Breached embankment and raised defences upstream

8 Damage methodology

Flood damage assessment can include direct, indirect, tangible and intangible aspects of flooding, as shown in the Figure 7-1. Direct damages are the most significant in monetary terms, although the MCM and additional research provide additional methodologies, recommendations and estimates to account for the indirect and intangible aspects of flood damage.

Figure 8-1: Aspects of flood damage



Flood damage estimates have been derived for the following items:

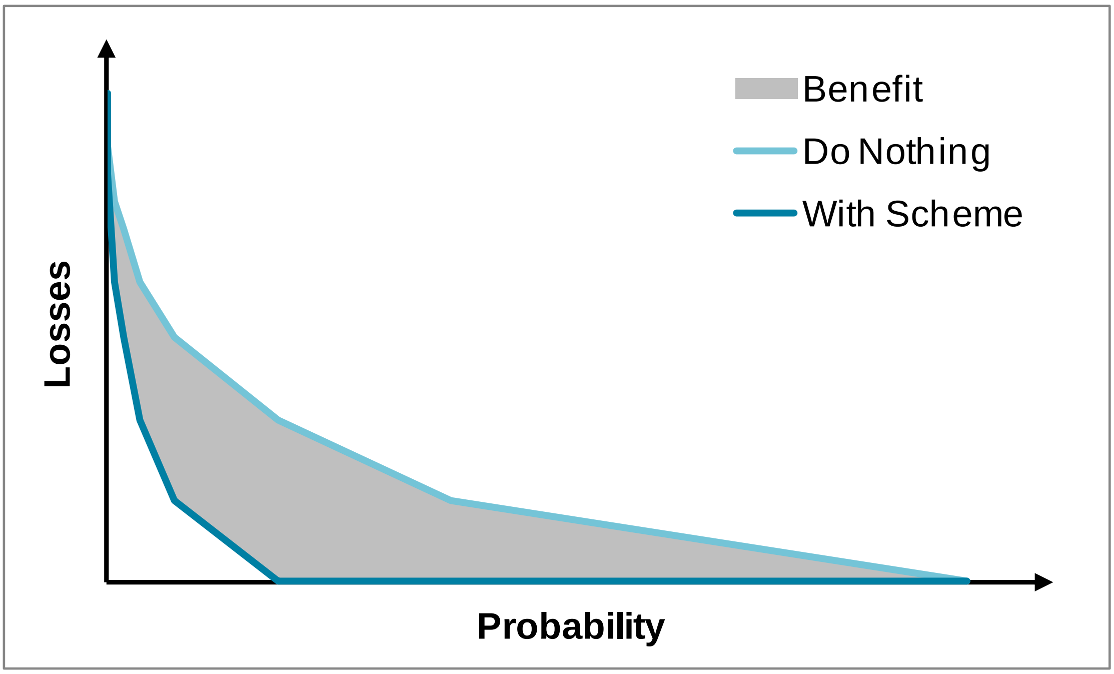
1. Direct damages to residential properties;
2. Direct damages to commercial and industrial properties;
3. Indirect damages (emergency services);
4. Intangible damages associated with the impact of flooding;
5. Damage to vehicles;
6. Emergency evacuation and temporary accommodation costs.

The following assumptions and additional data were used to improve and provide the necessary information to supplement the above datasets.

8.1 Direct damages - methodology

The process to estimate the benefits of an intervention option is to plot the two loss-probability curves: that for the situation now, and that with the proposed option as shown in Figure 7-2. The scale on the y axis is the event loss (£); the scale on the x axis is the probability of the flood events being considered. When the two curves are plotted then the difference in the areas beneath the curve is the annual reduction in flood losses to be expected from the scheme or mitigation approach.

Figure 8-2: Loss Probability Curve



To derive these two curves, straight lines are drawn between the floods for which there are data from the threshold event (the most extreme flood which does not cause any damage) to an extreme flood above the intended standard of protection. The greater the number of flood event probabilities, the more accurately the curves can be plotted.

8.1.1 Flood damage calculation and data

The FHRC Multi Coloured Manual (MCM) provides standard flood depth/direct damage datasets for a range of property types, both residential and commercial. This standard depth/damage data for direct and indirect damages has been utilised in this study to assess the potential damages that could occur under each of the options. Flood depths within each property have been calculated from the hydraulic modelling by comparing predicted water levels at each property to the surveyed threshold levels.

A flood damage estimate was generated using JBA's in-house flood damage tools. These estimate flood damages using FHRC data and the modelled flood level data. Each property data point was mapped on to its building's footprint. A mean, minimum and maximum flood level within each property is derived using GIS tools based on the range of flood levels around the building footprint. The inundation depth is calculated by comparing water levels with the surveyed threshold level. The mean (based on mean flood water level across the building floor's area) flood damage estimates have been calculated and are presented in Table 8-2.

The following assumptions, presented in the Table 8-1, were used to generate direct flood damage estimates.

Table 8-1: Damage considerations and method

Aspect	Values used	Justification
Flood duration	<12hrs	Flood water is not anticipated to inundate properties for prolonged periods.
Residential property type	MCM codes broken down by type and age.	Appropriate for this level of analysis.
Non-residential property type	Standard 2013 MCM codes applied.	Best available data used.
Upper floor flats	Upper floor flats have been	Whilst homeowners may be

Aspect	Values used	Justification
	removed from the flood damage estimates.	affected it is assumed that no direct flood damages are applicable.
MCM damage type	MCM 2013 data with no basements.	Most up to date economic analysis data used. Basements are not appropriate for the type of properties within the study area.
MCM flood type	MCM 2013 fluvial depth damages for combined fluvial-tidal scenario.	Best available data used.
Threshold level	Thresholds surveyed by surveyor for the majority of properties in area of interest.	Best available data used.
Socio-economic equity	Distributional Impacts (DI) impacts derived from the 2001 census show no significant difference in "DE" social grades compared to the national average.	As per Treasury Green Book recommendations, analysis of DI is not deemed to be necessary and has been excluded.
Property areas	NEXTMap used to define property floor areas.	Best available data used.
Capping value	Residential properties based on house prices from Zoopla. Commercial properties valued from rateable values for individual properties (supplied by SAA).	Best available data used.

8.1.2 Property data set

The property dataset was compiled for all residential and commercial properties. The majority of these properties were visited by a JBA Surveyor during the threshold survey.

8.1.3 Capping

The FHRC and appraisal guidance suggests that care should be exercised for properties with high total (Present Value) damages which might exceed the market value of the property. In most cases it is prudent to assume that the long-term economic losses cannot exceed the capital value of the property.

The present value flood damages for each property were capped at the market value using average property values obtained from internet sources (e.g. Zoopla).

Market values for non-residential properties were initially estimated from a properties rateable value based on the following equation:

Capital Valuation = (100/Equivalent Yield) x Rateable Value

Rateable values for all available properties in Moniaive were obtained from the Scottish Assessors Association website[14]. Equivalent yield varies regionally and temporarily, but is recommended to be a value of 10-12.5 for flood defence purposes[15]. A value of 12.5 was used.

However the resulting property valuations were judged as been undervalued. An alternative approach was used where by the estimated value is 3 times the max depth damage MCM curve damage value for the commercial property type multiplied by the properties ground floor area.

8.1.4 Updating of Damage Values

The MCM data used is based on January 2015 values and therefore do not need to be brought up to date to compare the costs and benefits.

[14] www.saa.gov.uk
[15] Environment Agency (2009). Flood and Coastal Erosion Risk Management - Appraisal Guidance.

8.1.5 Socio-economic equity

Work on the impacts of flooding on individuals has shown that flooding may affect people according to aspects such as their income. The rationale being that a loss will matter more to a person on low income compared to someone with a high income. Current advice from the Scottish Government, based on advice from the Treasury Green Book recommends that Distributional Impacts (DI) analysis should be undertaken if it is 'necessary and practical'. Analysis has been carried out with and without the influence of Distributional Impacts.

Assessing whether it is necessary is based on the mix of social grades and levels of income within the appraised area. Analysis of the 2001 Census data for Moniaive indicates that there are a high proportion of lower social group households. Table 8-2 illustrates this proportion and indicates that 25% of people in Moniaive are in the 'DE' social grade. This is less than the Scottish avertage and less than the average for Dumfries and Galloway, thus the analysis of DI is deemed not to be necessary.

Table 8-2: Proportion of social grades within Moniaive

Location	AB	C1	C2	DE
Moniaive	17%	32%	26%	25%
Dumfries & Galloway	14%	25%	32%	30%
Scotland	19%	31%	24%	26%
Difference	-2%	1%	2%	-1%
The total number of people represents those aged 16+ for which a grade can be applied.				

The above analysis suggests that if comparing Moniaive with another area requiring funding, the socio-economic aspects of flooding should not be considered as a pound spent at Moniaive is unlikely to have a greater benefit than that spent at an alternative location with a lower social impact.

We recommend that distributional impacts are not considered at this stage and the recommended scaling of the total damages by the social grade weighting factors provided in Table 7-4 is not undertaken.

Table 8-3: Total weighted factors by social grade group

Class	AB	C1	C2	DE
Weighting	0.74	1.12	1.22	1.64
Factors are provided in Chapter 5 (section 4.1.22) of the Scottish Government's Flood Prevention Scheme guidance document.				

8.2 Intangible damages

Current guidance indicates that the value of avoiding health impacts of fluvial flooding is of the order of £286 per year per household. This value is equivalent to the reduction in damages associated with moving from a do-nothing option to an option with an annual flood probability of 1:100 year standard. A risk reduction matrix has been used to calculate the value of benefits for different pre-scheme standards and designed scheme protection standards.

8.3 Indirect damages

The multi coloured manual provides guidance on the assessment of indirect damages. It recommends that a value equal to 10.7% of the direct property damages is used to represent emergency costs. These include the response and recovery costs incurred by organisations such as the emergency services, the local authority and SEPA.

8.3.1 Indirect commercial damages

Obtaining accurate data on indirect flood losses is difficult. Indirect losses are of two kinds:

- losses of business to overseas competitors, and

- the additional costs of seeking to respond to the threat of disruption or to disruption itself which fall upon firms when flooded.

The first of these losses is unusual and is limited to highly specialised companies which are unable to transfer their productive activities to a branch site in this country, and which therefore lose to overseas competitors. The second type of loss is likely to be incurred by most Non Residential Properties (NRPs) which are flooded. They exclude post-flood clean-up costs but include the cost of additional work and other costs associated with inevitable efforts to minimise or avoid disruption. These costs include costs of moving inventories, hiring vehicles and costs of overtime working. These costs also include the costs of moving operations to an alternative site or branch and may include additional transport costs.

Chapter 5, Section 5.7 of the MCM (2013)[16] recommends estimating and including potential indirect costs where these are the additional costs associated with trying to minimise indirect losses. This is by calculating total indirect losses as an uplift factor of 3% of estimated total direct NRP losses at each return period included within the damage estimation process.

8.3.2 Evacuation losses

The MCM (2013) provides guidance on the losses associated with evacuation (getting people safely out of homes during an event and temporary accommodation costs whilst properties are repaired). Costs recommended are based on flood depths and property type as shown in the Table 7-5. Total property counts per return period for each depth classification have been extracted and used to total evacuation losses based Mid values of Table 7-5.

Table 8-4: Evacuation losses from the FHRC MCM (2013)

MAXIMUM DEPTH INSIDE PROPERTY (CM)	EVACUATION COSTS BY PROPERTY TYPE (£)											
	DETACHED			SEMI-DETACHED			TERRACED			FLAT		
	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High
0-1	681	1,007	1,631	609	865	1,419	588	838	1,387	532	782	1,330
1-10	1,308	1,928	3,126	1,169	1,653	2,714	1,126	1,600	2,652	1,018	1,491	2,540
10-20	2,511	3,662	5,954	2,232	3,108	5,126	2,146	3,002	5,001	1,928	2,781	4,776
20-30	2,694	3,928	6,387	2,394	3,334	5,499	2,302	3,221	5,364	2,069	2,984	5,123
30-60	3,625	5,269	8,575	3,216	4,458	7,363	3,090	4,303	7,179	2,772	3,980	6,850
60-100	4,342	6,299	10,256	3,848	5,320	8,793	3,696	5,134	8,572	3,312	4,744	8,175
100+	6,965	10,045	16,383	6,154	8,438	13,981	5,905	8,132	13,617	5,275	7,491	12,965

8.3.3 Vehicle losses

Chapter 4, Section 4.5.7 of the MCM (2013) recommends that the average loss associated with vehicle damage during flood events should be determined using a value of £3,600 per property flooding to a depth greater than 0.35m. This value has been applied to all properties flooding to a depth greater than 0.35m within Moniaive for each return period flood event assessed and the AAD and PVd calculated as normal.

[16] Penning-Rowsell et al., 2013. Flood and Coastal Erosion Risk Management - A Manual for Economic Appraisal

9 Summary of total flood damages

9.1 Properties at risk

The total number of properties inundated for the Do Minimum Scenario has been assessed are provided in Table 9-1.

Table 9-1: Number of properties flooded within appraisal area for the Do Minimum Scenario

	2 year	5 year	10 year	25 year	50 year	100 year	200 year	1000 year
Residential	0	0	0	0	0	4	11	41
Non-residential	0	0	0	0	1	2	8	18
Total	0	0	0	0	1	6	19	59

9.2 Do Minimum event damages

Event damages have been calculated for a range of return periods. The FRISM output provides event damages based on MCM depth damage curves. Full results are provided in Appendix H. The event damage for each option is provided in Table 9-2. These represent the total potential flood damages based on the modelled flood levels for Moniaive for the current existing case. Damages include all direct and indirect property flood damages.

Table 9-2: Total property flood damage for each scenario (£) (prior to capping)

	25 year	50 year	100 year	200 year	1000 year
Residential	0	0	54,481	228,113	957,337
Non-residential	0	370	3,861	226,442	878,875
Total	0	370	58,343	454,555	1,836,212

9.2.1 Calibration

Flood mapping and property damages were presented to the public at a public meeting in Moniaive on the 16 November. Following this, the results of the flood damages were adjusted to ensure that the results are as accurate as possible. This is acceptable due to the anecdotal evidence collected from recent flooding at Moniaive and the uncertainty in flood mapping due to the lack of LiDAR data within the region.

Properties along Dunreggan were adjusted to ensure that those that were not shown to be at risk were included in the analysis and the flood depths adjusted based on anecedotal evidence of property inundation flood depths collected during the public meeting. The revised property counts and flood damages are provided in Table 9-3.

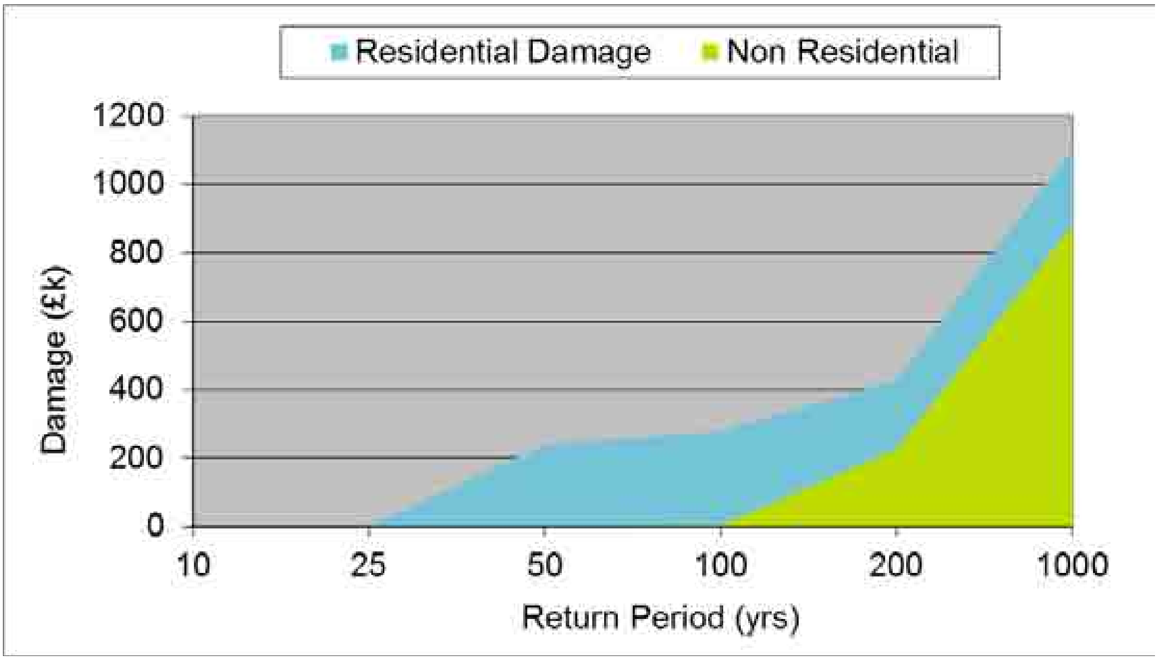
Based on the validation of the model results against observed flood levels in Section 4.2, the estimated properties at risk for the 100 year - 200 year flood seem to match the number of properties flooded in the most recent flood events. However, without river flow gauging there is uncertainty in the river flows and whether the two December events were actually this large. A further sensitivity test on the economic damages is provided in Section 11.5 to test the uncertainty in flow estimates.

Table 9-3: Total property flood damage for each scenario (£) (prior to capping)

	25 year	50 year	100 year	200 year	1000 year
Total properties at risk	0	10	14	26	63
Total damages	0	241,161	281,866	653,094	1,988,583

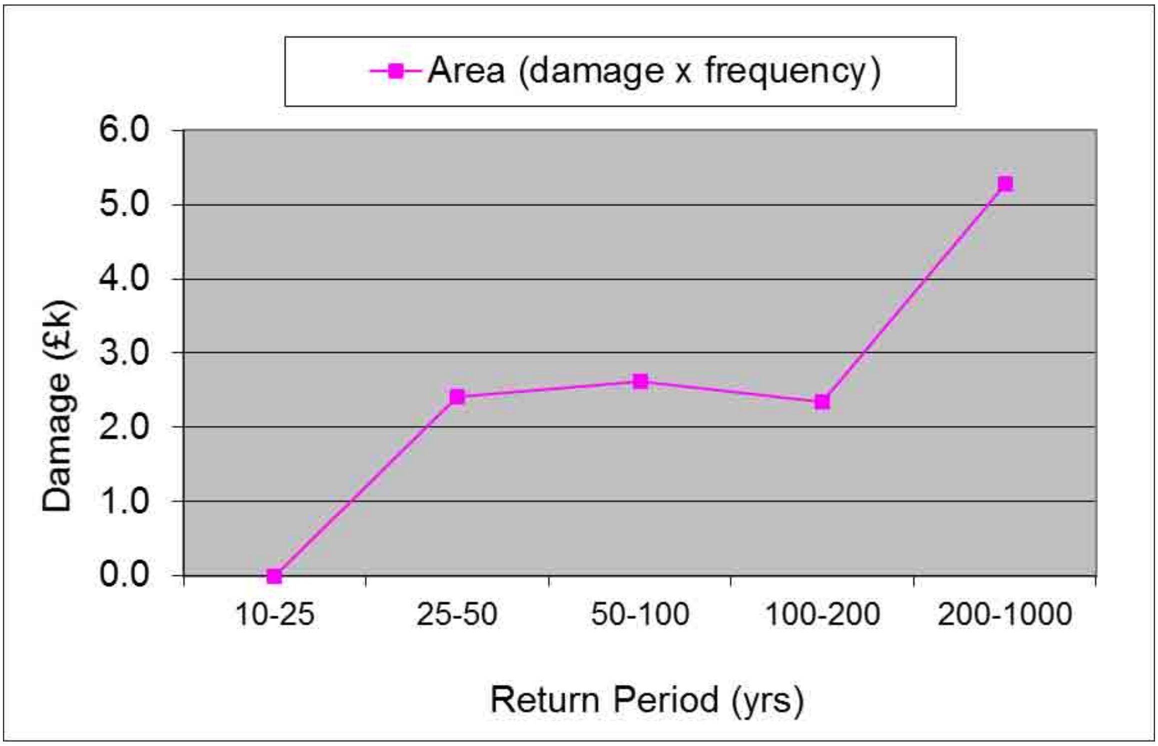
The above damages are used to calculate Annual Average Damages (AAD). Plotting the damages against the frequency of flooding (annual probabilities) allows us to determine the AAD as the area beneath the curve (Figure 9-1). This figure shows that flood damages are relatively small for the lower to medium flood events, but rises significantly for the more extreme flood events.

Figure 9-1: Loss probability curve for the Do Minimum baseline



Typically, the majority of the benefits arise from the reduction in losses from the more frequent events. The interval benefits for Moniaive are presented in Figure 9-2. This shows that the majority of flood damages occur at the higher, less frequent flood events.

Figure 9-2: Interval benefits for the Do Minimum baseline



9.2.2 Key beneficiaries

The flood damages derived have been ranked and assessed in terms of the proportion of flood damages per property. This highlights key beneficiaries of the scheme and is a useful auditing tool. The top 10 properties with highest flood damages from all sources have been listed in Table 9-4 below.

This illustrates that the highest flood damages are generated from a mix of residential and commercial properties. The properties listed correspond to the area of previous known flooding and ponding of flood water

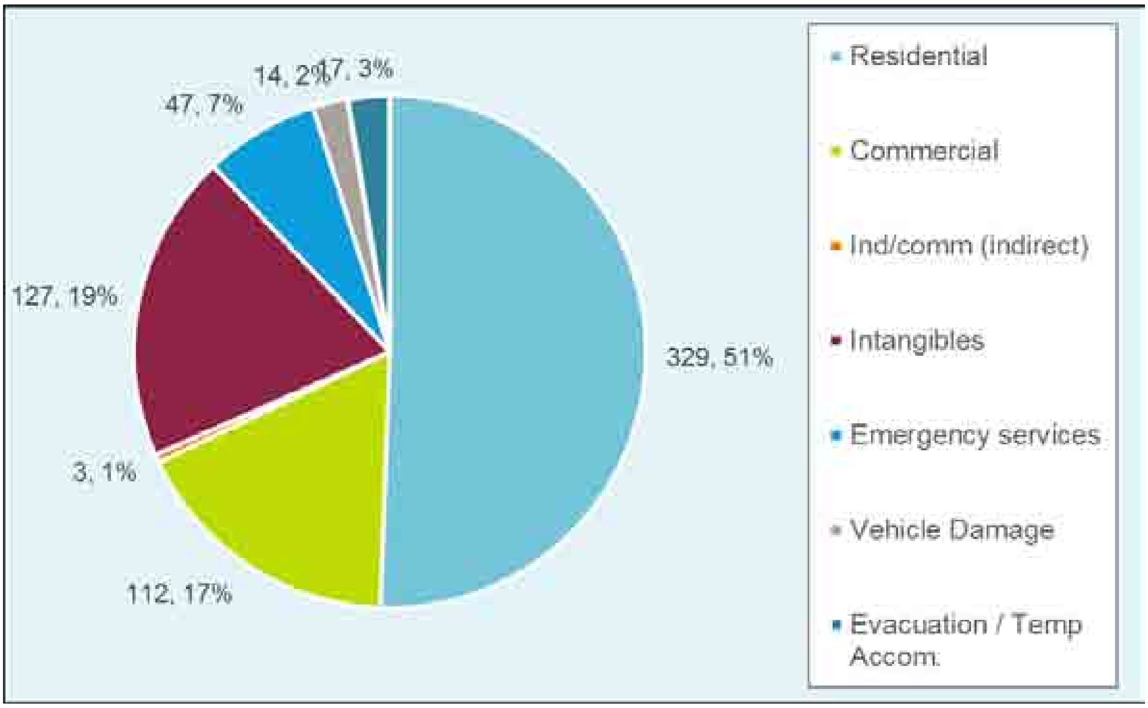
Table 9-4: Top 10 highest damage contributors for the Do Minimum Scenario

Rank	Property address	PVd (£k)	Percentage of total PVd
1	TOLL COTTAGE	55.2	13%
2	CRAIGOWER	52.7	12%
3	THE GEORGE HOTEL	35.7	8%
4	MUIR COTTAGE	27.2	6%
5	WOODBINE	25.0	6%
6	1 BRIDGEND COTTAGE	20.4	5%
7	CRAIGDARROCH ARMS HOTEL	18.0	4%
8	MO-DHACHAIDH	17.5	4%
7	CNOCRUADH	16.7	4%
10	DALWHAT GARAGE	12.7	3%

9.2.3 Do Minimum Indirect and intangible damages

The indirect and intangible damages have been estimated for the Do Minimum option based on the methodology outlined in the Chapter 8. A summary of the total and proportion of damages by damage component is provided in Figure 9-3.

Figure 9-3: Total PV damages for the Do Nothing by damage component (£k)



9.3 Option 1 - Property Level Protection Damages

Analysis of the property level protection option has been assessed by reducing flood damages for those properties at risk that have flood depths less than 0.6m. The total flood damages for each modelled return period is presented in Table 9-5.

Even with PLP there is generally some residual damage as a result of flooding, such as damage due to overtopping of PLP products for properties with depths exceeding 0.6m.

Table 9-5: Comparison of Do Minimum and PLP properties at risk and direct property damages (£k)

Scenario	25 year	50 year	100 year	200 year	1000 year
Do Minimum - properties at risk	0	10	14	26	63
PLP Option - properties at risk	0	0	1	4	20
Do Minimum - flood damages	0	241	282	653	1,989
PLP Option - flood damages	0	0	3	119	805

Total AAD and PVd for the PLP option is presented in Table 9-6. The use of PLP reduces damages by approximately 80% compared to the Do Minimum baseline assuming all properties at risk have PLP installed.

Table 9-6: Summary of flood damages for direct defence option (£k)

Scenario	AAD damages (£k)	PV direct damage (£k)	PV indirect damage (£k)	PV total damage	PV damage avoided (£k)
Do Minimum	14.8	441	209	650	-
Option 1 - PLP (200yr)	3.1	91	31	122	528 (475)

It is assumed that the damages avoided by the PLP option are reduced by 10% to allow for the risk of failure of the measures during flood events (operator or product failure). This reduces the damages avoided from £528k to £475k. A small reduction is applied as the assumption is that automatic measures would be used in Moniaive.

9.4 Option 2 - Raised defences

Analysis of the raised defence option has been assessed by assuming zero flood damages for each return period assessed up to and including the design flood. Flood damages for above design events are assumed to be the same as the Do Minimum option. The total flood damages for each modelled return period are presented in Table 9-7.

Table 9-7: Comparison of Do Minimum and raised defence option properties at risk and direct property damages (£k)

Scenario	25 year	50 year	100 year	200 year	1000 year
Do Minimum - properties at risk	0	10	14	26	63
Raised Defences Option - properties at risk	0	0	0	0	63
Do Minimum - flood damages	0	241	282	653	1,989
Raised Defences Option - flood damages	0	0	0	0	1,989

Total AAD and PVd for the Raised Defence option is presented in Table 9-8. The raising of defences reduces flood damages by approximately 60% compared to the Do Minimum baseline. This option provides a 200 year standard of protection to the community.

Table 9-8: Summary of flood damages for direct defence option (£k)

Scenario	AAD damages (£k)	PV direct damage (£k)	PV indirect damage (£k)	PV total damage	PV damage avoided (£k)
Do Minimum	14.8	441	209	650	-
Option 2/4	6.2	185	53	238	412

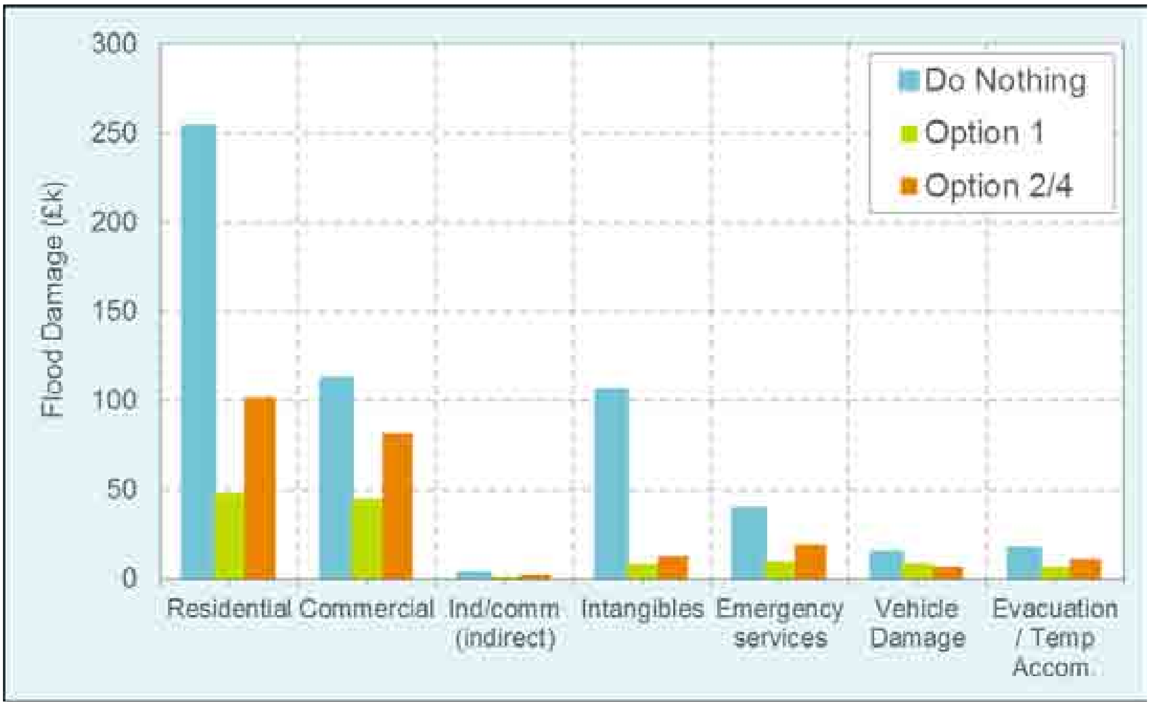
9.5 Option 4 - Breached embankment and raised defence upstream

Analysis of the raised defence option has been assessed by assuming zero flood damages for each return period assessed up to and including the design flood. Flood damages for above design events are assumed to be the same as the Do Minimum option. The total flood damages for each modelled return period are therefore the same as those calculated for Option 2 as a 200 year standard of protection can be achieved.

9.6 Summary of flood damages

A summary of the damage reductions for each option assessed by damage category is provided in Figure 9-4 below. This shows that Option 1 (PLP) significantly reduces flood damages. Options 2 and 4 (raised defences and a combined breach and raised defence option) do not significantly reduce flood damages. This difference is partly due to the fact that the PLP scheme would also benefit properties for above design events.

Figure 9-4: Total PV damages for each option assessed broken down by damage component (£k)



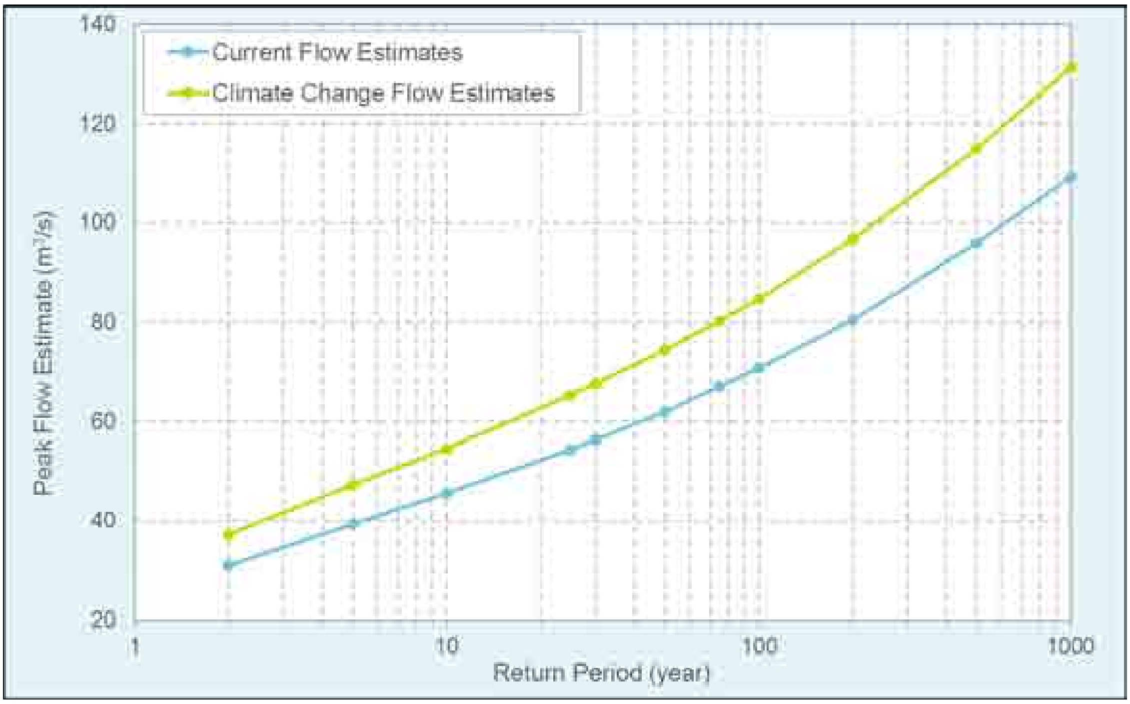
9.7 Impact of climate change

The impact of climate change over the life of a scheme was undertaken to see if the impact of a 20% increase in flood flows by 2080 for all return periods assessed would significantly increase the flood damages and thus the benefits of protecting the scheme to a 200 year standard with an allowance for climate change. The assumption is that over the life of the scheme, and assuming that the design included the allowance for increasing flows, the economic benefits would increase over the scheme life.

This has been assessed by estimating what a specific return period today would be by 2080 assuming a 20% uplift in flows for all return periods. An example of this process is shown graphically in Figure 9-5. The chart shows that, for example, a 200 year flood today will be equivalent to 75 year flood in 2080. The severity of the flood will be the same but it will be occurring more regularly on average.

Figure 9-5 highlights the importance considering climate change. It shows that the current 50 year standard of protection would reduce to approximately a 20 year flood by 2080, thus it would be over topped on average every 20 years.

Figure 9-5: Difference in flows under the climate change scenario



9.7.1 Methodology

Guidance on incorporating climate change[17] into benefit-cost assessments recommends that for each option, climate change allowances on flood flows at future time steps are applied over the evaluation period. The economic loss results are summed using agreed discount factors to determine the whole life benefits.

The impact of climate change on the scheme has been assessed by calculating the present day and the 2080 average annual benefits for the Do Minimum and each option. 2080 AAD have been calculated by changing the annual probability for each flood return period assessed, using Figure 9-5 as a guide.

Thus the annual average damages have been derived at years 2015 and 2080. The results for each intervening period have been linearly interpolated and discounted to obtain the total present value damage over the 100 year appraisal period.

9.7.2 Results

Total AADs for the two periods assessed are provided below, along with the resultant whole life present value estimates and damages avoided for each option assuming climate change can be built into the designs.

[17] Defra/EA, 2003. UK Climate Impacts Programme 2002. Climate change scenarios: Implementation for Flood and Coastal Defence Users. R&D Technical Report W5B-029/TR.

Table 9-9: Impact of climate change on Do Minimum scenario (£k)

	AAD damages (£k) 2015	AAD damages (£k) 2080	AAD damages (£k) 2114	PV total damage (£k)	PV damages avoided (£k)
Do Minimum	21.8	56.5	56.5	1,058	
Option 1	4.1	12.1	12.1	216	842 (758)
Option 2/4	8.0	25.7	25.7	446	612

Based on these assumptions, the total flood damages are estimated to increase from £18k per annum at the present day to £57k per annum by 2080. This would increase the baseline present value flood damages from £650k to £1,058k. Damages for Option 1 (PLP) increase from £122k to £216k (without any adjustment for reliability) and damages for Options 2 and 4 increase from £238k to £446k.

10 Cost estimates

10.1 Price Base Date

The price base date is January 2015. Cost calculations have therefore been updated to the same date in order to compare the benefits and costs on an equal basis. The costs and benefits have been discounted over the 100 year life of the scheme to determine present values.

10.2 Whole life cost estimates

The outputs from SEPA's 'Costing of Flood Risk Management Measures'[18] project were used for the purpose of this assessment. This project was undertaken by JBA and provided a range of cost summary reports for use by SEPA in their Flood Risk Management Strategies. The data provides a range of costs for a portfolio of flood defence measures and is ideally suited to strategic level studies.

Whole life costs are typically compiled from the following four key cost categories:

1. Enabling costs. These costs relate to the next stage of appraisal, design, site investigation, consultation, planning and procurement of contractors.
2. Capital costs. These costs relate to the construction of the flood mitigation measures and include all relevant costs such as project management, construction and materials, licences, administration, supervision and land purchase costs (if relevant).
3. Operation and maintenance costs. Maintenance of assets is essential to ensure that the assets remain fit for purpose and to limit asset deterioration. Costs may include inspections, maintenance and intermittent asset repairs/replacement.
4. End of life replacement or decommissioning costs. These costs are only required when the design life of assets is less than the appraisal period. Most assets are likely to have a design life in excess of the 100 year financial period, therefore these costs are unlikely.

Whole life (present value) costs have been estimated based on the above enabling, capital and maintenance costs. The following assumptions have been made:

1. The life span of the scheme and appraisal period is 100 years.
2. Discounting of costs are based on the standard Treasury discount rates as recommended by the 2003 revision to the HM Green Book (3.5% for years 0-30, 3.0% for years 31-75 and 2.5% for years 76-99).
3. Capital costs are assumed to occur in year 1 (equivalent to 2016).
4. Enabling costs are assumed to be complete in year 0.

10.3 Optimism bias

An optimism bias of 60% has been applied and is representative of a scheme at the appraisal design stage of development. This provides a significant safety factor for cost implications and risks.

10.4 Option 1 - Property Level Protection costs

In order to assess the economic benefits of PLP the costs of implementation have been determined. A whole life cost approach has been undertaken to ensure that all aspects of the PLP process are included and an appropriate and realistic economic appraisal is provided. Whole life costs estimates were provided by the Scottish Government report 'Assessing the Flood Risk Management Benefits of Property Level Protection'[19]. This project, conducted by JBA, provides cost summaries for use when estimating the costs of community-scale PLP. Therefore in addition to the standard product and installation costs, the following additional cost elements have been included:

[18] SEPA, 2013.Costing of Flood Risk Management Measures (F4006): Category 13 - Fluvial Defence Measures

[19] The Scottish Government, 2014, Assessing the Flood Risk Management Benefits of Property Level Protection: Technical and Economic Appraisal Report

- Survey costs
- Administration costs
- Operation and maintenance costs
- Aftercare and monitoring costs

The costs prepared are a realistic estimate of the total costs of PLP for the options assessed. They cannot cover every eventuality, property type and property construction, but aim to represent the typical costs for a range of properties. It is possible that non-standard, very old/large or listed properties could have significantly higher costs that can only be estimated by professional surveyors and independent property surveys.

Whole life (Present Value) costs (PVc) have been assessed assuming the following:

- A 25 year appraisal period has been assumed
- Standard HM Treasury discount rates assumed
- Enabling, capital, maintenance and intermittent costs assumed

Table 10-1: Whole life cost results for automatic systems (£ per property)

Category	Whole Life Cost - Lower	Whole Life Cost - Average	Whole Life Cost - Upper
Detached	10,772	18,606	25,696
Semi-detached	16,273	17,817	24,682
Terraced	9,197	12,749	17,558
Flat	9,322	12,925	17,784
Shop	17,023	24,206	32,647
Office	19,214	27,274	36,591
Residential average	11,391	15,524	21,430

The cost of PLP as a flood mitigation option for each return has been calculated using the average whole life cost for automatic PLP. Moniaive does not benefit from flood warning, automatic approaches to PLP are assumed in this case as flood warning cannot provide sufficient warning lead time at this location. The costs assume that all costs are born by Dumfries and Galloway Council and none by the residents themselves.

A lower cost option would be to utilise the Council's subsidy scheme in Moniaive. This would have savings as the cost of purchasing the PLP products would be borne by the homeowners.

This PLP option incorporates all properties that have a flood depth less than 0.6m. Table 10-2 outlines the total number of properties at risk in Moniaive that could benefit from PLP. This analysis has been done for both hydrological estimates to highlight the difference between the analysis undertaken.

Table 10-2: Number of properties at risk requiring PLP measures for each hydrological estimate

2 year	5 year	10 year	25 year	50 year	100 year	200 year	200 year CC
-	-	-	-	7	11	24	40

Table 10-3: Whole life (PVc) cost for PLP to all properties (£) assuming a 0.5% or 0.5%CC AP flood standard (protecting only those properties at risk from the 200 year event or the 200 year event with climate change)

Category	Whole Life Cost - Average (£)	Number of properties at risk	Whole Life Cost - Average (£)	Number of properties at risk
	200 year		200 year with climate change	
Detached	£186,060	10	£204,666	11
Semi-detached	£178,170	10	£249,438	14
Terraced	£101,992	8	£203,984	16
Flat	-	0	£12,925	1
Shop	£48,412	2	£72,618	3
Office	£190,918	7	£190,918	7
Total	£705,552	37	£934,549	52

Some non-residential properties do not fit directly into the broad categories used within the 'Assessing the Flood Risk Management Benefits of Property Level Protection' report which meant that the most relevant category was used in each instance.

10.5 Option 2 - Raised flood defences costs

Costs for this option assume that to raise the embankments low walls would be needed on top of the current embankment crests. In some instances it will be necessary to create a new embankment, install wall along a currently undefended reach or to increase the height of walls already in place.

The total length of defence where modelled 0.5% AP flood levels currently exceed the elevation of the current defences is 320m or 640m with 0.5% AP climate change flood levels. Defence increases have been calculated to ensure sufficient freeboard throughout the reach.

The direct defence costs have been based on values provided in SEPA's Cost of Flood Risk Management Measures Report[18]. The cost estimates account for all costs associated with the project over its expected life. Tables of the costs for new walls, raising current walls and sheet piled walls are compiled below in Table 10-4 to Table 10-6.

Table 10-4: Wall cost per metre (£/m)

Length (m)	< 1.2m	1.2 - 2.1 m	2.1 - 5.3m	> 5.3m
Average	1,419	2,905	3,577	1,1168
Minimum	7,75	1,144	1,950	3,505
Maximum	1,624	4,591	4,615	13,105

Table 10-5: Wall raising cost per metre (£/m)

Length (m)	< 1.2m	1.2 - 2.1 m
Average	1,029	2,177
Minimum	7,75	1,073
Maximum	1,378	2,390

Table 10-6: Sheet piling cost per metre (£/m)

Length (m)	Urban < 100m	Urban > 100m	Rural
Average	9,148	2,476	1,843
Minimum	4,168	1,309	370
Maximum	15,565	3,563	2,811

The earth embankments costs were based on a JBA excel tool that works out the average cost per metre of embankment based on the chosen height, crest width (2-3m assumed) and slope (1 in 3 or 1 in 4 assumed). The tool was used to form the basis of the earth embankment cost estimates based on unit rates per m^3 for embankment construction from SEPA's Cost of Flood Risk Management Measures Report[18].

Table 10-7: Embankment cost per metre length (£/m)

Length (m)	50m	100m	250m
Small	1,028	1,028	5,14
Medium	1,798	1,798	1,798
Large	3,340	3,340	2,274

The defences which require additional protection of current assets and those that are wholly new are summarised in Table 10-8 and Table 10-9 below. The height of defences were calculated as an average for each length. The average height of each length of defence was calculated based on flood levels plus 0.3m freeboard and based on current flood levels and ground levels. It is assumed that Asset 04, the sheet piled wall, is not to current design standards and will need to be replaced in full rather than simply raised. For the calculation of PVc Asset 04 was replaced at the same time as the other capital costs occurred.

Table 10-8: Unit and total estimated defence costs - 200 year event

Location	Defence type	Typical defence height (m)	Length (m)	Average Unit cost	Total cost
Asset 01	Wall	0.45	57	£1,419	£80,883
Asset 02	Wall	0.11	28	£1,419	£39,732
Asset 03	Raise wall	1.2	1.4	£1,029	£1,440
New embankment	Embankment	0.5	43	£1,028	£44,204
Asset 04	Sheet piled wall	Replace existing (2.2m)	34	£9,148	£306,458
Asset 05	Wall	0.15	23	£1,419	£32,637
Asset 06	Wall	0.11	135	£1,419	£191,565
		Total	321	Total	£696,920

Table 10-9: Unit and total estimated defence costs - 200 year event with climate change

Location	Defence type	Typical defence height (m)	Length (m)	Average Unit cost	Total cost
Asset 01	Wall	0.64	57	£1,419	£80,883
Asset 02	Wall	0.31	28	£1,419	£39,732
Asset 03	Raise wall	0.31	1.4	£1,029	£1,440
New embankment	Embankment	1.2	99	£1,798	£178,002
Asset 04	Sheet piled wall	Replace existing (2.2m)	34	£9,148	£306,458

Location	Defence type	Typical defence height (m)	Length (m)	Average Unit cost	Total cost
New wall	Wall	> 0.5	53	£1,419	£75,207
Asset 05	Wall	0.26	45	£1,419	£63,855
Asset 06	Wall	0.27	225	£1,419	£319,275
New wall	Wall	0.4	99	£1,419	£140,481
		Total	640	Total	£1,205,334

In addition to the above the following additional costs are assumed:

- Enabling costs of 15% have been assumed
- Annual maintenance costs of up to £1,829/annum (PVc of £50,938).

Therefore the total cost for this option is in the region of £0.8m to £1.4m. The average costs have been assumed since the risk is unclear at this stage whilst the style and placement of the defences selected likely minimises any potential risk. Risks could emerge from multiple landowners being involved, the proximity to unknown services and mixed access meaning that the river itself may be required for access in places.

Table 10-10: Whole life (PVc) costs for Option 2

Element	200 year return period	200 Year return period with climate change
Enabling cost	£104,538	£180,800
Capital cost	£673,352	£1,164,574
O&M cost	£42,554	£50,938
Total	£820,444	£1,396,312

10.6 Option 4 - Breached embankment and raised defences upstream costs

Defence costs are based on the same unit costs and assumptions as Option 1. The total defence length is the same as in Option 1 but additional works are required to produce three breaches of 10m in length across the width of the embankment and construction of timber footbridges to cross each breach to maintain pedestrian access.

Table 10-11: Unit and total estimated defence costs for the 200 year event

Location	Defence type	Typical defence height (m)	Length (m)	Average Unit cost	Total cost
Asset 01	Wall	0.45	57	£1,419	£80,883
Asset 02	Wall	0.11	28	£1,419	£39,732
Asset 03	Raise wall	1.2	1.4	£1,029	£1,440
New embankment	Embankment	0.5	43	£1,028	£44,204
Asset 04	Sheet piled wall	Replace existing (2.2m)	34	£9,148	£306,458
Excavation of embankment	Excavation	1.6	30	£62 (/m^3)	£2,985
Bridge	Timber footbridge	-	36	£1,190	£42,840
		Total	321	Total	£518,543

In addition to the above the following additional costs are assumed:

- Enabling costs of 15% have been assumed
- Annual maintenance costs of up to £772/annum (PVc of £21,495).

Therefore the total cost for this option is in the region of £0.6m. The average costs have been assumed since the risk is unclear at this stage whilst the style and placement of the defences selected likely minimises any potential risk. Risks could emerge from multiple landowners being involved, the proximity to unknown services and mixed access meaning that the river itself may be required for access in places.

Table 10-12: Whole life (PVc) costs for Option 4

Element	200 year return period
Enabling cost	£77,781
Capital cost	£501,007
O&M cost	£21,495
Total	£600,284

10.7 Cost summary

A summary of costs with optimism bias applied is presented in Table 10-14 below.

Table 10-13: Option cost summary with optimism bias (£k)

Option	200 year	200 year with climate change
PLP	£642,842	£871,839
Raise defences	£820,444	£1,396,312
Raise defences and breach embankment	£600,284	Not considered

10.8 Low-cost alternative - Raised defences upstream only

This option offers a lower standard of protection than options 2 and 4 but given that the defences targeted in this option are those critical to protecting a large proportion of the town, it may be cost-effective relative to other more complete options. The key difference is that no works (other than maintenance and minor refurbishment works) would be undertaken to the embankment in the downstream reach. This embankment currently offers a 200 year standard of protection but with limited freeboard at the downstream end.

Defence costs are based on the same unit costs and assumptions as the above options.

Table 10-14: Unit and total estimated defence costs for the 200 year event

Location	Defence type	Typical defence height (m)	Length (m)	Average Unit cost	Total cost
Asset 01	Wall	0.45	57	£1,419	£80,883
Asset 02	Wall	0.11	28	£1,419	£39,732
Asset 03	Raise wall	1.2	1.4	£1,029	£1,440
New embankment	Embankment	0.5	43	£1,028	£44,204
		Total	129	Total	£166,259

In addition to the above the following additional costs are assumed:

- Enabling costs of 15% have been assumed

- Annual maintenance costs of up to £452/annum (PVc of £12,584).

Therefore the total cost for this option is in the region of £0.2m. The average costs have been assumed since the risk is unclear at this stage whilst the style and placement of the defences selected likely minimises any potential risk. Risks could emerge from multiple landowners being involved, the proximity to unknown services and mixed access meaning that the river itself may be required for access in places.

Table 10-15: Whole life (PVc) costs for Low-cost option

Element	200 year return period
Enabling cost	£24,939
Capital cost	£160,637
O&M cost	£12,584
Total	£198,160

11 Benefit-cost analysis

11.1 Introduction

This section discusses the economic appraisal carried out during this study. The methods of calculating the benefits and costs are outlined together with an assessment of the benefit-cost ratios for the range of options assessed.

Benefit cost analysis looks at a flood risk management strategy or practice and compares all the benefits that will be gained by its implementation to all the costs that will be incurred during the lifetime of the project.

In accordance with the Scottish Government appraisal guidance, benefits are taken as annual average damages avoided, expressed as their present value using Treasury discount rates. These are compared with the whole life cost of the capital and maintenance costs of selected options, expressed as present value. If the benefits exceed the costs for the option, the scheme is deemed to be cost effective and worthwhile for promotion.

Benefits are assessed as the flood damages that will be avoided by the implementation of a project. To calculate these it is necessary to assess the damages that are likely to occur under both the Do Nothing and Do Something scenarios. The benefits of any particular Do Something option can then be calculated by deducting the Do Something damages from the Do Nothing damages.

11.2 Guidance and standard data

The principles of benefit-cost ratio calculations are summarised as follows:

- Derive the damages associated with do-nothing;
- Derive the damages associated with each scheme option;
- Derive the benefits (damages avoided) associated with each option;
- Derive the costs for each option; and
- Derive the benefit-cost ratios for each option.

11.3 Benefit-cost results

A summary of the flood damage results for the proposed options are provided in Table 11-1. The results suggest that the damages avoided for each of the options vary between £410k-£530k. This is not significant and the indicative cost of works to provide a 1 in 200 year standard of protection are in most cases significantly greater than the benefits of flood protection. As a result the benefit-cost ratios for each option are significantly less and unity.

The exception is the low cost option to upgrade and raise the defence standard in the upstream reach - observed as a flood route in December 2013 and December 2015 on the left and right banks. This option, with an optimism bias of 60% suggests is marginal with a benefit-cost ratio of 1.3.

Table 11-1: Summary of benefit-cost calculation (£k)

	Do Minimum	Option 1	Option 2	Option 4	Defences U/S only
Total PV costs (£k)	59	643	820	518	198
Total PV costs + Optimism bias (£k)	-	1,029	1,312	829	317
PV damage (£k)	650	122	238	238	238
PV damage avoided (£k)	-	528	412	412	412
Benefit-cost ratio	-	0.5	0.3	0.5	1.3

The above results assume that maintenance of the existing defences is undertaken. If this is not undertaken, deterioration of the defences is likely and the risk of defence failure or breaching is increased. This breach risk is not assumed in the above analysis.

11.4 Benefit-cost results with the inclusion of climate change

A summary of the flood damage results for the proposed options to provide a 200 year standard of protection with an allowance for climate change is provided in Table 11-2. Only Option 1 or 2 is technically viable (Option 4 is not technically viable). Whilst the damages avoided as a result of the scheme increase, the costs associated with the additional works to adapt to increased flows associated with climate change also increase, ultimately with no significant increase in the benefit-cost ratio for the Options assessed.

Table 11-2: Summary of benefit-cost calculation (£k)

	Do Minimum	Option 1	Option 2	Option 4
Total PV costs (£k)	59	872	1,396	N/A
Total PV costs + Optimism bias (£k)	-	1,395	2,234	N/A
PV damage (£k)	1,058	216	446	N/A
PV damage avoided (£k)	-	842	612	N/A
Benefit-cost ratio	-	0.6	0.3	N/A

The above results assume that maintenance of the existing defences is undertaken. If this is not undertaken, deterioration of the defences is likely and the risk of defence failure or breaching is increased. This breach risk is not assumed in the above analysis.

11.5 Sensitivity tests

A sensitivity test has been undertaken to vary the probability of design flood events. The flood mapping undertaken is constrained by the quality of the DTM and lack of LiDAR data in the region as discussed in Section 3.5.11 and Section 4.3.

Adjusting the probability of design flood events has been undertaken in order to adjust the flood damage calculations and to make up for inaccuracies in the flood mapping. In this test it has been assumed that the 200 year flood damages are equivalent to the 100 year event damages, the 100 year equivalent to the 50 year damages and so on. This is a non-standard approach, but one that attempts to adjust the results to match what actually occurred in the December 2013 and 2015 floods. As a result it is presented as a sensitivity test.

The results are presented in Table 11-3. The flood damages are significantly increased under this sensitivity test, although the benefit-cost ratios are still below unity for options 2 and 3. Option 1 and the low cost option to provide and raise flood defences in the upstream reach are economically viable. Under this latter low cost option, the benefit cost ratio increases to 2.5 and is economically viable.

Table 11-3: Summary of benefit-cost calculation (£k)

	Do Minimum	Option 1	Option 2	Option 4	Defences U/S only
Total PV costs (£k)	59	643	820	518	198
Total PV costs + Optimism bias (£k)	-	1,029	1,312	829	317
PV damage (£k)	1,555	357	775	775	775
PV damage avoided (£k)	-	1,198	780	780	780
Benefit-cost ratio	-	1.2	0.6	0.9	2.5

11.6 Economic preferred option

The preferred aim for any upgrade to the flood defences in Moniaive is to provide a 1 in 200 year flood with an allowance for climate change. The only viable long term structural option to achieve this is via raised defences, although this is not without technical challenges. A non-structural approach to flood mitigation would be to undertake a PLP scheme in Moniaive.

Neither of these options is economically viable although the provision of PLP measures via the Councils subsidy scheme would provide some benefit and at a lower cost than a full PLP scheme as described in this report.

The main reason the options assessed are not economically viable is that the Flood Prevention Scheme that is already present has a reasonable standard of protection. This therefore avoids any frequent flood damages that contribute towards the annual average Do Minimum damages. This is the case assuming that the Council undertakes maintenance of the defences over the long term. If this is not the case, the risk of breaching may increase.

The only option that is economically viable is the low cost option to improve and upgrade the flood defences in the upper reach upstream of the main road bridge. This option could provide a 1 in 200 year standard of protection (without climate change and with limited freeboard on certain assets) but could potentially protect flooding to 24 properties and may have protected the town from the 2015 flood if it was implemented after the 2013 flood.

12 Conclusion and Recommendations

This report presents the results of a detailed flood risk appraisal of Moniaive from the Dalwhat Water and the Craigdarroch Water. Moniaive flooded in December 2013 and December 2015 causing flooding to properties predominantly along Dunreggan and the High Street. A Flood Prevention Scheme for the village was constructed in 1963. Prior to 2013 flood records of the town precede the construction of the flood defences.

A detailed hydrological assessment of the two burns has been undertaken to derive flow inputs into a hydraulic model of the rivers through Moniaive. An estimate of the event rarity for the December 2013 and 2015 events is difficult to ascertain without gauging of flows. However, analysis of rainfall and flows on adjacent catchments would suggest that the event may have been in the region of a 25 to 50 year flood event (estimated to be in the region of 54-62 m^3/s). However, comparison of modelled water levels against flood photographs and surveyed levels suggests that the two most recent flood events could have been much higher and in the region of a 100-200 year return period (estimated to be in the region of 70-80 m^3/s). This assessment should be treated with caution in the absence of any gauging station and records of flow for the watercourse.

Whilst the flow estimates are carried out using standard methodologies, without any gauging of the watercourses the design flow estimates should be treated with caution.

Survey was undertaken to build a 1D model and a linked 1D/2D TuFLOW flood model generated. Flood mapping has been undertaken and is based on the 1D-2D modelling and the underlying topographical data. Flood maps were prepared for each event and include the 2, 5, 10, 25, 50, 100, 200, 200 plus climate change, and 1000 year return periods. The flood mapping is an improvement on available national datasets from SEPA and should be used by the Council for planning considerations.

Whilst it is becoming standard for appraisal studies to use LiDAR data, unfortunately this key dataset does not currently cover the area of Moniaive. As a result the mapping is of a lower standard than other similar studies carried out by Dumfries and Galloway Council.

The model results estimate that 24 properties would be affected during a 200 year flood; the majority of which are residential. Annual average flood damages are estimated to be £18,300 with a Present Value damage in the region of £0.55 million. Flood damages are not significant due to the fact that the scheme reduces flooding for return periods up to and including the 25 year flood.

12.1 Data and modelling recommendations

It is recommended that LiDAR is collected for the region to ensure that any future work is based on suitable topographic data for flood mapping purposes. This should be aligned with any more Scotland wide data collation by SEPA/Scottish Government or perhaps using a lower cost drone system.

12.2 Hydrometry and warning recommendations

Any flood defence improvements or significant capital spend would benefit from some flow gauging over a period of time to improve the flow estimates. This would also support future flood warning and forecasting on the catchment by providing the necessary evidence to calibrate flood warning models.

12.3 Asset maintenance recommendations

Asset inspections have suggested that a variable condition in the defences and a general lack of regular maintenance of some defences. Despite this, the defences withstood the overtopping of the flood waters during the December 2013 and 2015 floods, with no reports of breaching or failure of defences.

Further structural inspection and maintenance of these assets is recommended to ensure that they are fit for purpose. Furthermore, the overall condition and standard of the defences could be improved by maintenance and minor refurbishments to locally raise and set a uniform crest gradient.

Without this maintenance the defences will deteriorate over time to the point where the defences no longer function as they should. At this point they will either need to be replaced or refurbished which may be more costly than frequent maintenance works.

It is clear from the CCTV footage that the culverts are in need of regular maintenance. Major blockages should be removed as a priority. Recommendations for culverts include the removal of blockages, cleaning of culverts, regular inspections and remedial works to flap valves. If it is deemed necessary the damaged culverts should be repaired or replaced.

12.4 Options appraisal

A number of flood mitigation options have been considered including; property level protection; raised direct defences via flood walls and embankments; and breaching of the agricultural land downstream.

A summary of the flood damage results for the proposed options are provided in Table 11-1. The results suggest that the damages avoided for each of the options vary between £300k-£400k. This is not significant and the indicative cost of works to provide a 1 in 200 year standard of protection are in most cases significantly greater than the benefits of flood protection. As a result the benefit-cost ratios for each option are significantly less and unity.

Alternative options for flood mitigation include self-help via the Councils property level protection subsidy scheme or a lower cost flood mitigation option to upgrade and raise the defence standard in the upstream reach - observed as a flood route in December 2013/December 2015 on the left and right banks. This option has a benefit-cost ratio of 1.0 and is therefore only considered to be marginal economically. This option could provide a 1 in 200 year standard of protection (without climate change and with limited freeboard on certain assets) but could potentially protect flooding to 24 properties.

Appendices

A Appendix A - Photographic evidence

A.1 December 2013 flood photographs

Flood photographs from a number of sources have been collated below.

Table A-1: Photographs of December 2013 flood event

	Looking upstream of A702 High Street Bridge. Source: Glencairn Gazette
	Looking upstream of A702 High Street Bridge to left bank and overtopping of embankment. Source: Glencairn Gazette
	Flooding on A702 Dunreggan (left bank downstream of High Street Bridge). Source: Facebook/Ffyona Fergusson

	Flooding on Dunreggan Brae looking west towards High Street Bridge Source: Facebook/Ffyona Fergusson
	Flood water pouring onto Dunreggan Brae adjacent High Street Bridge. Photograph looking north (upstream) towards Dalwhat Water. Source: Facebook/Ffyona Fergusson
	Source: Glencairn Gazette
	Flooding on Dunreggan Brae adjacent to High Street Bridge Source: Facebook/Ffyona Fergusson

	Looking north along A702 towards High Street Bridge and Dunreggan Brae. Source: Glencairn Gazette
	Looking south along the A702 outside Muir Cottage Source: Glencairn Gazette

	Garage and backyard of property opposite Airlie house on the A702, approximately 30m downstream from High Street Bridge. Source: Glencairn Gazette
	Dalwhat Garage adjacent to High Street Bridge. Glencairn Gazette Source: Glencairn Gazette
	
	Glencairn Gazette

	Forestry commission building by A702 Glencairn Gazette
	Glencairn Gazette

A.2 December 2015 flood photographs

	Flooding in the fields upstream of Moniaive (right bank, looking upstream) *Source*: https://www.facebook.com/hugh.Travel writer/posts/10153546475749039
	Moniaive High Street from bridge *Source*: https://www.facebook.com/hugh.Travel writer/posts/10153546475749039

	Moniaive High Street *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Moniaive High Street *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Moniaive High Street *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Moniaive High Street *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039

	Flooding around garage - shows flow path from fields upstream *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flow path from car park on left bank *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flooding on Dunreggan Brae adjacent to High Street Bridge *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	In bank flows downstream of road bridge *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039

	Flow path down Dunreggan *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flow path down Dunreggan *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flow path down Dunreggan *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flooding on right bank downstream of village (upstream of WWTW) *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039

	Point of bank overtopping upstream of WWTW *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Floodplain ponding as a result of flow path from WWTW *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	In bank flows downstream of Moniaive (upstream of footbridge) *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039
	Flood level at footbridge. Estimated to be approximately 0.7m from bridge soffit. *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039

	Ponded flood water in floodplain downstream of footbridge *Source*: https://www.facebook.com/hugh.Travelwriter/posts/10153546475749039

A.3 Historical photographs

The photos below provide an indication of where flooding occurred in the past and what properties were effected. The first photo shows a resident with a door guard in place at the house thought to be Railway View House today. The height of the board with the depth of the step indicates the depth of flooding the residents expected.

The second and third set of photos location within Moniaive is unclear. One possibility is looking at the upstream face of High Street Bridge before the wooden footbridge was constructed. The lady in the photo is thought to be showing the height that the flood water reached.

Table 12-2: Historical photos after a large flood event

	This historical photo shows the use of "door boards" at Railway View House on A702 south of High Street Bridge at the first bend in the road.
	Presumed to be taken from the right bank of the Dalwhat Water looking downstream to the upstream face of the main road bridge (prior to the construction of the sheet pile wall). The second picture is a lady indicating the height to which the flood waters from the Dalwhat Water reached.

B Appendix B - Hydraulic structures

B.1 General procedures for all structures

This section provides information on the structures within the model reach.

A table is provided for each significant structure (bridge, culvert, weir) whether formally included in the model scheme or not. Any assumptions made in the modelling of structures are recorded in the following tables.

B.2 Dalwhat Water

Name of structure	Hall bridge
Included in model (state reason if not):	No - no constraint to flow in 1D domain
Model label:	MON_1621
Type:	Beam Bridge
Skew angle:	0°
How has structure been modelled?	Not modelled
 Upstream face	
Is surveyed XS flow area representative? (i.e. is it necessary to allow for blockage or ineffective flow?)	Yes, it is representative. Blockage won't be tested here.
Assumptions made? (e.g. bridge/culvert parapets assumed to block in floods; modelled as solid barriers)	n/a
Any limitations in the method of modelling used? (e.g if model is used for other flow rates would it require modification)	The bridge deck is not modelled. This is valid up to the 1,000-year event.

Name of structure	Informal weir
Included in model (state reason if not):	No - no constraint to flow in 1D domain
Model label:	MON_1062
Type:	Rock weir
Skew angle:	0°
How has structure been modelled?	Not modelled

From right bank

Is surveyed XS flow area representative? (i.e. is it necessary to allow for blockage or ineffective flow?)	n/a
Assumptions made? (e.g. bridge/culvert parapets assumed to block in floods; modelled as solid barriers)	The influence on the flow regime is assumed to be very small, hence this structure is not modelled.
Any limitations in the method of modelling used? (e.g if model is used for other flow rates would it require modification)	n/a

Name of structure	High Street bridge
Included in model (state reason if not):	Yes
Model label:	MON_981bu
Type:	Arch bridge (with wooden footbridge immediately upstream)
Skew angle:	0°
How has structure been modelled?	Modelled as an arch bridge with no parallel spill.
 Upstream face (view of wooden bridge with stone are visible downstream)	 Downstream face
Is surveyed XS flow area representative? (i.e. is it necessary to allow for blockage or ineffective flow?)	Yes, representative. Blockage will be assessed here during options modelling.
Assumptions made? (e.g. bridge/culvert parapets assumed to block in floods; modelled as solid barriers)	The bridge is modelled as a single arch, using the stone arch's springing point and the wooden bridge's soffit level (that is, the lowest of each).
Any limitations in the method of modelling used? (e.g if model is used for other flow rates would it require modification)	Spilling over the parapet is not modelled in the 1D domain, as this is not a dominant flow route and the 2D domain floods first, on both banks.

Name of structure	Playing Fields footbridge
Included in model (state reason if not):	Yes
Model label:	MON_530bu
Type:	Timber beam bridge
Skew angle:	0°
How has structure been modelled?	Modelled as a USBPR bridge with no parallel spill.
 From left bank	
Is surveyed XS flow area representative? (i.e. is it necessary to allow for blockage or ineffective flow?)	Yes, representative. The span is clear and blockage won't be tested here.
Assumptions made? (e.g. bridge/culvert parapets assumed to block in floods; modelled as solid barriers)	-none-
Any limitations in the method of modelling used? (e.g if model is used for other flow rates would it require modification)	Spilling over the bridge parapet is not represented in the 1D domain, as this is not a dominant flow regime. At flows above the 1,000-year event additional surcharging may occur due to debris on the railings. The railings are not modelled.

B.3 Craigdarroch Water

Name of structure	A702 Road Bridge
Included in model (state reason if not):	Yes
Model label:	CRAI_bu
Type:	Masonry Arch bridge
Skew angle:	0°
How has structure been modelled?	Modelled as an arch bridge with no parallel spill.
 Upstream face	
Is surveyed XS flow area representative? (i.e. is it necessary to allow for blockage or ineffective flow?)	Yes, representative.
Assumptions made? (e.g. bridge/culvert parapets assumed to block in floods; modelled as solid barriers)	-none-
Any limitations in the method of modelling used? (e.g if model is used for other flow rates would it require modification)	Spilling over the bridge parapet is not represented in the 1D domain, as this does not occur within the range of flows modelled. Flow from bank to bank over the road surface is not modelled as water levels do not reach the required level in the range of modelled flows.

C Flood Estimation

C.1 Introduction

This section provides further details on the estimation of flows using the FEH.

C.2 Additional checks on catchment characteristics and choice of method

Although the FEH CD-ROM BFIHOST values appeared reasonable in comparison to the available geological information[20], the BFI Scotland map[21] suggested a BFI value of 0.24 for both the Dalwhat Water and Craigdarroch Water. This value is much smaller than the BFIHOST value of circa 0.46 derived from the FEH CD-ROM.

The choice of BFI (and SPR) value was therefore investigated using a BFI value of 0.45 and SPR value of 54.76[22] to generate an alternative set of peak flows for both watercourses using the FEH Statistical method. From Table C-3 it can be seen that the flows are much higher than those derived from the unadjusted datasets (for example, the 0.5% AP, 200 year, flow is estimated to be 81 m^3/s for the Dalwhat Water before BFI and SPR adjustment and 131 m^3/s after adjustment; for the Craigdarroch Water the corresponding flows for this magnitude of event were 50 m^3/s and 85 m^3/s, respectively). When input to the hydraulic model, the higher flows generated a frequency of flooding which was inconsistent with the flood history (i.e. flooding was estimated to occur too frequently). The default BFI and SPR values from the FEH CD-ROM were therefore retained and the resulting flows used within the hydraulic model.

With respect to choice of approach for estimating flood flows, the FEH Statistical method was judged to be the most appropriate method given the rural nature of the catchments and the availability of the nearby Scar Water at Capenoch as a potential donor site, the Statistical method was therefore assumed to be the most reasonable approach for estimating flood flows for the watercourses near the site. Comparisons were also made with both ReFH2 and the FEH Rainfall Runoff method (both Rainfall Runoff methods were considered because of the newness of the ReFH2 approach). The results are summarised in Table C-4 to Table C-5 for the Dalwhat Water and Craigdarroch Water, respectively. In each case, the Scar Water at Capenoch was used as a donor site for QMED estimation and the Generalised Logistic distribution was used to fit the growth curve.

Table C-3: Comparison of FEH Statistical Estimates without and with BFI and SPR adjustments

Annual Probability (AP)	Return period (years)	Dalwhat Water No Adjustments to BFI or SPR (m^3/s)	Dalwhat Water BFI and SPR adjusted (m^3/s)	Craigdarroch Water No Adjustments to BFI or SPR (m^3/s)	Craigdarroch Water BFI and SPR adjusted (m^3/s)
50	2	31	50	20	34
20	5	39	64	26	43
10	10	46	74	29	50
4	25	54	88	35	60
3.33	30	56	91	36	62
2	50	62	101	40	67
1.33	75	67	109	42	72
1	100	71	115	45	76
0.5	200	81	131	50	85
0.5 + 20% CC	200 + 20% CC	97	157	60	103
0.2	500	96	156	59	100
0.1	1000	109	178	66	112

[20] http://mapapps.bgs.ac.uk/geologyofbritain/home.html

[21] Institute of Hydrology (1986), Base Flow Index Scotland map.

[22] Per FEH Volume 3, equation 13.25.

Table C-4: Comparison of FEH methods: Dalwhat Water

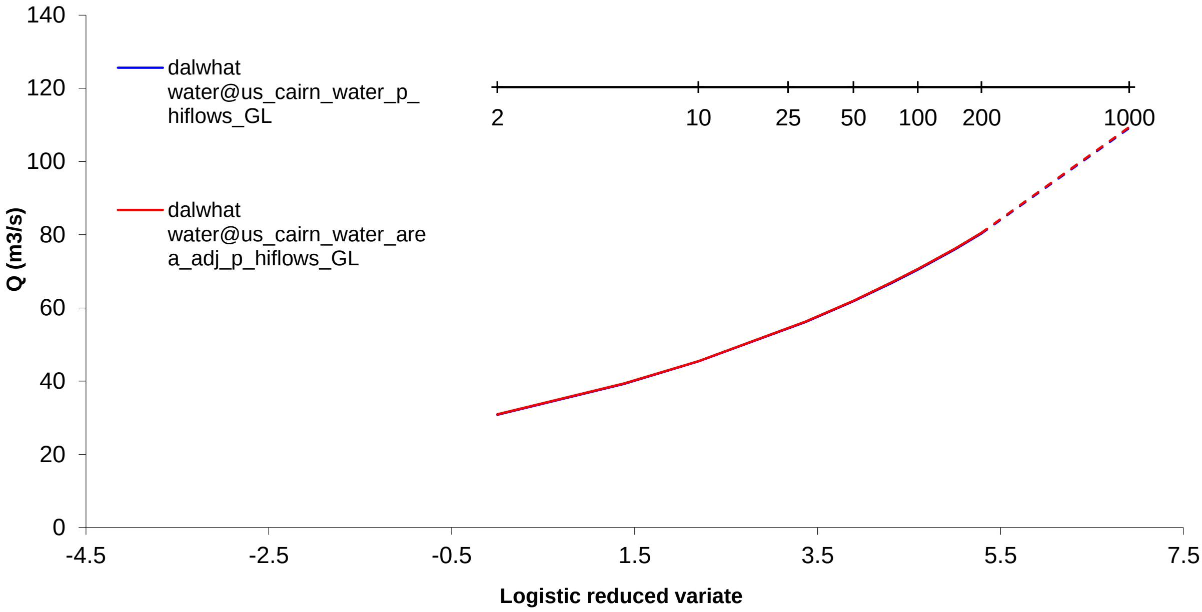
Annual Probability (AP)	Return period (years)	Statistical (m^3/s)	FEH Rainfall Runoff (m^3/s)	ReFH2 (m^3/s)
50	2	31	22	23
20	5	39	32	30
10	10	46	39	36
4	25	54	49	46
3.33	30	56	51	48
2	50	62	58	55
1.33	75	67	63	61
1	100	71	67	66
0.5	200	81	77	79
0.5 + 20% CC	200 + 20% CC	97	93	95
0.2	500	96	94	103
0.1	1000	109	111	126

Table C-5: Comparison of FEH methods: Craigdarroch Water

Annual Probability (AP)	Return period (years)	Statistical (m^3/s)	FEH Rainfall Runoff (m^3/s)	ReFH2 (m^3/s)
50	2	20	13	14
20	5	26	19	18
10	10	29	24	22
4	25	35	30	27
3.33	30	36	31	29
2	50	40	36	33
1.33	75	42	39	37
1	100	45	41	40
0.5	200	50	48	48
0.5 + 20% CC	200 + 20% CC	60	57	57
0.2	500	59	58	62
0.1	1000	66	69	75

C.3 FEH Statistical Method supporting information

FEH STATISTICAL FLOOD ESTIMATION SUMMARY SHEET			
Site	Dalwhat Water above Cairn Water		
NGR	NX 7850 9025		
Type of problem/objective of	Flood flows for input to Moniaive flood options study		
Type of catchment	Rural		
$QMED_{site\ cd}$	26.8	m^3/s	
Donor/ Analogue Sites Considered			
Site name	Capenoch		
Station number	79004		
NGR	NX 8450 9400		
Proximity (km)	9.00		
Adjustment	1.1551		
Site Chosen	Y		
$QMED_{site}$ adjusted by data transfer (m^3/s)	30.9	Specific Q (l/s/ha)	9.2
Q_{100} growth curve factor	2.28	Q100/ area (l/s/ha)	20.9
Q_{100} (m^3/s)	**70.7**		
Summary Data			
FEH catchment area	33.76		km^2
Adjusted catchment area	33.76		km^2
URBEXT 1990	0.001		
URBEXT 2010	0.003		
URBEXT Adjustment Method	Urbext2000		
SAAR	1618		
Method Used	FEH Statistical Method		
Variation from Chosen Method			
Index Used	BFIHOST		
QMED	30.93		m^3/s
5	39.37		m^3/s
10	45.50		m^3/s
30	56.29		m^3/s
50	62.01		m^3/s
75	66.94		m^3/s
100	70.67		m^3/s
200	80.55		m^3/s
1000	109.40		m^3/s
Climate Change Region	South-West Scotland		
Climate change adjustment	20.0%		
200 + cc	96.7		m^3/s
Donor/ Analogues Used	Capenoch		
Calcs by:	David Cameron	Date:	28/07/2015
Checked by:	Angus Pettit	Date:	06/10/2015



POOLING GROUP DETAILS

Original Default Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
72007 (Brock @ U/s a6)	0.357	34	31.410	0.184	0.257	1.731
76811 (Dacre Beck @ Dacre Bridge)	0.391	12	54.705	0.144	0.047	0.953
48001 (Fowey @ Trekeivesteps)	0.400	43	17.073	0.220	0.290	0.111
21017 (Ettrick Water @ Brockhoperig)	0.436	41	60.364	0.203	0.276	0.096
73009 (Sprint @ Sprint Mill)	0.457	43	43.072	0.197	0.191	0.315
47014 (Walkham @ Horrabridge)	0.460	39	37.958	0.212	0.240	0.297
48004 (Warleggan @ Trengoffe)	0.485	43	9.799	0.268	0.287	0.996
47021 (Kensey @ Launceston Newport)	0.495	10	18.320	0.174	0.486	3.787
25012 (Harwood Beck @ Harwood)	0.514	43	33.265	0.189	0.251	0.857
47009 (Tiddy @ Tideford)	0.532	43	5.916	0.171	0.144	0.331
48009 (st Neot @ Craigshill Wood)	0.614	12	8.469	-0.245	-0.373	4.286
84020 (Glazert Water @ Milton of Campsi	0.618	37	56.483	0.132	0.064	0.385
46007 (West Dart @ Dunnabridge)	0.623	31	74.662	0.171	0.122	0.229
49003 (de Lank @ de Lank)	0.654	46	13.559	0.232	0.241	0.253
27032 (Hebden Beck @ Hebden)	0.681	46	4.082	0.211	0.258	0.372
Total		523				
Weighted means				0.173	0.199	

Default Pooling Group Catchment Descriptors

Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 2000
72007 (Brock @ U/s a6)	0.357	31.530	1361.000	0.053	1.000	0.000
76811 (Dacre Beck @ Dacre Bridge)	0.391	33.970	1428.000	0.072	0.999	0.000
48001 (Fowey @ Trekeivesteps)	0.400	36.800	1636.000	0.043	0.938	0.003
21017 (Ettrick Water @ Brockhoperig)	0.436	38.590	1740.000	0.012	1.000	0.000
73009 (Sprint @ Sprint Mill)	0.457	34.800	2011.000	0.061	0.997	0.000
47014 (Walkham @ Horrabridge)	0.460	44.310	1664.000	0.023	1.000	0.008
48004 (Warleggan @ Trengoffe)	0.485	25.260	1445.000	0.035	0.978	0.003
47021 (Kensey @ Launceston Newport)	0.495	34.830	1298.000	0.022	0.998	0.017
25012 (Harwood Beck @ Harwood)	0.514	24.580	1577.000	0.021	1.000	0.000
47009 (Tiddy @ Tideford)	0.532	37.370	1276.000	0.024	1.000	0.011
48009 (st Neot @ Craigshill Wood)	0.614	22.910	1512.000	0.022	0.982	0.002
84020 (Glazert Water @ Milton of Camp	0.618	51.900	1561.000	0.052	0.991	0.010
46007 (West Dart @ Dunnabridge)	0.623	47.49	1987	0.049	1	0.003
49003 (de Lank @ de Lank)	0.654	21.610	1628.000	0.064	0.998	0.000
27032 (Hebden Beck @ Hebden)	0.681	22.200	1433.000	0.021	0.997	0.000

Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
72007 (Brock @ U/s a6)	0.357	34	31.410	0.184	0.257	1.731
76811 (Dacre Beck @ Dacre Bridge)	0.391	12	54.705	0.144	0.047	0.953
48001 (Fowey @ Trekeivesteps)	0.400	43	17.073	0.220	0.290	0.111
21017 (Ettrick Water @ Brockhoperig)	0.436	41	60.364	0.203	0.276	0.096
73009 (Sprint @ Sprint Mill)	0.457	43	43.072	0.197	0.191	0.315
47014 (Walkham @ Horrabridge)	0.460	39	37.958	0.212	0.240	0.297
48004 (Warleggan @ Trengoffe)	0.485	43	9.799	0.268	0.287	0.996
47021 (Kensey @ Launceston Newport)	0.495	10	18.320	0.174	0.486	3.787
25012 (Harwood Beck @ Harwood)	0.514	43	33.265	0.189	0.251	0.857
47009 (Tiddy @ Tideford)	0.532	43	5.916	0.171	0.144	0.331
48009 (st Neot @ Craigshill Wood)	0.614	12	8.469	-0.245	-0.373	4.286
84020 (Glazert Water @ Milton of Campsi	0.618	37	56.483	0.132	0.064	0.385
46007 (West Dart @ Dunnabridge)	0.623	31	74.662	0.171	0.122	0.229
49003 (de Lank @ de Lank)	0.654	46	13.559	0.232	0.241	0.253
27032 (Hebden Beck @ Hebden)	0.681	46	4.082	0.211	0.258	0.372
Total		523				
Weighted means				0.173	0.199	

Final Pooling Group

Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 2000
72007 (Brock @ U/s a6)	0.357	31.530	1361.000	0.053	1.000	0.000
76811 (Dacre Beck @ Dacre Bridge)	0.391	33.970	1428.000	0.072	0.999	0.000
48001 (Fowey @ Trekeivesteps)	0.400	36.800	1636.000	0.043	0.938	0.003
21017 (Ettrick Water @ Brockhoperig)	0.436	38.590	1740.000	0.012	1.000	0.000
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48004 (Warleggan @ Trengoffe)	0.485	25.260	1445.000	0.035	0.978	0.003
47021 (Kensey @ Launceston Newport)	0.495	34.830	1298.000	0.022	0.998	0.017
25012 (Harwood Beck @ Harwood)	0.514	24.580	1577.000	0.021	1.000	0.000
47009 (Tiddy @ Tideford)	0.532	37.370	1276.000	0.024	1.000	0.011
48009 (st Neot @ Craigshill Wood)	0.614	22.910	1512.000	0.022	0.982	0.002
84020 (Glazert Water @ Milton of Camp	0.618	51.900	1561.000	0.052	0.991	0.010
46007 (West Dart @ Dunnabridge)	0.623	47.49	1987	0.049	1	0.003
49003 (de Lank @ de Lank)	0.654	21.610	1628.000	0.064	0.998	0.000
27032 (Hebden Beck @ Hebden)	0.681	22.200	1433.000	0.021	0.997	0.000

DERIVING A POOLED GROWTH CURVE

Site	Dalwhat Water upstream of Cairn Water	√	Ungauged site
NGR	NX 7850 9025		Gauged site

Attached Printouts

	WINFAP-FEH station details
	WINFAP-FEH summary information if gauged site

Initial Pooling Group Details

Name	p_hiflows_dalwhat_default
Site of interest	
Return period of interest	200 years
Other information	
Version of WIN-FAP FEH	Version 3.0
Data Files	Other
If 'Other' chosen in Data Files enter file path here	G:\FEH\FEH CD_ROM and WINFAP\HiFlows-UK data_v3.3.4_(Aug 2014)

Adjustment/ Changes made to Default Pooling Group.
Also note sites that were investigated but retained in the group (i.e. for discordancy)

Station number	Name	Addition/ Deletion/ Move/ Investigate	Reason

Final Pooling Group Details

Heterogeneity Measure

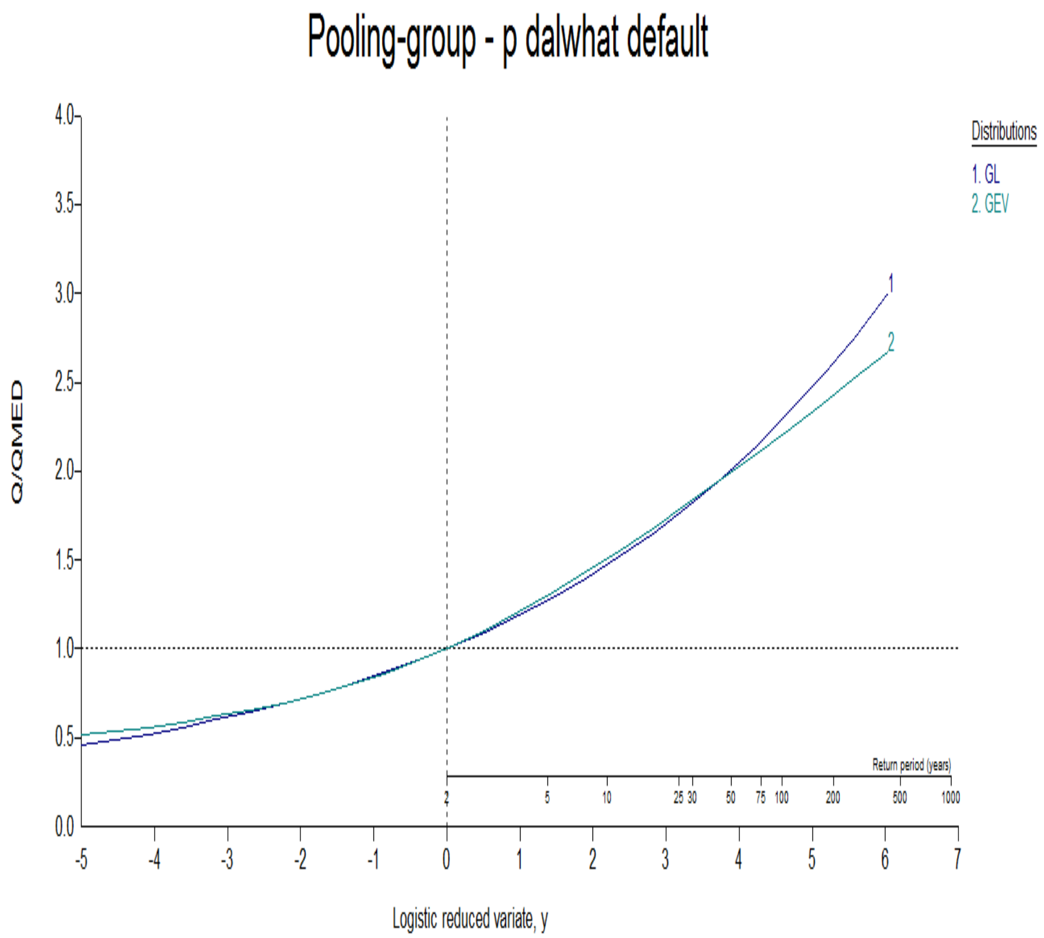
H1	Acceptably Homogeneous
H2	Acceptably Homogeneous

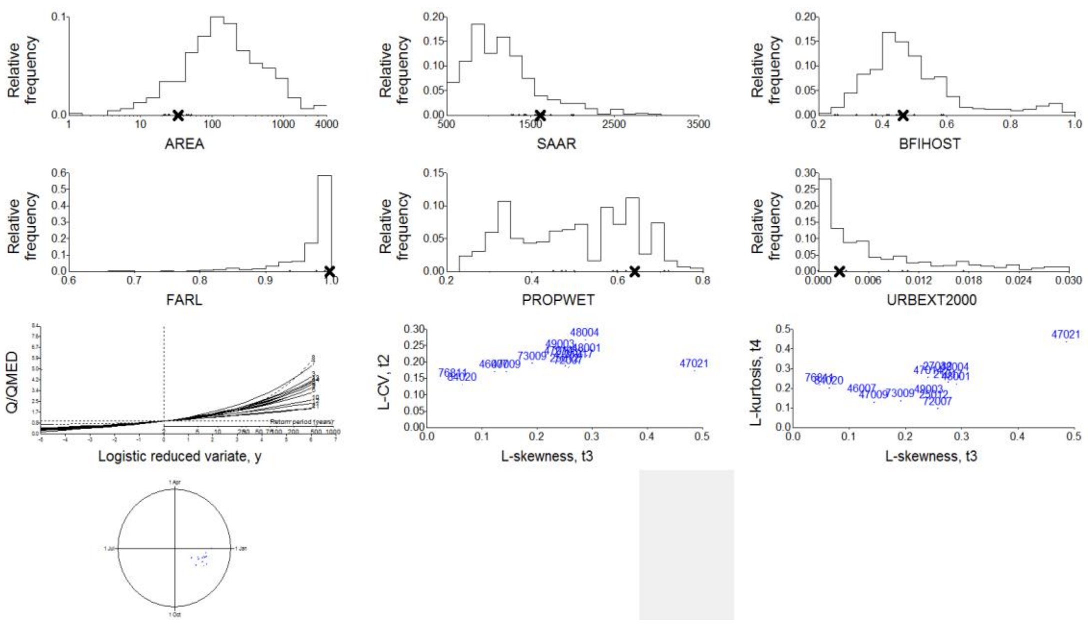
Goodness of Fit

Acceptable Fit	Distribution
√	Generalised Logistic
√	Generalised Extreme Value
	Pearson Type iii
	Generalised Pareto

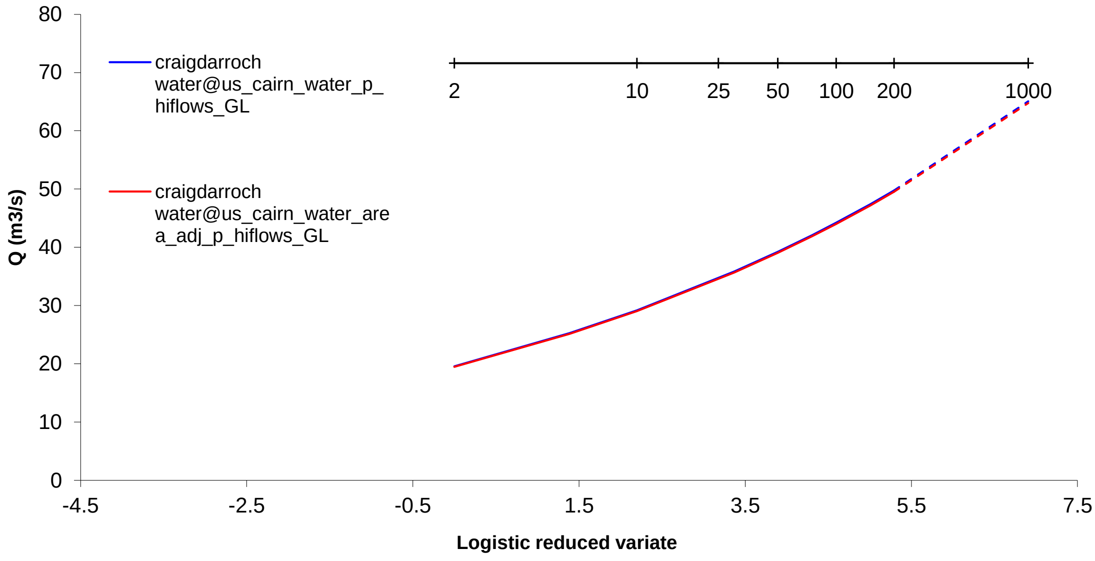
Growth Curve Fittings

Attached print outs	√	WINFAP-FEH growth curve fittings
	√	WINFAP-FEH growth curve
Name of Final Pooling Group		p_hiflows_dalwhat_default


Pooling-group - p dalwhat default
Distributions
1. GL
2. GEV
Q/QMED
Return period (years)
Logistic reduced variate, y


Relative frequency
AREA
SAAR
BFIHOST
FARL
PROPWET
URBEXT2000
Q/QMED
Logistic reduced variate, y
L-CV, t2
L-skewness, t3
L-kurtosis, t4
48004
47021

FEH STATISTICAL FLOOD ESTIMATION SUMMARY SHEET			
Site	Craigdarroch Water above Cairn Water		
NGR	NX 7850 9025		
Type of problem/objective of	Flood flows for input to Moniaive flood options study		
Type of catchment	Rural		
$QMED_{site\ cd}$	17.1	m^3/s	
Donor/ Analogue Sites Considered			
Site name	Capenoch		
Station number	79004		
NGR	NX 8450 9400		
Proximity (km)	10.00		
Adjustment	1.1388		
Site Chosen	Y		
$QMED_{site}$ adjusted by data transfer (m^3/s)	19.5	Specific Q (l/s/ha)	9.2
Q_{100} growth curve factor	2.26	Q100/ area (l/s/ha)	22.4
Q_{100} (m^3/s)	**47.2**		
Summary Data			
FEH catchment area	21.20		km^2
Adjusted catchment area	21.08		km^2
URBEXT 1990	0.001		
URBEXT 2010	0.001		
URBEXT Adjustment Method	Urbext2000		
SAAR	1519		
Method Used	FEH Statistical Method		
Variation from Chosen Method			
Index Used	BFIHOST		
QMED	19.48		m^3/s
5	25.14		m^3/s
10	29.06		m^3/s
30	35.67		m^3/s
50	39.04		m^3/s
75	41.89		m^3/s
100	44.01		m^3/s
200	49.52		m^3/s
1000	64.77		m^3/s
Climate Change Region	South-West Scotland		
Climate change adjustment	20.0%		
200 + cc	59.4		m^3/s
Donor/ Analogues Used	Capenoch		
Calcs by:	David Cameron	Date:	28/07/2015
Checked by:	Angus Pettit	Date:	06/10/2015



POOLING GROUP DETAILS

Original Default Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
49003 (de Lank @ de Lank)	0.236	46	13.559	0.232	0.241	0.168
48009 (st Neot @ Craigshill Wood)	0.310	12	8.469	-0.245	-0.373	3.655
27032 (Hebden Beck @ Hebden)	0.314	46	4.082	0.211	0.258	1.235
48004 (Warleggan @ Trengoffe)	0.323	43	9.799	0.268	0.287	1.287
25012 (Harwood Beck @ Harwood)	0.356	43	33.265	0.189	0.251	0.763
51002 (Horner Water @ West Luccombe)	0.511	31	8.354	0.382	0.326	0.935
72007 (Brock @ U/s a6)	0.599	34	31.410	0.184	0.257	1.323
46005 (East Dart @ Bellever)	0.620	48	38.510	0.162	0.082	0.520
206006 (Annalong @ Recorder)	0.717	48	15.330	0.189	0.052	1.172
76811 (Dacre Beck @ Dacre Bridge)	0.730	12	54.705	0.144	0.047	0.331
72014 (Conder @ Galgate)	0.778	45	17.703	0.193	0.059	0.703
203046 (Rathmore Burn @ Rathmore Brid	0.781	30	10.934	0.136	0.091	0.157
47022 (Tory Brook @ Newnham Park)	0.793	19	7.331	0.257	0.071	1.359
73015 (Keer @ High Keer Weir)	0.794	21	12.239	0.156	0.001	0.524
25011 (Langdon Beck @ Langdon)	0.804	26	15.878	0.241	0.326	0.867
Total		504				
Weighted means				0.186	0.155	

Default Pooling Group Catchment Descriptors

Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 2000
49003 (de Lank @ de Lank)	0.236	21.610	1628.000	0.064	0.998	0.000
48009 (st Neot @ Craigshill Wood)	0.310	22.910	1512.000	0.022	0.982	0.002
27032 (Hebden Beck @ Hebden)	0.314	22.200	1433.000	0.021	0.997	0.000
48004 (Warleggan @ Trengoffe)	0.323	25.260	1445.000	0.035	0.978	0.003
25012 (Harwood Beck @ Harwood)	0.356	24.580	1577.000	0.021	1.000	0.000
51002 (Horner Water @ West Luccomb	0.511	20.380	1485.000	0.003	0.978	0.000
72007 (Brock @ U/s a6)	0.599	31.530	1361.000	0.053	1.000	0.000
46005 (East Dart @ Bellever)	0.620	22.270	2095.000	0.042	1.000	0.000
206006 (Annalong @ Recorder)	0.717	13.660	1720.000	0.024	0.980	0.000
76811 (Dacre Beck @ Dacre Bridge)	0.730	33.970	1428.000	0.072	0.999	0.000
72014 (Conder @ Galgate)	0.778	28.990	1183.000	0.082	0.975	0.006
203046 (Rathmore Burn @ Rathmore Br	0.781	22.510	1043.000	0.073	1.000	0.000
47022 (Tory Brook @ Newnham Park)	0.793	13.45	1403	0.023	0.942	0.014
73015 (Keer @ High Keer Weir)	0.794	30.060	1158.000	0.075	0.976	0.003
25011 (Langdon Beck @ Langdon)	0.804	12.790	1463.000	0.013	1.000	0.001

Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
49003 (de Lank @ de Lank)	0.236	46	13.559	0.232	0.241	0.168
48009 (st Neot @ Craigshill Wood)	0.310	12	8.469	-0.245	-0.373	3.655
27032 (Hebden Beck @ Hebden)	0.314	46	4.082	0.211	0.258	1.235
48004 (Warleggan @ Trengoffe)	0.323	43	9.799	0.268	0.287	1.287
25012 (Harwood Beck @ Harwood)	0.356	43	33.265	0.189	0.251	0.763
51002 (Horner Water @ West Luccombe)	0.511	31	8.354	0.382	0.326	0.935
72007 (Brock @ U/s a6)	0.599	34	31.410	0.184	0.257	1.323
46005 (East Dart @ Bellever)	0.620	48	38.510	0.162	0.082	0.520
206006 (Annalong @ Recorder)	0.717	48	15.330	0.189	0.052	1.172
76811 (Dacre Beck @ Dacre Bridge)	0.730	12	54.705	0.144	0.047	0.331
72014 (Conder @ Galgate)	0.778	45	17.703	0.193	0.059	0.703
203046 (Rathmore Burn @ Rathmore Brid	0.781	30	10.934	0.136	0.091	0.157
47022 (Tory Brook @ Newnham Park)	0.793	19	7.331	0.257	0.071	1.359
73015 (Keer @ High Keer Weir)	0.794	21	12.239	0.156	0.001	0.524
25011 (Langdon Beck @ Langdon)	0.804	26	15.878	0.241	0.326	0.867
Total		504				
Weighted means				0.186	0.155	

Final Pooling Group

Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 2000
49003 (de Lank @ de Lank)	0.236	21.610	1628.000	0.064	0.998	0.000
48009 (st Neot @ Craigshill Wood)	0.310	22.910	1512.000	0.022	0.982	0.002
27032 (Hebden Beck @ Hebden)	0.314	22.200	1433.000	0.021	0.997	0.000
48004 (Warleggan @ Trengoffe)	0.323	25.260	1445.000	0.035	0.978	0.003
25012 (Harwood Beck @ Harwood)	0.356	24.580	1577.000	0.021	1.000	0.000
51002 (Horner Water @ West Luccomb	0.511	20.380	1485.000	0.003	0.978	0.000
72007 (Brock @ U/s a6)	0.599	31.530	1361.000	0.053	1.000	0.000
46005 (East Dart @ Bellever)	0.620	22.270	2095.000	0.042	1.000	0.000
206006 (Annalong @ Recorder)	0.717	13.660	1720.000	0.024	0.980	0.000
76811 (Dacre Beck @ Dacre Bridge)	0.730	33.970	1428.000	0.072	0.999	0.000
72014 (Conder @ Galgate)	0.778	28.990	1183.000	0.082	0.975	0.006
203046 (Rathmore Burn @ Rathmore Br	0.781	22.510	1043.000	0.073	1.000	0.000
47022 (Tory Brook @ Newnham Park)	0.793	13.45	1403	0.023	0.942	0.014
73015 (Keer @ High Keer Weir)	0.794	30.060	1158.000	0.075	0.976	0.003
25011 (Langdon Beck @ Langdon)	0.804	12.790	1463.000	0.013	1.000	0.001

DERIVING A POOLED GROWTH CURVE

Site	Dalwhat Water upstream of Cairn Water	√	Ungauged site
NGR	NX 7850 9025		Gauged site

Attached Printouts

	WINFAP-FEH station details
	WINFAP-FEH summary information if gauged site

Initial Pooling Group Details

Name	p_hiflows_craigdarroch_default
Site of interest	
Return period of interest	200 years
Other information	
Version of WIN-FAP FEH	Version 3.0
Data Files	Other
If 'Other' chosen in Data Files enter file path here	G:\FEH\FEH CD_ROM and WINFAP\HiFlows-UK data_v3.3.4_(Aug 2014)

Adjustment/ Changes made to Default Pooling Group.
Also note sites that were investigated but retained in the group (i.e. for discordancy)

Station number	Name	Addition/ Deletion/ Move/ Investigate	Reason
48009	st Neot @ Craigshill Wood	I	Discordancy of 3.655

Final Pooling Group Details

Heterogeneity Measure

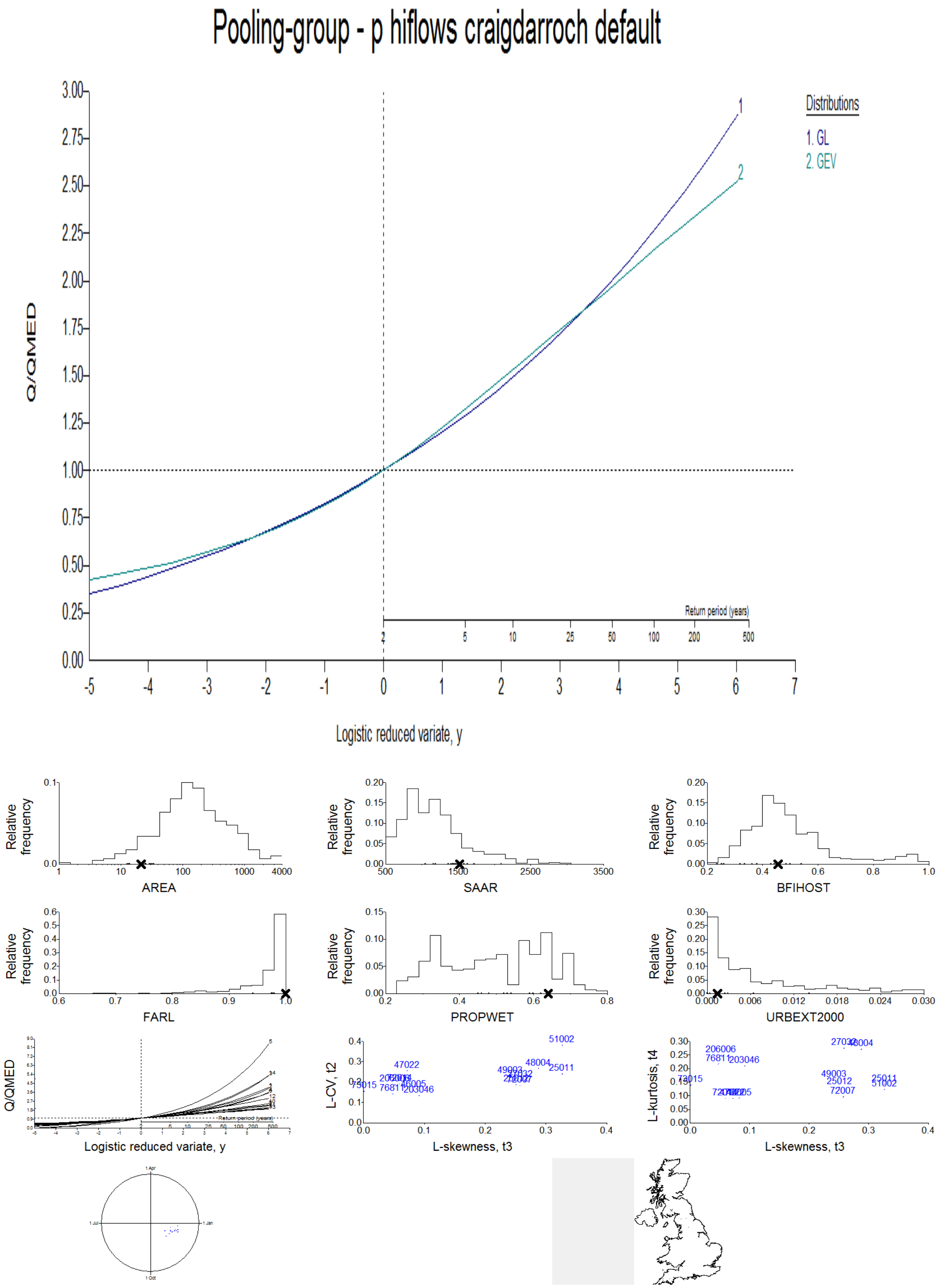
H1	Strongly Heterogeneous
H2	Heterogeneous

Goodness of Fit

Acceptable Fit	Distribution
√	Generalised Logistic
√	Generalised Extreme Value
	Pearson Type iii
	Generalised Pareto

Growth Curve Fittings

Attached print outs	√	WINFAP-FEH growth curve fittings
	√	WINFAP-FEH growth curve
Name of Final Pooling Group		p_hiflows_craigdarroch_default


Pooling-group - p hiflows craigdarroch default
Distributions
1. GL
2. GEV
Q/QMED
Return period (years)
Logistic reduced variate, y
Relative frequency
AREA
SAAR
BFIHOST
FARL
PROPWET
URBEXT2000
L-CV, t2
L-skewness, t3
L-kurtosis, t4

D Asset survey

D.1 Moniaive Flood Prevention Scheme, Dalwhat Water

A full walkover survey was undertaken to assess the condition of individual flood defence assets in Moniaive. These structures (listed below) collectively make up the Moniaive Flood Prevention scheme, which dates from 1963.

Culvert outfall structures are provided in a separate section (see part 2).

Name: Embankment, upstream Left Bank	Ref: 01
 *Looking downstream from left bank*	
Type: Embankment Bank: Left Upstream Grid Ref: (277965 , 591060) Height (m) (river side): Height (m) (landward side): 0.6m (upstream) to 1.4m Width (m): 0.5m (upstream) to 1.5m Length (m): 77.0m Material: Earth	Condition: Grade 4 (Poor) Part of FPS: Yes Comments: • Overgrown • Mature trees • Narrow crest at upstream • Steep on river side • Ties into high ground at upstream

Name: Embankment and Wall upstream of High Street Bridge	Ref: 02
 *Looking Downstream*	 *Looking upstream*
Type: Embankment with wall Bank: Left Upstream Grid Ref: (277982 , 590995) Height (m) (river side): Height (m) (landward side): 1.0m Width of wall (m): 0.40m Width of embankment (m): 1m (upstream) - 0m Length (m): 19.0m (to stone building) Material: Earth (with stone wall)	Condition: Grade 4 (Poor) - not to current standards Part of FPS: Yes Comments: • Stone toe revetment, eroded at d/s section • Tree at upstream end • One flapped outlet, downstream • One unflapped outlet, upstream • Ties into stone building • Maintained by owner of adjacent property

Name: Stone wall upstream of bridge, tied into building and bridge abutment	Ref: 03
 *From Left Bank*	 *From Right Bank*
Type: Stone Wall Bank: Left Upstream Grid Ref: (277989 , 590962) Height (m) (river side): 1.4m Height (m) (landward side): 1.1m Width (m): 0.4m Length (m): 1.4m Material: Stone and mortar	Condition: Grade 2 (Good) Part of FPS: Yes Comments: • Ties into mass concrete below footbridge

Name: Sheet Pile wall	Ref: 04
	 *Looking upstream*
Type: Sheet Pile Wall Bank: Right Upstream Grid Ref: (277970 , 590987) Height (m) (river side): 2.2m Height (m) (landward side): 1.1m Width (m): 0.3m Length (m): 33.5m Material: Steel	Condition: Grade 4 (Poor) Part of FPS: Yes Comments: • Moderate movement • Concrete beam is not cracked • Corrosion but within typical constraints • Toe is protected at downstream end • Minimal toe protection at upstream end • Several unflapped drainage pipes

Name: Embankment, left bank downstream of High Street Bridge	Ref: 05
 *Looking downstream*	 *Looking downstream along crest*
Type: Embankment Bank: Left Upstream Grid Ref: (277995 , 590952) Height (m) (river side): 1.5m Height (m) (landward side): 1.0m Width (m): 2.0m (crest) Length (m): 85.0m Material: Earth Condition: Grade 3 (Fair) Part of FPS: Yes	Comments: • Telegraph poles in crest • Upstream is well maintained • Crest is uniform in level • Over steepened slope on river side • Gardens on landward face • Trees on riverbank • Well tied into bridge at upstream end

Name: Downstream section of the above	Ref: 06
 *Looking downstream along crest*	 *Looking upstream - note overgrowth on crest*
Type: Embankment Bank: Left Upstream Grid Ref: (278036 , 590877) Height (m) (river side): Height (m) (landward side): Width (m): 2.0m (crest) Length (m): 270.0m Material: Earth	Condition: Grade 4 (Poor) Part of FPS: Yes Comments: • Steeper on river face • Overgrown • Dip in crest level between the two sections • Potential space for setting back of embankment, between current line and garden boundaries

Name: Embankment upstream of footbridge, right bank	Ref: 07
 *Looking upstream*	
Type: Embankment Bank: Right Upstream Grid Ref: (278200 , 590737) Height (m) (river side): Height (m) (landward side): Width (m):2.5m Length (m): 100.0m Material: Earth Condition: Grade 2 (Good) Part of FPS: Yes	Comments: • Tarmac footpath on crest • Steep side slopes Crest level is uniform

<table>
<tr><th>Name: Embankment downstream of footbridge, right bank</th><th>Ref: 08</th></tr>
<tr><td>
Looking upstream</td><td>
Looking downstream</td></tr>
<tr><td>Type: Embankment
Bank: Right
Upstream Grid Ref: (278276 , 590675)
Height (m) (river side):
Height (m) (landward side):
Width (m): 2.5m
Length (m): 220.0m
Material: Earth and Stone
Condition: Grade 3 (Fair)
Part of FPS: Yes</td><td>Comments:
• Some erosion of crest
• Crest not uniform in level
• Very steep on river side</td></tr>
</table>

D.2 Outfalls within Moniaive

<table>
<tr><th colspan="2">Ref: Outfall 01</th></tr>
<tr><td>
From right bank</td><td>
From above the outfall</td></tr>
<tr><td>Type: Outfall
Bank: Left
Diameter (m):
Condition: Grade 5 (Very Poor)
Part of FPS: Yes</td><td>Comments:
• Flap is fixed open - structure does not function
• Supporting structure is sound
• Slight corrosion on flap
• Pipe not inspected</td></tr>
</table>

Ref: Outfall 02

 *Photographs from left bank*	
Type: Outfall Bank: Right Diameter (m) : Condition: Grade 5 (Very Poor) Part of FPS: Yes	Comments: • Flap is fixed open - structure does not function • Supporting structure is sound • Slight corrosion on flap • Pipe not inspected

Name: Left Bank outfall near sewage works	Ref: Outfall 03
 *From opposite bank*	Type: Outfall Bank: Left Diameter (m) : Condition: Grade 2 (Good) Part of FPS: Yes Comments: • Concrete structure is sound • Minimal corrosion to flap • No leakage detected • Flap not inspected for range of movement • Pipe not inspected

E Appendix E - CCTV review

E.1 Introduction

A full walkover survey was undertaken to assess the condition of individual flood defence assets in Moniaive. These defence assets (listed below) collectively make up the Moniaive FPS.

Table E-6: CCTV culvert inspection data

Category	Comments
Date of inspection(s)	Inlet inspections - 22 June 2015 CCTV Survey - 26 & 27 August 2015
Inspector(s)	Angus Pettit Underground Inspection Services
Nature of culverts	4 culverts in total. Full details are provided in the CCTV report and in the summary below.
Location of culverts	The culverts are shown on Figure E-1 and Figure E-2
Nature of inspection(s)	The inspections were walkover surveys and visual inspection of the culvert inlets and outlets. A full CCTV survey was undertaken by UIS. No jetting or directional drilling was undertaken to clear debris or blockages.
Comments from Residents	No comments were received from residents regarding any of the culverts.
Associated reports	UIS CCTV Survey Report (36714), 17-08-2015

E.2 Location map of CCTV

Figure E-1: Culvert survey map provided by Underground Investigation Services

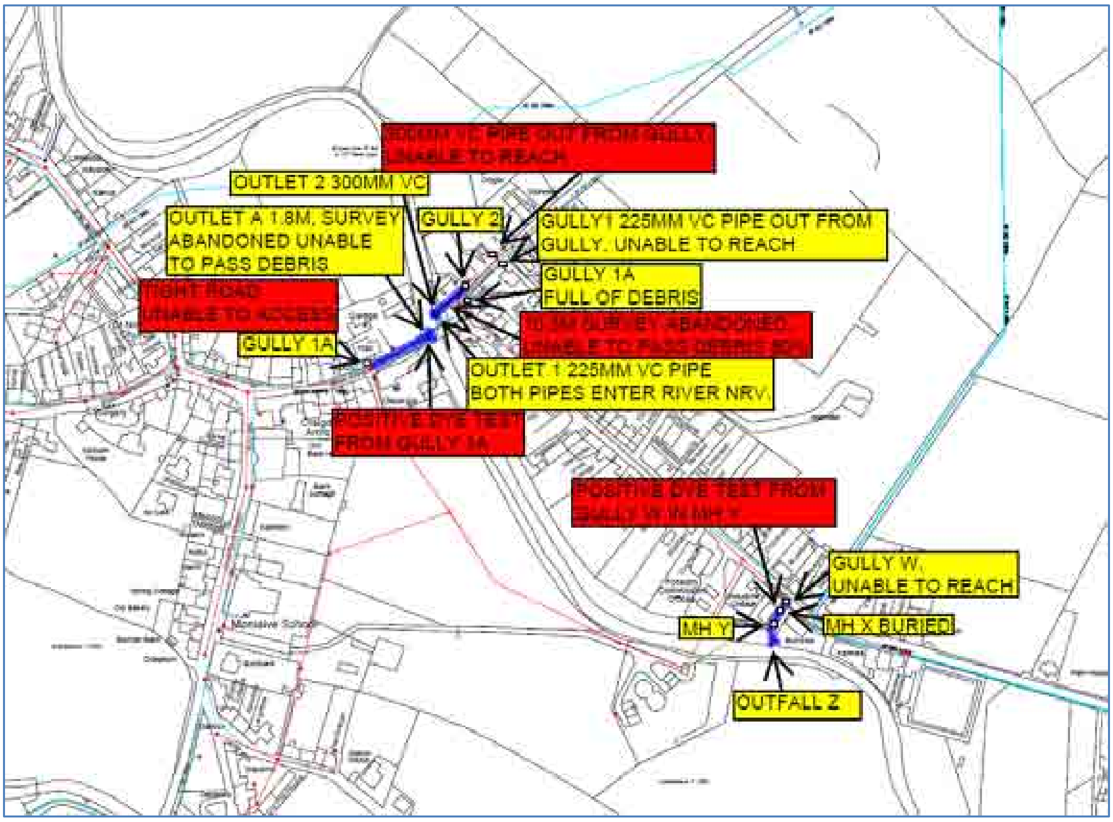
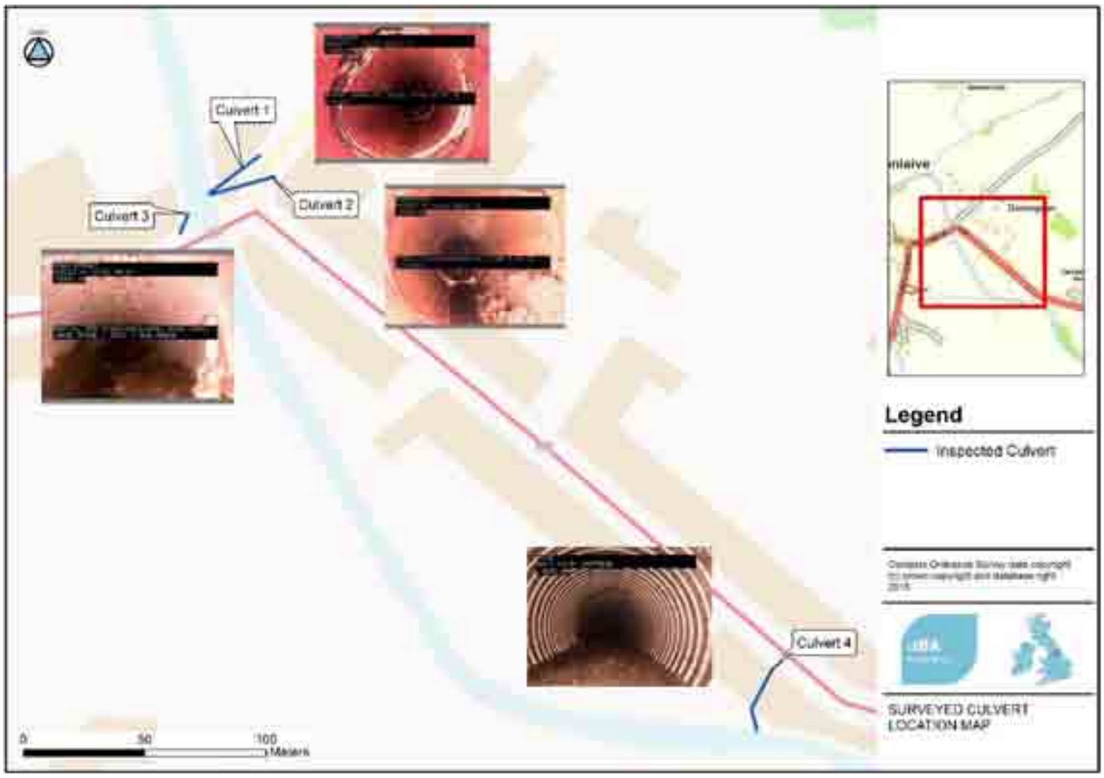


Figure E-2: Surveyed culverts location map



E.3 Analysis of CCTV

E.3.1 Culvert 1

Table E-7: Culvert 1 data and condition assessment

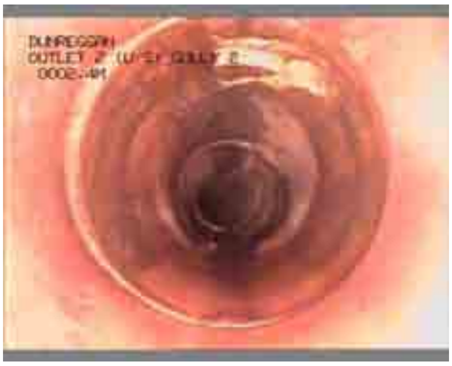
Location: Dunreggan Street with the outlet located upstream of High Street Bridge on the left bank	
CCTV reference: Outlet 1 (DS), Gully 1 (US) Upstream Grid Ref: NX 78035 90998 Downstream Grid Ref: NX 77984 90970 Surveyed length (m): 10.3 Diameter (m): 0.225 Material: Vitrified clay Part of FPS: Yes Number of Manholes: Unknown Invert level of outlet: Approximately 104.16mAOD. (Not specifically surveyed)	Overall condition: Poor Outlet flapped: YES Maintenance recommendations: • Remove blockage • Clean culvert • Regular inspections • Remedial work to flap valve Condition assessment: The culvert is in poor condition. The survey of this culvert was abandoned after 10m because of a large blockage of gravel and cobbles occupying 80% of the culvert's cross section. 0.6m from the outlet end the culvert has 360 degree break at the joint. The flap valve at the outlet is seized in a semi open position.

Displaced joint

Outlet

E.3.2 Culvert 2

Table E-8: Culvert 2 data and condition assessment

Location: Dunreggan Street with the outlet located upstream of High Street Bridge on the left bank	
CCTV reference: Outlet 2 (DS), Gully 2 (US) Upstream Grid Ref: NX 78006 90988 Downstream Grid Ref: NX 77984 90970 Surveyed length (m): 18.7 Diameter (m): 0.3 Material: Vitrified clay Part of FPS: Yes Number of Manholes: Unknown Invert level of outlet: Approximately 104.16mAOD. (Not specifically surveyed)	Overall condition: Poor Outlet flapped: YES Maintenance recommendations: • Consider sliplining • Regular inspections • Remedial work to flap valve Condition assessment: Although the culvert is relatively free of debris and silt except for a bar of mud close to the culvert exist the culvert is in poor condition. There are several circumferential cracks and longitudinal cracks throughout as well as joint displacement and holes through the ceiling of the culvert. The flap valve at the outlet is seized in a semi open position.
Mud deposits  Damage to culvert ceiling 	Outlet 

E.3.3 Culvert 3

Table E-9: Culvert 3 data and condition assessment

<table>
<tr><th colspan="2">Location: High Street with the outlet located upstream of High Street Bridge on the right bank</th></tr>
<tr><td>CCTV reference: Outlet A
Upstream Grid Ref:
Downstream Grid Ref: NX 77972 90964
Surveyed length (m): 1.8
Diameter (m): 0.225
Material: Vitrified clay
Part of FPS: Yes
Number of Manholes: Unknown
Invert level of outlet: 104.02mAOD</td><td>Overall condition: Poor
Outlet flapped: YES
Maintenance recommendations:
• Remove blockage
• Clean culvert
• Regular inspections
• Remedial work to flap valve

Condition assessment:
Within 2m of the culvert outlet the culvert obstructed by a large stone and mud, beyond this there is more debris, mud and silt.
The flap valve at the outlet is seized in a semi open position.</td></tr>
<tr><td>Significant mud deposits

</td><td>Outlet
</td></tr>
</table>

E.3.4 Culvert 4

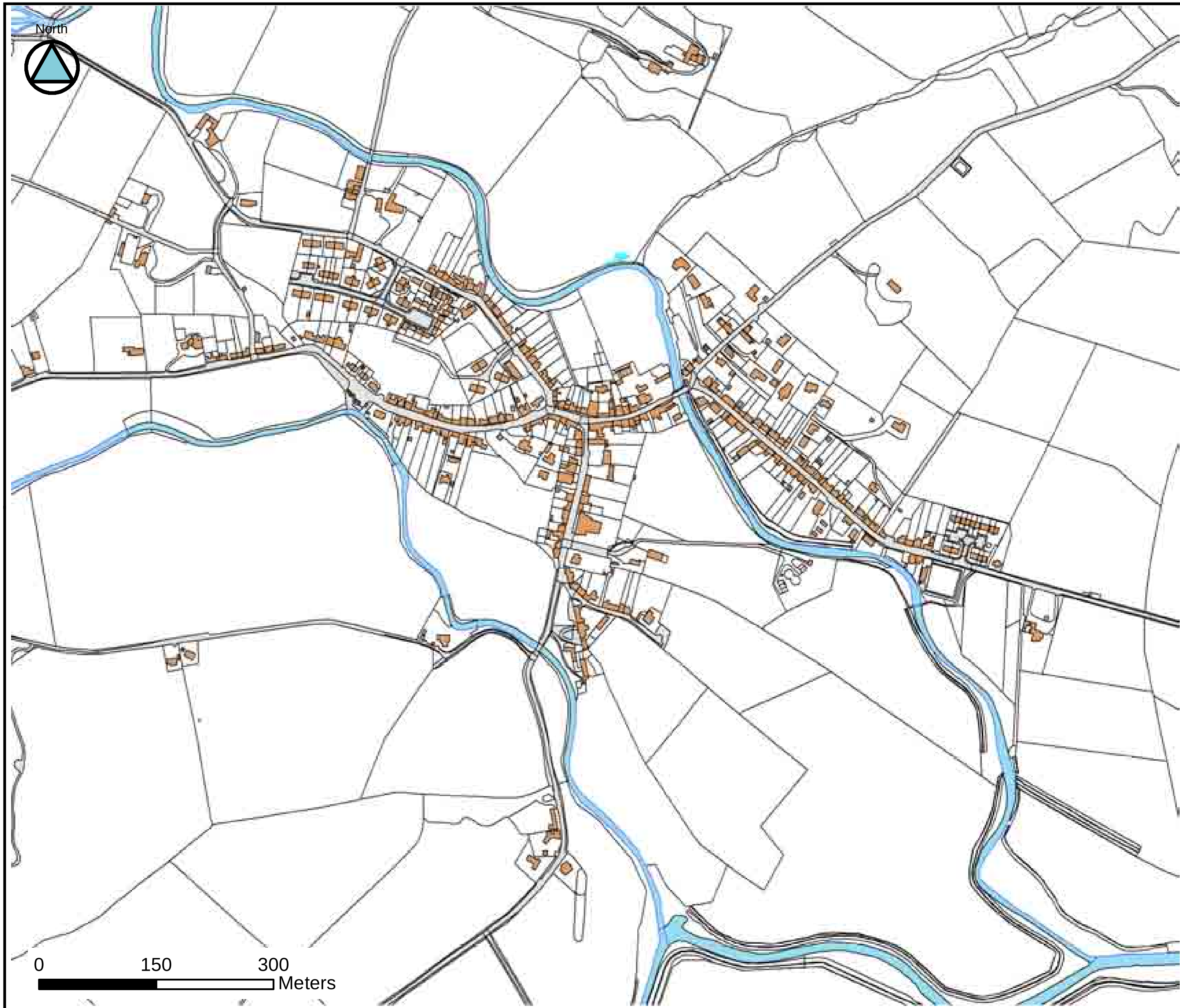
Table E-10: Culvert 4 downstream data and condition assessment

Location: Garden between Woodbine Cottage and Burnside along A702	
CCTV reference: MH Y Upstream Grid Ref: NX 78203 90763 Downstream Grid Ref: NX 78210 90746 Surveyed length (m): 16.50 Diameter (m): 0.5 (PVC), 0.6 (concrete) Material: Polyvinyl chloride (PVC), Concrete Part of FPS: Yes Number of Manholes: Unknown Invert level of outlet: N/A	Overall condition: Good Outlet flapped: Yes Maintenance recommendations: • Regular inspection Condition assessment: This culvert is in good condition. It is clear throughout its length. After 4m the pipe changes from 0.5m PVC pipe to a 0.6m concrete pipe. 2.5 m from the entrance point there is a 0.15 PVC pipe connection protruding approximately 0.15m into the culvert.
0.15m pipe connection in culvert side 	Outlet 

Table E-11: Culvert 4 upstream data and condition assessment

Location: Garden between Woodbine Cottage and Burnside along A702	
CCTV reference: MH Y Upstream Grid Ref: NX 78214 90771 Downstream Grid Ref: NX 78203 90763 Surveyed length (m): 9.50 Diameter (m): 0.5 (PVC) Material: Polyvinyl chloride (PVC), Concrete Part of FPS: Yes Number of Manholes: Unknown Invert level of outlet: Approximately 102.33mAOD	Overall condition: Good Outlet flapped: Yes Maintenance recommendations: • Regular inspection Condition assessment: Structurally the culvert appears to be in good condition. Over a length of approximately 4m there is a silt build up which occupies approximately 20% of the cross section. A buried manhole at the end of surveyed pipe length reduces the pipe cross sectional area by approximately 40%.
Silt build up in upstream section 	Outlet 

F Appendix F - Flood maps



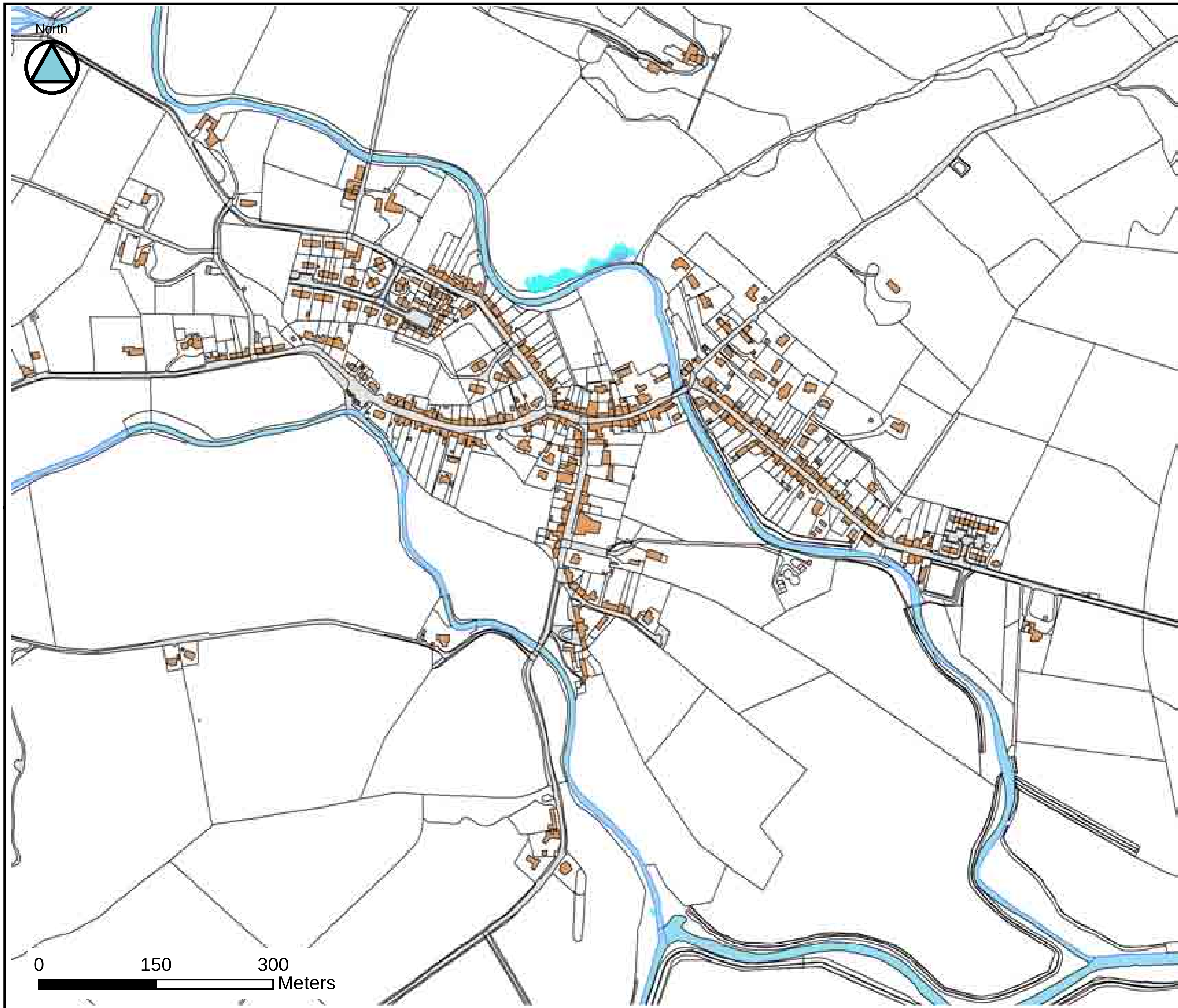
LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

JBA consulting

FLOOD DEPTH MAP FOR THE 2 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

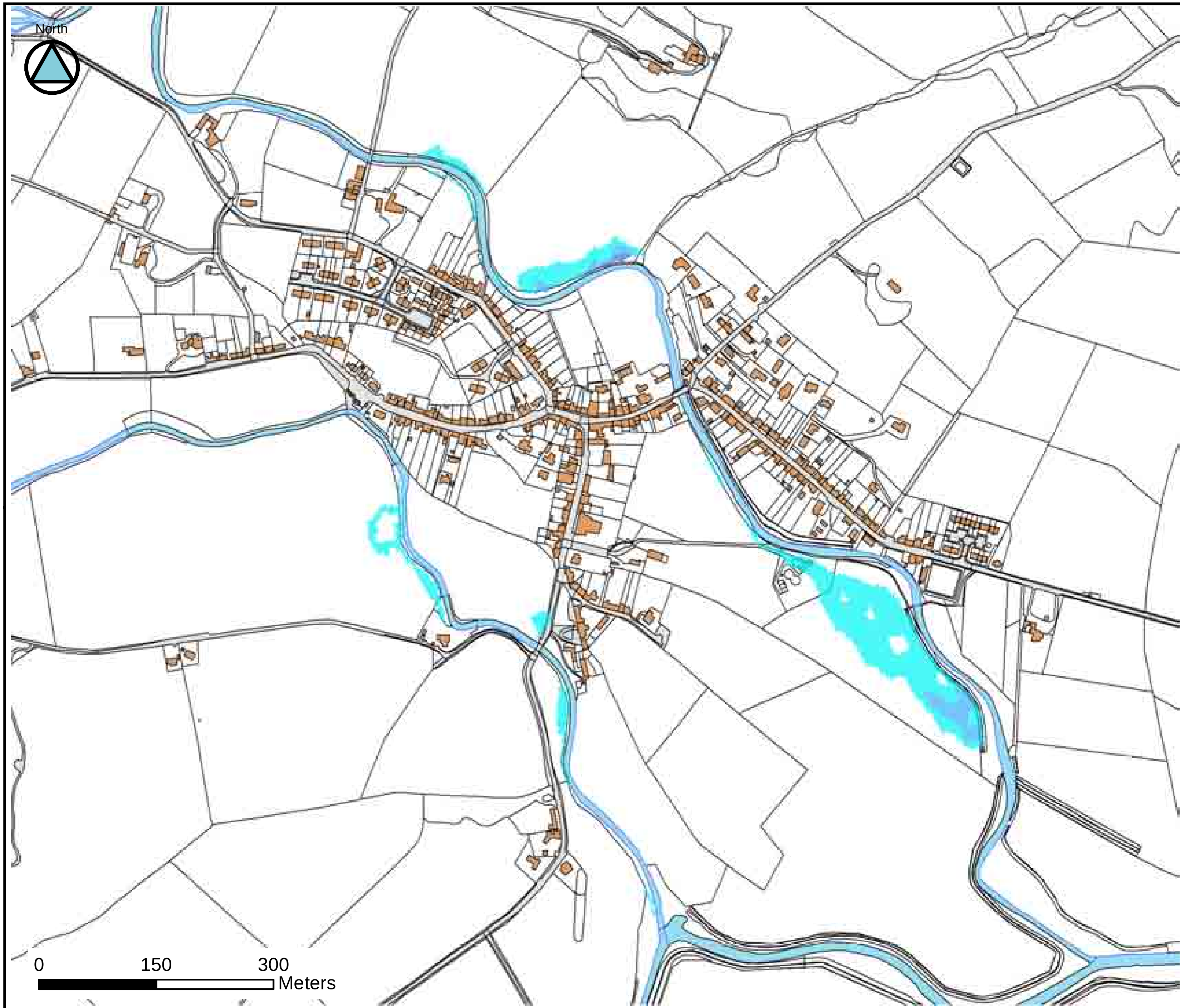


LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP FOR THE 10 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS



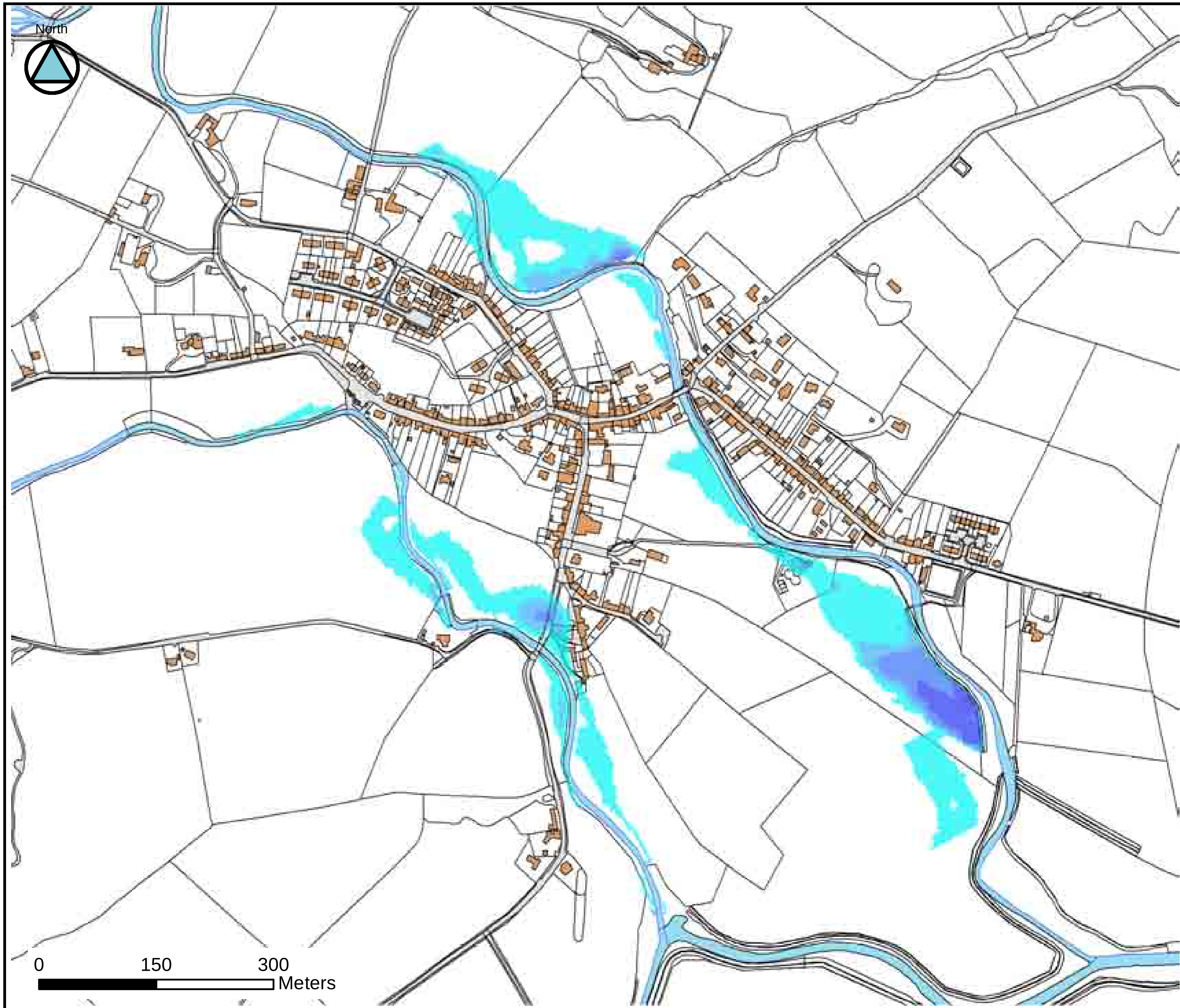
LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

JBA consulting

FLOOD DEPTH MAP FOR THE 25 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

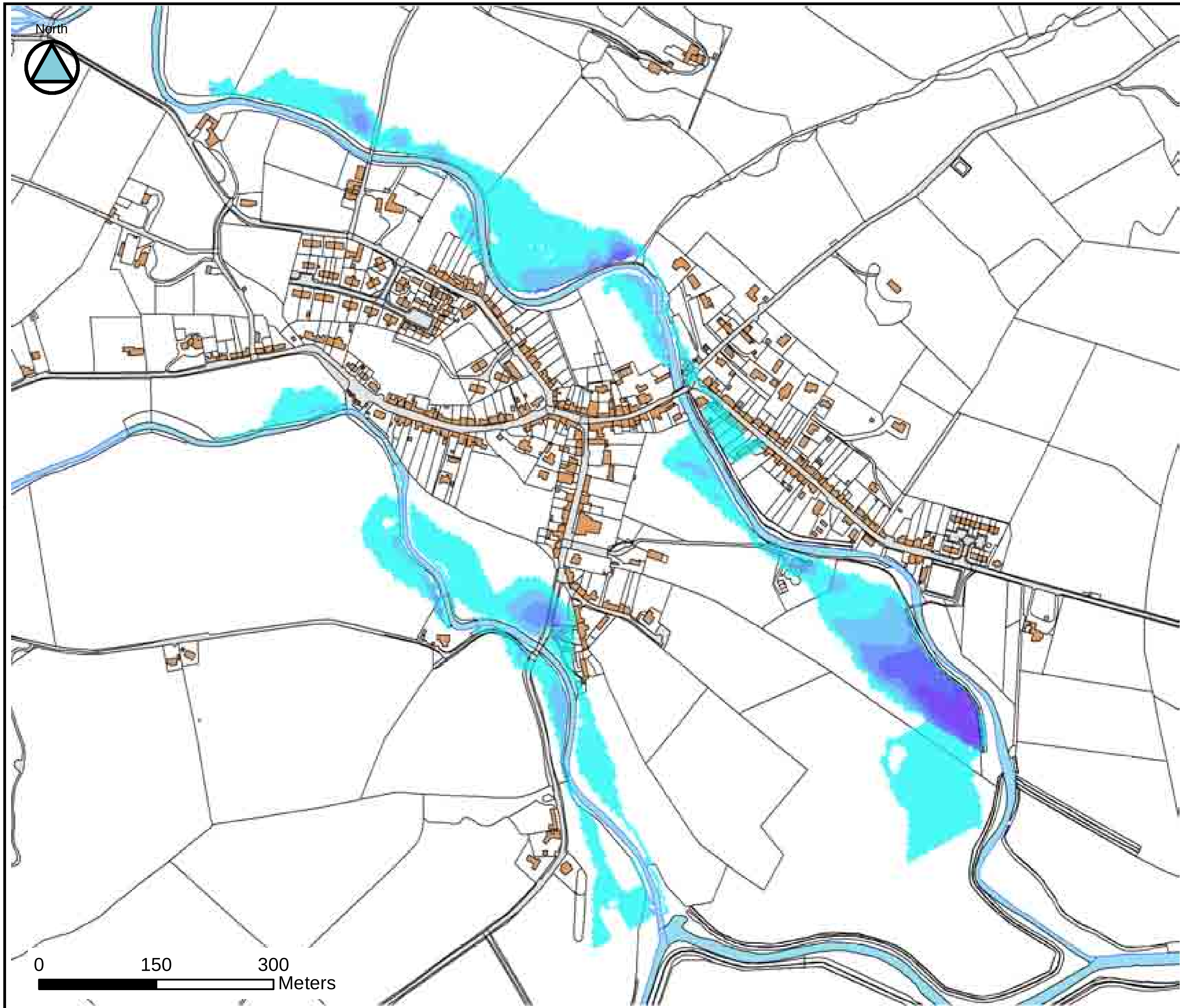


LEGEND

Depth (m)

0 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00

FLOOD DEPTH MAP FOR THE 50 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

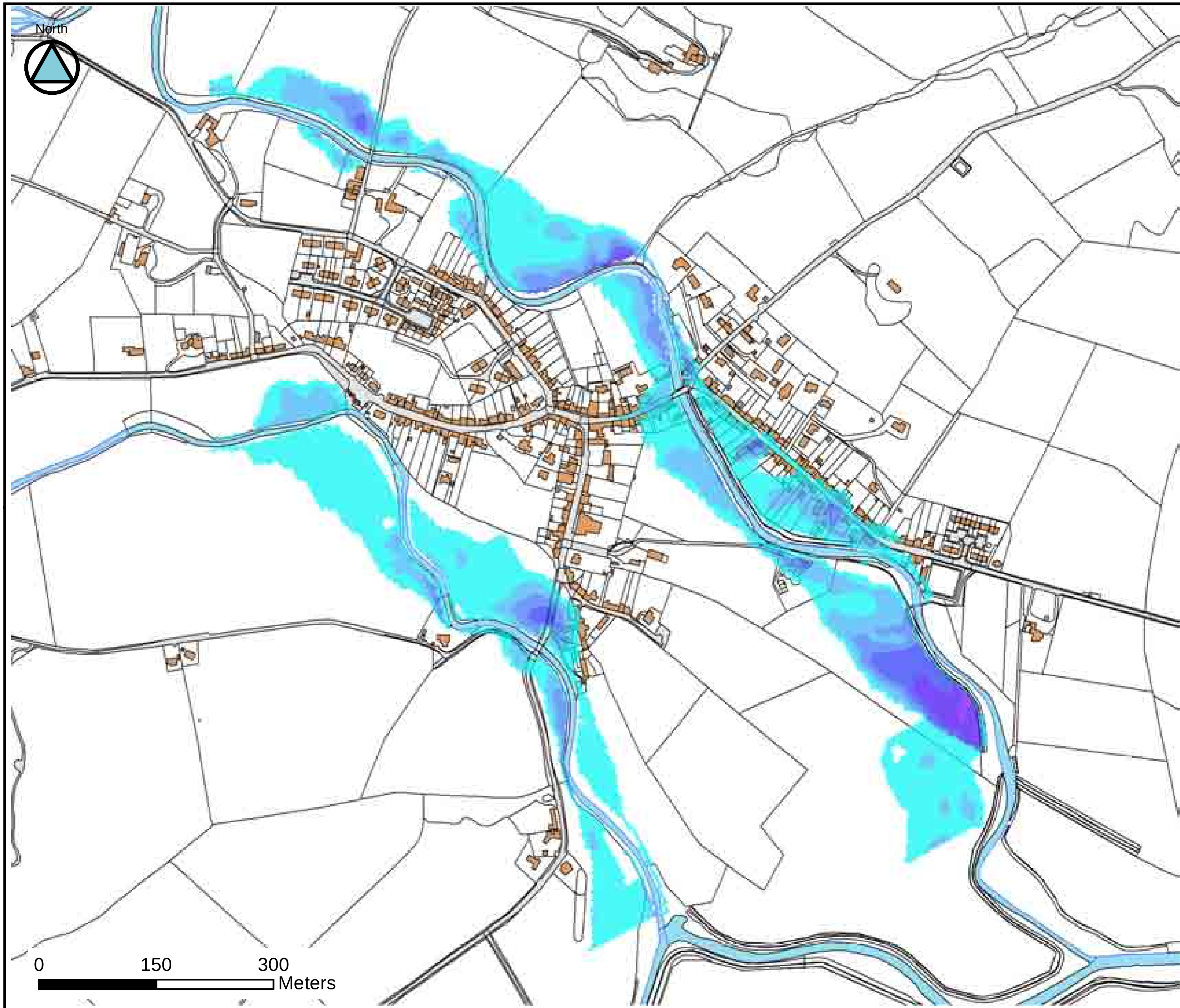


LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP FOR THE 100 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

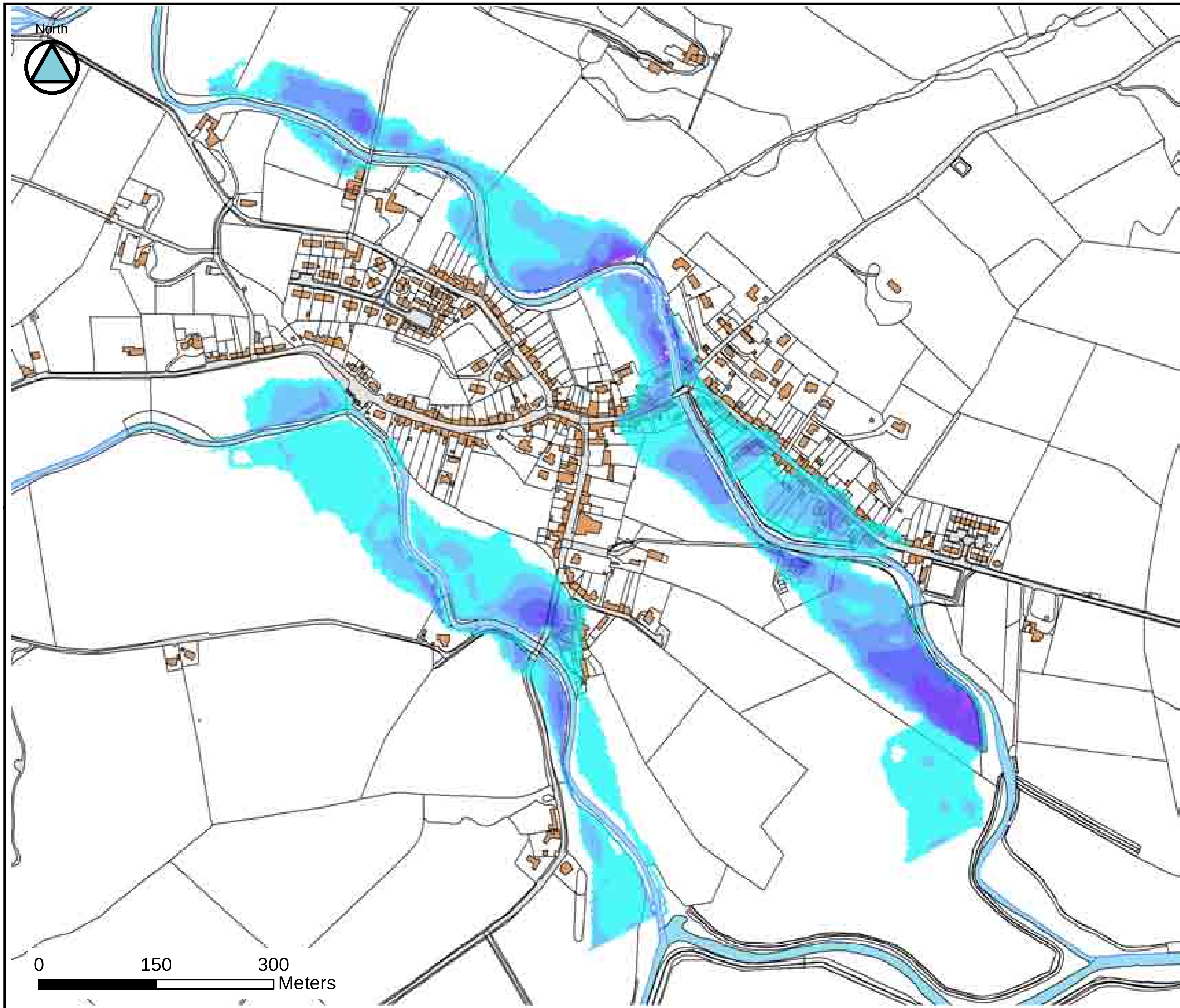


LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP FOR THE 200 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

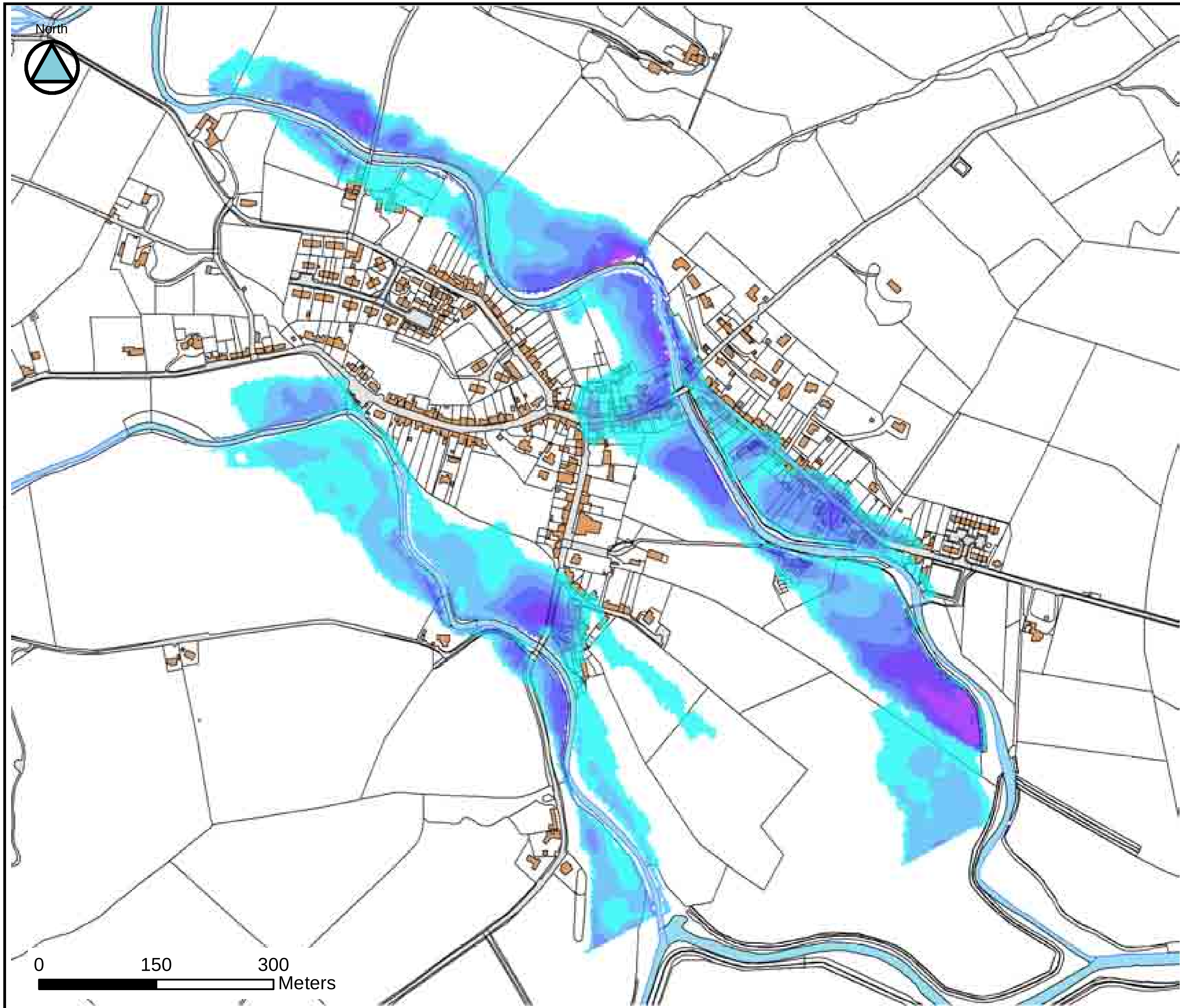


LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP FOR THE 200 YEAR FLOOD EVENT WITH CLIMATE CHANGE FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS

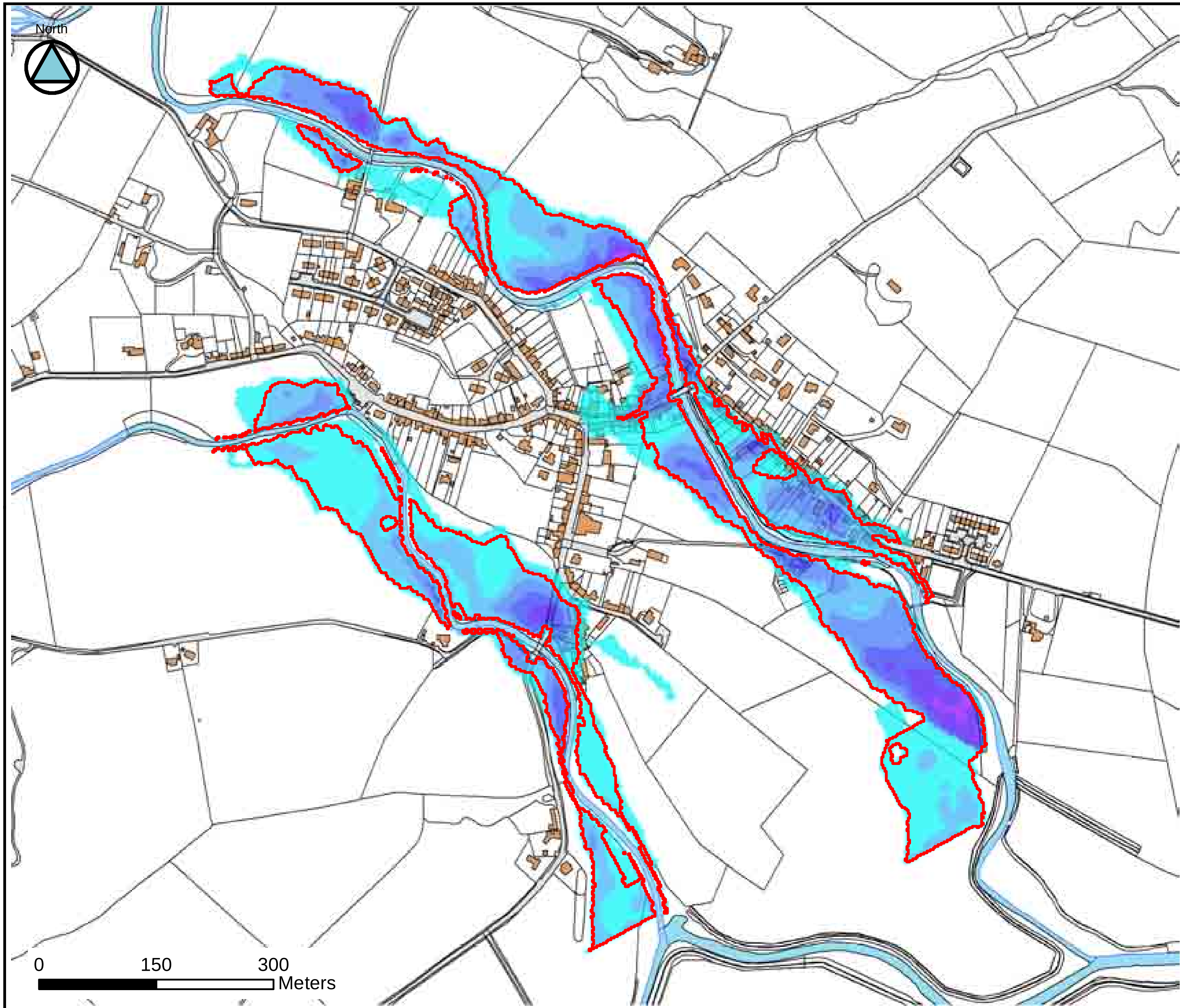


LEGEND

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP FOR THE 1000 YEAR FLOOD EVENT FOR THE DALWHAT WATER AND CRAIGDARROCH WATERS



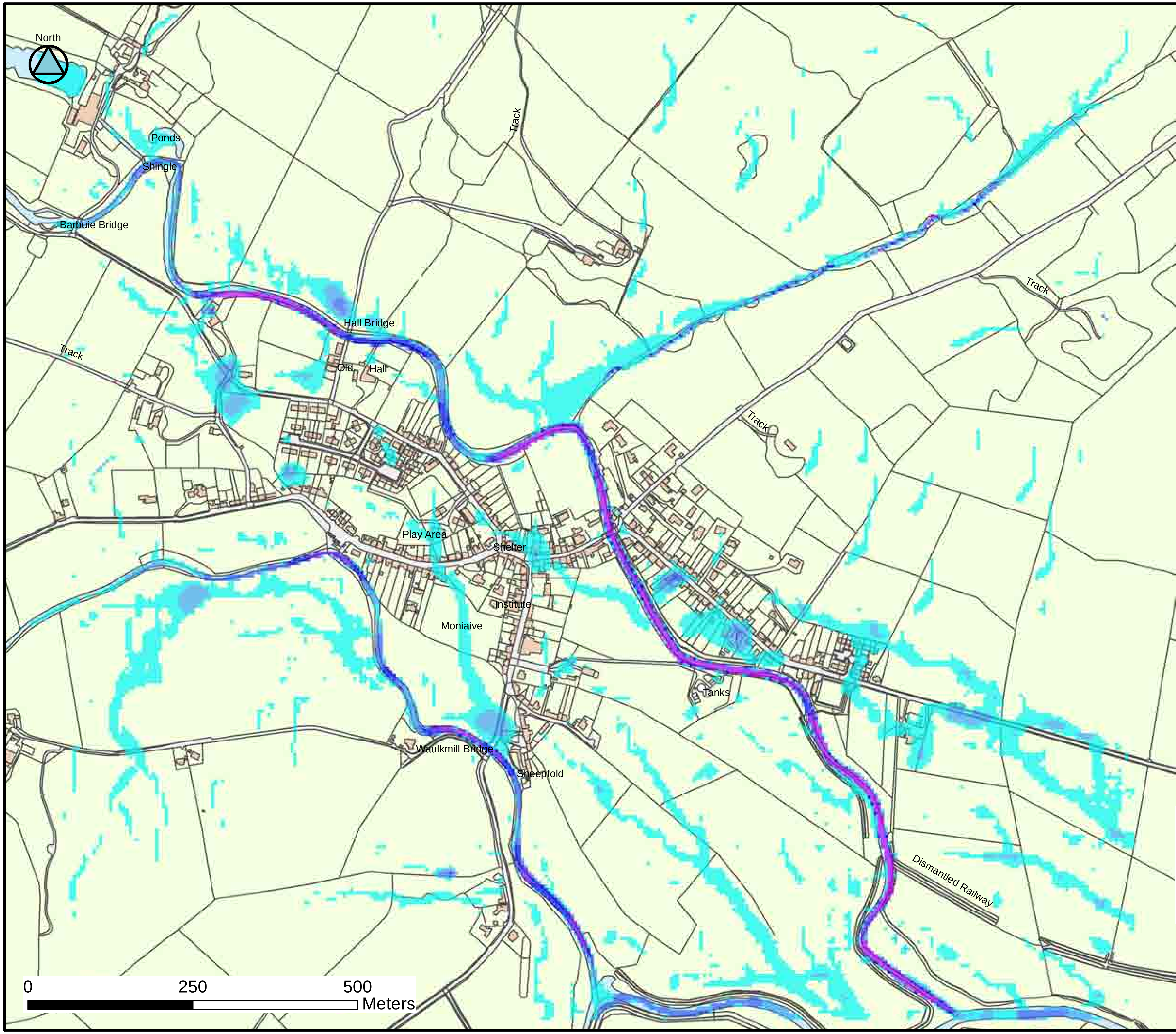
LEGEND

Baseline 200 year flood outline

Depth (m)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

FLOOD DEPTH MAP COMPARING MODEL RUNS WITH BFI LEVELS WITH THE 200 YEAR FLOOD EVENT FOR THE DALWHAT AND CRAIGDARROCH WATERS



Legend

200 year 1hr Duration

Depth (m)

- 0.05 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 2.00
- 2.00 - 5.00

SURFACE WATER FLOOD DEPTH & VELOCITY MAP FOR THE 200 YEAR 1 HOUR DURATION STORM

G Appendix G - Model results

G.1 Current conditions water surface

Table G-1: Current conditions model results for the 2 year to 1000 flood flow on the Dalwhat Water

Label	2 yr	10 yr	25 yr	50 yr	100 yr	200yr	200 yr + CC	1000 yr
MON_1840	109.63	109.95	110.13	110.28	110.41	110.45	110.47	110.58
MON_1710	108.63	108.96	109.17	109.38	109.53	109.70	109.85	110.05
MON_1621	108.11	108.44	108.61	108.82	108.96	109.19	109.41	109.77
MON_1528	107.66	108.02	108.29	108.43	108.50	108.55	108.60	108.71
MON_1418	106.90	107.32	107.54	107.70	107.83	107.92	107.99	108.09
MON_1349	106.38	106.75	106.95	107.07	107.19	107.28	107.37	107.47
MON_1233	105.76	106.04	106.24	106.37	106.45	106.58	106.70	106.89
MON_1156	105.19	105.49	105.67	105.83	106.00	106.17	106.37	106.62
MON_1062	104.55	104.89	105.10	105.28	105.59	105.86	106.04	106.28
MON_1021	104.36	104.64	104.83	105.00	105.19	105.54	105.87	106.20
MON_981	104.22	104.51	104.71	104.90	105.06	105.26	105.48	105.79
MON_972	104.22	104.51	104.70	104.85	104.98	105.10	105.23	105.39
MON_908	103.82	104.12	104.29	104.42	104.51	104.64	104.78	104.94
MON_857	103.53	103.82	103.97	104.12	104.32	104.51	104.74	104.96
MON_764	103.21	103.50	103.58	103.62	103.64	103.70	103.77	103.86
MON_707	102.90	103.24	103.37	103.47	103.55	103.65	103.76	103.93
MON_607	102.29	102.52	102.64	102.74	102.84	102.96	103.11	103.28
MON_530	101.88	102.14	102.25	102.35	102.46	102.59	102.74	102.86
MON_528.5	101.88	102.14	102.25	102.35	102.46	102.59	102.74	102.86
MON_449	101.26	101.56	101.69	101.80	101.91	102.04	102.20	102.45
MON_357	100.51	100.85	101.09	101.28	101.47	101.65	101.86	102.14
MON_209	99.51	99.83	100.04	100.24	100.41	100.63	100.83	101.09
MON_0	98.68	98.98	99.20	99.36	99.53	99.73	99.96	100.25

Table G-2: Current conditions model results for the 2 year to 1000 flood flow on the Craigdarroch Water

Label	2 yr	10 yr	25 yr	50 yr	100 yr	200yr	1000 yr
CRAI01_1057	108.65	108.96	109.15	109.29	109.42	109.48	109.56
CRAI01_0949	107.96	108.25	108.41	108.54	108.72	108.95	109.16
CRAI01_0866	107.22	107.52	107.71	107.85	108.00	108.16	108.30
CRAI01_0815	106.71	107.02	107.22	107.36	107.51	107.69	107.81
CRAI01_0738	106.18	106.47	106.62	106.70	106.72	106.73	106.83
CRAI01_0633	105.33	105.57	105.70	105.82	105.93	106.06	106.17
CRAI01_0553	104.45	104.70	104.88	105.01	105.12	105.23	105.73
CRAI01_0495	103.83	104.15	104.41	104.57	104.69	104.80	105.05
CRAI01_0442	103.75	104.14	104.42	104.63	104.79	104.95	105.28
CRAI01_0433	103.58	103.88	104.04	104.20	104.33	104.50	104.87
CRAI01_0400	103.35	103.64	103.81	103.93	103.94	104.05	104.49
CRAI01_0375	103.19	103.47	103.63	103.74	103.90	104.03	104.43
CRAI01_0315	102.86	103.11	103.26	103.39	103.54	103.69	104.10
CRAI01_0256	102.51	102.71	102.84	102.94	103.04	103.13	103.28
CRAI01_0154	101.75	101.95	102.07	102.17	102.28	102.36	102.54

H Appendix H - Properties at risk

Table H-1: Key to properties at risk

No flooding to properties	
Flooding below threshold level (sub floor level, -0.3- 0.0m)	-0.10
Flooding above threshold level	0.15

H.1 Properties at risk from the Dalwhat Water

Table H-2: Properties at risk of flooding and depths for range of flood events modelled

Property address	MCM code	25-yr	50-yr	100-yr	200-yr	200-yr CC	1000yr
WOODBINE COTTAGE	111				-0.14	-0.02	0.20
CNOCRUADH	131					-0.18	0.04
CRAIGOWER	111				0.44	0.56	0.76
BURNSIDE	111				-0.14	-0.03	0.14
ALDERSYDE	121				-0.08	0.03	0.22
RAILWAY VIEW	121				-0.04	0.07	0.26
MEDWAY	111					-0.25	-0.07
GARWALD	131					0.03	0.17
INVER	121					0.24	0.38
GLENCROSS COTTAGE	121				0.02	0.09	0.23
WATERSIDE SMIDDY	121				-0.07	0.00	0.14
GLENAFTON	131					0.04	0.20
MARNOCK	121					-0.22	-0.05
SIDEFIELD	111				-0.06	0.07	0.31
THE COTTAGE	131				-0.10	0.03	0.26
MARCAM	121				-0.27	-0.15	0.09
HOLMLEA	131					-0.24	0.00
OLD WATERSIDE	121				-0.26	-0.15	0.08
CROSSHILL	131					-0.27	-0.03
DANELL	121					-0.17	0.01
AMBERLEY	131					-0.06	0.01
STRATHLAURIE COTTAGE	131					-0.01	0.12
RIO COTTAGE	121			0.00	0.04	0.11	0.17
LINNCAIRN	121			-0.02	0.06	0.16	0.31
FIDRA	131				-0.02	-0.02	0.05
CAIRN COTTAGE	111			0.01	0.13	0.26	0.39
AIRLIE	111			-0.06	0.04	0.15	0.30
AFTON	115				-0.15	-0.06	0.12
TOLL COTTAGE	111		0.45	0.45	0.68	0.80	0.99
Garage/Shed	8			0.70	0.92	1.04	1.19
1 BRIDGEND COTTAGE	121		0.45	0.45	0.68	0.80	0.99
STW	8		0.01	0.14	0.25	0.34	0.47
Forestry Office outbuilding	8				0.24	0.37	0.61
THE FORESTRY OFFICE	3				0.02	0.15	0.38
THORNGOWER	114				-0.01	0.12	0.35
Walmet Cottage	131				-0.22	-0.10	0.13
PARK VIEW	131				-0.22	-0.10	0.13
JASMINE COTTAGE	131				-0.07	0.06	0.29
2 BRIDGEND	121			0.43	0.68	0.84	1.05

Property address	MCM code	25-yr	50-yr	100-yr	200-yr	200-yr CC	1000yr
COTTAGES							
Sub Station	960				0.48	0.65	0.89
WATERSIDE SMIDDY	121			-0.29	0.12	0.19	0.35
THE SHEILING	121					0.40	0.66
JAMES CALLANDER	3					0.49	0.67
POST OFFICE	2				0.36	0.59	0.85
FLAT	2					0.47	0.68
DALWHAT GARAGE	2					0.17	0.49
HALL	6				-0.06	0.19	0.46
Property adjacent to George Hotel	131				0.24	0.46	0.66
THE GEORGE HOTEL	51				0.23	0.44	0.65
DALWHAT GARAGE	2				0.47	0.74	1.02
THE CHALET GEORGE HOTEL	51				-0.28	-0.21	-0.08
Restaurant	2					0.42	0.62
WESTFIELD HOUSE	121				0.14	0.37	0.61
EBRUCHIE	131					0.42	0.60

H.2 Properties at risk from the Craigdarroch Water

Table H-3: Properties at risk of flooding and depths for range of flood events modelled

Property address	MCM code	25-yr	50-yr	100-yr	200-yr	200-yr CC	1000yr
GARAGE 3	8						0.31
GARAGE 5	8						0.10
GARAGE 1	8						0.06
GARAGE 2	8						0.23
CESSNOCK	121					-0.36	-0.20
WAULKMILL	121					-0.40	-0.21
Steel Shed/Barn	4					-0.19	-0.04
Stone shed/barn	4		-0.23	-0.11	-0.03	0.03	0.17
Garage	8					0.09	0.19

I Appendix I - Economic Appraisal

Project Summary Sheet

Client/Authority				Prepared (date)	
Dumfries and Galloway Council				Printed	10/08/2016
Project name				Prepared by	
Moniaive FPS Appraisal				Checked by	
Project reference	2015s2864			Checked date	
Base date for estimates (year 0)	Sep-2015				
Scaling factor (e.g. £m, £k, £)	£k	(used for all costs, losses and benefits)			
Year	0	30	75		
Discount Rate	3.5%	3.00%	2.50%		
Optimism bias adjustment factor	60%				

Costs and benefits of options

	Costs and benefits £k				
Option name	Do Minimum	Option 1 (PLP)	Option 2 (Raised defence)	Option 4 (Breach & raised defence)	Option 2a (Raised Defences U/S only)
COSTS:					
PV capital costs	0	643	820	518	198
PV operation and maintenance costs	0	0	0	0	0
PV other	0	0	0	0	0
Optimism bias adjustment	0	386	492	311	119
Total PV Costs £k excluding contributions	0	1,029	1,312	829	317
BENEFITS:					
PV monetised flood damages	650	122	238	238	238
PV monetised flood damages avoided		528	412	412	412
PV damages (from scoring and weighting)					
PV damages avoided/benefits (from scoring and weighting)					
PV benefits from ecosystem services					
Total PV damages £k	650	122	238	238	238
Total PV benefits £k		528	412	412	412
DECISION-MAKING CRITERIA:					
excluding contributions					
Based on total PV benefits (includes benefits from scoring and weighting and ecosystem services)					
Net Present Value **NPV**		-501	-900	-417	95
Average benefit/cost ratio **BCR**		0.5	0.3	0.5	1.3
Incremental benefit/cost ratio **IBCR**			-0.4	0.0	0.0
					Highest bcr

Brief description of options:

Option 1	Do Minimum
Option 2	Option 1 (PLP)
Option 3	Option 2 (Raised defence)
Option 4	Option 4 (Breach & raised defence)
Option 5	Option 2a (Raised Defences U/S only)

Comments and assumptions:

Summary Annual Average Damage

Sheet Nr.

Client/Authority
Dumfries and Galloway Council
Project name
Moniaive FPS Appraisal
Project reference 2015s2864

Base date for estimates (year 0)	42248	First year of damage:	0	Prepared (date)	00/01/1900
Scaling factor (e.g. £m, £k, £)	£k	Last year of period:	99	Printed	10/08/2016
Discount rate	3.5%	PV factor for mid-year 0:	29.813	Prepared by	0
				Checked by	0
Applicable year (if time varying)				Checked date	0

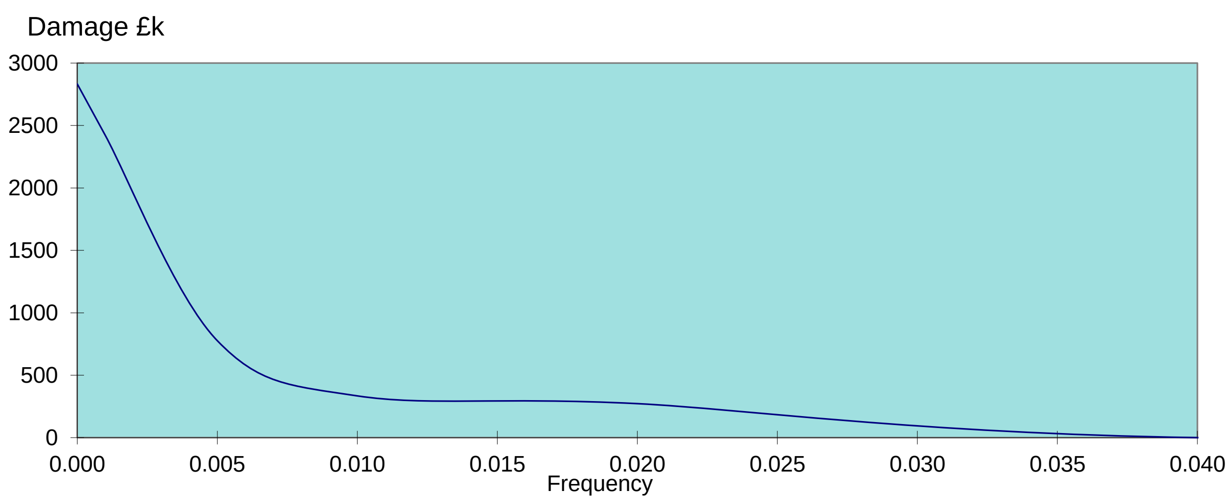
Option:
Do nothing

		Average waiting time (yrs) between events/frequency per year										Total PV
		1	2	5	10	25	50	100	200	1000	Infinity	£k
		1.000	0.500	0.200	0.100	0.040	0.020	0.010	0.005	0.001	0	
Direct Damage category		Damage £k										
Residential property		0	0	0	0	0	241	278	427	1110	1280	329
Ind/commercial (direct)		0	0	0	0	0	0	4	226	879	1042	112
Indirect Damage category		Damage £k										
Ind/comm (indirect)		0	0	0	0	0	0	0	7	26	31	3
Traffic related											0	0
Emergency services	0.107	0	0	0	0	0	26	30	70	213	249	47
Vehicle Damage		0	0	0	0	0	5	10	21	75	89	14
Evacuation / Temp Accom.		0	0	0	0	0	0	12	26	119	142	17
											0	0
Total damage	£k	0	0	0	0	0	31	52	124	433	510	
Area (damagexfrequency)			0.0	0.0	0.0	0.0	0.3	0.4	0.4	1.1	0.5	

Present value (assuming no change in damage or event frequency)	441	14.8	
Capped PVd (direct property damage) from previous sheet	441	(no DI)	
Check on PVd capping	0		
Total area, indirect damages	3		
Present value (assuming no change in damage or event frequency)	82		
Intangible AAD (Low Estimate (£286/yr)	4		
Intangible AAD (High Estimate (£2513/yr)	37		
Intangible PVd (Low Estimate)	127		
Intangible PVd (High Estimate)	1113		
Total Present Value (assuming no change in damage or event freq.)	650	21.8	523

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Project: Moniaive FPS Appraisal **Option: Do nothing**



Summary Annual Average Damage

Sheet Nr.

Client/Authority
Dumfries and Galloway Council
Project name
Moniaive FPS Appraisal

Option:
Option 1 (PLP)

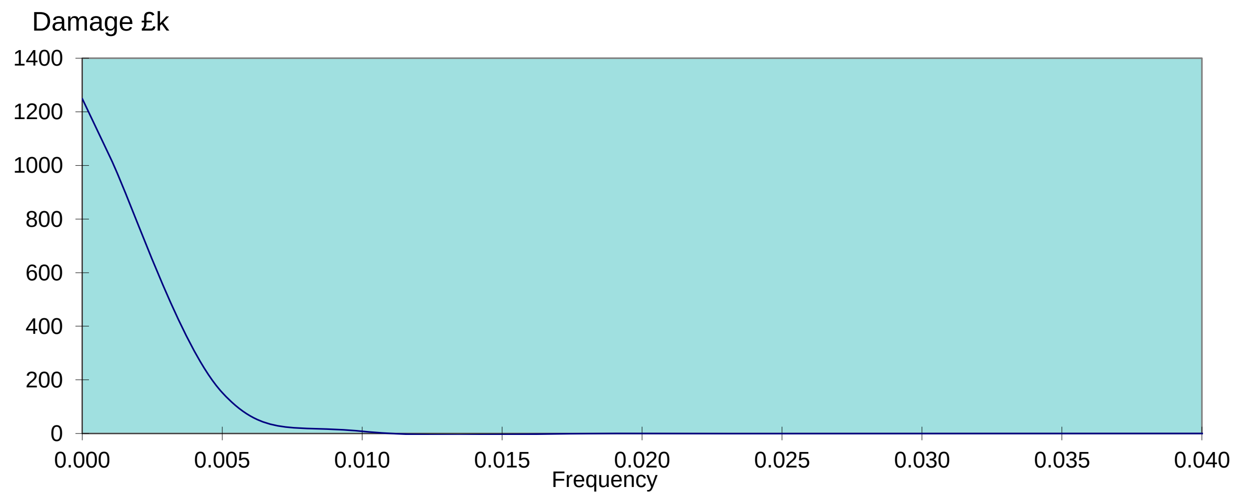
Project reference	2015s2864				
Base date for estimates (year 0)	42248	First year of damage:	0	Prepared (date)	00/01/1900
Scaling factor (e.g. £m, £k, £)	£k	Last year of period:	99	Printed	10/08/2016
Discount rate	3.5%	PV factor for mid-year 0:	29.813	Prepared by	0
				Checked by	0
Applicable year (if time varying)				Checked date	0

		Average waiting time (yrs) between events/frequency per year										Total PV
		1	2	5	10	25	50	100	200	1000	Infinity	£k
		1.000	0.500	0.200	0.100	0.040	0.020	0.010	0.005	0.001	0	
Direct Damage category		Damage £k										
Residential property		0	0	0	0	0	0	0	116	320	371	45
Ind/commercial (direct)		0	0	0	0	0	0	3	3	485	606	46
Indirect Damage category		Damage £k										
Ind/comm (indirect)		0	0	0	0	0	0	0	0	15	18	1
Traffic related											0	0
Emergency services	0.107	0	0	0	0	0	0	0	13	86	105	10
Vehicle Damage		0	0	0	0	0	0	3	8	75	92	9
Evacuation / Temp Accom.		0	0	0	0	0	0	3	13	49	58	7
											0	0
Total damage	£k	0	0	0	0	0	0	6	34	225	272	
Area (damagexfrequency)			0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.2	

Present value (assuming no change in damage or event frequency)	91	3.1	
Capped PVd (direct property damage) from previous sheet	91	(no DI)	
Check on PVd capping	0		
Total area, indirect damages	1		
Present value (assuming no change in damage or event frequency)	27		
Intangible AAD (Low Estimate (£286/yr)	0		
Intangible AAD (High Estimate (£2513/yr)	1		
Intangible PVd (Low Estimate)	4		
Intangible PVd (High Estimate)	37		
Total Present Value (assuming no change in damage or event freq.)	122	4.1	118

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Project: Moniaive FPS Appraisal **Option: Option 1 (PLP)**



Summary Annual Average Damage

Sheet Nr.

Client/Authority
Dumfries and Galloway Council
Project name
Moniaive FPS Appraisal
Option:
Option 2 (Raised defence)

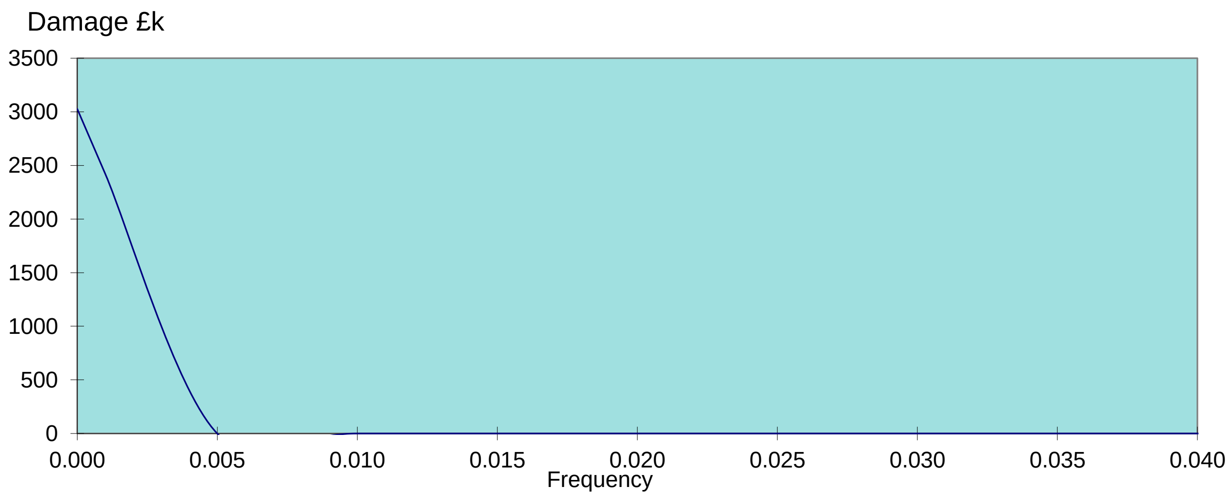
Project reference	2015s2864					
Base date for estimates (year 0)	42248	First year of damage:	0	Prepared (date)	00/01/1900
Scaling factor (e.g. £m, £k, £)	£k	Last year of period:	99	Printed	10/08/2016
Discount rate	3.5%	PV factor for mid-year 0:	29.813	Prepared by	0
				Checked by	0
Applicable year (if time varying)				Checked date	0

	Average waiting time (yrs) between events/frequency per year										Total PV
	1	2	5	10	25	50	100	200	1000	Infinity	£k
	1.000	0.500	0.200	0.100	0.040	0.020	0.010	0.005	0.001	0	
Direct Damage category	Damage £k										
Residential property	0	0	0	0	0	0	0	0	1110	1387	103
Ind/commercial (direct)	0	0	0	0	0	0	0	0	879	1099	82
Indirect Damage category	Damage £k										
Ind/comm (indirect)	0	0	0	0	0	0	0	0	26	33	2
Traffic related										0	0
Emergency services 0.107	0	0	0	0	0	0	0	0	213	266	20
Vehicle Damage	0	0	0	0	0	0	0	0	75	94	7
Evacuation / Temp Accom.	0	0	0	0	0	0	0	0	119	149	11
										0	0
Total damage £k	0	0	0	0	0	0	0	0	433	541	
Area (damagexfrequency)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.5	

Present value (assuming no change in damage or event frequency)	185	6.2	
Capped PVd (direct property damage) from previous sheet	185	(no DI)	
Check on PVd capping	0		
Total area, indirect damages	1		
Present value (assuming no change in damage or event frequency)	40		
Intangible AAD (Low Estimate (£286/yr)	0		
Intangible AAD (High Estimate (£2513/yr)	4		
Intangible PVd (Low Estimate)	13		
Intangible PVd (High Estimate)	110		
Total Present Value (assuming no change in damage or event freq.)	238	8.0	226

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Project: Moniaive FPS Appraisal **Option: Option 2 (Raised defence)**



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