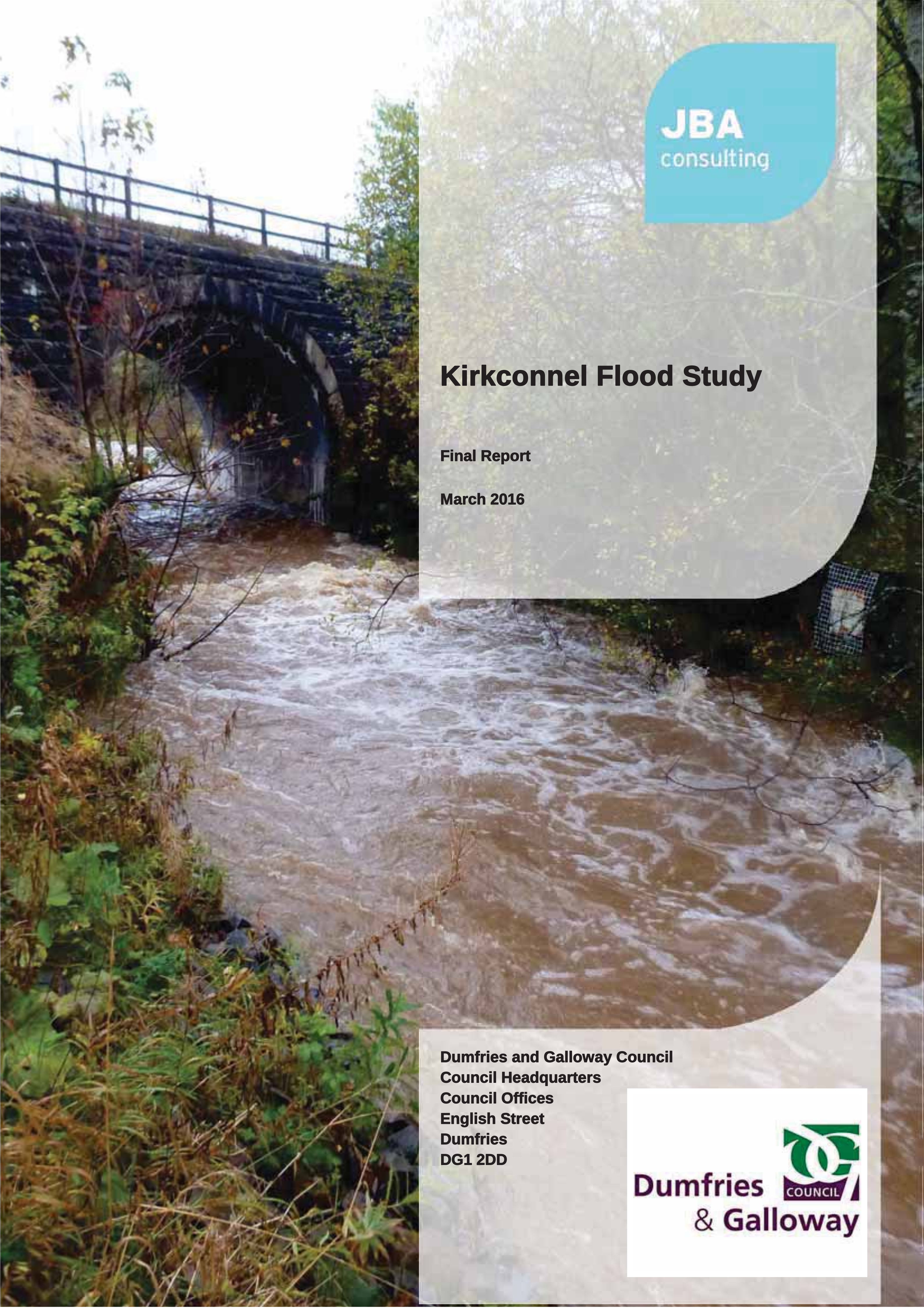


Kirkconnel Flood Study

Final Report

March 2016

Dumfries and Galloway Council
Council Headquarters
Council Offices
English Street
Dumfries
DG1 2DD

JBA Project Manager

Angus Pettit BSc MSc CEnv CSci MCIWEM C.WEM
Port Neuk
1 Longcraig Road
South Queensferry
Edinburgh
EH30 9TD

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Draft Report v1.0 / March 2015	-	Ross Gibson
Draft Report v2.0 / April 2015	Minor amendments to text / figures.	Ross Gibson
Final Report v2.0 / July 2015	Minor amendments following review	James McLeod
Final Report v2.1 / Mar 2016	Minor amendments following review	James McLeod

Contract

This report describes work commissioned by James McLeod, on behalf of Dumfries and Galloway Council, by a letter dated 16 October 2014. Dumfries and Galloway's representative for the contract was Ross Gibson of Dumfries and Galloway Council. David Cameron, Jonathan Garrett and Angus Pettit of JBA Consulting carried out this work.

Prepared by .... David Cameron BSc PhD MCIWEM CWEM CSci

Senior Chartered Analyst

Prepared by .... Jonathan Garrett BEng

Senior Chartered Analyst

Reviewed by .... Angus Pettit

Principal Analyst

Reviewed by .... David Bassett BSc MSc CEnv MCIWEM C.WEM

Director

Purpose

This document has been prepared as a Final Report for Dumfries and Galloway Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Dumfries and Galloway Council.

Acknowledgements

JBA wishes to thank SEPA for providing hydrometric information.

JBA would like to thank Ross Gibson and Brian Templeton for providing assistance and information to support the project.

JBA would also like to thank Dumfries and Galloway Housing Partnership for assistance and information relating to the project.

Copyright

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 462g if 100% post-consumer recycled paper is used and 588g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Executive Summary

Reason for works

Kirkconnel flooded in December 2013 causing flooding to approximately 50 properties. The estimated magnitude of the flood is approximately a 1.25% Annual Probability (80 year) flood. This represented the first major flood to the town since 1966. The area has been classified as a priority area by Dumfries and Galloway Council and as a Potentially Vulnerable Area by SEPA with the town identified as a specific community for flood risk reduction.

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. These include the following:

- Option 1. Property Level Protection
- Option 2. Bridge removal
- Option 3. Direct Defences

In addition to these options it is recommended that flood warning is improved by SEPA in Kirkconnel amongst other communities on the River Nith in the short term.

Expected benefits

There are 93 properties at risk from flooding in Kirkconnel. Based on the flood hydrology and modelling undertaken the annual average flood damages are estimated to be £121,000 with a Present Value damage in the region of £2.4 million.

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 – variable costs depending on SOP (£1.3m for 200 year standard)
- Option 2 - Bridge removal – single cost of £0.6m.
- Option 3 - Direct Defences - variable costs depending on SOP (£5.2m for 200 year standard)

These costs include an allowance for both capital costs and operation and maintenance costs over a 100 year financial period. They also include a 60% optimism bias which is standard for this level of strategic appraisal.

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 property level protection option. Neither the bridge removal nor direct defence options can be considered cost effective.

Whilst the PLP option may be considered the most cost effective this option is not as reliable as other options due to the risks associated with overtopping of defences (some properties would be at risk from lower return period even with PLP measures due to high flood depths witnessed in 2013), the need for residents to act themselves to protect their homes, and the poor flood warning and lead time associated with the scheme.

Contents

Contents

List of Figures

List of Tables

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 October 2014 in order to gain a greater understanding of the flood mechanisms and improve upon SEPA's Flood Risk Management maps in Kirkconnel 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 Kirkconnel 13th 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 2011, as part of the Flood Risk Management (Scotland) Act 2009, SEPA has completed a National Flood Risk Assessment and identified Kirkconnel as a Potentially Vulnerable Area (PVA) with 47 (7%) residential properties and 47 (8%) non-residential properties identified at flooding risk. Estimated Weighted Annual Damages for the PVA were £280k-£330k.

In response to the above findings and to investigate a large flood event that occurred in Kirkconnel in December 2013 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 River Nith and the Polbower Burn in Kirkconnel. 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:

- 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)

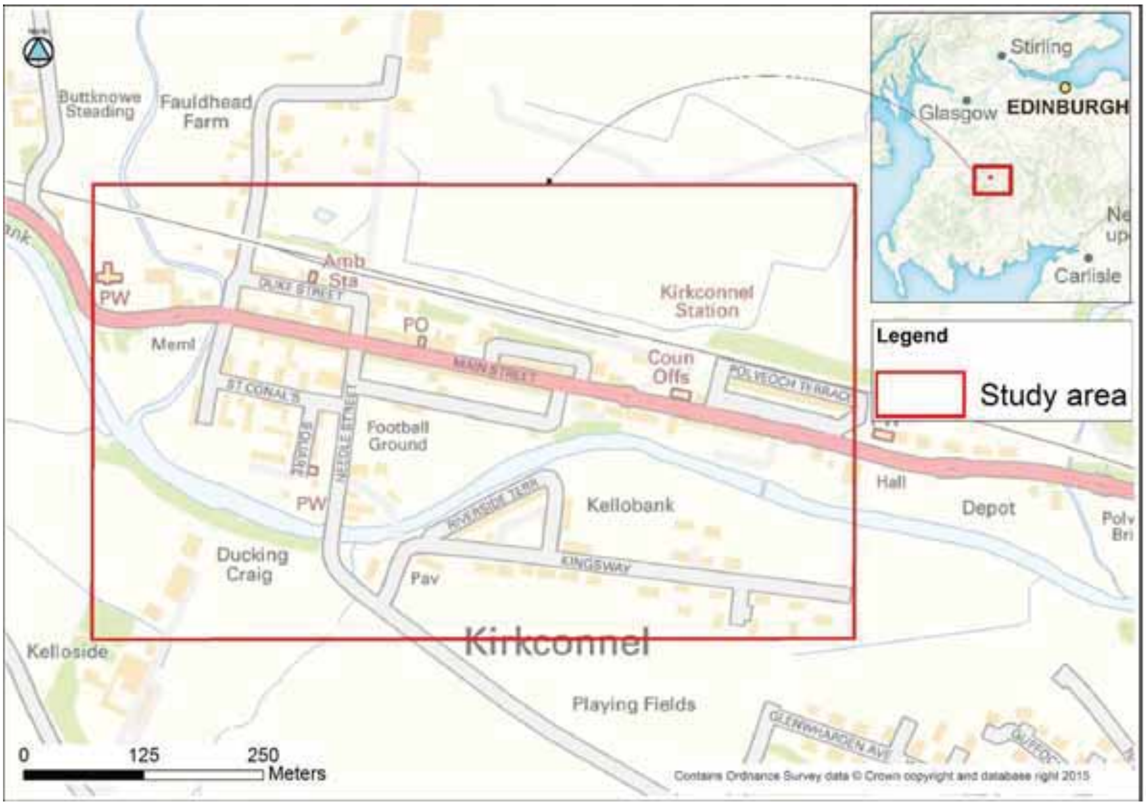
Three outline designs have been proposed to achieve a:

a. 0.5% AP with an allowance for climate change level of protection
b. 2.0% AP level of protection
c. A level of protection for the greatest benefit/cost ratio for a return period event between 1:1 and 1:200 + climate change.

1.3 Extent of study area and description

Kirkconnel is located approximately midway between Kilmarnock and Dumfries, approximately 55km to the south east of Glasgow. The town is located on the north and south side of the River Nith and to the east of the Polbower Burn. 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 River Nith from upstream of the Polbower Burn confluence from National Grid Reference (NGR) NN 72791 12222 and continues downstream to Polveoch Bridge at NGR 73778 11996. The red square shown in Figure 1-1 frames the main area of interest.

1.4 Catchment description

The catchment of the River Nith drains a large area of south west Scotland and discharges into the Solway Firth downstream of Dumfries. At Kirkconnel the catchment area is 187.2 km^2, which includes two tributaries that join the Nith - the Polbower Burn from the north which has a catchment area of 12.9 km^2 and the Gillan Burn from the south which has a catchment area of 0.97 km^2. These areas derived from the FEH CD-ROM and have been checked against Ordnance Survey maps requiring minor adjustment. The Polbower Burn catchment was increased up from 12.82 km^2 to account for the flood protection scheme drainage system installed in 1978.

The catchment land use is typically hill grazing with some forestry. The area of the catchment at Kirkconnel is underlain by sedimentary bedrock of the Scottish Coal Measures Group (mudstone, siltstone, sandstone, coal and ironstone) with superficial deposits of alluvium, till, sand and gravel.

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 chance of a flood exceeding the 100-year flood in any one year. 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(such as the 10 years since the last flood), 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 Estimation

2.1 Introduction

The town of Kirkconnel has flooded historically, most recently in 2013 and also notably in 1966. The principle sources of fluvial flood risk to Kirkconnel are the River Nith and its tributary, the Polbower Burn. Flooding from these sources has been modelled using an ISIS-TUFLOW model. This model requires the following inputs: design peak flood flows (for a variety of annual probabilities, APs or return periods) and hydrographs. The purpose of this section of the report is therefore to document the estimation of those flood flows and hydrographs for both the River Nith and Polbower Burn. A subsequent section of the report will detail the modelling itself.

2.1.1 Descriptions of historical flooding

There are several records available from the Chronology of British Hydrological Events[1] which note historic flood events on the River Nith including the following:

- **25 December 1852** - "...In Scotland, the inundations were not less formidable. The impetuous streams of that country were greatly swollen, and did great damage. The Tay and the Earn, in Perthshire, rolled down in immense floods. The whole neighbourhood of Perth was a vast lake, the beautiful Inches were covered, and much of the "fair city" laid under water. In the western counties, ***the Nith***, the Annan, the Moffat, and the Dee, ***rose over the adjacent country. In every part large numbers of sheep were drowned, and the labours of the husbandman suspended."***
- **December 1897** - Rainfall observer at Moniave, Maxwelton House, noted "...much heavy rain and floods, from 25th to the end."
- **1 November 1898** - Rainfall observer at Maxwelton House, Dumfries noted "Rain 2.22 inches; with one exception the greatest fall in 12 years, and the highest flood remembered."
- **19 May 1899** - Rainfall observer at Moniaive (Maxwelton House), Dumfrieshire, noted "... Exceptionally heavy rain for the time of year on 18th and 19th (2.24 in.); Rivers in high flood."
- **19 January 1909** - Observer at Jardington, Dumfries, noted "Stormy day with heavy rain during the night and S. W wind which melted the snow on the higher ground causing the heaviest flood for about 30 years."
- **25 July 1909** - Rainfall observer at Lincluden House, Dumfries, noted "severe thunderstorm with heavy rain causing floods which did much damage to the hay crops."
- **12 October 1909** - Observer at Jardington, Dumfries, noted "Stormy evening, with high wind and flood"
- **1933** - "At Afton Reservoir, in Ayrshire, the duration of the 3.5 inches recorded, was 15.8 hours."
- **1936** - "FLOOD IN DUMFRIES [filmed as a local topical for the Regal Cinema, Dumfries] 1936 Flood waters breaking over the banks of the River Nith in Dumfries town centre. People are seen standing in doorways and wading through the water."

More recent records of flooding on the River Nith were recorded in 1966 and 2013 and are summarised below.

2.1.2 August 1966

The flood which occurred in August 1966 on the River Nith caused extensive damage in Kirkconnel and across the catchment. In the minutes of a Parliamentary debate on the topic of flood damage in Scotland in 1967[2]. In the speech by Mr. Hector Munro (Dumfries MP) he noted that:

---

1 Chronology of British Hydrological Events (http://www.dundee.ac.uk/geography/cbhe/)

2 Commons and Lords Hansard - the Official Report of debates in Parliament, 23 March 1967 vol. 743 (http://hansard.millbanksystems.com/index.html)

"…torrential rain…brought the Nith and its tributaries down in high flood. ***Damage to the roads alone totalled £144,000*** *and there was untold damage to farms and households. Perhaps the total might not be far short of £200,000, which is almost as much as the damage caused in Ross-shire in December. In this case the Government gave only the normal percentage grants for roads, which* ***left the ratepayers to stump up £65,000 to put the roads back into the order*** *in which they were before. There was no question of improvement. Of course,* ***there was nothing for householders or for the shopkeepers of Kirkconnel who lost a great deal of stock; neither was there anything for private roads, for damage to crops and loss of livestock****."*

2.1.3 December 2013

Torrential rain at the end of December 2013 across the whole of Scotland caused severe flooding in Kirkconnel which was documented by various news articles[3]. Approximately 40 homes were evacuated by emergency services of which 15 (owned by the Dumfries and Galloway Housing Partnership) were subsequently deemed uninhabitable when the floods receded. The worst affected area was St. Conal's Square where the River Nith burst its banks and also Riverside Terrace. A refuge centre was established at the Miners Hall where volunteers provided support and supplies for those affected. Councillor John Syme noted that "*It's good DGHP will be keeping tenants up to date and looking to prevent this happening again. The flooding's not happened as bad as that before but who knows what the future will bring?"*

2.2 Historical context

Anecdotal information on flooding on the River Nith extends to December 1852. From the descriptions of the flooding alone (see above), it is possible that the August 1966 and December 2013 events are the largest since 1852. A preliminary estimate of the annual probabilities (APs) associated with those events can therefore be made from Gringorten plotting positions. On this basis, the largest event would have an AP of about 0.34 (290 years), and the second largest an AP of about 0.96 (103 years). It is unknown whether the 1966 or 2013 event was the larger of the two, although some accounts suggest that the 1966 event was the larger. In addition, this approach assumes stationarity in the dataset (i.e. no significant changes in physical factors such as land use or climate since 1852 which would influence the flood response).

2.3 Flood flows: River Nith at Hall Bridge gauging station

A map of the Nith catchment and relevant SEPA gauges in shown in Figure 2-1. The SEPA gauging station at Hall Bridge (station number 79003) is the closest gauging station to Kirkconnel. Fifty five years of AMAX data (1959 to 2013) are available (Figure 2-2), suggesting a reasonable record length for analysis. However, inspection of the data indicates that the magnitude of the 1966 event is fairly small: 87 m^3/s. This value is slightly larger than the median annual flood value, QMED of 71 m^3/s (as calculated from the full AMAX record) and is therefore not in keeping with the historical accounts of the 1966 flood being one of the largest floods experienced at Kirkconnel, although the burns could have flooded more seriously

The explanation for this discrepancy can be attributed to the stage hydrograph recorded at Hall Bridge for this event (Figure 2-3). It can be seen that, following the rising limb, the hydrograph flatlines (right hand side of the plot; this could have been caused by some physical effect at the gauging station such as the float becoming stuck), and it is then assumed that the peak following the flatline is the true peak of the event. Given the historical context, this assumption does not seem to be valid. An improvement to estimation of the peak could perhaps be undertaken using rainfall-runoff modelling (assuming that a rainfall record is available for this event), but this was outwith the scope of the current study. As the existing 1966 flood flow estimate is the only value currently available, it was retained in the analysis (section 2.4). A sensitivity test indicated that removing the existing flood flow from the series had a minimal effect on the resulting statistical flood estimates. This can be explained by the relatively small magnitude of the flow (i.e. only slightly bigger than QMED, see above).

---

[3] BBC news article, 30 December 2013 (http://www.bbc.co.uk/news/uk-scotland-25554284)
Daily Record news article, 17 January 2014 (http://www.dailyrecord.co.uk/news/local-news/dghp-keep-flood-victims-up-3031894)
Cumnock Chronicle news article, 9 January 2014
(http://www.cumnockchronicle.com/news/roundup/articles/2014/01/09/484364-floods-worst-ever-seen-in-upper-nithsdale/)

It is also worth highlighting that a rating review of Hall Bridge was not part of this commission but would be worthwhile. The highest gauging was undertaken at a stage of 1.966 m (about 65 m^3/s, i.e. below QMED) and the December 2013 event had a stage of 4.015 m. This means that the flow derived for the December 2013 event (230 m^3/s) was based upon over 2 m of extrapolation in terms of stage. Hydraulic modelling could be used at the gauging station to check the rating and/or develop a new rating if desired.

Figure 2-1: River Nith catchment and gauging stations

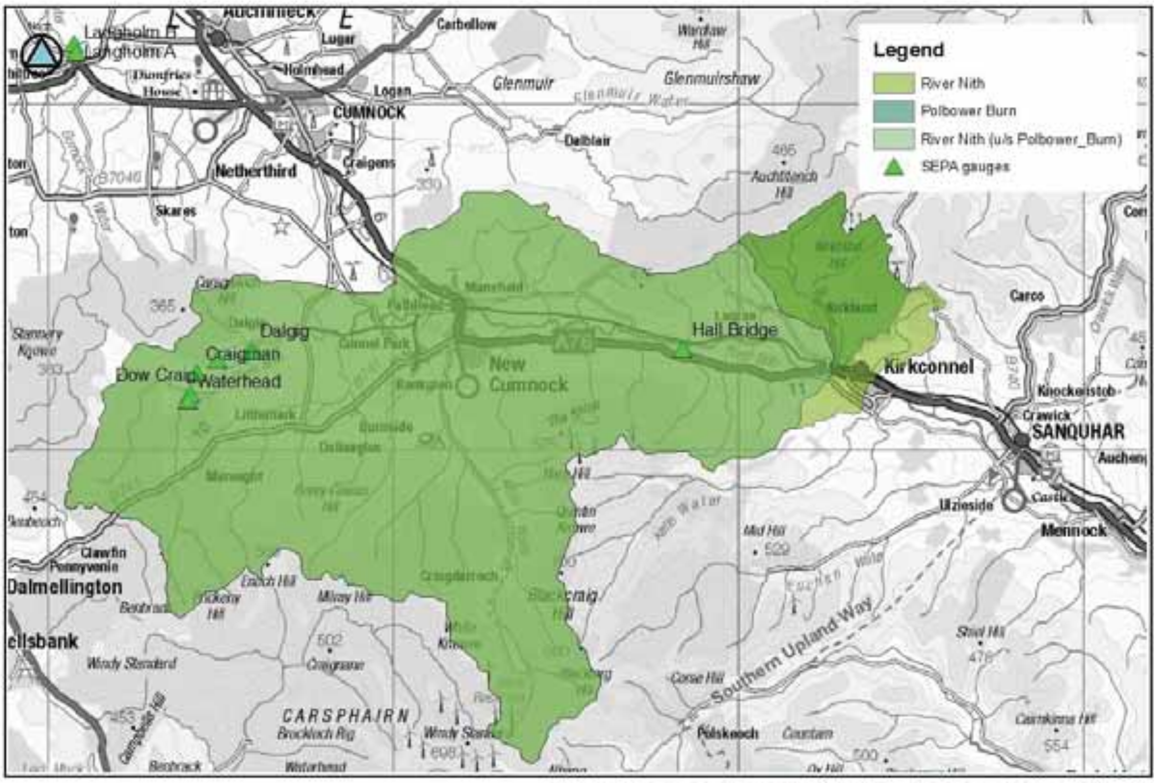


Figure 2-2: AMAX data for the River Nith at Hall Bridge

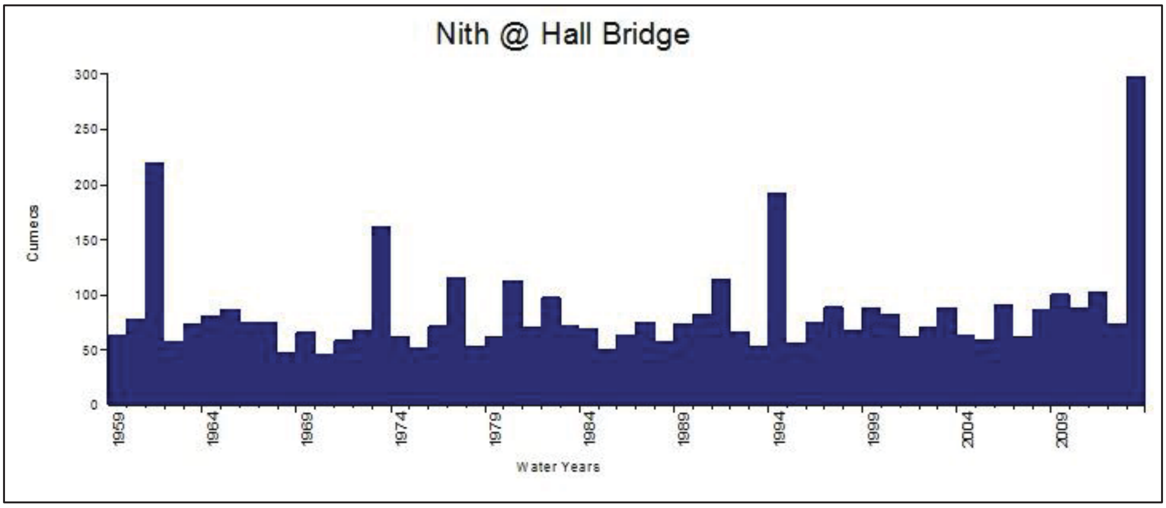
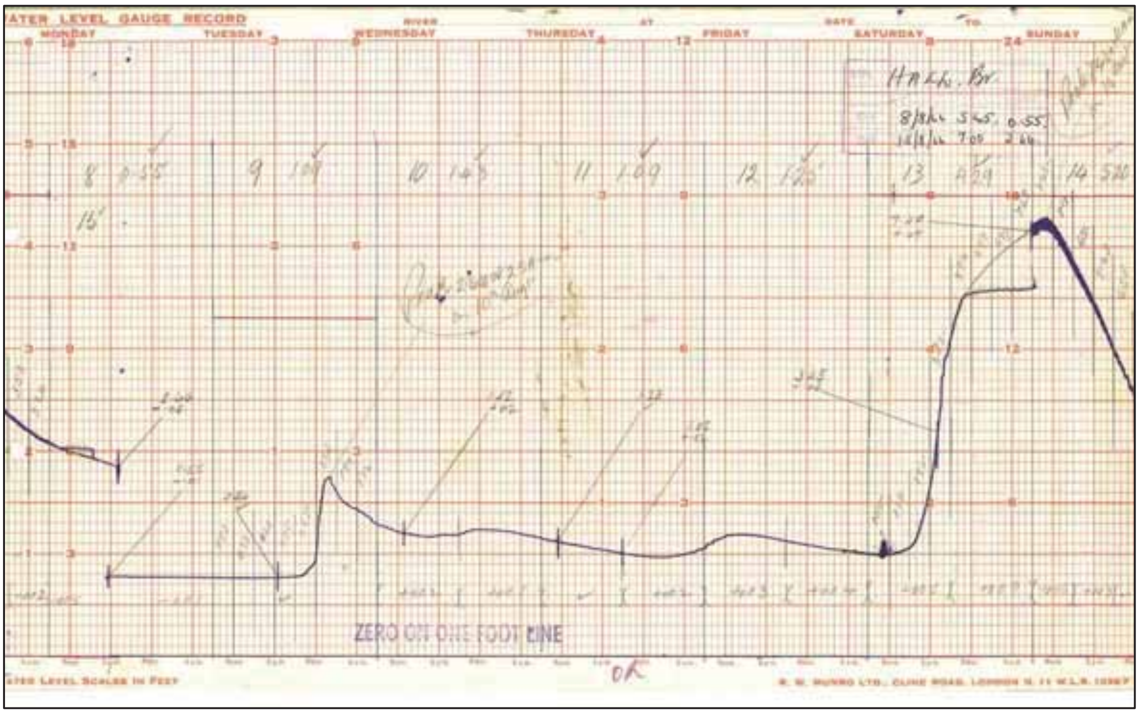


Figure 2-3: August 1966 stage hydrograph (note imperial units)



2.4 Flood frequency estimation using FEH

Important inputs into a flood study 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 analysis. The Rainfall Runoff method combines design rainfall with a unit hydrograph derived for the subject site. 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 2-1) for both the River Nith and the Polbower Burn.

Flood flows on the Polbower Burn were estimated using the Rainfall Runoff method. The Rainfall Runoff method was updated in 2006 by the ReFH (Revitalised Flood Hydrograph) method. This method supersedes the Rainfall Runoff method in England and Wales but is not widely accepted by SEPA for use in Scotland; however, flows calculated using this method are included for comparative purposes only. The Polbower Burn has a catchment area of 12.85 km^2 (adjusted after comparison with OS mapping) based on the relatively small catchment area the Rainfall Runoff method was selected after testing a variety of different options (Appendix C). Using this method, the flow for the Polbower Burn at a 0.5% AP (200 year) event is 35 m^3/s.

In addition, it is understood that flood protection works undertaken in 1978[4] intercept surface water from just south of the Polbower Burn catchment boundary and divert it into the Polbower Burn via a concrete pipe. The additional catchment area associated with this diversion is 0.35 km^2, giving an overall catchment area of 13.2 km^2. Rainfall Runoff calculations were also undertaken using this increased catchment area (Table 2-2) and there is a slight increase in the 0.5% AP (200 year) event to 36 m^3/s.

[4] Drawing Number 6680/3R Dumfries and Galloway Regional Council Flood Prevention Works, Kirkconnel, Sections and Plans, September 1978.

Table 2-1: Catchment descriptors for the Polbower Burn and River Nith

Catchment Descriptor	Polbower Burn	River Nith upstream of Polbower Burn	River Nith at Hall Bridge Gauging Station
AREA (km^2)	12.9 adjusted (12.8 FEH CD-ROM)	173.4 adjusted (174.9 FEH CD-ROM)	151.8 adjusted (155.8 FEH CD-ROM)
ALTBAR (m above sea level)	317	323	331
BFIHOST	0.38	0.35	0.36
DPLBAR (km)	4.58	19.51	15.67
FARL	1	0.976	0.973
FPEXT	0.014	0.063	0.066
FPDBAR	0.182	0.862	0.906
SAAR (mm)	1395	1495	1512
SAAR4170 (mm)	1561	1553	1508
SPRHOST (%)	42.56	45.35	45.55
URBEXT1990	0.0018	0.0015	0.0017
URBEXT2000	0.0036	0.0026	0.0029

The River Nith upstream of the Polbower Burn is a very large and rural catchment (173.39 km^2 after adjustment against OS background mapping and accounting for flow direction to the north of the Loch of the Lowes[5]). Given the catchment area, rural nature and presence of gauged data within the catchment the FEH Statistical method was judged to be the most appropriate technique to use for design flow estimation. The SEPA gauging station on the River Nith at Hall Bridge (SEPA gauging station number 79003) is located about 4 km upstream of the confluence with the Polbower Burn. As this was the gauging station in closest proximity to the location upstream of the Polbower Burn and the catchment descriptors for the gauging station are very similar to those of the Nith upstream of Polbower Burn (Table 2-1), it was assumed that the most appropriate estimates for flood flow could be achieved by applying the flood growth curve for the gauging station to the desired location. This was achieved by scaling the growth curve produced for the Hall Bridge gauging station using QMED estimated for the Nith upstream of Polbower Burn (Hall Bridge also being used as the donor site for QMED estimation). Both single site analysis and enhanced single site analysis were investigated as possible options for estimating flood flows (pooling group analysis was also investigated initially, but did not produce a growth curve consistent with flood response at the site). Single site analysis is based directly upon the gauging station AMAX data only. Enhanced single site analysis utilises a pooling group but with large weight attributed to the site of interest (in this case Hall Bridge).

The results of both analyses are summarised for Hall Bridge in Table 2-3 and for the Nith upstream of Polbower Burn in Table 2-4 (further details such as growth curves are provided in Appendix C). From Table 2-3, it can be seen that there is divergence in the flood estimates from about the 10% AP (10 year) event, with the enhanced single site analysis results yielding substantially lower flow values than the single site analysis results.

To put the analysis results in context, the AP of the December 2013 event (230 m^3/s) was considered. Under enhanced single site analysis, the AP of this event is less than 0.5% (in excess of 200 years). In comparison, this event is estimated to be around 1.25% AP (80 years) under single site analysis. A single site analysis of the AMAX stage data for Hall Bridge was also undertaken and, using a Generalised Logistic (GL) distribution yielded a similar AP estimate to the single site analysis of AMAX flows (the AMAX stage analysis removes rating uncertainty but assumes that the gauging station has been at the same location, with no changes in high flow control, throughout the period of operation).

[5] In a description of the New Cumnock wetlands, the SEPA River Nith Catchment Management Plan states that "Site comprised of three lochs: Loch o' th' Lowes drains into the Nith, the other two drain away".

An estimate of 1.25% (80 years) for the December 2013 event therefore seems reasonable and the single site flow analysis results were used for the purposes of this study. In addition, SEPA have expressed a preference for single site analysis[6]. Based upon the single site growth curve the flow for a 0.5% AP (200 year) event is 330 m^3/s at Hall Bridge and 400 m^3/s upstream of Polbower Burn.

A test of adjusting BFIHOST and SPR using the BFI Scotland Map value was also conducted. However, when tested at Hall Bridge gauging station, there was a larger difference between QMED estimated from flow data and QMED estimated from the adjusted catchment descriptors than when the FEH CD-ROM values of BFIHOST and SPRHOST were used. BFIHOST and SPRHOST were therefore retained at their default values.

Table 2-2: Design peak flows (m^3/s): Polbower Burn

Return period (years)	Annual Probability (AP)	FEH Rainfall Runoff Method - Flow (m^3/s)	FEH Rainfall Runoff Method Including FPS Diversion - Flow (m^3/s)
2	50	9.6	9.8
5	20	13.8	14.1
10	10	16.9	17.3
25	4	21.6	22.2
30	3.33	22.7	23.3
50	2	25.8	26.5
75	1.33	28.0	28.8
100	1	29.9	30.7
200	0.5	34.8	35.7
200 (+ 20% CC)	0.5	41.8	42.9
200 (+ 25% CC)	0.5	43.5	44.7
500	0.2	42.6	43.7
1000	0.1	51.0	52.3

Table 2-3: Design peak flows (m^3/s): River Nith at Hall Bridge gauging station

Return period (years)	Annual Probability (AP)	FEH Statistical Method Single Site Analysis - Flow (m^3/s)	FEH Statistical Method Enhanced Single Site Analysis - Flow (m^3/s)
2	50	71	71
5	20	93	93
10	10	115	110
25	4	154	136
30	3.33	164	142
50	2	196	159
75	1.33	227	175
100	1	252	187
200	0.5	330	219
200 (+ 20% CC)	0.5	396	262
200 (+25% CC)	0.5	413	273
500	0.2	479	270
1000	0.1	640	318

[6] Email from Nicholas Gair, SEPA, 25 November 2014.

Table 2-4: Design peak flows (m^3/s): River Nith, upstream of the Polbower Burn

Return period (years)	Annual Probability (AP)	FEH Statistical Method Single Site Analysis - Flow (m^3/s)	FEH Statistical Method Enhanced Single Site Analysis - Flow (m^3/s)
2	50	86	86
5	20	113	113
10	10	139	134
25	4	187	165
30	3.33	199	172
50	2	237	193
75	1.33	275	212
100	1	306	226
200	0.5	400	265
200 (+ 20% CC)	0.5	481	318
200 (+25% CC)	0.5	501	332
500	0.2	581	328
1000	0.1	777	386

With respect to climate change, SEPA's current guidance is to apply a 20% increase for climate change for the 2080's[7]. In addition, recent guidance for England and Wales[8] has provided regionalised estimates of how climate change will impact upon river flows through the next century based on the UKCP09 projections. Data are available for the Solway, Tweed River basins and Northumberland. These three regions are presented below in Table 2-5 to inform the choice of climate change estimates for the Polbower Burn and River Nith.

From Table 2-5, it can be seen that the "best estimate" for the Solway (the most relevant area for the Nith) is 25% and this is the climate change allowance used in the model simulations. Climate change effects from both a 20% and 25% uplift in the 0.5% AP (200 year) flood flows are therefore presented in the accompanying flood flow tables (Table 2-2 to Table 2-4).

Table 2-5: Comparison between current and previous assessments

Region	Total potential change for 2020s	Total potential change for 2050s	Total potential change for 2080s
Tweed			
Upper range	25%	35%	35%
Best estimate	15%	20%	30%
Lower range	0%	5%	15%
Northumberland			
Upper range	25%	30%	50%
Best estimate	10%	15%	20%
Lower range	0%	0%	5%
Solway			
Upper range	25%	35%	65%
Best estimate	15%	20%	25%
Lower range	0%	5%	15%

[7] SEPA – Technical Flood Risk Guidance for Stakeholders, Version 8, February 2014
[8] Environment Agency (2011). Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities.

The final design flows used are shown below in Table 2-6.

Table 2-6: Design peak flows for the River Nith and the Polbower Burn

Return period (years)	Annual Probability (AP)	River Nith, upstream of Polbower Burn (using Statistical Single Site Growth Curve from Hall Bridge) - Flow (m^3/s)	Polbower Burn FEH Rainfall Runoff Method Including FPS Diversion - Flow (m^3/s)
2	50	86	9.8
5	20	113	14.1
10	10	139	17.3
25	4	187	22.2
50	2	237	26.5
100	1	306	30.7
200	0.5	400	35.7
200 (+25% CC)	0.5	501	44.7
1000	0.1	777	52.3

2.5 Design hydrograph

Design hydrographs for the River Nith and Polbower Burn were required for input to the hydraulic model. Previous JBA Consulting experience[9] suggested that, where gauged information is available, then the most appropriate approach to use is to average a representative sample of historical hydrographs. For the River Nith, this option was investigated using the 15 minute hydrographs recorded on the Nith at Hall Bridge gauging station for the top 3 events since 1991:

- 30 December 2013.
- 12 December 1994.
- 22 December 1991.

Earlier large events (such as 1966 were not readily available in electronic format and therefore could not be easily used. Smaller recent events (such as those of 2007, 2009, 2010 and 2011) were also rejected as not being sufficiently representative of a large flood.

A comparison of the 3 selected events is shown in Figure 2-4 (note that the x-axis, time, has been normalised to allow direct comparison).

[9] JBA Consulting, Caol and Lochyside Flood Protection Scheme Appraisal Final Report, October 2014

Figure 2-4: Three highest flood events since 1991

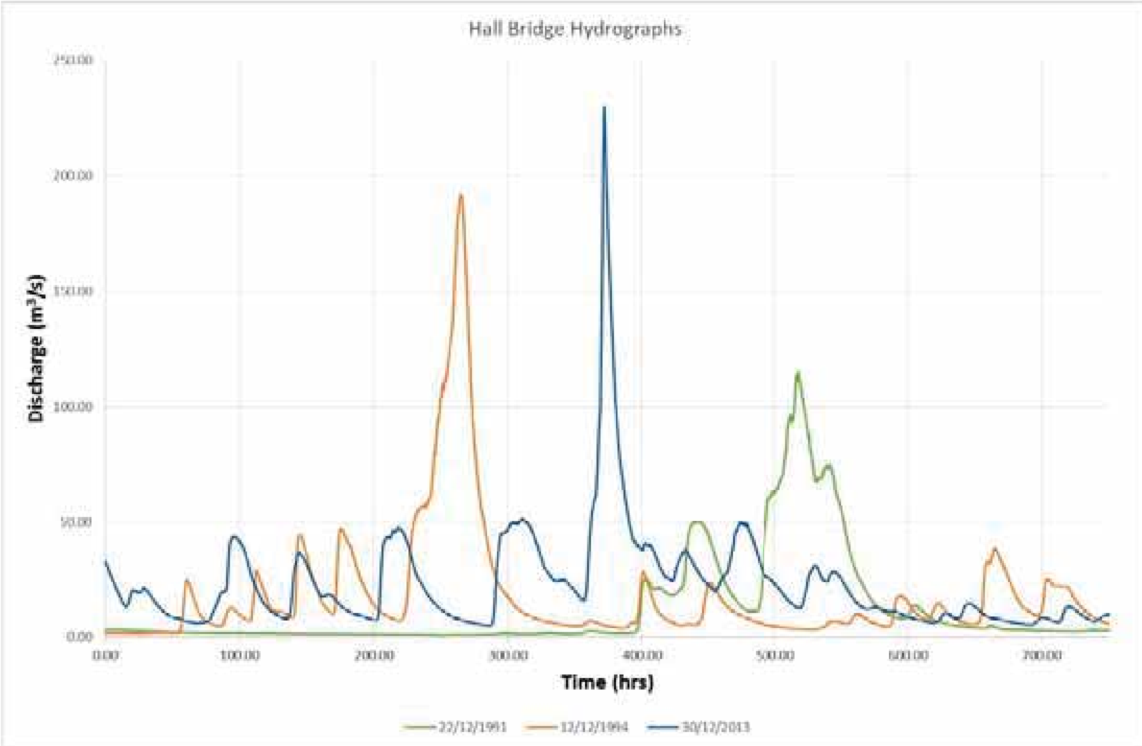
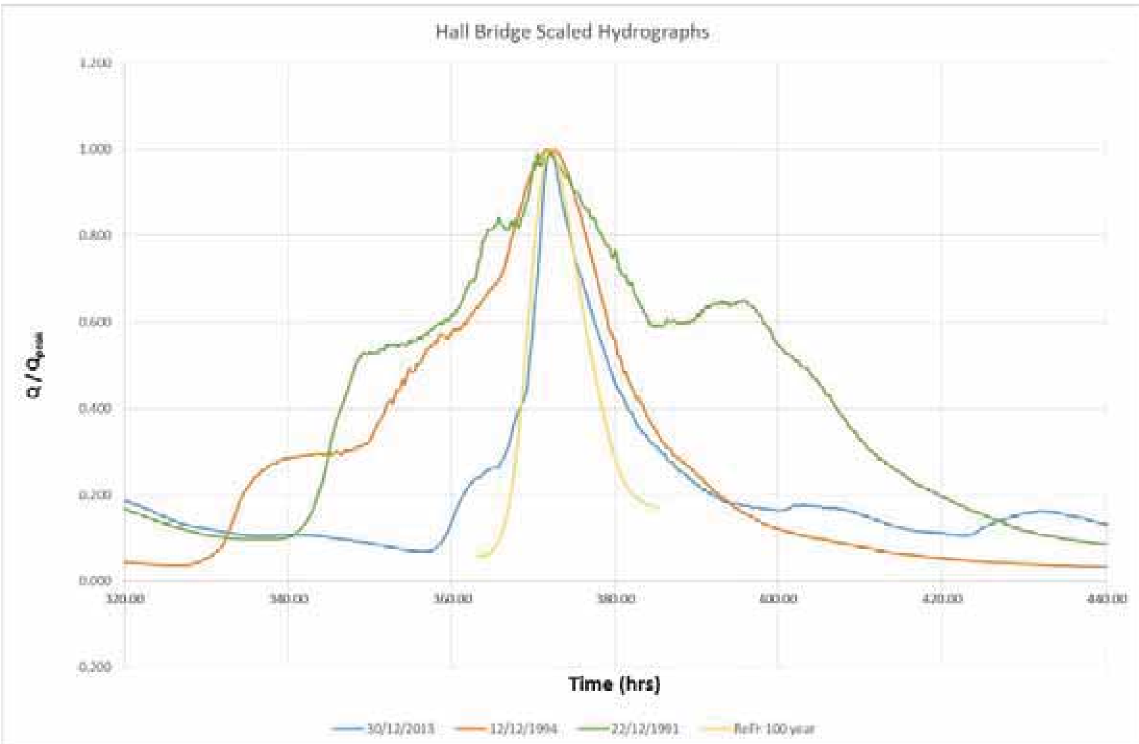


Figure 2-5: Scaled and aligned peaks of hydrographs for the River Nith



To provide a more direct comparison of hydrograph shape, each of the three hydrographs was normalised by the corresponding peak flow. The results are shown in Figure 2-5. For comparative purposes only, a synthetic hydrograph was generated using the revitalised FEH (ReFEH) Rainfall-Runoff Method and is also shown.

It can be seen that the December 2013 event has a distinctly different shape from the other two hydrographs. For example, the rising limb is much steeper, the time to peak is much shorter and the overall duration of the event is shorter. It was therefore assumed that the December 2013 event hydrograph was more representative of an extreme event hydrograph than would have been achievable through averaging the 1991, 1994 and 2013 hydrographs. The December 2013 hydrograph was therefore chosen to represent the design event and each peak design flow on the River Nith was scaled to this hydrograph.

In the absence of gauge data, the Polbower Burn hydrograph was generated using the ReFEH Rainfall-Runoff method. Note that ReFH was only used to generate the hydrograph shape. Peak flows were obtained from the Rainfall Runoff method per the preceding section.

In the hydraulic modelling, to account for the worst case flood event for a given return period the hydrograph peaks on the River Nith and Polbower Burn were assumed to coincide.

2.6 Comment on impact of upstream reservoir

The Afton Water has been blamed by some within the community as a reason for the December 2013 flood. The Afton Water is a reservoir operated for water supply purposes. There used to be a gauge located at the outlet of the reservoir to measure compensation flows and high flow spillage from the reservoir. This gauge operated from 1965 to 1981 and recorded daily mean flows throughout.

There are two factors to consider in terms of the impact of this reservoir on flood flows in the Nith:

- The catchment area to the reservoir is a relatively small proportion of the overall catchment to Kirkconnel. The reservoir catchment area at the reservoir outlet is 8.5 km^2. The total catchment area to Kirkconnel is 173 km^2. The catchment to the reservoir therefore represent 5% of the total Nith catchment to Kirkconnel.
- The Flood Attenuation by Reservoirs and Lakes (FARL) index, developed for the Flood Estimation Handbook, provides a guide to the degree of flood attenuation attributable to reservoirs and lakes in the catchment above a gauging station. Values close to unity indicate the absence of attenuation due to lakes and reservoirs whereas index values below 0.8 indicate a substantial influence on flood response. The FARL value for the catchment to Kirkconnel is 0.976 indicating the impact of reservoirs and lakes is small.
- Maximum flow recorded between 1965 and 1981 is no more than 9 m^3/s (see Figure 2-5). Whilst the flow during the December 2013 flood is unknown it is unlikely to have significantly generated a flow greater than 10 m^3/s.

Based on the above information, it is unlikely that the Afton Water reservoir was a cause of the flooding. The rapid increase in water levels present on the River Nith is more likely to be due to the natural response of the catchment rather than any anthropogenic impact associated with the reservoir.

Figure 2-6: Afton Water flow duration curve (courtesy of CEH[10])

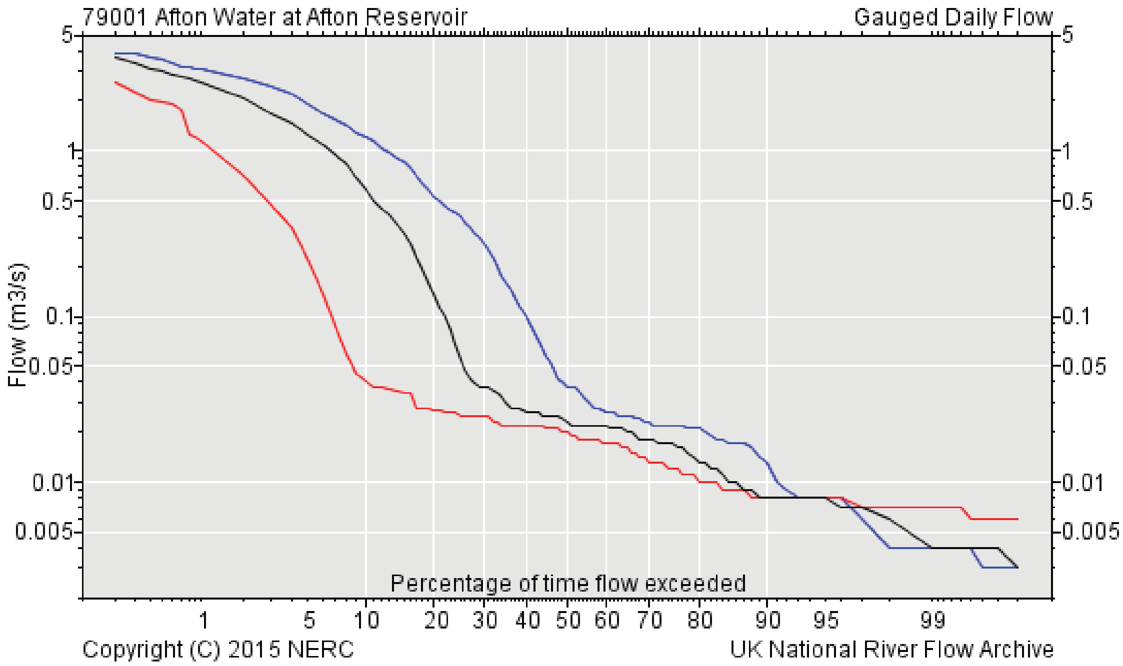
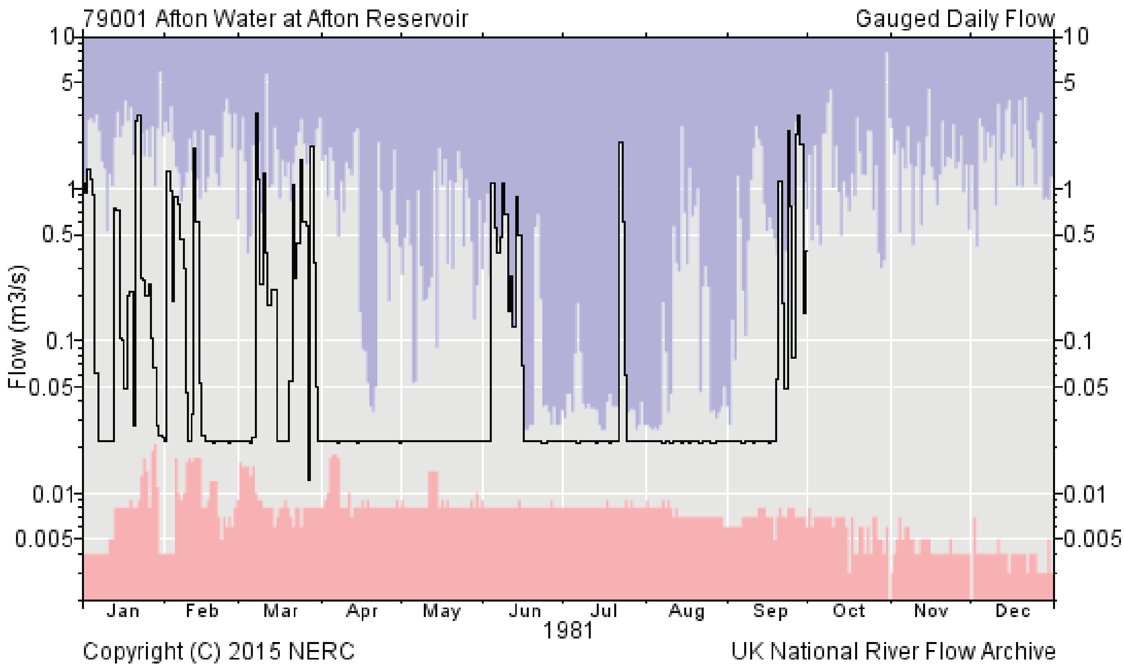


Figure 2-7: Afton Water daily min/max flows over 1965 - 1981 record (courtesy of CEH[11])



2.7 Comment on upstream storage

Analysis of the flood hydrographs for the Hall Bridge gauging station illustrate the impact of upstream storage on flood flows. The recorded peak events shown in Figure 2-4 show that many floods are 'capped' at approximately 50m^3/s, some with a clear plateau in the peak at this level. This is a classic response to significant upstream storage, where floodplains attenuate flows significantly up to a point, above which the storage capacity is reached and any additional

10 http://www.ceh.ac.uk/data/nrfa/data/meanflow.html?79001

11 http://www.ceh.ac.uk/data/nrfa/data/meanflow.html?79001

peak flows are discharged downstream. This can be seen in Figure 2-4 for the three major floods; there is a definite reduction in the hydrograph rate of rise from 40-60 m^3/s before a kink in the rising limb at the point of maximum storage before the rate of rise increases substantially.

The storage area that causes this can be observed on SEPA maps[12] downstream of New Cumnock and is shown in Figure 2-8.

Figure 2-8: Flooding in the upstream catchment between New Cumnock and Kirkconnel (22 January 2015; one week after high flow event on the River Nith)

[12] http://map.sepa.org.uk/floodmap/map.htm

3 Hydraulic Model

3.1 Model method

ISIS TUFLOW 1D-2D software was used to build the hydraulic model. The river channels, where flow is predominately in the downstream direction, were modelled as 1D elements. Areas where the flood flows overtopped the channel banks and entered the floodplain were modelled in 2D. This linked 1D-2D modelling approach allows for a more realistic representation of flood flows over the floodplain. The rivers channels were modelled using surveyed cross sectional data while the floodplain was modelled using LiDAR data.

3.2 Topographic datasets

Over the course of 4 days (28, 29, 30 October and 6 November) JBA undertook a property threshold survey and a cross sectional survey of both river channels and each hydraulic structure.

3.2.1 JBA cross section survey

13 cross sections were taken to represent the River Nith channel from upstream at NGR NS 7279 1222 to downstream at NGR NS 7377 1199 and 11 cross sections were taken to represent the Polbower Burn channel from upstream at NGR NS 7282 1240 to downstream at NGR NS 7284 1216 as shown in Figure 3-1.

Figure 3-1: Cross section location map

3.2.2 JBA hydraulic structure survey

Five hydraulic structures were surveyed. Three on the River Nith and two on the Polbower Burn. The structures are listed below and represented graphically in Table 3-1 as both a photo of the structure and its form when modelled in ISIS.

River Nith structures include the following:

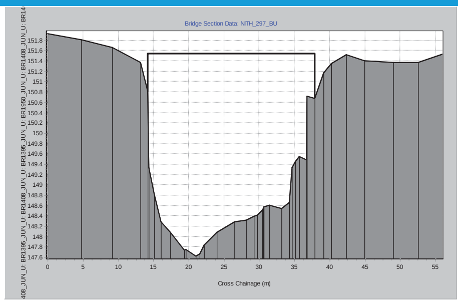
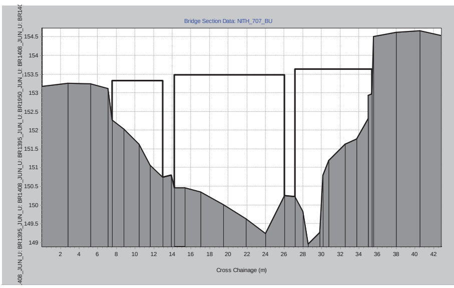
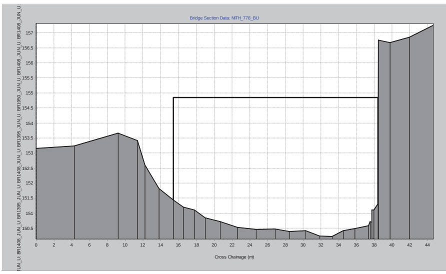
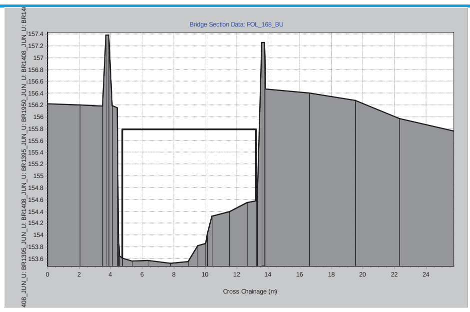
- Upstream face of footbridge at cross section NITH_297 leading to Kingsway

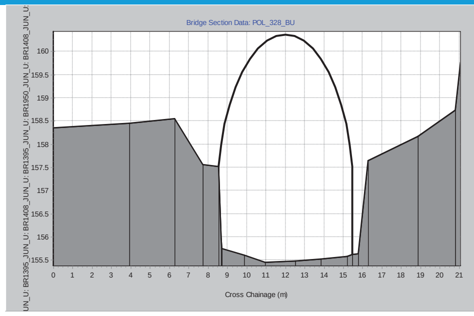
- Upstream face of old road bridge at cross section NITH_707 leading to Kingsway
- Upstream and downstream face of Road Bridge at cross section NITH_778 on Needle Street

Polbower Burn structures include the following:

- Upstream and downstream face of Road Bridge at cross section POL_168 on Main Street
- Upstream face of rail culvert at chainage POL_328

Table 3-1: Hydraulic structures on the River Nith and the Polbower Burn

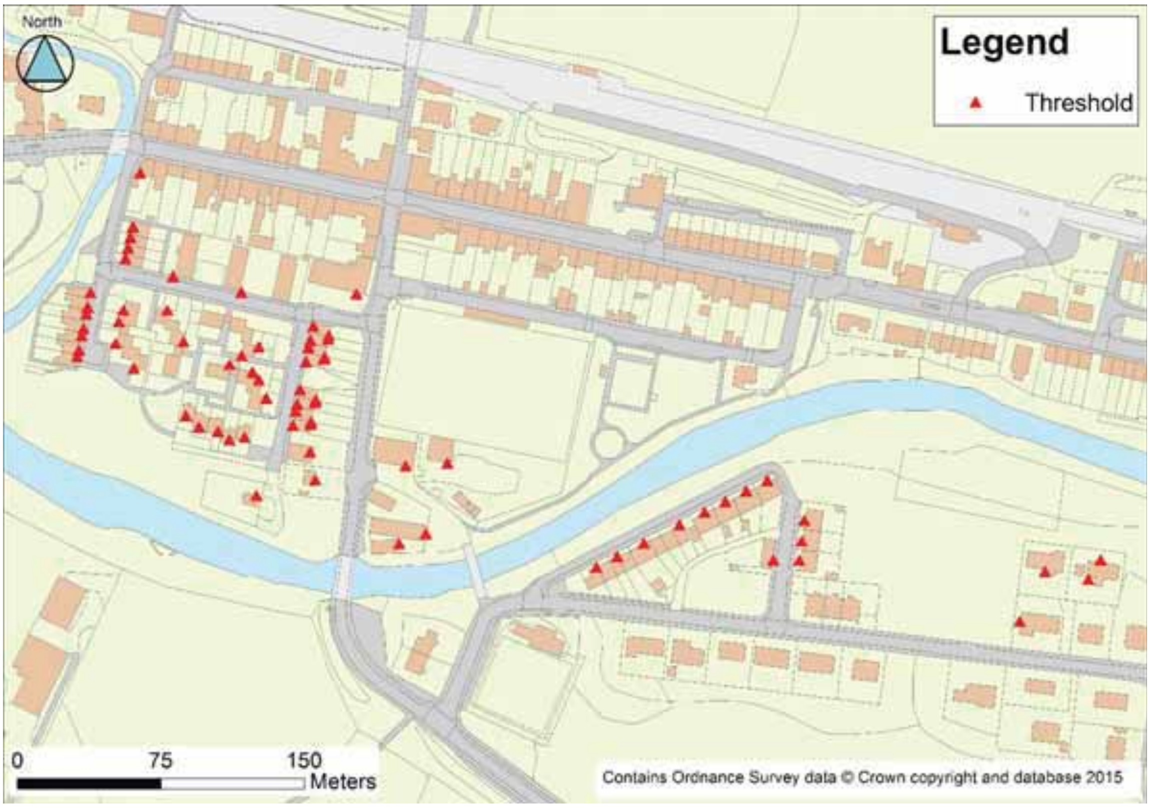
Structure	Photograph	Model representation
Foot Bridge to Kingsway. NITH_297		
Note that the pipe shown in the photograph has been modelled in ISIS by removing the area of the pipe.		
Old Road Bridge to Kingsway. NITH_707		
Road Bridge at 778 on Needle Street. NITH_778		
Road Bridge on Main Street POL_168		
Note that the pipe shown in the photograph has been modelled in ISIS by removing the area of the pipe.		

Structure	Photograph	Model representation
Rail culvert POL_328		

3.2.3 JBA threshold survey

To accurately determine the flood damage caused to property a property level threshold was carried out on properties that fell within the SEPA Flood Risk Management Maps 2014 or in areas that were considered to be at flood risk. 71 floor level points were surveyed. Figure 3-2 shows the location of each property threshold point.

Figure 3-2: Property threshold survey location map



3.2.4 LiDAR - Digital Terrain Model

Dumfries and Galloway Council provided a 2 m LiDAR DTM of the River Nith and adjoining land. This was trimmed to the area of interest. The DTM has been used to provide elevations to the 2D element of the model. The 2D element has been modelled using 3m grid squares.

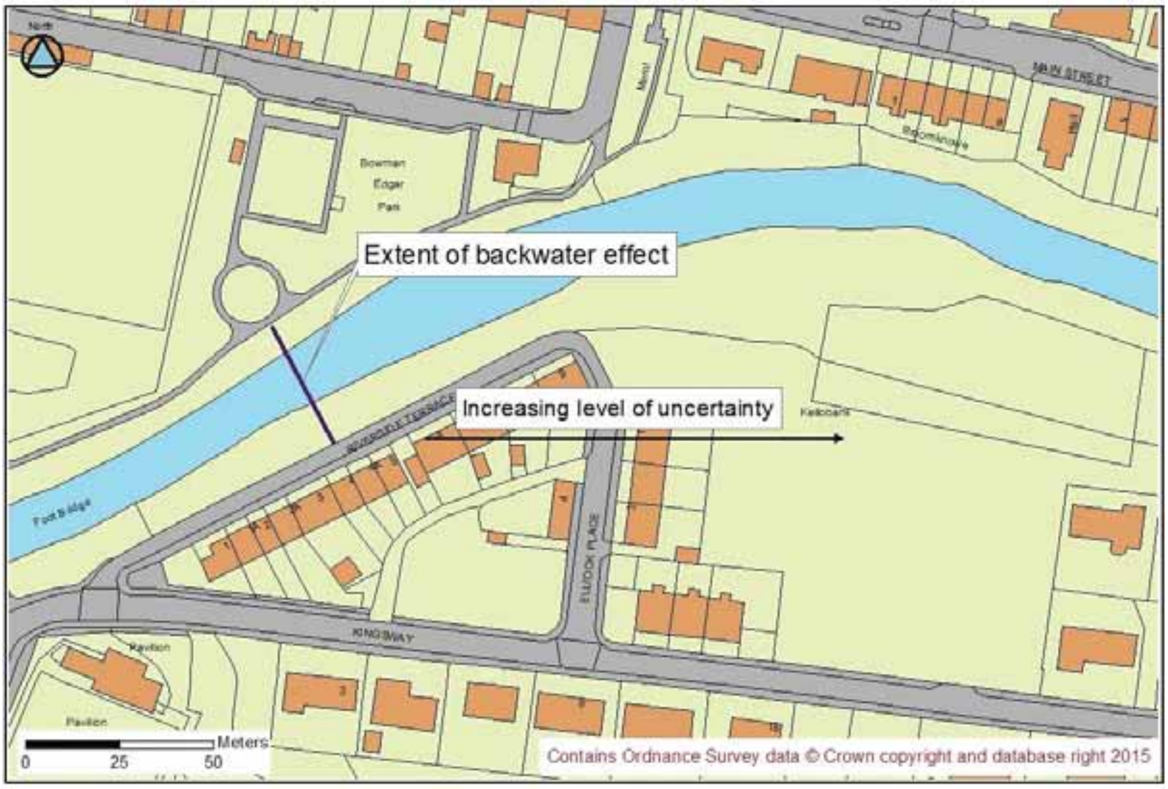
3.3 Model boundaries

Flows enter the hydraulic model at cross section NITH_1116 and POL_365 and are represented by a hydrographs as outlined in Chapter 2. No lateral inflows have been added to the 2D domain so water will only enter the 2D domain when the banks of either the River Nith or Polbower Burn are overtopped.

The downstream boundary is represented by a normal depth boundary unit at cross section NITH_0. The boundary represents the normal depth based on the bed slope. The backwater effect extends 620 m upstream from the NITH_0, this reaches the last two houses on Riverside Terrace as shown in Figure 3-3. This means the calculated water level within this stretch is effected by the assumptions made at the downstream boundary. The level of uncertainty increases with proximity to the downstream boundary.

The 2D element has a downstream boundary on both sides of cross section NITH_0. These downstream boundaries are also normal depth boundaries and are based on spot heights from LiDAR data from NITH_0 to 30m downstream.

Figure 3-3: Property threshold survey location map

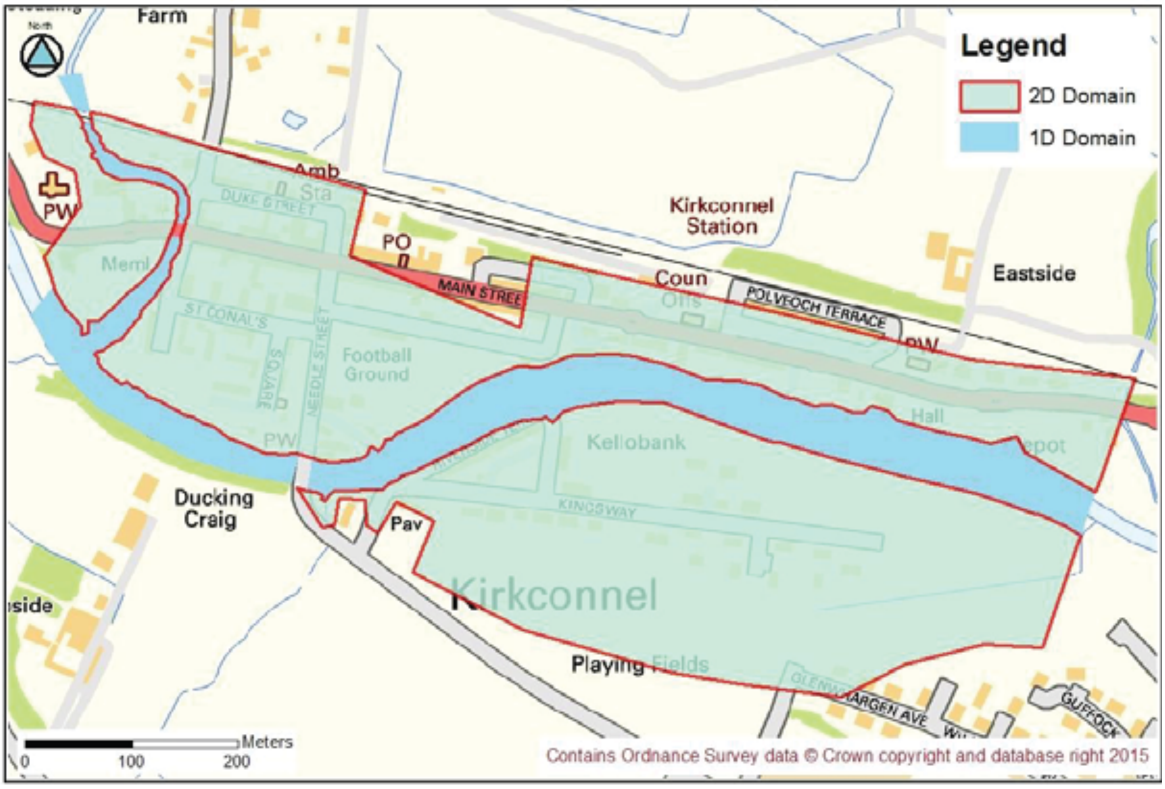


3.4 Model set-up

The boundary that forms the link between the 1D and 2D domain was determined based on the top of embankment and top of wall levels. For example the channel defences along the Polbower Burn were defined using surveyed levels. Where no defence was present the boundary was defined based on a combination of LiDAR and topographic survey. The 1D and 2D domain is shown in Figure 3-4.

Buildings have been removed from the DTM as a flood depth over the property is required for economic analysis however the building footprint has been given a very high roughness factor with a Manning's 'n' of 0.3 to represent the difficulty of flow through the building.

Figure 3-4 1D & 2D Model domains



3.5 Model Roughness

3.5.1 1D Model roughness

A Manning's 'n' value was used to assign a roughness to different surfaces encountered by the modelled flow. Table 3-3 shows the minimum and maximum Manning's 'n' values used at a glance for the channel as well as the left and right 1D floodplain.

Table 3-2: Manning's 'n' values in 1D model

	Min	Mean	Max
Left bank	0.023	0.040	0.100
Channel bed	0.030	0.035	0.040
Right bank	0.030	0.050	0.100

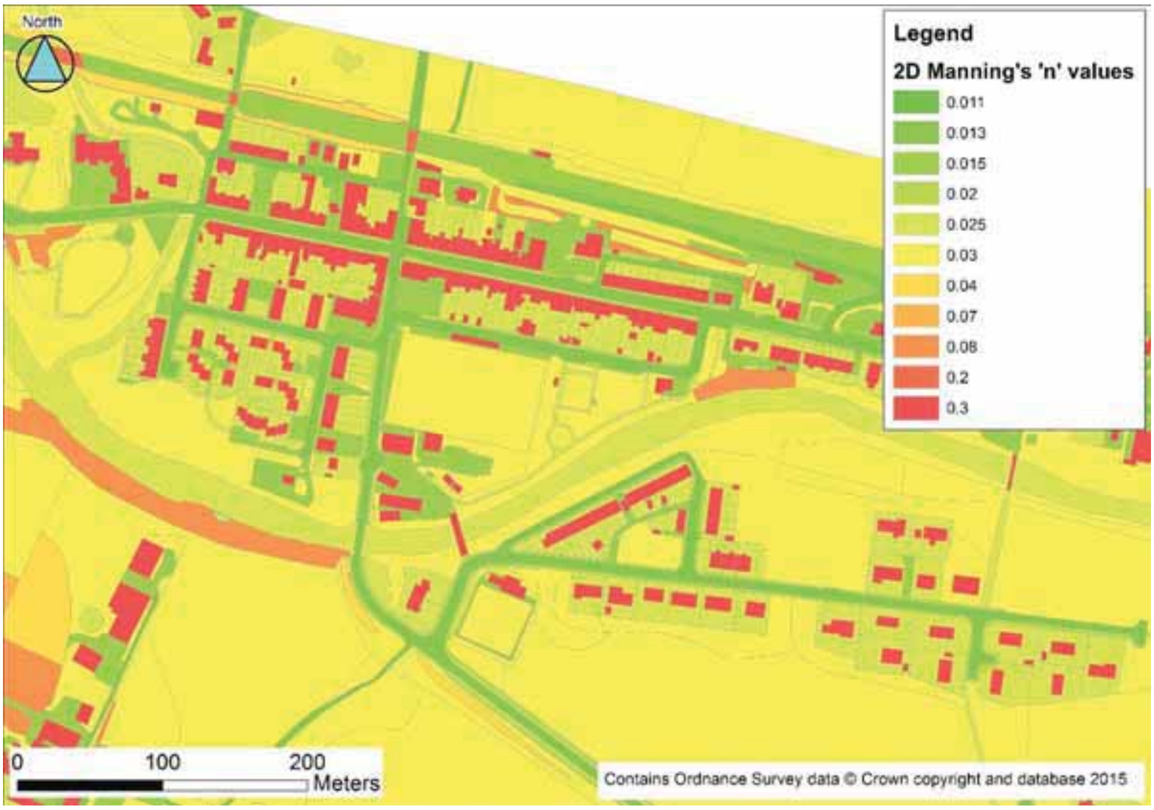
3.5.2 2D Model roughness

The 2D model Manning's roughness was assigned using OS MasterMap detailed mapping. Each MasterMap element was assigned a code that corresponded to roughness factor. A summary of the values used are shown in Table 3-4 and a graphical representation by colour is displayed in Figure 3-5.

Table 3-3: Manning's "n" values in 2D model

	Min	Mean	Max
Left bank	0.023	0.040	0.100
Channel bed	0.030	0.035	0.040
Right bank	0.030	0.050	0.100

Figure 3-5 2D Roughness assignment



3.6 Model calibration

Model calibration is carried out to give confidence to a model. A good calibration method is to compare a flood event which has already occurred to the same event simulated in the model. A large quantity of flood data in the form of surveyed points, photographs and anecdotal evidence for the December 2013 flood event was collected. The December 2013 flood has been estimated as a 80 year return period flood event with a flow of 230 m^3/s.

Using the collected flood data a flood level was assigned to each property where flood data was available. The simulated December 2013 flood level was also assigned to each property. The collected flood data level was then subtracted from the simulated flood level. The difference in level is displayed in Table 3-5. The data shown in Table 3-5 is shown graphically in Figure 3-6. Figure 3-6 is also available in Appendix E.

A quality column has been included to give an idea of confidence in the collected data. A quality level of 1 represents high quality. All surveyed levels were assigned a level of 1. Level 3 quality data refers to anecdotal evidence where the determined flood level is somewhat ambiguous.

The results show a good comparison. On average the results under estimate the flood by 0.005m with a maximum over estimation of 0.19m and maximum under estimation of -0.46m. This under estimation which occurs at TH50 is thought to be erroneous data as the property is positioned in the middle of a row of three properties where the two properties on either side, TH49 and TH52, are over estimated by 0.07m.

Table 3-4: Model calibration with the December 2013 flood event

TH_ref	Address	Level Difference	Quality	Flood Comment
TH1	49 St Conal's Square	0.01	2	Flooding almost to height of window ledge.
TH2	48 St Conal's Square	0.02	3	Park last flooded last 2 years ago.
TH12	St Conal's Square	0.19	2	Wrack 154.05m AOD at approximately this location.
TH13	7 St Conal's Square	-0.17	1	Flooded. Wrack mark surveyor = 154.74m.
TH14	6 St Conal's Square	-0.14	1	Flooded. Wrack mark surveyor = 154.74m.
TH15	5 St Conal's Square	-0.03	1	Flooded. Wrack mark = 154.74m.
TH17	45 St Conal's Square	0.13	2	Flooding almost to height of window ledge.
TH18	46 St Conal's Square	0.08	2	Flooding almost to height of window ledge.
TH19	47 St Conal's Square	0.07	2	Flooding almost to height of window ledge.
TH20	Needle Street	-0.20	2	Wrack Mark on fence at garage = 153.66 - 153.59.
TH27	8 Riverside Terrace	0.06	3	9 inches outside. Flood on road12yrs.Bank collapse.
TH28	9 Riverside Terrace	0.02	1	Flooded (acc to no 8).Now has PLP. Surveyor=152.73.
TH29	Needle Street	-0.13	2	Wrack Mark on fence at garage = 153.66 - 153.59.
TH30	Needle Street	0.00	2	Wrack Mark on fence at garage = 153.66 - 153.59.
TH31	Needle Street	0.15	2	Old Flood Lvl = 153.07m & Dec 2013 Flood Lvl=153.47m.
TH35	4 St Conal's Square	0.16	2	Back in home in April. Flooded to radiator base.
TH36	3 St Conal's Square	-0.13	3	6-12inch d. Applied for move. Out of home for 3 months.
TH48	St Conal's Square	0.13	1	Wrack Mark picked up by surveyors 154.05mAOD.
TH49	37 St Conal's Square	0.07	2	Flooding through floor, to depth above toilet seat.
TH50	36 St Conal's Square	-0.46	3	Table height.1994 flood around house. Flooded in 66.
TH52	34 St Conal's Square	0.07	3	Flooded to knee height.
Average Difference (m)		-0.005		
Standard Deviation (m)		0.155		

Figure 3-6 Model calibration with the December 2013 event

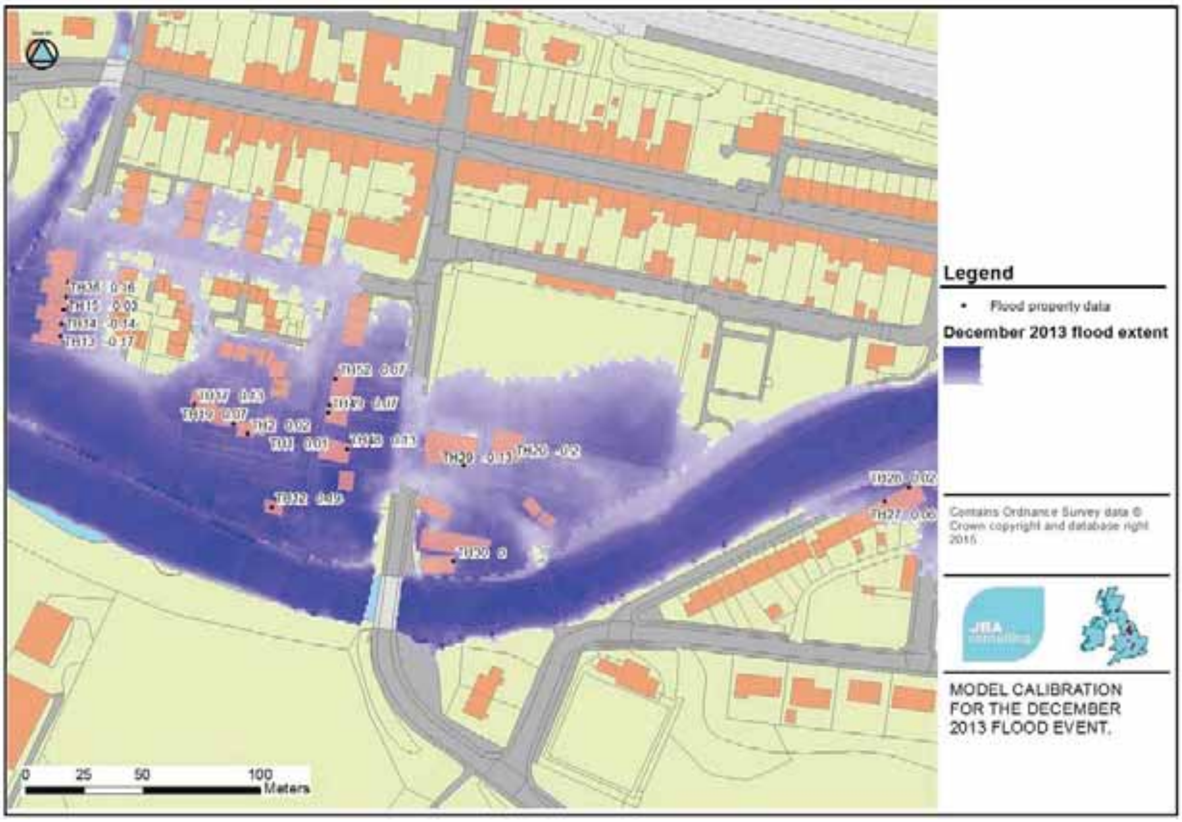


Figure 3-7 and 3-8 provide further evidence on the calibration achieved. These photographs show a good comparison between the actual flood event and the simulated flood event.

Figure 3-7 December 2013 simulated flood extent with flood photos of the event. Figure 1 of 2. (Photographs courtesy of http://kirkconnel.org/)

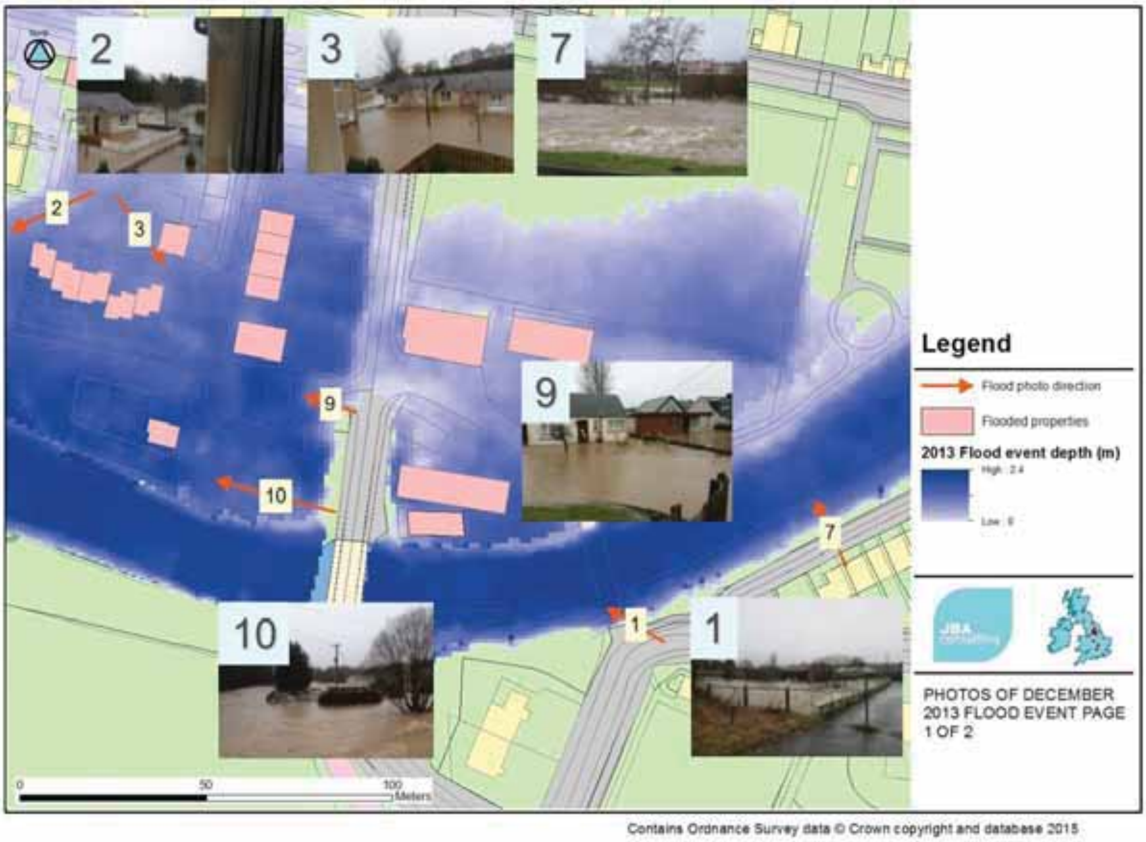
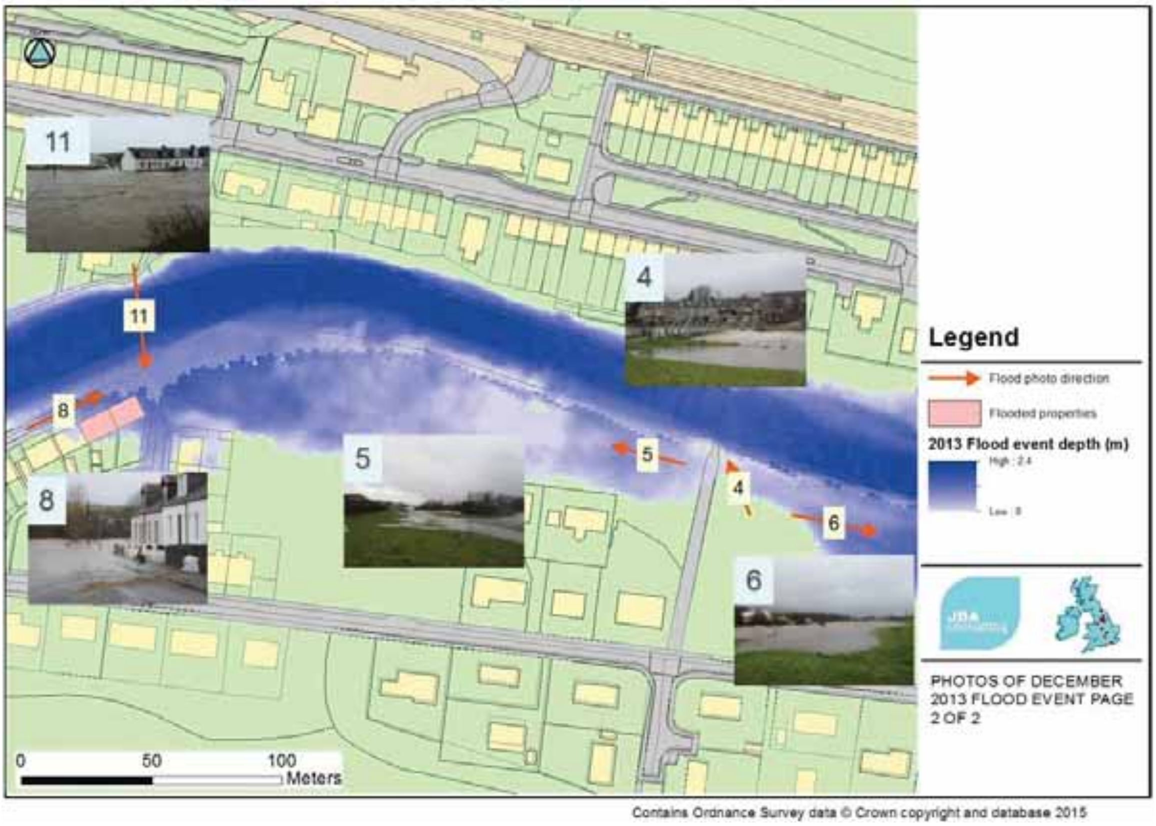


Figure 3-8 December 2013 simulated flood extent with flood photos of the event. Figure 2 of 2. (Photographs courtesy of http://kirkconnel.org/)



3.7 Model results

The model results have been displayed graphically as flood maps in Appendix F.

The flood levels in mAOD at each cross section for each return period are contained in Appendix G. A summary of that table with the maximum water levels selected for the 2 year (50% AP), 200 year (0.5% AP), 200 year accounting for climate change (0.5%+CC AP) and the joint 200 year (0.5% AP) event are tabulated in Table 3-6 below. Refer to Figure 3-1 for the cross section locations.

Table 3-5: Summary of model results

Cross section	Location	2 year	200 year	200 year +CC	Joint 200 year
POL_365		156.97	157.95	158.83	157.95
POL_328		156.58	157.75	158.74	157.75
POL_328_BUS	Upstream face of rail culvert	156.54	157.69	158.71	157.69
POL_314		156.53	157.65	158.32	157.65
POL_314_WUS		156.53	157.64	158.31	157.64
POL_314_WDS		155.77	156.78	157.28	156.80
POL_274		155.43	156.41	156.85	156.53
POL_231		155.04	156.12	156.75	156.49
POL_199		154.81	155.72	156.61	156.35
POL_168		154.51	155.71	156.55	156.32
POL_168_BUS	Upstream face of Main Street Bridge	154.43	155.71	156.52	156.30
POL_155		154.37	155.70	156.15	155.90
POL_119		153.91	155.69	155.98	155.85
POL_80		153.55	155.54	156.03	155.75
POL_28		153.43	155.53	155.91	155.66
POL_28_JU		153.34	155.56	155.95	155.69
NITH_1011_JU		153.34	155.56	155.95	155.69
NITH_1011		153.34	155.56	155.95	155.69
NITH_879		152.81	155.19	155.54	155.29
NITH_778		152.54	154.86	155.34	154.97
NITH_778_BUS	Upstream face of Needle Street Bridge	152.55	154.74	155.20	154.84
NITH_768		152.53	154.67	155.05	154.77
NITH_707		152.34	154.64	154.95	154.73
NITH_707_BUS	Upstream face of Old Road Bridge	152.36	154.89	155.26	154.99
NITH_707_BDS		152.28	154.24	154.52	154.31
NITH_634		151.88	153.94	154.36	154.06
NITH_545	Downstream end of Riverside Terrace	151.62	153.31	153.67	153.39
NITH_411		150.79	152.91	153.36	153.00
NITH_297	Upstream face of Foot Bridge	150.41	152.37	153.04	152.55
NITH_128		149.91	151.76	151.98	151.82
NITH_0		149.33	151.00	151.28	151.07

3.7.1 Present bridge capacity

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 analysis below includes the presence of the pipes beneath the Nith footbridge and the Main Street Bridge on the Polbower Burn, but no blockage scenarios. The structures in this model have a varying degree of capacity. The bridge with the smallest capacity is the Old Road Bridge on the River Nith.

Table 3-2 shows each structure and modelled bridge capacity. The old road bridge only has capacity for the 25 year flood before its soffit is partially reached.

Table 3-6: Bridge capacity

Bridge	Watercourse	Lowest soffit level	Return period at which soffit is reached
Rail Bridge	Polbower Burn	160.36	Soffit not reached
Main Street Bridge	Polbower Burn	155.79	200 year + Climate change
Needle Street Bridge	River Nith	154.84	200 year + Climate change
Old Road Bridge	River Nith	153.32	25 year
Footbridge	River Nith	151.54	50 year

3.8 Flood mapping deliverables

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.

To make the flood maps in the region of the channel technically correct, the 1D model results were assigned to the channel cross sections. A surface water elevation was generated in ArcMap based on the assigned flood levels at each section. For each return period surface water elevation the ground level LiDAR DTM was subtracted to produce a flood depth map. These 1D channel flood depth maps were then merged with the 2D model flood depth maps.

The following flood maps listed and described in Table 3-7 have been produced and are contained in Appendix F. These maps have also been created as 0.25m flood depth contours. These have been supplied digitally to Dumfries and Galloway Council in MapInfo and AutoCAD format.

Table 3-7: Summary of model results

Name	Figure number	Description
N2_P2	Figure 1	2 year flow on River Nith with 2 year flow on Polbower Burn
N2_P5	Figure 2	2 year flow on River Nith with 5 year flow on Polbower Burn
N2_P10	Figure 3	2 year flow on River Nith with 10 year flow on Polbower Burn
N2_P25	Figure 4	2 year flow on River Nith with 25 year flow on Polbower Burn
N2_P50	Figure 5	2 year flow on River Nith with 50 year flow on Polbower Burn
N2_P100	Figure 6	2 year flow on River Nith with 100 year flow on Polbower Burn
N2_P200	Figure 7	2 year flow on River Nith with 200 year flow on Polbower Burn
N2_P200CC	Figure 8	2 year flow on River Nith with 200 year plus climate change flow on Polbower Burn
N2_P500	Figure 9	2 year flow on River Nith with 500 year flow on Polbower Burn
N2_P1000	Figure 10	2 year flow on River Nith with 1000 year flow on Polbower Burn
N2_P2_NITH	Figure 11	2 year flow on River Nith with 2 year flow on Polbower Burn
N5_P2	Figure 12	5 year flow on River Nith with 2 year flow on Polbower Burn
N10_P2	Figure 13	10 year flow on River Nith with 2 year flow on Polbower Burn
N25_P2	Figure 14	25 year flow on River Nith with 2 year flow on Polbower Burn
N50_P2	Figure 15	50 year flow on River Nith with 2 year flow on Polbower Burn
N100_P2	Figure 16	100 year flow on River Nith with 2 year flow on Polbower Burn
N200_P2	Figure 17	200 year flow on River Nith with 2 year flow on Polbower Burn

Name	Figure number	Description
N200CC_P2	Figure 18	200 year plus climate change flow on River Nith with 2 year flow on Polbower Burn
N500_P2	Figure 19	500 year flow on River Nith with 2 year flow on Polbower Burn
N1000_P2	Figure 20	1000 year flow on River Nith with 2 year flow on Polbower Burn
N200_P200	Figure 21	200 year flow on River Nith with 200 year flow on Polbower Burn
DECEMBER 2013	Figure 22	The flood event which occurred in December 2013
BLOCKAGE P_200	Figure 23	2 year flow on River Nith with 200 year flow on Polbower Burn with the following blockage applied: 30% blockage on Main Street Bridge, 2m increase in width on each pier on Old Road Bridge, 30% blockage on Foot Bridge
BLOCKAGE N_200	Figure 24	200 year flow on River Nith with 2 year flow on Polbower Burn with the following blockage applied: 30% blockage on Main Street Bridge, 2m increase in width on each pier on Old Road Bridge, 30% blockage on Foot Bridge

4 Existing flood defence measures

4.1 Background

In 1978 a Flood Prevention Scheme (FPS) was installed in Kirkconnel. The aim of the 1978 FPS scheme was to intercept surface water falling on the catchment to the north of Kirkconnel and divert it into the Polbower Burn approximately 110 upstream of the railway culvert. To help cater with the additional flow the Polbower Burn channel was modified and the banks were reinforced in places.

The following work was carried out in the Polbower Burn:

- Regrading/dredging of 330 m of the channel from 110 m upstream of the rail culvert to 55 m below the A76 Road Bridge.
- Profiling of the left bank from the rail culvert to the upstream end of the wingwalls of the A76 Road Bridge.
- 60 m length of gabion wall on the inside of the bend upstream of the A76 Road Bridge.
- Combination of stone retaining walls and concrete retaining walls in vulnerable areas over a length of approximately 150 m.
- Concrete apron under the A76 Road Bridge.

4.2 Current condition

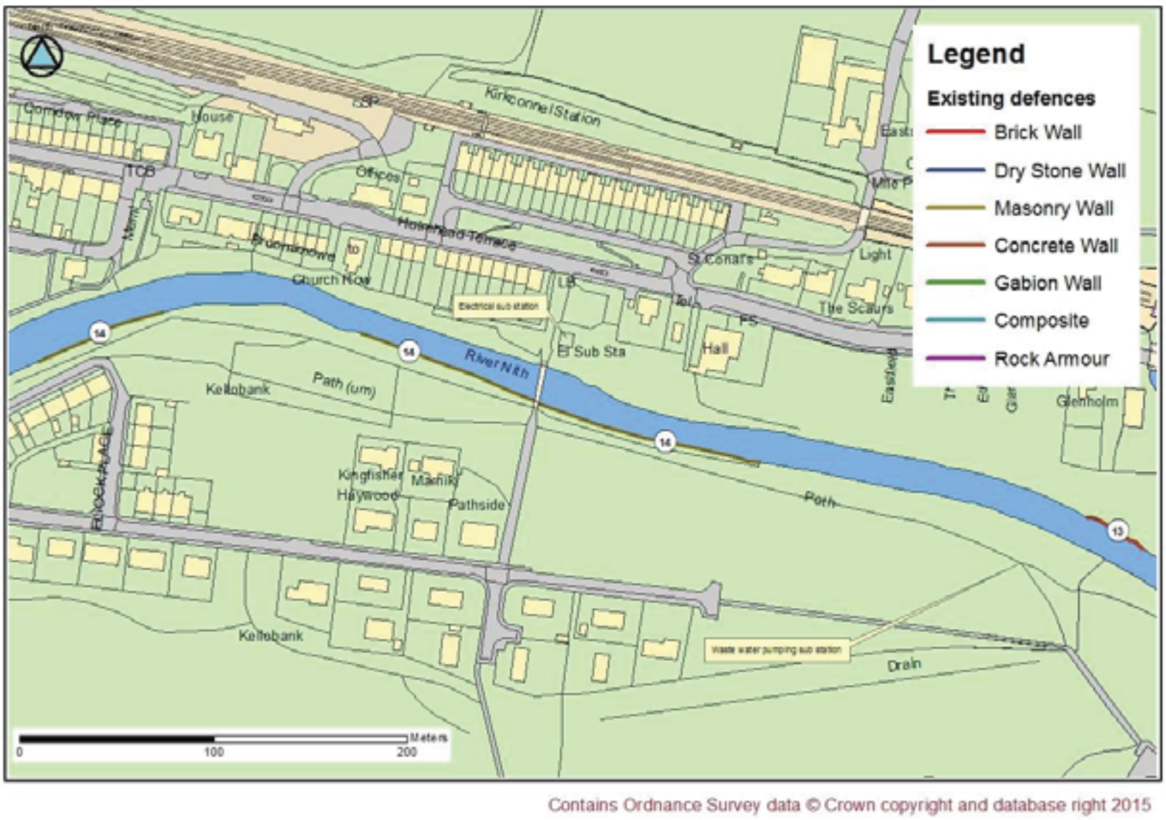
Dumfries and Galloway Council's requested JBA to carry out an assessment of the existing Kirkconnel FPS defences in terms of structural condition, overall effectiveness and suggested improvements.

Angus Pettit (Principal Flood Analyst) accompanied by Jonathan Garrett (Graduate Civil Engineer) of JBA Consulting carried out the assessment of FPS infrastructure during a walk over on the 6 January 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 4-1 displays the assessment classification and location. Figure 4-1 is repeated in the Appendix D at a larger scale to be read in conjunction with the condition assessment report. 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 4-1 Location map of Polbower Burn existing defences

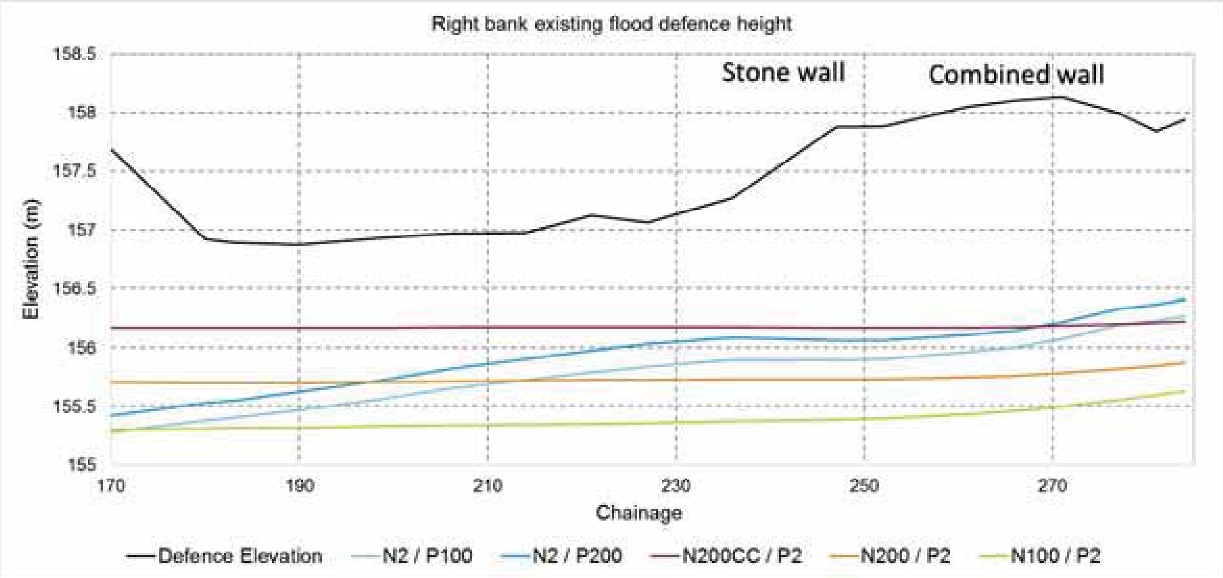
Figure 4-2 Location map of River Nith existing defences



4.2.1 Current standard of defences

The defence elevations have been compared against the modelled water levels to determine the current standard of protection for those defences along the Polbower Burn. This analysis is shown in Figure 4-3.

Figure 4-3 Defence height vs. water surface elevation on the Polbower Burn



As Figure 4-3 shows there is sufficient freeboard from the top of the defence to the water surface elevation of an extreme event. Freeboard heights based on the 200 year flow event on the Polbower Burn vary from between 1 m and 2.3 m.

The portion of defence labelled above in Figure 4-3 as stone wall is asset defence reference number 10. The structure condition assessment identified this section of wall to be in poor condition. The wall is 1.25 m in height. In the model the defence height has been taken as the top of the wall which unless the wall is brought to a good standard is an over estimation of the flood defence height. At this location the freeboard from the 200 year flow on the Polbower Burn is in the region of 1.5 m so without the wall there would still be a freeboard of approximately 0.25 m.

4.3 Recommendations

Overall the FPS defence is in good condition but is showing signs of localised damage. The non FPS works are generally in a poor condition. Table 4-1 below provides a summary of the assessment.

Table 4-1: Asset assessment summary

Ref	Type	Comments
01	Brick wall	Fair condition with aesthetic defects such as surface cracks and missing capping stones.
02	Stone wall	In very poor condition with several through holes. Risk of collapse.
03	Masonry wall	Fair to poor. Loss of mortar. Scour has begun to undercut the base of the wall at channel bed level.
04	Masonry wall	Good condition. Possible undercutting at wall base. Localised damage at upstream extent.
05	Concrete wall	Good condition. With some leaching visible.
06	Gabion Baskets	Good condition. Slight bulging with small amount of vegetation. Removal of tree(s) is recommended to prevent further degradation.

Ref	Type	Comments
07	Rock armour	The rock armour is relatively new however very little effort was made to interlock the armour. One boulder has been pushed to the centre of the channel and the channel bed is being scoured in the armour vicinity.
08	Gabion Basket	Good condition. Slight bulging with small amount of vegetation. Removal of tree(s) is recommended to prevent further degradation.
09	Combination	Poor condition. Numerous trees through structure, stone wall element in poor condition. Concrete section appears to be in fair condition.
10	Stone wall	Poor condition. One stone thick in places with visible through holes.
11	Gabion Baskets with concrete block back wall	Good condition. Slight bulging.
12	Stone wall	Very poor condition. Wall has collapsed in places.
13	Concrete wall (Nith)	Good condition. Bank protection - no flood risk benefit.
14	Stone wall (Nith)	Fair condition with local bank collapse. Bank protection - no flood risk benefit. Ownership of wall unknown.

5 Options for flood mitigation

5.1 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.

5.1.1 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[13] 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)[14] has been recently updated.

5.2 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[15] 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% exceedence 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, particularly if the 0.5% AP level of protection is not cost effective or acceptable to local residents.

Each option has been assessed to achieve a:

1. 0.5% AP with an allowance for climate change level of protection
2. 2.0% AP level of protection
3. A level of protection for the greatest benefit/cost ratio for a return period event between 1:1 and 1:200 + climate change.

5.3 Freeboard Allowance

For the flood defences considered, a standard freeboard allowance of 0.3 m has been applied for hard defences (i.e., walls) and a freeboard of 0.6 m for soft defences (i.e., earth embankments). 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.

[15] Sensitive infrastructure requires a higher level of protection (i.e. 1 in 1000 year).
[15] Sensitive infrastructure requires a higher level of protection (i.e. 1 in 1000 year).
[15] Sensitive infrastructure requires a higher level of protection (i.e. 1 in 1000 year).

5.4 Long list of options

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

Table 5-1: 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. However, in this community relocation may be applicable due to the low proportion of owner occupied properties (most are owned by Dumfries and Galloway Housing Partnership). As a result this may be a cost effective option that could be considered in more detail. ***Decision: Viable option that could be assessed further.***
Prepare	Flood warning	Flood warning is currently not available for Kirkconnel 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[16] suggest that they are planning to extend coverage of flood warning on the Nith catchment. They are doing some work as part of this to consider the potential for upstream extension to Kirkconnel but nothing has been finalised yet. ***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 in the process of being supplied to DGPH properties via DGHP as part of 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; as property repairs have already been undertaken this option it unlikely to be viable. This option is also not ideal for flats or bungalows. ***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[17]. Natural flood management options should focus on the catchment rather than single sites such as Kirkconnel. As multiple strategies are currently being undertaken for the catchment by D&G council and third parties, this option will not be assessed as part of this project.

[16] Pers. Comm. Michael Cranston (January 2015).

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

		Decision: Being assessed by third parties. Excluded from this assessment.
	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 Kirkconnel will unlikely to be technically or practically suitable due to the long length of defences required to extend along the River Nith, the short lead time and large staff numbers required to install. ***Decision: Unlikely to be a practical option. Option not progressed further.***
	Direct defences	Direct defences to Kirkconnel may be applicable but would need to extend along the banks of the River Nith and Polbower Burn to tie into high ground. Defence elevations would need to be reviewed against modelled flood levels to ensure that wall heights could be acceptable to the town and local residents. ***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 River Nith, not least the fact that the river is a salmon river (Atlantic salmon is listed under Annex II of the EC Habitats Directive (1992) and is a UK Biodiversity Action Plan (UK BAP) priority species). The volume of flood water between the 25 year and 200 year return period floods is in the region of 1,000,000m3. 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 £5-10/m3 of stored water, the total cost of storage on the River Nith could be in the region of £5-10million. ***Decision: Unlikely to be a practical or cost effective option for Kirkconnel. Option not progressed further as part of this report, but could be reviewed at a catchment level if this option is supported by SEPA's FRMS.***
	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 and the presence of commercial buildings adjacent to the river and through the Kirkconnel reach. ***Decision: Unlikely to be a practical option. Option not progressed further.***
	Diversion	There is no scope for channel diversion of either the River Nith or Polbower Burn within the vicinity of Kirkconnel. ***Decision: Unlikely to be a practical option. Option not progressed further.***
	Bridge adjustments	The two footbridges in the town surcharged during the December 2013 flood event. This can increase water levels upstream and can cause water levels to increase upstream rapidly. Removal or amending these footbridges may reduce flood levels locally within Kirkconnel but is unlikely to be a solution to flood risk in isolation. ***Decision: Unlikely to be an option in its own right but option to be investigated further.***

5.5 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.

Current consultation documents on the Solway Local Plan District are currently available on the FRM-Scotland website. In December 2015, following feedback from this consultation, SEPA will publish a Flood Risk Management Strategy for each of the 14 Local Plan Districts covering Scotland.

These strategies will confirm the immediate priorities for flood risk management as well as set out the future direction to be taken by all flood risk authorities. Shortly afterwards in June 2016, the lead local authority in each Local Plan District – on behalf of all 32 local authorities in Scotland – will publish delivery plans clearly setting out how flood risk will be managed, coordinated, funded and delivered between 2016 and 2022.

The PVA covering Kirkconnel has the reference 14/01. The PVA documents suggest that there are approximately 90 residential properties at risk of flooding from all sources with Annual Average Damages (AAD) of approximately £150,000. It is important to note that the above analysis is based on broad scale mapping and has not been undertaken at the same level of detail as this study. As such the above values should be used with caution and are not directly comparable with the outputs from this study.

5.5.1 Objectives

The consultation reports suggest that the reduction in river flood risk to properties in Kirkconnel is a primary objective for this Kirkconnel PVA.

5.5.2 Actions

The actions proposed by SEPA are as follows:

- Maintenance of existing flood protection schemes
- Modification of conveyance
- Construction of direct flood defences
- Property level protection
- Improved understanding (this report)
- Relocation

6 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.

6.1.1 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 Kirkconnel 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.

6.1.2 Do Minimum

The 'Do Minimum' option represents the current situation with ongoing maintenance of the watercourse, channel banks and defence assets. This assumes that no blockage (other than permanent fixtures) is present on any structure.

6.1.3 Option 1 - property level protection

Property level protection is flood resistance and resilience measures however it generally takes the form of demountable door guards and air brick covers. To assess the feasibility of Property Level Protection (PLP) the number of properties protected from direct flooding as a result of installing PLP to a level of 0.6 m is displayed in Table 6-1.

Table 6-1: Number of properties at risk and protected

Scenario	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Do Minimum	0	0	2	12	37	41	87	103	103
No. properties at risk with PLP assuming a 0.6m limit	0	0	0	1	5	23	38	81	103
No. of properties protected by PLP	0	0	2	11	32	18	49	22	0
The property counts represent both residential and commercial properties and include all properties flooded above the surveyed floor level.									

Based on the above table, the use of PLP may be a useful flood mitigation measure for many properties at a range of flood magnitudes. However, due to the variable property levels there are still some properties that are at risk to flooding at the 25-50 year floods due to flood waters exceeding the 0.6m threshold. Thus, whilst this option can provide a significant benefit throughout the range of floods modelled, a specific standard of protection cannot be defined.

This option has been assessed further for its costs and benefits to determine the economic viability.

6.1.4 Option 2 - bridge replacement

In Section 3, Table 3-6 the capacity of each of the bridges on the two watercourses were assessed. The Old Road Bridge was highlighted as having a much lower return period capacity than the other structures. Option 2 assesses the impact of lifting the bridge above the 200 year plus climate change (0.5% +CC AP) water surface elevation. Figure 8-2 below compares the water surface elevation during the 200 year (0.5% AP) event with and without the Old Road Bridge on the River Nith. The purple line represents the water surface with the bridge removed.

Figure 6-1: Water surface comparison for the 200 year event with and without the Old Road Bridge

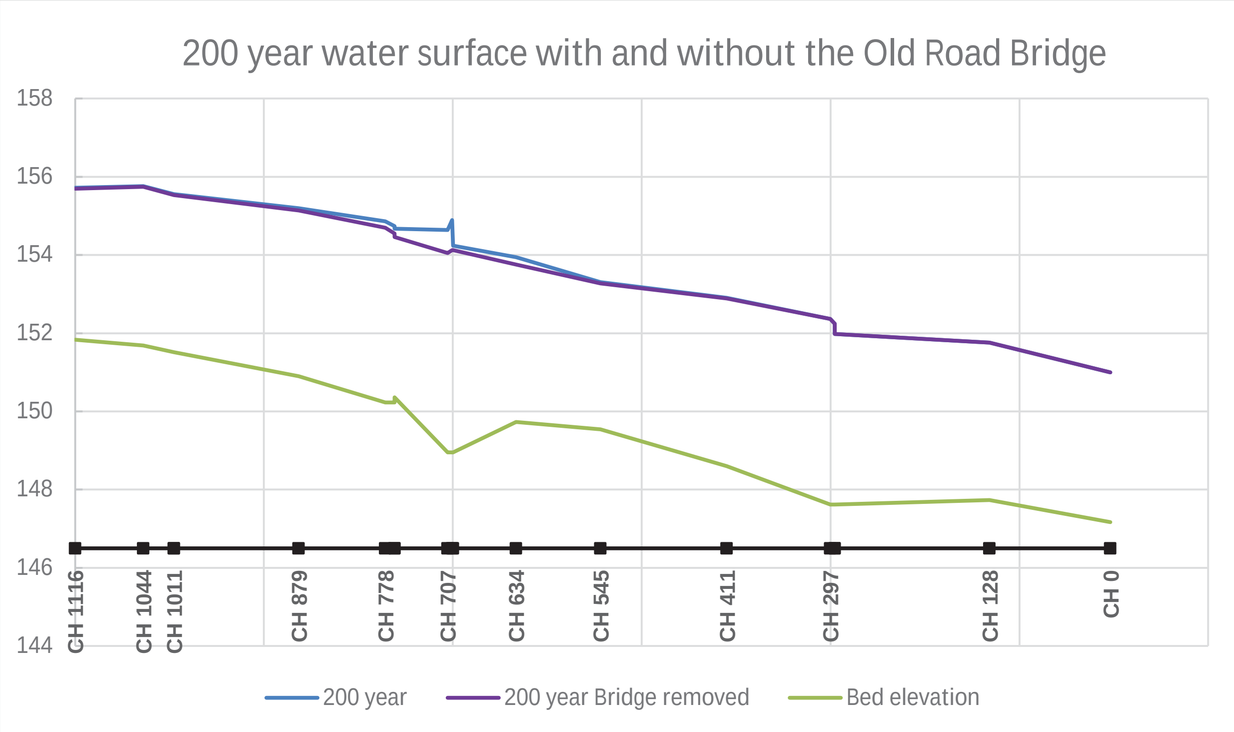


Table 6-2 shows the difference in water surface level (m) for the 25 to 200 year return period for the area of greatest reduction in water surface level due to the bridge removal. The complete set of data with its effect on the Polbower burn is available in Appendix G. This option assumes the Old Road Bridge is replaced at a level outwith the 200 year plus climate water surface level and has therefore been removed from the model.

Table 6-2: Effect of bridge removal on water surface elevation in metres

Label	25 year	50 year	100 year	200 year
NITH_879	-0.07	-0.03	-0.06	-0.05
NITH_778	-0.11	-0.11	-0.24	-0.16
NITH_778_BUS	-0.10	-0.11	-0.26	-0.19
NITH_768	-0.11	-0.11	-0.27	-0.21
NITH_707	-0.27	-0.33	-0.46	-0.59
NITH_707_BUS	-0.25	-0.33	-0.57	-0.76
NITH_707_BDS	-0.03	-0.08	-0.10	-0.11
NITH_634	0.00	0.00	-0.09	-0.19
NITH_545	0.00	0.00	0.00	-0.03
NITH_879	-0.07	-0.03	-0.06	-0.05
NITH_778	-0.11	-0.11	-0.24	-0.16

The above analysis suggests that the removal of the bridge would have some significant benefits locally between the Old Road Bridge and Needle Street Bridge. This therefore might have benefits to the commercial properties in this region. However, once upstream of the Needle Street Bridge where most of the flood risk occurs, the impact is reduced. Thus, whilst this option could have benefits locally, the option is unlikely to significantly reduce the frequency or impact of flooding to St Conal's Square.

This option has been assessed further for its costs and benefits to determine the economic viability.

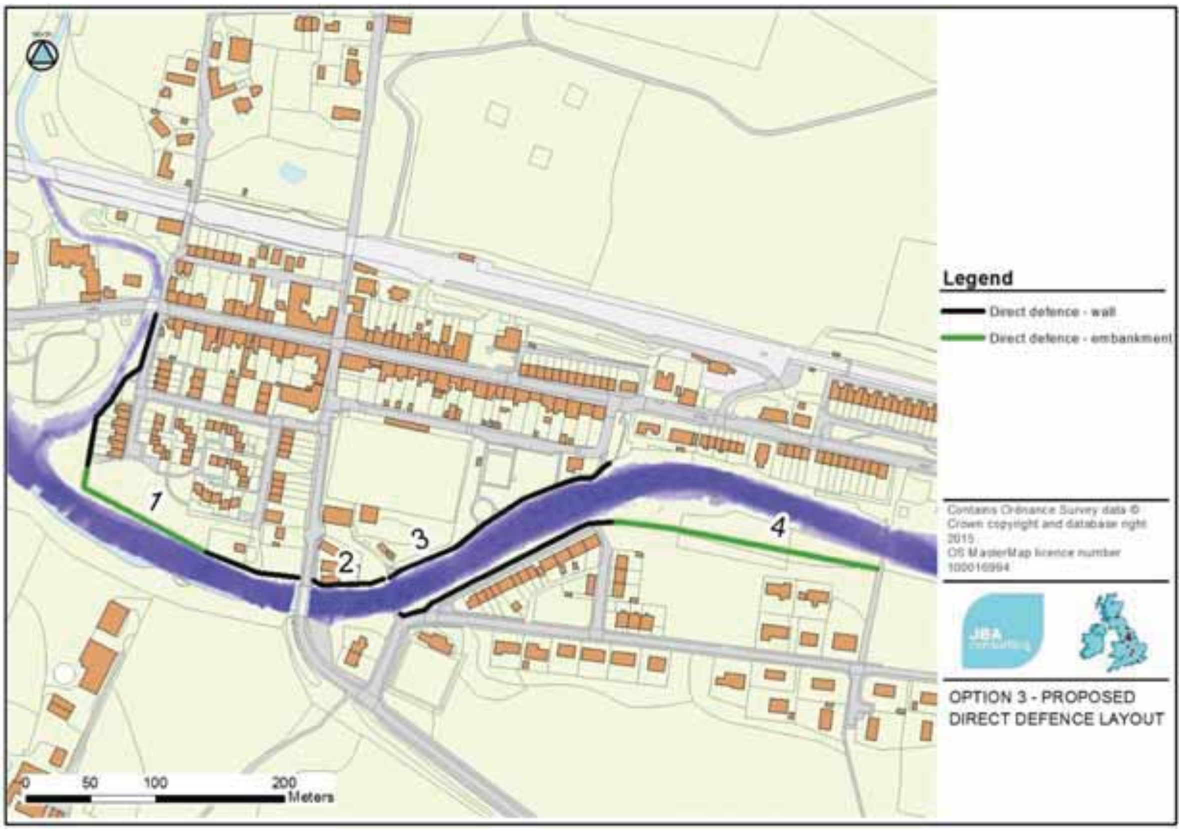
6.1.5 Option 3 - direct defences

Direct defences generally take the form of concrete or sheet piled walls or earth embankments. Figure 6-2 below shows the proposed layout in plan of the direct defence option. The black line indicates a concrete flood wall while the green line depicts the location of earth embankments. There are natural breaks in the defence at high ground or at existing bridges which split the defence into 4 sections.

These section lengths are labelled 1-4. Table 6-3 shows the length of each section with the corresponding average height of the flood defence for each return period. Freeboard has been included in these heights (300mm for walls and 600mm for embankments).

For the extreme flood events such as the 500 year return period the flood defence height is over 5 m. Defence heights of this level are impractical for earth embankments in an urban location and visually too intrusive however the heights have been included to show the level of increase at each return period and for cost comparisons.

Figure 6-2: Direct defence proposed layout



This option has been assessed further for its costs and benefits to determine the economic viability.

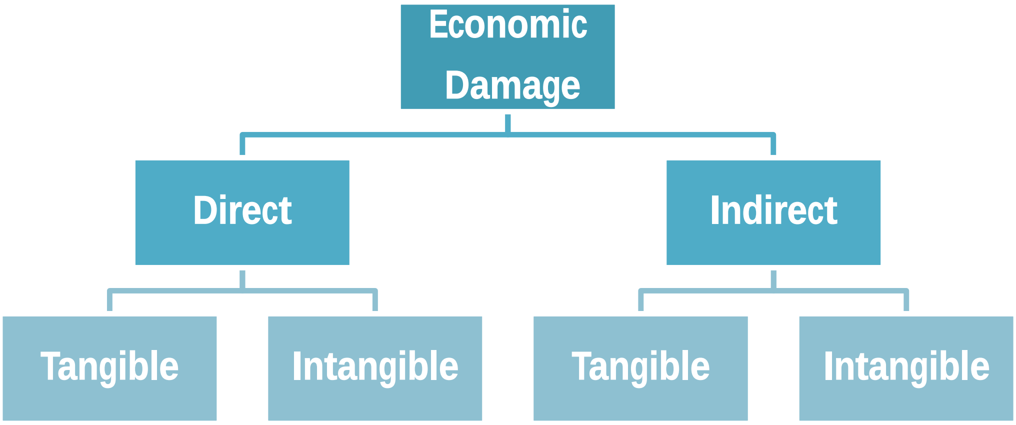
Table 6-3: Average direct defence height in metres

Section	Length (m)	25 year	50 year	100 year	200 year	200+CC year	500 year
1	330	0.68	1.02	1.66	3.26	4.74	5.64
2	55	0.64	0.97	1.67	2.68	3.78	4.26
3	194	0.40	0.69	1.14	2.04	3.14	5.21
4	389	0.46	0.73	1.19	2.25	3.40	5.46

7 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 7-1: Aspects of flood damage



Flood damage estimates have been derived for the following items:

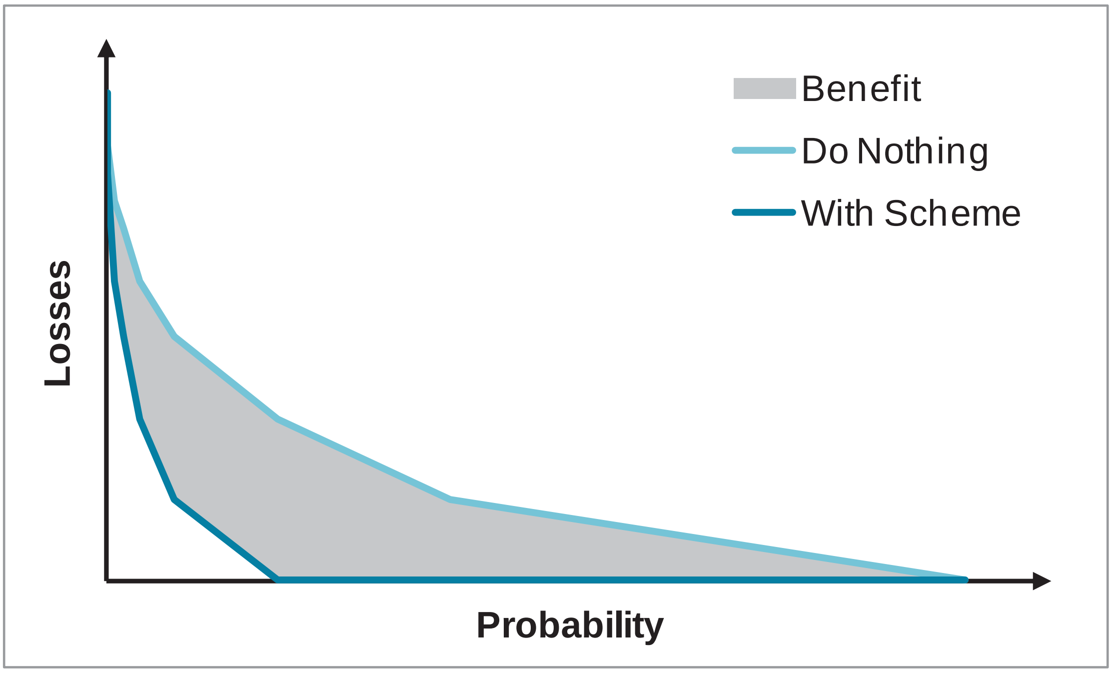
1. Direct damages to residential properties;
2. Direct damages to commercial and industrial properties;
3. Indirect damages (emergency services);
4. Intangible damages associated with the impact of flooding;
5. Damage to vehicles;
6. Emergency evacuation and temporary accommodation costs.

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

7.1 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 7-2: 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.

7.1.1 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 FRISM - JBA's in-house flood damage software. FRISM is an ArcGIS add-in that computes a range of flood risk metrics based on flood hazard and receptor data. Each property data point was mapped on to its building's footprint. A mean, minimum and maximum flood depth within each property is derived by FRISM based on the range of flood depths within the building footprint. FRISM was then used to calculate the damage that occurs from the depth of flooding over the floor area of the building. The mean (based on mean flood water depth 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 7-1, were used to generate direct flood damage estimates.

Table 7-1: 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 a high "DE" social grade compared to the national average.	Treasury Green Book recommends that Distributional Impacts (DI) analysis should be undertaken if it is 'necessary and practical'.
Property areas	OS MasterMap 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.

7.1.2 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.

7.1.3 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 Kirkconnel were obtained from the Scottish Assessors Association website[18]. Equivalent yield varies regionally and temporarily, but is recommended to be a value of 10-12.5 for flood defence purposes[19]. 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.

7.1.4 Updating of Damage Values

The base date for the analysis is December 2014. The MCM data used is based on January 2013 values and therefore need to be brought up to date to compare the costs and benefits. The damages have been updated using the Consumer Price Index (CPI) using the values provided in Table 7-2 which have been extracted from the Statistics Authority. The uplift in flood damages based on this approach is approximately 3%.

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

Table 7-2: Consumer Price Index Uplift to Damages

Index	Jan 2013 CPI	December 2014 CPI	Factor
CPI	124.4	128.2	1.031

7.1.5 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 Kirkconnel indicates that there are a high proportion of lower social group households. Table 7-3 illustrates this proportion and indicates that 53% of people in Kirkconnel are in the 'DE' social grade. Thus, the 'DE' social grade is predominant and significantly higher than the Scottish average; the analysis of DI is deemed to be necessary.

Table 7-3: Proportion of social grades within Kirkconnel

Location	AB	C1	C2	DE
Kirkconnel	5%	16%	27%	53%
Scotland	19%	32%	22%	28%
Difference	-14%	-16%	5%	25%
The total number of people represents those aged 16+ for which a grade can be applied.				

The above analysis suggests that if comparing Kirkconnel with another area requiring funding, the socio-economic aspects of flooding should be considered as a pound spent at Kirkconnel may have a greater benefit than that spent at an alternative location with a lower social impact.

We recommend that distributional impacts are considered at this stage by scaling the total damages by the social grade weighting factors provided in Table 7-4.

Table 7-4: 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.				

7.2 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.

7.3 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.

7.3.1 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)[20] 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.

7.3.2 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 7-5: 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

7.3.3 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 Kirkconnel for each return period flood event assessed and the AAD and PVd calculated as normal.

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

8 Summary of total flood damages

8.1 Properties at risk

The total number of properties inundated for the Do Minimum Scenario has been assessed are provided in Table 8-1.

Table 8-1: 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	500 year	1000 year
Residential	0	0	2	18	50	71	84	93	93
Non-residential	0	0	2	6	7	8	9	10	10
Total	0	0	4	24	57	79	93	103	103

8.2 Do Minimum event damages

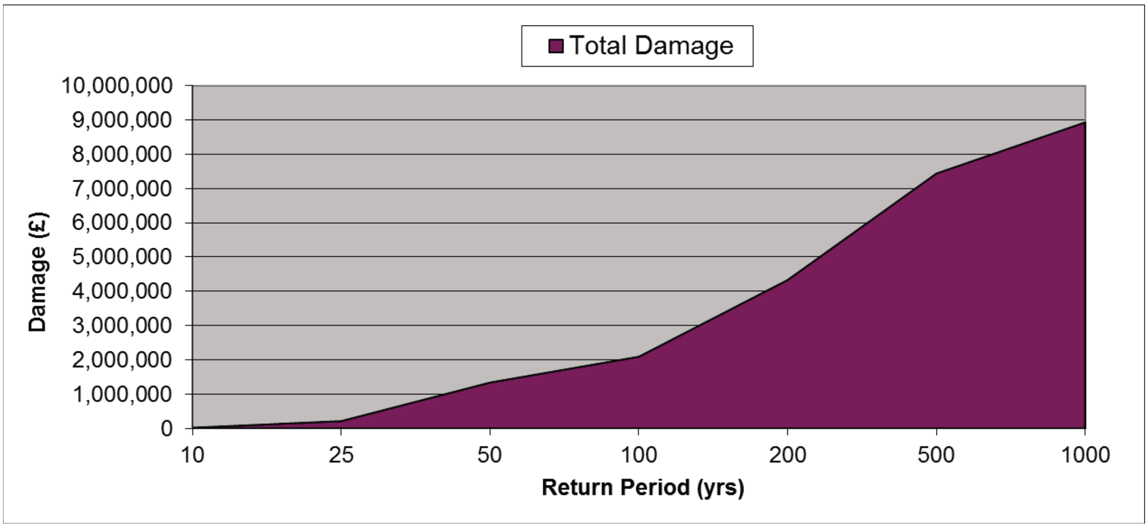
Event damages have been calculated for a range of return periods. The FRISM output provides event damages based on MCM depth damage curves. Full results are provided in Appendix H. The event damage for each option is provided in Table 8-2. These represent the total potential flood damages based on the modelled flood levels for Kirkconnel for the current existing case. Damages include all direct and indirect property flood damages.

Table 8-2: Total property flood damage for each scenario (£k) (prior to capping)

	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Residential	0	0	4	161	976	1,534	3,553	6,310	7,597
Non-residential	0	0	16	53	363	559	780	1,129	1,335
Total	0	0	21	214	1,339	2,093	4,332	7,439	8,932

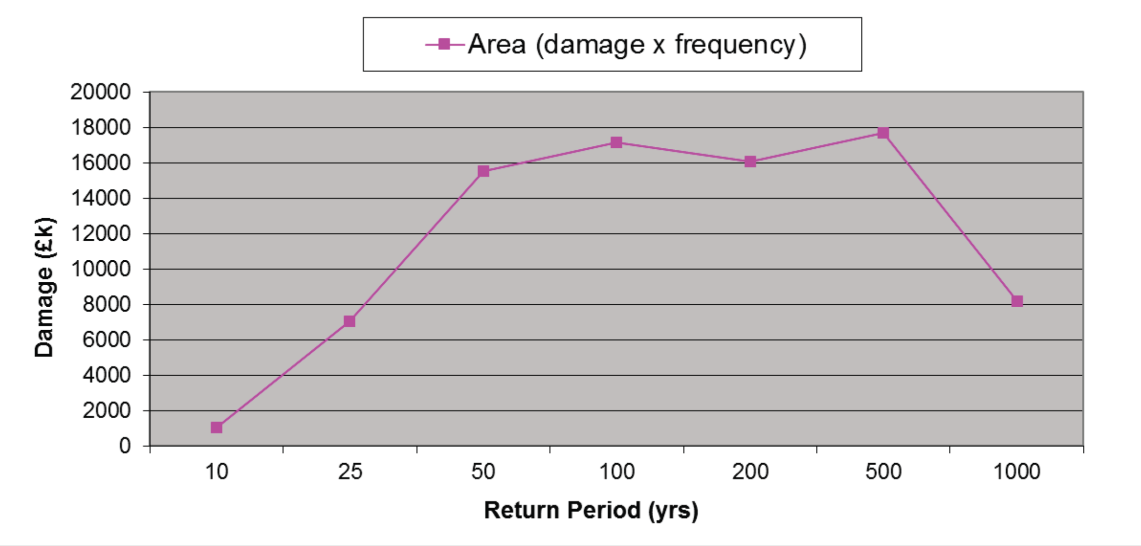
The above damages are used to calculate Annual Average Damages (AAD). Plotting the damages against the frequency of flooding (annual probabilities) allows us to determine the AAD as the area beneath the curve (Figure 8-1). This figure shows that flood damages are relatively small for the lower to medium flood events, but rises significantly for the more extreme flood events.

Figure 8-1: 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 Kirkconnel are presented in Figure 8-2. This shows that the majority of flood damages occur in the 50 - 500 year return period events, despite the rarity of these extreme floods. This is partly due to the significant increase in properties flooded at higher magnitude flood events. This suggests that any option that only reduces flood risk for the more frequent flood event will not significantly reduce overall flood damages to Kirkconnel.

Figure 8-2: Interval benefits for the Do Minimum baseline



The breakdown between the number of residential and non-residential properties at risk and the total AAD is provided in Table 8-3. This illustrates that 90% of the total properties at risk for the 200 year flood event are residential properties, but these only account for 78% of the total damages; this is to be expected as commercial properties tend to generate higher flood damages.

Table 8-3: Total Properties Protected and Flood Damages

Scenario	Properties at risk at 200 yr	Proportion of properties at risk	Total direct property damages (AAD) (£k)	Proportion of total damage
Residential	84	90%	71,784	78%
Non-residential	9	10%	20,565	22%
Total	93	100%	£92,349	100%

8.2.1 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 8-4 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. The reason for high flood damages relates to high flood depths and frequent flooding in each of the properties most are flooded at the 10% AP (10 year) flood. Many properties in Conal's Square are ranked equally in 5th place due to capping to their market values.

Table 8-4: Top 10 highest damage contributors for the Do Minimum Scenario

Rank	Property address	PVd Capped?	PVd (£)	Percentage of total PVd
1	Store by Football Ground, Needle Street	Yes	118,860	4.93%
2	9 Riverside Terrace	No	81,955	3.40%

Rank	Property address	PVd Capped?	PVd (£)	Percentage of total PVd
3	Garage Needle Street	Yes	70,380	2.92%
4	Football ground store	No	55,591	2.30%
5	35 St Conal's Square	Yes	53,276	2.21%
5	38-44 St Conal's Square	Yes	53,276	2.21%
5	38-44 St Conal's Square	Yes	53,276	2.21%
5	38-44 St Conal's Square	Yes	53,276	2.21%
5	38-44 St Conal's Square	Yes	53,276	2.21%
5	38-44 St Conal's Square	Yes	53,276	2.21%

8.2.2 Impact of social aspects and Distributional Impact (DI) analysis

The annual average damage (AAD) is the damage that would be caused every year if the flood damage was distributed evenly over the length of the appraisal. Table 8-5 displays the total damage in the form of AAD and Present Value damages.

Table 8-5: Summary of total flood damage (£k)

Scenario	AAD damages (£k)	PV damage (£k)	PV damage capped (£k)
Do Minimum	92.35	2,753	2,412

A comparison has been undertaken with the inclusion of distributional impact (DI) analysis to take into account the social aspects of flooding. When DI are applied the total damage increases significantly. The DI damages are displayed in Table 8-6 and Table 8-7. All subsequent damage data presented includes this allowance for social aspects through distributional analysis.

Table 8-6: Total property flood damage for each scenario with distributional analysis (£k) (prior to capping)

	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Total damages with DI	0	22	279	1,733	2,712	5,767	9,988	12,001

Table 8-7: Summary of total flood damage with DI (£k)

Scenario	AAD damages (£k)	PV damage (£k)	PV damage capped (£k)
Do Minimum	121.35	3,618	3,226

8.3 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 and with flood depths less than 0.6m. The total flood damages for each modelled return period is presented in Table 8-8.

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 8-8: PLP damages avoided (£k)

Scenario	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Do Minimum	0	22	279	1,733	2,712	5,767	9,988	12,001

Scenario	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Option 1 - PLP (500yr)	0	0	7	203	1,358	2,921	7,792	12,001
Option 1 - PLP (200yr)	0	0	7	203	1,358	2,921	9,988	12,001
Option 1 - PLP (100yr)	0	0	7	203	1,358	5,767	9,988	12,001
Option 1 - PLP (50yr)	0	0	7	203	2,712	5,767	9,988	12,001
Option 1 - PLP (25yr)	0	0	7	1,733	2,712	5,767	9,988	12,001

Total AAD and PVd for the PLP option is presented in Table 8-9. The use of PLP approximately halves the AAD compared to the Do Minimum baseline assuming all properties at risk from the 500 year return period have PLP installed. However, using PLP alone may be acceptable as it only provides a 10 year standard of protection to the community with some properties still at risk at the 25 year return period and above.

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

Scenario	AAD damages (£k)	PV damage (£k)	PV damage capped (£k)	PV damage avoided (£k)
Do Minimum	121.3	3,618	3,226	-
Option 1 - PLP (500yr)	60.9	1,815	1,750	1,476
Option 1 - PLP (200yr)	64.2	1,913	1,848	1,378
Option 1 - PLP (100yr)	75.5	2,252	2,188	1,038
Option 1 - PLP (50yr)	85.7	2,555	2,490	736
Option 1 - PLP (25yr)	108.7	3,239	2,977	249

8.4 Option 2 - Replacement of Old Road Bridge

The resulting damage after the Old Road Bridge has been removed is shown in Table 8-10 and Table 8-11. The reduction in flood damages with this option is limited but may provide some local benefit primarily to the properties at risk in the region of the bridge and upstream.

Table 8-10: Total Flood Damages after bridge replacement (£k)

Scenario	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
Non-Residential	0	0	16	30	327	455	628	955	1,233
Residential	0	0	4	114	896	1,466	3,318	5,913	7,311
Total	0	0	21	144	1,223	1,922	3,946	6,868	8,545

The reduction in flood damages as a result of the bridge replacement is modest with a reduction of approximately £180,000. This represents a reduction in flood damages of approximately 5.5%.

Table 8-11: Summary of total flood damages for Option 2 - Bridge Replacement (£k)

Scenario	AAD damages (£k)	PV damage (£k)	PV damage capped (£k)	PV damage avoided (£k)
Do Minimum	121.3	3,618	3,226	-
Bridge replacement	110.1	3,281	3,049	177

8.5 Option 3 - Direct defences

The direct defence option has been assessed to defend against a range of return periods. The AAD for each standard of protection assessed have been assessed using standard FCERM-AG spreadsheets and converted into Present Value damages (PVd) as shown in Table 8-12.

Table 8-12: Summary of flood damages for direct defence option (£k)

Scenario	AAD damages (£k)	PVd damages (£k)	PVd capped (£k)	PV damage avoided (£k)
Do Minimum	121.3	3,618	3,226	-
500 year SOP	24	716	716	2,511
200 year SOP	39	1,162	1,162	2,064
100 year SOP	62	1,850	1,850	1,376
50 year SOP	82	2,456	2,392	835
25 year SOP	108	3,231	2,969	258

The above results suggest that the present value damages avoided for a scheme to protect Kirkconnel to a 0.5% AP (200 year) flood is in the order of £2,064k. This includes all flood savings in relation to direct property flood damages, emergency services, vehicle losses, intangible damages and indirect damages.

It is clear that even with a 200 year scheme there would be significant residual flood damages (over £1.1m for the 200 year standard). This is due to the large increase in design flows in the River Nith at Kirkconnel and the large flood damages that this derives for the larger more extreme flood events.

9 Cost estimates

9.1 Price Base Date

The price base date is December 2014. Benefit 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.

9.2 Whole life cost estimates

The outputs from SEPA's 'Costing of Flood Risk Management Measures' 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 there 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 complied 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 2 (equivalent to 2016).
4. Enabling costs have been spread over years 0-1.

9.3 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.

9.4 Option 1 - Property Level Protection

In order to assess the economic benefits of PLP the costs of implementing PLP 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. Therefore in addition to the standard product and installation costs, the following additional cost elements have been included:

- 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 9-1: Whole life cost results for manual systems (£ per property)

Category	Whole Life Cost - Lower	Whole Life Cost - Average	Whole Life Cost - Upper
Detached	6,691	10,194	14,571
Semi-detached	6,117	9,175	13,312
Terraced	5,269	7,942	11,718
Flat	5,320	8,044	11,846
Shop	8,073	12,722	17,900
Office	8,966	14,507	20,131
Residential average	5,849	8,839	12,862

Table 9-2: 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 manual PLP where the flood water is at or above the floor level and the low whole life cost where flood water is within 0.3m of the floor level (i.e. flooding to the solum of the property between the ground levels and floor level.

Manual approaches to PLP are assumed in this case as this method closely aligns to the approach that Dumfries and Galloway currently employs for PLP based on their subsidy scheme. However, the costs assume that all costs are born by Dumfries and Galloway Council and none by the residents themselves. If this option is undertaken by Dumfries and Galloway Council's current subsidy scheme, the actual cost of PLP installation may be significantly less than the values presented in Table 9-3.

This PLP option incorporates all properties that have a flood depth less than 0.6m. Table 9-3 outline the total costs with and without a 60% optimism bias. The total for a 0.5% AP (200 year scheme) would be £1,297k. It should be noted that this would not protect all properties in Kirkconnel as some properties at the 200 year flood have flood depths greater than 0.6m.

Table 9-3: Whole life cost for PLP to all properties (£k)

Scenario	5 year	10 year	25 year	50 year	100 year	200 year	500 year
PLP	0	44	201	461	590	811	912
PLP with optimism bias	0	70	322	737	945	1,297	1,460

9.5 Option 2 - Bridge replacement

The cost of replacing the Old Road Bridge has been broken down into bridge removal, service removal and construction of a new bridge. A high level cost estimate was derived using SPON'S Civil Engineering and Highway Works Price Book 2014. The cost estimate of removal and relocation of the services that cross under the bridge was provided by Dumfries and Galloway Council.

A breakdown of the bridge replacement cost is provided in Appendix H and a summary is provided in Table 9-4. Uplifting cost for inflation has not been considered due to the high level estimation. Operation and maintenance costs have not been considered as these are existing costs.

Table 9-4: Bridge replacement costs (£)

Action	Cost (£k)
Bridge removal	12.6
Services removal	150.0
New bridge	188.4
Total cost	351.1
Total cost with optimism bias	561.7

9.6 Option 3 - Direct defences

This option represents a portfolio of measures to reduce flood risk. The direct defence's costs have been based on concrete walls and earth embankments.

9.6.1 Whole life costs

The direct defence costs have been based on values provided in SEPA's Cost of Flood Risk Management Report. The cost estimates accounts for all costs associated with the project over its expected life. The table for a hard flood defence wall is reproduced below in Table 9-5. The average cost per metre has been used in this cost estimation.

Table 9-5: Flood wall cost per metre

Height (m)	Lower cost (£/m)	Average cost (£/m)	Higher cost (£/m)
<1.2	923	1,674	1,913
1.2-2.1	1,353	3,407	5,373
2.1-5.3	2,293	4,191	5,401
>5.3	4,107	13,043	15,302
All heights	1,247	3,499	4,723

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 and slope. 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 Report.

The flood defence is composed of 4 lengths as shown in Figure 8-2. The height of the flood defence was calculated at 1 m intervals. The average height of each length of wall was calculated based on flood elevation plus 0.3 m freeboard for hard defence and 0.6 m for earth embankments. Each return period was run with the return period flows on one watercourse with the 2 year return period flows on the other. The flood elevation at each section was taken as the max elevation of the two corresponding return periods. The defence heights were based on flood walls being located at the edge of the 1D cross section.

Table 9-6 summaries the cost to provide direct defences for the assessed range of return periods.

Table 9-6: Direct defence cost for each SOP (£k)

SOP	25 year	50 year	100 year	200 year	200+CC year	500 year
Scheme cost	1,245	1,316	1,878	3,002	3,547	5,518
Scheme cost with optimism bias	1,992	2,106	3,005	4,803	5,676	8,829

9.7 Cost summary

A summary of costs with optimism bias applied is presented in Table 9-7 below.

Table 9-7: Option cost summary with optimism bias (£k)

Option	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year
PLP	-	-	£70	£322	£737	£945	£1,297	£1,460
Bridge replacement	Single option assessed - £562							
Direct defences	-	-	-	£1,992	£2,106	£3,005	£4,803	£8,829

10 Benefit-cost analysis

10.1 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.

10.2 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.

10.3 Benefit-cost results for Option 1 - PLP

A range of standards of protection for the PLP option have been assessed. A summary of the flood damage results for the proposed PLP option are provided in Table 10-1.

Table 10-1: Summary of benefit-cost calculation (£k)

	Do Nothing	PLP 25 year SOP	PLP 50 year SOP	PLP 100 year SOP	PLP 200 year SOP	PLP 500 year SOP
Properties protected		11	32	18	49	22
Total PV costs (£k)	-	201	461	590	811	912
Total PV costs + Optimism bias (£k)	-	322	737	945	1,297	1,460
PV damage (£k)	3,226	2,977	2,490	2,188	1,848	1,750
PV damage avoided (£k)	-	249	736	1,038	1,378	1,476
Benefit-cost ratio	-	0.77	1.00	1.10	1.06	1.01

The above results indicate that the preferred standard of protection for the PLP option based on the economic aspects alone would be the 100 year standard as this is the option with the highest benefit-cost ratio. All of the alternative standards of protection assessed are cost effective other than the 25 year standard. This is due to the fact that the 25 year standard of protection option provides relatively few benefits in terms of properties protected.

It is important to note that for each standard assessed, not all properties benefit from PLP as some may flood to a depth greater than the standard 0.6m and cannot be guaranteed to protect against inundation of the property.

It is also worth reiterating that the costs for PLP assumed represent current best practice approaches to the installation of manual PLP approaches (based on the Scottish Government Blueprint) and may be considered to be relatively high when compared with the Dumfries and Galloway PLP subsidy scheme. Thus the costs of providing PLP may be substantially cheaper and the benefit cost ratio higher than presented here.

10.4 Benefit-cost results for Option 2 - Bridge Removal

A summary of the flood damage results for the proposed bridge removal option are provided in Table 10-2.

Table 10-2: Summary of benefit-cost calculation (£k)

	Do Nothing	Bridge removal
Total PV costs (£k)	-	351.1
Total PV costs + Optimism bias (£k)	-	561.7
PV damage (£k)	3,226	3,049
PV damage avoided (£k)	-	177
Benefit-cost ratio	-	0.3

The option to raise or remove the old road bridge in Kirkconnel will have local benefits mainly restricted to the commercial properties on the left river bank (north bank) between this bridge and the Needle Street road bridge. As such this option as a method to reduce flood risk to St Conal's Square - the main residential area at risk in Kirkconnel is limited.

However, Dumfries and Galloway Council have suggested that this bridge may need to be replaced or upgraded in the future for asset management purposes rather than for flood risk reasons. Thus, the flood benefits generated by such an option may help to offset this cost to the Council

10.5 Benefit-cost results for Option 3 - Direct Defences

A summary of the flood damage results for the direct defence options are provided in Table 10-3.

Table 10-3: Summary of benefit-cost calculation (£k)

	Do Nothing	Defence 25 year SOP	Defence 50 year SOP	Defence 100 year SOP	Defence 200 year SOP	Defence 500 year SOP
Total PV costs (£k)	-	1,245	1,316	1,878	3,002	5,518
Total PV costs + Optimism bias (£k)	-	1,992	2,106	3,005	4,803	8,829
PV damage (£k)	3,226	2,969	2,392	1,850	1,162	716
PV damage avoided (£k)	-	258	835	1,376	2,064	2,511
Benefit-cost ratio	-	0.13	0.40	0.46	0.43	0.28

The results suggest that none of the direct defence standard of protection options offer a cost effective option to mitigate against flooding from the River Nith as all have a benefit-cost ratio less than unity. A 100 year standard of protection provided by direct defences is the most cost effective option of the alternative standards assessed, although with a benefit cost ratio of only 0.46 the costs are almost double the damages avoided.

10.6 Economic preferred option

A summary of the most cost effective options for each of the three main options assessed is summarised in Table 10-4. Of these only the PLP is cost effective. There may be a range of actions that are more cost effective (e.g. defences for one area and PLP for another for example), but this combination of options has not been assessed at this stage.

Table 10-4: Summary of benefit-cost calculation (£k)

	Do Nothing	PLP 100 year SOP	Bridge removal	Defence 100 year SOP
Total PV costs (£k)	-	590	351	1,878
Total PV costs + Optimism bias (£k)	-	945	562	3,005
PV damage (£k)	3,226	2,188	3,049	1,850
PV damage avoided (£k)	-	1,038	177	1,376
Benefit-cost ratio	-	1.10	0.30	0.46

11 Conclusion and Recommendations

This report presents the results of a detailed flood risk appraisal of Kirkconnel from River Nith and the Polbower Burn. A Strategic Flood Risk Assessment undertaken by Dumfries and Galloway Council in 2007 identified Kirkconnel as a priority area in Dumfries and Galloway in terms of the number of properties potentially at risk of flooding. More recently the area has been classified as a Potentially Vulnerable Area by SEPA and is an identified action for flood risk reduction.

Kirkconnel flooded in December 2013 causing flooding to approximately 50 properties. The estimated magnitude of the flood is approximately a 1.25% Annual Probability (80 year) flood. This represented the first major flood to the town since 1966.

A detailed hydrological assessment of the River Nith and Polbower Burn has been undertaken to derive flow inputs into a hydraulic model of the river through Kirkconnel. Survey was undertaken to build a 1D model of the River Nith and Polbower Burn and a linked 1D/2D TuFLOW flood model generated.

The 1D/2D mathematical models of River Nith and Polbower Burn were calibrated against recorded flood levels and anecdotal evidence collated from the community for the December 2013 event. The modelled flood extent and flood levels matched well with the observed/recorded data.

From this a range of flood inundation maps for a number of return period flood events have been assessed to improve the understanding of flood risk to the town and to identify a range of possible flood alleviation measures. 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 model results estimate that 93 properties would be affected during a 200 year flood; the majority of which are residential. Four properties are predicted to flood at the 10 year return period. Annual average flood damages are estimated to be £121,000 with a Present Value damage in the region of £2.4 million. The number of properties and thus damages rises rapidly between the 50 year and 200 year flood, as a result the majority of the flood benefits can only be realised by providing a good standard of protection for Kirkconnel.

A number of flood mitigation options have been considered including; property level protection; direct defences via flood walls and embankments; and removal the Old Road Bridge. Each option is assessed further below:

- Option 1. The PLP option is useful for properties that flood up to 0.6m in depth. As flood levels rise with flood flows the number of properties that benefit from PLP reduce. Therefore, whilst this option is a useful option to mitigate flood risks to Kirkconnel it does not provide a defined standard of protection. Furthermore there will be risks associated with this option in terms of the ability of the community to respond to warnings in sufficient time. Flood warning improvements may also be required in parallel with this option.
- Option 2. The bridge removal option has been modelled and shows that flood levels immediately upstream of the Old Road Bridge would reduce, however the impact is limited in the area of St Conal's Square. Therefore, this option is unlikely to offer any significant flood risk benefits as a standalone solution to flood risk in Kirkconnel, but could offer benefits as part of a wider scheme.
- Option 3. The direct defence option would necessitate almost a kilometre of flood defences through the town to protect all properties at risk. Flood defence heights are such that providing a 200 year standard would be difficult to achieve due to excessively high flood defences and the aesthetic and intrusive nature of the defences.

A benefit-cost analysis has been undertaken for the baseline (Do Minimum) option and each of the above options. Flood damages for the current situation have been assessed and include a number of aspects such as direct damage to properties, clean-up costs, indirect and intangible aspects (health and wellbeing), evacuation and temporary accommodation costs and an allowance for the social variables. The total flood damages for Kirkconnel are estimated to be £121,000 per annum with a present value estimate of £3.2 million (it is the present value estimate that is compared with the costs in a benefit-cost analysis).

Costs for each option and a range of standards of protection have been assessed based on unit costs from SEPA. An optimism bias factor of 60% has been added to the total costs to allow for uncertainties in the design at this level of appraisal and is typical for schemes at an early stage of appraisal.

The benefit cost analysis for the three options assessed provides the following recommendations:

- Property Level Protection is a viable option for mitigating the flood risk to the town. The most cost effective option is to provide all properties at risk of flooding at the 100 year standard PLP which returns a benefit-cost ratio of 1.1. Thus for every £1 spent on PLP, there is a return of £1.10. This assumes a relatively high cost for implementation of PLP that could be reduced if the Council's subsidy scheme is used as the primary mechanism for implementation of this option. Improved flood warning by SEPA would be a pre-requisite for this option to improve the warning lead time on the River Nith for this community.
- The bridge removal option for the Old Road Bridge in Kirkconnel has a benefit cost ratio of 0.3 suggesting that as an independent option this does not generate sufficient benefits to offset the cost of the works. However, this option may play an important role as part of a combined option if appropriate.
- The direct defence option has been assessed for a number of protection standards. None of the options assessed have sufficient benefits to outweigh the costs of construction and long term maintenance. This is primarily due to the high defence heights required, indeed protection to the 200 year standard would be a challenge due to the aesthetics of the defence heights.

To summarise, only the PLP option is cost effective as a long term option to mitigate flood risk to Kirkconnel. There may well be a range of actions that are more cost effective (e.g. defences for one area and PLP for another for example), but this combination of options has not been assessed at this stage.

The costs for this option include allowances for the purchase, administration, demolition and landscaping of the site. The flood damages assume that the properties at risk are removed from the analysis. Two options have been assessed depending on the level of protection. The analysis suggests that relocation of the at-risk community of St Conal's may be cost effective, with the 50 year scheme option having a positive benefit-cost ratio.

This approach requires a medium to long term strategy to be implemented by a number of organisations together to ensure that the benefits of flood risk reduction can be achieved without significant impact on the social aspects for those residents in St Conal's Square and the community as a whole.

Appendices

A Appendix A - December 2013 flood photographs

The Kirkconnel Parish Heritage Society[21] website and photos from news articles, posted numerous photographs of the 2013 floods affecting homes, land and bridges in Kirkconnel:

Table A-1: Photos of the 2013 flood event in Kirkconnel

 Source: Kirkconnel Parish Heritage Society	 Source: Kirkconnel Parish Heritage Society
Taken from house 38 in St Conal's Square	Taken from house 38 in St Conal's Square
 Source: Kirkconnel Parish Heritage Society	 Source: Kirkconnel Parish Heritage Society
Taken from house 38 in St Conal's Square	Taken from house 38 in St Conal's Square
 Source: Kirkconnel Parish Heritage Society	 Source: Kirkconnel Parish Heritage Society
Taken from house 38 in St Conal's Square	Houses on Riverside Terrace

[21] Kirkconnel Parish Heritage Society (http://kirkconnel.org/info/)

 Source: WeatherForecast.co.uk[22]	 Source: Mail Online[23]
Gospel Hall, upstream left bank of road bridge	St. Conal's Square, upstream of road bridge
 Source: ITV News[24]	 Source: Kirkconnel Parish Heritage Society
	Taken from house 38 in St Conal's Square looking towards playground
 Source: Kirkconnel Parish Heritage Society	 Source: Kirkconnel Parish Heritage Society
Football Grounds	Footbridge from Main Street to Kingsway

[22] WeatherForecast.co.uk, 30 December 2013 (http://www.weatherforecast.co.uk/blog/kirkconnel-flood-30th-december-2013-heavy-rain-brings-floods-dumfries-galloway/)

[23] The Mail Online, 31 December 2013 (http://www.dailymail.co.uk/news/article-2531712/Washout-2014-Britain-braced-severe-weather-New-Years-Day-forecasters-predict-rain-gales-MONTH.html)

[24] ITV News, 30 December 2013 (http://www.itv.com/news/border/update/2013-12-30/gardens-under-water-in-kirkconnel/)


Source: Kirkconnel Parish Heritage Society

Footbridge downstream of Needle Street road bridge


Source: Kirkconnel Parish Heritage Society

Footbridge downstream of Needle Street bridge


Source: Kirkconnel Parish Heritage Society

Flooded garages


Source: Kirkconnel Parish Heritage Society

Road bridge on Hyslop Street


Sourc: Kirkconnel Parish Heritage Society

Floods near A76 road bridge


Source: Kirkconnel Parish Heritage Society

Floods near A76 road bridge

B Appendix B - Hydraulic structures

Table B-1: Table of structures on the River Nith and Polbower Burn

Name: A76 road bridge	
 Courtesy of the Kirkconnel Parish Heritage Society	Location: Upstream of Kirkconnel OS NGR: 272192 612342

Name: Needle Street road bridge	
	Location: Needle Street OS NGR: 273049 612032

Name: Footbridge downstream of Needle Street bridge	
	Location: Downstream of Needle Street OS NGR: 273117 612028

Name: Footbridge joining Main Street and Kingsway	
	Location: Main Street and Kingsway OS NGR: 273049 612032

Name: Railway bridge over the Polbower Burn	
	Location: Railbridge over Polbower Burn OS NGR: 272844 612367

Name: Road bridge over the Polbower Burn	
	Location: Road bridge over the Polbower Burn (adjacent to St. Conel's Square OS NGR: 272926 612259

C Flood Estimation on the River Nith and Polbower Burn

C.1 Summary of methodologies

As described in the main body of the report, the statistical method (single site growth curve from Hall Bridge) was used to estimate flood flows on the River Nith and the Rainfall Runoff method was used for Polbower Burn. This decision was made after considering many different alternate analyses, the results of which are summarised in Table A-1 and Table A-2. For the River Nith, the estimates obtained via the single site growth curve obtained from Hall Bridge appeared to be most consistent with the understanding of historical flood response on the catchment. For the Polbower Burn, the Rainfall Runoff method was selected as being most suitable given the catchment size. However, it is worth noting that the pooling group approach for the Polbower Burn, using Hall Bridge as a donor provides very similar results to those obtained using the Rainfall Runoff method.

Table C-1: Summary of flood estimation methodologies considered: River Nith

AP(%)	T (years)	Hall Bridge Gauging Station Single Site (m^3/s)	Hall Bridge Gauging Station Enhanced Single Site (m^3/s)	Upstream of Polbower Burn Single Site, Adjusted Area (m^3/s)	Upstream of Polbower Burn Enhanced Single Site, Adjusted Area (m^3/s)	Downstream of Polbower Burn Single Site, Adjusted Area (m^3/s)
50	2	71	71	86	86	96
20	5	93	93	113	113	126
10	10	115	110	139	134	155
4	25	154	136	187	165	208
3.33	30	164	142	199	172	221
2	50	196	159	237	193	264
1.33	75	227	175	275	212	306
1	100	252	187	306	226	341
0.5	200	330	219	400	265	446
0.5 + 20% CC	200 + 20% CC	396	262	481	318	536
0.5 + 25% CC	200 + 25% CC	413	273	501	332	558
0.2	500	479	270	581	328	647
0.1	1000	640	318	777	386	866

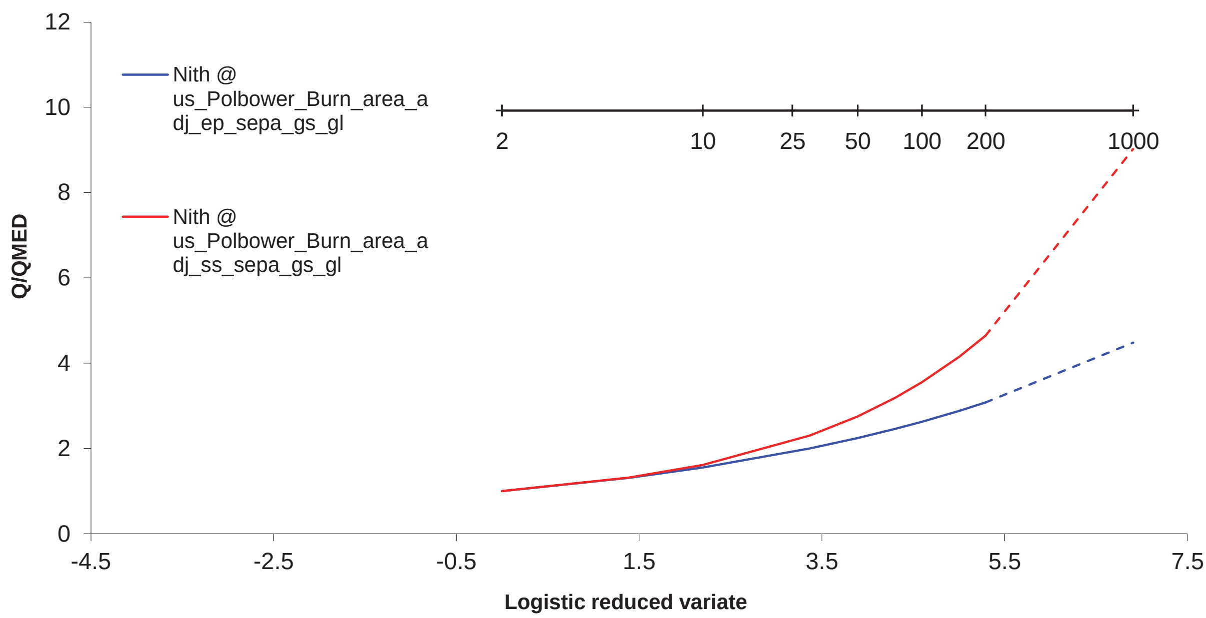
Table C-2: Summary of flood estimation methodologies considered: Polbower Burn

AP(%)	T (years)	Rainfall-runoff (FES). Adjusted Area plus FPS diversion area. (m^3/s)	Rainfall-runoff (FES). Adjusted area (m^3/s)	Statistical, Adjusted Area. Hall Bridge as donor (m^3/s)	Statistical, Adjusted Area, same growth curve as Hall Bridge (m^3/s)	Calculated from Nith Single Site, Adjusted Area (Nith Downstream - Nith Upstream) (m^3/s)
50	2	10	10	11	11	10
20	5	14	14	14	14	13
10	10	17	17	17	17	16
4	25	22	22	22	23	21
3.33	30	23	23	23	24	23
2	50	26	26	25	29	27
1.33	75	29	28	28	34	31
1	100	31	30	30	38	35
0.5	200	36	35	35	49	46
0.5 + 20% CC	200 + 20% CC	43	42	42	59	55
0.5 + 25% CC	200 + 25% CC	45	44	44	61	57
0.2	500	44	43	44	71	67
0.1	1000	52	51	51	95	89

C.2 Growth curves: River Nith at Hall Bridge

Figure A-1 shows the growth curves computed for single site analysis and enhanced single site analysis for the River Nith at Hall Bridge gauging station. It can be seen that the single site curve is steeper which is consistent with the understanding of historical flood response.

Figure A-1: Alternative growth curves for the River Nith at Hall Bridge



D Asset survey

D.1 River Nith

A full walkover survey was undertaken to identify flood defence assets. No flood defence assets or structures that would significantly influence flow paths on the River Nith were identified. However, other minor structures (low walls, pump stations, critical infrastructure) and other aspects were noted and are provided in the attached asset inspection survey plan.

Bridge and culvert structures are also provided in Appendix B.

D.2 Polbower Burn

The following structures have been identified along the Polbower Burn in Kirkconnel. These consist of flood defence structures (as defined under the Flood Prevention (Scotland) Act 1961), and other walls, that cannot be guaranteed to protect against flooding but may influence flood routes at lower flood flows.

Table D-1: Asset survey

Location: Brick wall downstream of main road	Ref: 01
 Photograph looking upstream	Bank: Left Height (m) (river side): 1m Height (m) (landward side): 1.35m Width (m): 0.2m Length (m): 25m Material: Brick Condition: Grade 3 (Fair) Part of FPS: No Comments: Missing coping stones Deterioration of brick Some cracking evident

Name: Stone wall downstream of road bridge	Ref: 02
 Photograph looking upstream	Bank: Left Height (m) (river side): 0.7-1.0m Height (m) (landward side): 1.05m Width (m): 0.2 - 0.4m Length (m): 24m Material: Stone and mortar Condition: Grade 5 (Very Poor) Part of FPS: No Comments: Holes in wall due to loss of mortar Listing slightly Missing mortar

<table>
<tr><th>Name: Extension of bridge parapet</th><th>Ref: 03</th></tr>
<tr><td>
Photograph looking downstream</td><td>Bank: Left
Height (m) (river side): 1.85m with further 1.72m drop to channel bend
Height (m) (landward side): 1.1m
Width (m): 0.5m
Length (m): 7m
Material: Stone and mortar
Condition: Grade 3/4 (Fair/Poor)
Part of FPS: Existed prior to FPS
Comments:
Wall on top of stone retaining wall
Degraded mortar
Signs of repair
Minor missing mortar
Possible scour at channel base</td></tr>
</table>

<table>
<tr><th>Name: Extension of bridge parapet upstream</th><th>Ref: 04</th></tr>
<tr><td>
Photograph looking upstream</td><td>Bank: Left
Height (m) (river side): 1.85m with further 2.50m drop to channel bend
Height (m) (landward side): 1.0-1.25m
Width (m): 0.4m
Length (m): 10.5m
Material: Stone and mortar
Condition: Wall - Grade 2 (Good)
Condition: Retaining wall - Grade 3 (Fair)
Part of FPS: Existed prior to FPS
Comments:
Wall on top of stone retaining wall
Localised damage at joint between stone and concrete retaining section of wall (Ref. 05).
Surface water drain through wall requires flap valve
Possible localised undercutting at channel base</td></tr>
</table>

Name: Concrete retaining section	Ref: 05
 Photograph looking upstream	Bank: Left Height (m) (river side): N/A Height (m) (landward side): 1.60m with further 0.94m drop to channel bend Width (m): N/A Length (m): 25m Material: Concrete Condition: Grade 2 (Good), although condition of base of structure behind rock armour unknown Part of FPS: Yes Comments: Rock armour placed on upstream end of wall Two culvert outfalls present (unflapped) Possible scour of base (reason for rock armour?)

Name: Gabion wall	Ref: 06
 Photograph looking upstream  End of gabion wall (U/S) showing bulging of basket	Bank: Left Height (m) (river side): 2m Height (m) (landward side): N/A Width (m): N/A Length (m): 20m Material: Gabion baskets (2 no. high) Condition: Grade 2 (Good) Part of FPS: No Comments: Slight bulging of baskets at upstream end Presence of tree growing through rock armour end downstream end

Name: Rock armour	Ref: 07
 Photograph looking upstream	Bank: Left Height (m) (river side): ~0.8m Height (m) (landward side): N/A Width (m): ~1m Length (m): ~7m Material: Granite rock armour Condition: Grade 2 (Good) Part of FPS: No (rock armour part of D&G maintenance operation in 2012) Comments: Non interlocking boulders Relatively short section on left bank Left bank floodplain currently being developed

Name: Gabion wall downstream of railway cuvlert	Ref: 08
 Photograph looking upstream	Bank: Right Height (m) (river side): N/A (level with floodplain) Height (m) (landward side): 2.3m Width (m): 1m Length (m): 37m Material: Gabion baskets (2 no. high) Condition: Grade 2 (Good) Part of FPS: No (rock armour part of D&G maintenance operation in 2012) Comments: Trees growing out of base Some undercutting at channel base

Name: Complex mix of defence types surrounding Kirkconnel Activity & Resource Centre	Ref: 09a
 Photograph looking upstream	Bank: Right Height (m) (river side): Variable: Concrete base = 0.75m Stone section = ~1m Wall = Variable Height (m) (landward side): 1.25m Width (m): ~4.5m from concrete retaining wall to rear wall Length (m): 25m Material: Variable (Concrete retaining wall, stone, earth and stone wall. Rock armour at base of structure. Condition: Grade 2-4 (Good-Poor) Part of FPS: No (rock armour part of D&G maintenance operation in 2012) Comments: Trees growing through structure Concrete section has rock armour at base Rock armour not interlocking Stone/earth section in poor condition Wall in poor condition (missing mortar)

Name: Complex mix of defence types surrounding Kirkconnel Activity & Resource Centre	Ref: 09b
 Photograph looking downstream	Bank: Right Height (m) (river side): Variable: Concrete base = ~1m Stone section = ~1m Wall = Variable Height (m) (landward side): 1.25m Width (m): ~4.5m from concrete retaining wall to rear wall Length (m): 1 Material: Variable (Concrete retaining wall, stone, earth and stone wall. Rock armour at base of structure. Condition: Grade 2-4 (Good-Poor) Part of FPS: No (rock armour part of D&G maintenance operation in 2012) Comments: Trees growing out of base Some undercutting at channel base Possible concrete benching located in short section Large loose rock boulder in channel bed Rock armour not interlocking

Name: Complex mix of defence types surrounding Kirkconnel Activity & Resource Centre	Ref: 09b
 Photograph looking downstream showing dislodged boulder in channel bed  Photograph looking downstream from right bank at the rear wall section  Grill - possible route of flood water through rear wall	

Name: Stone wall section around Kirkconnel Activity & Resource Centre	Ref: 10
 Photograph looking downstream	Bank: Right Height (m) (river side): 1.25m Height (m) (landward side): 1.25m Width (m): 1m Length (m): 6.5m Material: Stone with no mortar Condition: Grade 4 (Poor) Part of FPS: No Comments: Weak point in line of defence. Wall ties FPS section to upstream mixed wall/bank section. No obvious mortar in wall. Unlikely to withstand significant flood flows. Placed at top of bank.

Name: Gabion and concrete block defence upstream of road bridge	Ref: 11
 Photograph looking upstream  Photograph looking upstream  Photograph looking downstream - tie in point between gabion wall and existing concrete/stone wall section	Bank: Right Height (m) (river side): 1.8 - 2.7m Height (m) (landward side): 1m Width (m): 1.8m Length (m): 72m Material: Gabion basket with infill and concrete block wall (internal geo-membrane to provide water proofing) Condition: Grade 2 (Good) Part of FPS: No Comments: Slight bulging of gabion baskets at U/S end Rock armour placed along upper section of wall Some minor erosion to bed material on bend Presence of tree upstream of bridge Pipe exists gabion wall

Name: Gabion and concrete block defence upstream of road bridge	Ref: 11
 Photograph looking upstream at rear wall detail  Photograph looking from left bank to right bank - pipe through gabion	

Name: Stone wall downstream of road bridge	Ref: 12
 Photograph looking downstream	Bank: Right Height (m) (river side): 1.4m Height (m) (landward side): 0.6m Width (m): 0.2-0.35m Length (m): 69m Material: Stone Condition: Grade 3 (fair), Grade 5 (Very poor) downstream Part of FPS: No Comments: Wall is in good condition downstream of bridge, but deteriorates along park

Name: Stone wall downstream of footbridge bridge	Ref: 13
 Photograph looking from right bank to left bank	Bank: Right Height (m) (river side): 1.0m Height (m) (landward side): N/A Width (m): Unknown Length (m): 33m Material: Concrete Condition: Grade 3 (fair) Part of FPS: No Comments: Bank protection only. Does not provide any flood defence purpose. Reason for wall unclear.

Name: Stone wall in three clear sections from Riverside Terrace to downstream of footbridge	Ref: 14
 Photograph looking downstream to right bank	Bank: Right Height (m) (river side): 0.5-1.2m Height (m) (landward side): N/A Width (m): 0.3m Length (m): 70m, 69m, 118m. Material: Stone Condition: Grade 3 (fair), locally Grade 5 (Very poor) Part of FPS: No Comments: Bank protection only. Does not provide any flood defence purpose. Historical retaining wall.

E Appendix E - Calibration map

F Appendix F - Flood maps

G Appendix G - Model results

G.1 Current conditions water surface

Table G-1: Current conditions model results for the 2 year to 200 flood flow on the Polbower Burn

label	N2_P2	N2_P5	N2_P10	N2_P25	N2_P50	N2_P100	N2_P200
POL_365	156.97	157.16	157.29	157.47	157.63	157.78	157.95
POL_328	156.58	156.82	156.98	157.20	157.37	157.54	157.75
POL_328_BUS	156.54	156.77	156.92	157.14	157.31	157.47	157.69
POL_314	156.53	156.76	156.92	157.13	157.30	157.46	157.65
POL_314_WUS	156.53	156.75	156.91	157.12	157.29	157.45	157.64
POL_314_WDS	155.77	156.03	156.16	156.35	156.50	156.63	156.78
POL_274	155.43	155.67	155.81	156.00	156.15	156.28	156.41
POL_231	155.04	155.28	155.42	155.61	155.76	155.91	156.12
POL_199	154.81	155.04	155.14	155.30	155.44	155.57	155.72
POL_168	154.51	154.71	154.85	155.04	155.18	155.31	155.45
POL_168_BUS	154.43	154.62	154.76	154.95	155.09	155.22	155.35
POL_155	154.37	154.56	154.68	154.85	154.98	155.11	155.24
POL_119	153.91	154.15	154.27	154.42	154.54	154.65	154.77
POL_80	153.55	153.72	153.82	153.95	154.05	154.13	154.23
POL_28	153.43	153.54	153.63	153.72	153.80	153.86	153.92
POL_28_JU	153.34	153.39	153.42	153.47	153.52	153.56	153.62
NITH_1011_JU	153.34	153.39	153.42	153.47	153.52	153.56	153.62
NITH_1011	153.34	153.39	153.42	153.47	153.52	153.56	153.62
NITH_879	152.81	152.86	152.90	152.95	153.00	153.06	153.12
NITH_778	152.54	152.59	152.63	152.69	152.74	152.78	152.84
NITH_778_BUS	152.55	152.60	152.64	152.70	152.75	152.80	152.86
NITH_768	152.53	152.58	152.62	152.68	152.73	152.77	152.83
NITH_707	152.34	152.39	152.43	152.48	152.53	152.57	152.63
NITH_707_BUS	152.36	152.41	152.44	152.50	152.55	152.59	152.65
NITH_707_BDS	152.28	152.33	152.36	152.41	152.45	152.49	152.54
NITH_634	151.88	151.93	151.96	152.01	152.05	152.08	152.13
NITH_545	151.62	151.67	151.71	151.76	151.80	151.85	151.90
NITH_411	150.79	150.84	150.87	150.92	150.96	151.00	151.05
NITH_297	150.41	150.45	150.48	150.53	150.57	150.61	150.66
NITH_297_BDS	150.30	150.34	150.37	150.41	150.45	150.48	150.53
NITH_128	149.91	149.94	149.97	150.03	150.08	150.12	150.17
NITH_0	149.33	149.38	149.41	149.46	149.50	149.54	149.59
NITH_1116	153.69	153.71	153.72	153.74	153.76	153.78	153.82
NITH_1044	153.49	153.53	153.56	153.60	153.64	153.68	153.73
NITH_297_BUS	150.34	150.39	150.42	150.46	150.50	150.54	150.59

Table G-2: Current conditions model results for the 2 year to 200 flood flow on the River Nith

label	N2_P2	N5_P2	N10_P2	N25_P2	N50_P2	N100_P2	N200_P2
POL_365	156.97	156.97	156.97	156.97	156.97	156.97	156.97
POL_328	156.58	156.58	156.58	156.58	156.58	156.58	156.58
POL_328_BUS	156.54	156.54	156.54	156.54	156.54	156.54	156.54
POL_314	156.53	156.53	156.53	156.53	156.53	156.53	156.53
POL_314_WUS	156.53	156.53	156.53	156.53	156.53	156.53	156.53
POL_314_WDS	155.77	155.77	155.77	155.77	155.77	155.78	155.88
POL_274	155.43	155.43	155.43	155.43	155.43	155.51	155.78
POL_231	155.04	155.04	155.04	155.05	155.17	155.36	155.73
POL_199	154.81	154.81	154.81	154.83	155.08	155.34	155.71
POL_168	154.51	154.51	154.53	154.56	155.04	155.30	155.71
POL_168_BUS	154.43	154.43	154.44	154.50	155.03	155.30	155.71
POL_155	154.37	154.37	154.39	154.45	155.01	155.30	155.70
POL_119	153.91	153.92	154.04	154.35	155.00	155.24	155.69
POL_80	153.55	153.69	153.93	154.32	155.01	155.22	155.54
POL_28	153.43	153.67	153.91	154.34	154.70	155.12	155.53
POL_28_JU	153.34	153.63	153.89	154.34	154.80	155.14	155.56
NITH_1011_JU	153.34	153.63	153.89	154.34	154.80	155.14	155.56
NITH_1011	153.34	153.63	153.89	154.34	154.80	155.14	155.56
NITH_879	152.81	153.13	153.42	153.99	154.43	154.81	155.19
NITH_778	152.54	152.86	153.14	153.57	153.90	154.39	154.86
NITH_778_BUS	152.55	152.88	153.16	153.56	153.83	154.29	154.74
NITH_768	152.53	152.85	153.13	153.51	153.78	154.22	154.67
NITH_707	152.34	152.64	152.90	153.33	153.70	154.20	154.64
NITH_707_BUS	152.36	152.67	152.94	153.37	153.76	154.37	154.89
NITH_707_BDS	152.28	152.56	152.79	153.14	153.51	153.90	154.24
NITH_634	151.88	152.15	152.35	152.71	152.97	153.38	153.94
NITH_545	151.62	151.92	152.17	152.55	152.79	153.01	153.31
NITH_411	150.79	151.07	151.29	151.67	152.10	152.55	152.91
NITH_297	150.41	150.67	150.86	151.15	151.44	151.82	152.37
NITH_297_BDS	150.30	150.54	150.69	150.91	151.16	151.58	151.98
NITH_128	149.91	150.19	150.45	150.82	151.10	151.44	151.76
NITH_0	149.33	149.60	149.82	150.16	150.42	150.71	151.00
NITH_1116	153.69	154.01	154.27	154.64	155.05	155.35	155.72
NITH_1044	153.49	153.84	154.12	154.55	155.00	155.34	155.76
NITH_297_BUS	150.34	150.60	150.76	151.01	151.30	151.73	152.24

Table G-3: Current conditions model results for the 200 year with climate change to the 100 year flow for flood flows on the River Nith and Polbower Burn.

label	N2_P200cc	N2_P500	N2_P1000	N200cc_P2	N500_P2	N1000_P2	N200_P200
POL_365	158.83	158.22	158.65	156.97	156.99	157.27	157.95
POL_328	158.74	158.12	158.57	156.58	156.64	157.26	157.75
POL_328_BUS	158.71	158.07	158.53	156.54	156.61	157.24	157.69
POL_314	158.32	157.92	158.22	156.53	156.61	157.24	157.65
POL_314_WUS	158.31	157.91	158.21	156.53	156.60	157.24	157.64
POL_314_WDS	157.28	156.99	157.20	156.22	156.53	157.22	156.80
POL_274	156.85	156.62	156.75	156.20	156.52	157.23	156.53
POL_231	156.75	156.40	156.72	156.18	156.52	157.17	156.49
POL_199	156.61	155.93	156.16	156.17	156.51	157.16	156.35
POL_168	156.55	155.62	155.78	156.17	156.52	157.17	156.32
POL_168_BUS	156.52	155.51	155.67	156.18	156.52	157.18	156.30
POL_155	155.66	155.39	155.57	156.15	156.51	157.19	155.90
POL_119	155.15	154.93	155.10	155.98	156.31	156.74	155.85
POL_80	154.44	154.34	154.42	156.03	156.17	156.90	155.75
POL_28	154.12	154.00	154.09	155.91	156.19	156.73	155.66
POL_28_JU	153.84	153.70	153.80	155.95	156.23	156.78	155.69
NITH_1011_JU	153.84	153.70	153.80	155.95	156.23	156.78	155.69
NITH_1011	153.84	153.70	153.80	155.95	156.23	156.78	155.69
NITH_879	153.36	153.22	153.32	155.54	155.79	156.33	155.29
NITH_778	153.07	152.93	153.03	155.34	155.70	156.39	154.97
NITH_778_BUS	153.08	152.95	153.05	155.20	155.55	156.30	154.84
NITH_768	153.06	152.92	153.02	155.05	155.29	155.85	154.77
NITH_707	152.83	152.71	152.80	154.95	155.07	155.50	154.73
NITH_707_BUS	152.87	152.74	152.83	155.26	155.44	155.94	154.99
NITH_707_BDS	152.72	152.62	152.70	154.52	154.73	155.25	154.31
NITH_634	152.30	152.20	152.27	154.36	154.63	155.21	154.06
NITH_545	152.10	151.98	152.07	153.67	154.00	154.60	153.39
NITH_411	151.23	151.13	151.20	153.36	153.73	154.32	153.00
NITH_297	150.81	150.73	150.79	153.04	153.58	154.22	152.55
NITH_297_BDS	150.65	150.58	150.64	152.23	152.58	153.14	152.05
NITH_128	150.37	150.25	150.34	151.98	152.22	152.66	151.82
NITH_0	149.76	149.66	149.74	151.28	151.45	151.81	151.07
NITH_1116	154.02	153.89	153.98	156.07	156.29	156.79	155.82
NITH_1044	153.93	153.81	153.90	154.55	155.00	155.34	155.87
NITH_297_BUS	150.73	150.65	150.71	151.01	151.30	151.73	152.49

G.2 Option 2 - Bridge removal water surface

Table G-4: Option 2 - Removal of Old Road Bridge model results for the 25 year to 200 flood flow on the River Nith

label	N25_P2	N50_P2	N100_P2	N200_P2
POL_365	156.97	157.16	157.29	157.47
POL_328	156.58	156.82	156.98	157.20
POL_328_BUS	156.54	156.77	156.92	157.14
POL_314	156.53	156.76	156.92	157.13
POL_314_WUS	156.53	156.75	156.91	157.12
POL_314_WDS	155.77	156.03	156.16	156.35
POL_274	155.43	155.67	155.81	156.00
POL_231	155.04	155.28	155.42	155.61
POL_199	154.81	155.04	155.14	155.30
POL_168	154.51	154.71	154.85	155.04
POL_168_BUS	154.43	154.62	154.76	154.95
POL_155	154.37	154.56	154.68	154.85
POL_119	153.91	154.15	154.27	154.42
POL_80	153.55	153.72	153.82	153.95
POL_28	153.43	153.54	153.63	153.72
POL_28_JU	153.34	153.39	153.42	153.47
NITH_1011_JU	153.34	153.39	153.42	153.47
NITH_1011	153.34	153.39	153.42	153.47
NITH_879	152.81	152.86	152.90	152.95
NITH_778	152.54	152.59	152.63	152.69
NITH_778_BUS	152.55	152.60	152.64	152.70
NITH_768	152.53	152.58	152.62	152.68
NITH_707	152.34	152.39	152.43	152.48
NITH_707_BUS	152.36	152.41	152.44	152.50
NITH_707_BDS	152.28	152.33	152.36	152.41
NITH_634	151.88	151.93	151.96	152.01
NITH_545	151.62	151.67	151.71	151.76
NITH_411	150.79	150.84	150.87	150.92
NITH_297	150.41	150.45	150.48	150.53
NITH_297_BDS	150.30	150.34	150.37	150.41
NITH_128	149.91	149.94	149.97	150.03
NITH_0	149.33	149.38	149.41	149.46
NITH_1116	153.69	153.71	153.72	153.74
NITH_1044	153.49	153.53	153.56	153.60
NITH_297_BUS	150.34	150.39	150.42	150.46

G.3 Option 3 - Direct defences

Table G-4: Option 3 - Direct defence model results for the 25 year to 500 flood return period event.

label	25 year	50 year	100 year	200 year	200 year +CC	500 year
POL_365	157.47	157.63	157.78	157.95	158.33	159.21
POL_328	159.21	157.37	157.20	157.75	158.33	159.21
POL_328_BUS	159.21	157.31	157.14	157.69	158.32	159.21
POL_314	159.20	157.30	157.13	157.65	158.32	159.20
POL_314_WUS	159.20	157.29	157.12	157.64	158.32	159.20
POL_314_WDS	159.19	156.50	156.35	156.90	158.31	159.19
POL_274	159.20	156.15	156.00	156.90	158.31	159.20
POL_231	159.20	155.76	155.61	156.89	158.31	159.20
POL_199	159.19	155.44	155.30	156.89	158.31	159.19
POL_168	159.19	155.18	155.04	156.89	158.31	159.19
POL_168_BUS	159.19	155.09	154.95	156.89	158.31	159.19
POL_155	159.19	154.98	154.85	156.86	158.30	159.19
POL_119	159.19	154.76	154.42	156.86	158.30	159.19
POL_80	159.19	154.75	154.34	156.86	158.30	159.19
POL_28	159.19	154.75	154.34	156.86	158.30	159.19
POL_28_JU	159.19	154.75	154.34	156.86	158.30	159.19
NITH_1011_JU	159.19	154.75	154.34	156.86	158.30	159.19
NITH_1011	159.19	154.75	154.34	156.86	158.30	159.19
NITH_879	158.99	154.23	153.85	156.59	158.09	158.99
NITH_778	158.99	154.01	153.60	156.56	158.08	158.99
NITH_778_BUS	158.95	153.98	153.60	156.50	158.03	158.95
NITH_768	157.75	153.92	153.56	155.84	157.02	157.75
NITH_707	157.70	153.66	153.32	155.74	156.95	157.70
NITH_707_BUS	157.76	153.74	153.37	155.80	157.02	157.76
NITH_707_BDS	155.94	153.41	153.13	154.33	155.30	155.94
NITH_634	155.98	153.02	152.71	154.24	155.32	155.98
NITH_545	156.11	152.93	152.56	154.32	155.43	156.11
NITH_411	155.69	152.07	151.70	153.77	155.00	155.69
NITH_297	155.73	151.57	151.26	153.73	155.02	155.73
NITH_297_BDS	153.11	151.29	151.03	152.36	152.79	153.11
NITH_128	152.96	151.15	150.82	152.08	152.59	152.96
NITH_0	152.23	150.52	150.20	151.39	151.87	152.23
NITH_1116	159.45	155.20	154.77	157.16	158.56	159.45
NITH_1044	159.39	155.05	154.61	157.08	158.49	159.39
NITH_297_BUS	155.71	151.43	151.14	153.70	155.00	155.71

H Appendix H - Cost of options

H.1 Option 2 - Bridge replacement

Table H-1: Deck removal

Unit cost (m3)	Deck depth (m)	Deck width (m)	Deck length (m)	Deck volume (m3)	Element cost (£)	Contingency	Total cost (£)
6.35	1.2	3	25	90	571.5	2.1	1,200

Table H-2: Pier removal

Unit cost (m3)	Pier depth (m)	Pier width (m)	Pier length (m)	Pier volume (m3)	Element cost (£)	Contingency	Total cost (£)
150	3.022	2.4	5	36.264	5439.6	2.1	11,423

Table H-3: Service removal

Service removal unit cost	source	Total cost (£)
150,000	Dumfries and Galloways Council	150,000

Table H-4: New bridge construction

Unit cost (m3)	Deck width (m)	Deck length (m)	Deck area (m2)	Element cost (£)	Contingency	Total cost (£)
2512.5	3	25	75	188,438	1	188,438

Table H-5: Total bridge replacement cost

Item	Total cost (£)
Bridge replacement	351,061

H.2 Option 3 - Direct defences cost

Table H-6: Wall and embankment costs per section for the 500 year event.

	Wall			Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	5.38	2,686,858	125	6.08	450,916
2	56	4.47	234,696	0	0.00	0
3	195	3.83	817,245	0	0.00	0
4	182	3.54	762,762	208	4.55	565,761

Table H-7: Totalled Direct defence costs for the 500 year event with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	5.64	3,137,774	5,020,438
2	55	4.26	234,696	375,514
3	194	5.21	817,245	1,307,592
4	389	5.46	1,328,523	2,125,637
Sum	968	4.58	5,518,238	8,829,181

Table H-8: Wall and embankment costs per section for the 200 year event.

	Wall			Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	2.99	863,346	125	3.71	279,106
2	56	1.93	190,792	0	0.00	0
3	195	2.87	817,245	0	0.00	0
4	182	2.83	762,762	208	2.68	340,185

Table H-9: Totalled Direct defence costs for the 200 year event with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	3.26	1,142,452	1,827,923
2	55	1.93	190,792	305,267
3	194	2.87	817,245	1,307,592
4	389	3.17	1,102,947	1,764,715
Sum	968	2.58	3,253,436	5,205,498

Table H-10: Wall and embankment costs per section for the 200 year event accounting for climate change.

	Wall			Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	4.47	863,346	125	5.18	385,672
2	56	3.78	234,696	0	0.00	0
3	195	3.14	817,245	0	0.00	0
4	182	2.86	762,762	208	3.87	483,733

Table H-11: Totalled Direct defence costs for the 200 year event accounting for climate change with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	4.74	1,249,018	1,998,429
2	55	3.78	234,696	375,514
3	194	3.14	817,245	1,307,592
4	389	3.40	1,246,495	1,994,392
Sum	968	3.83	3,547,454	5,675,926

Table H-12: Wall and embankment costs per section for the 100 year event.

Wall				Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	1.39	701,842	125	2.10	162,392
2	56	1.67	190,792	0	0.00	0
3	195	1.14	326,430	0	0.00	0
4	182	0.88	304,668	208	1.45	191,810

Table H-13: Totalled Direct defence costs for the 100 year event with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	1.66	864,234	1,382,774
2	55	1.67	190,792	305,267
3	194	1.14	326,430	522,288
4	389	1.19	496,478	794,365
Sum	968	1.37	1,877,934	3,004,694

Table H-14: Wall and embankment costs per section for the 50 year event.

Wall				Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	0.78	344,844	125	1.43	113,821
2	56	0.97	93,744	0	0.00	0
3	195	0.69	326,430	0	0.00	0
4	182	0.47	304,668	208	0.96	132,702

Table H-15: Totalled Direct defence costs for the 50 year event with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	1.02	458,665	733,864
2	55	0.97	93,744	149,990
3	194	0.69	326,430	522,288
4	389	0.73	437,370	699,792
Sum	968	0.84	1,316,209	2,105,934

Table H-14: Wall and embankment costs per section for the 25 year event.

Wall				Embankment		
Section	Length (m)	Avg height (m)	Cost (£)	Length (m)	Avg height (m)	Cost (£)
1	206	0.47	344,844	125	1.03	84,823
2	56	0.64	93,744	0	0.00	0
3	195	0.40	326,430	0	0.00	0
4	182	0.28	304,668	208	0.61	90,482

Table H-15: Totalled Direct defence costs for the 25 year event with optimism bias.

Section	Length (m)	Average height (m)	Cost (£)	Optimism bias (£)
1	330	0.68	429,667	687,467
2	55	0.64	93,744	149,990
3	194	0.40	326,430	522,288
4	389	0.46	395,150	632,240
Sum	968	0.53	1,244,991	1,991,986

JBA consulting

Offices at

Coleshill

Doncaster

Dublin

Edinburgh

Exeter

Haywards Heath

Limerick

Newcastle upon Tyne

Newport

Saltaire

Skipton

Tadcaster

Thirsk

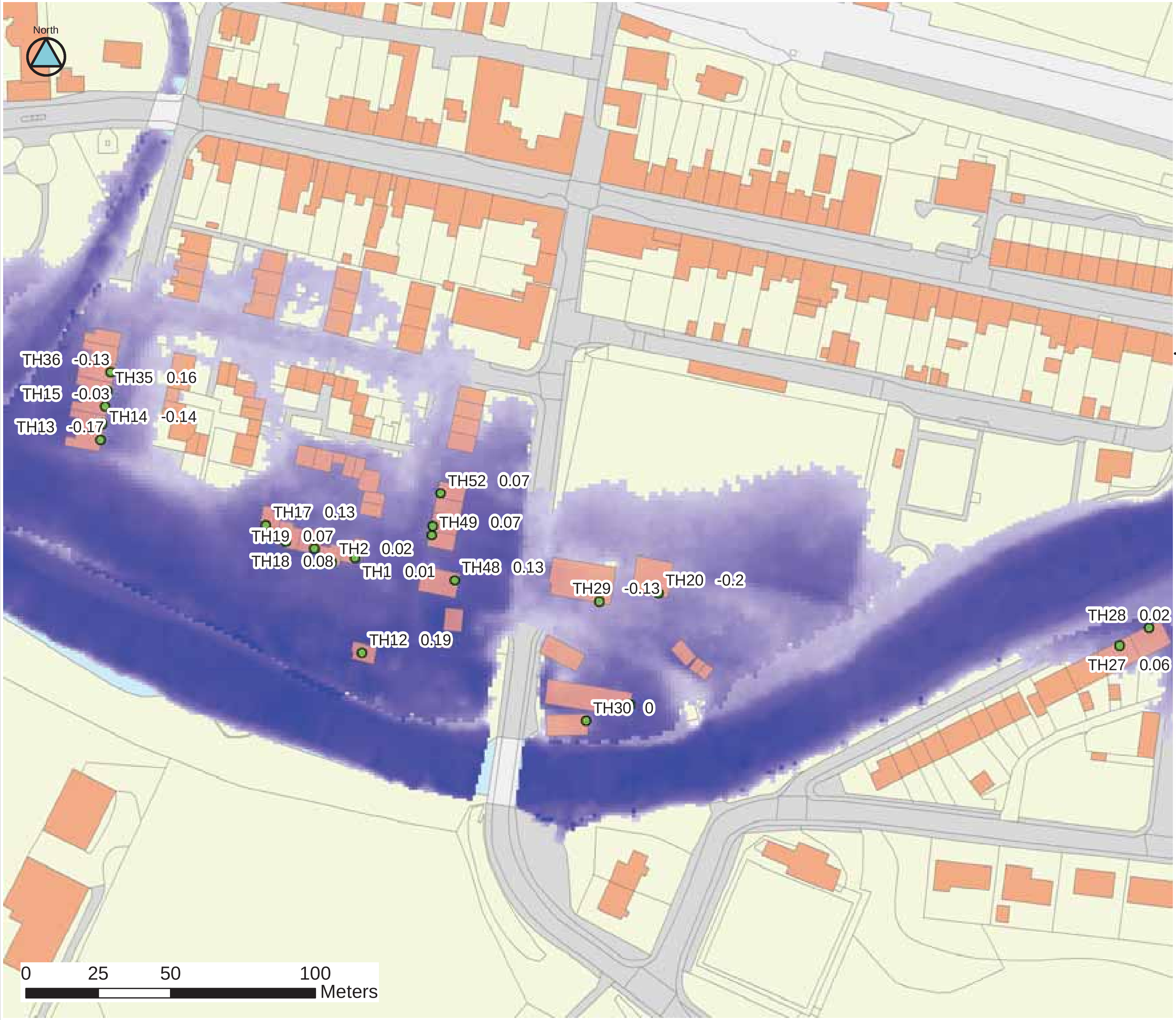
Wallingford

Warrington

Registered Office
South Barn
Broughton Hall
SKIPTON
North Yorkshire
BD23 3AE

t:+44(0)1756 799919
e:info@jbaconsulting.com

Jeremy Benn Associates Ltd
Registered in England
3246693



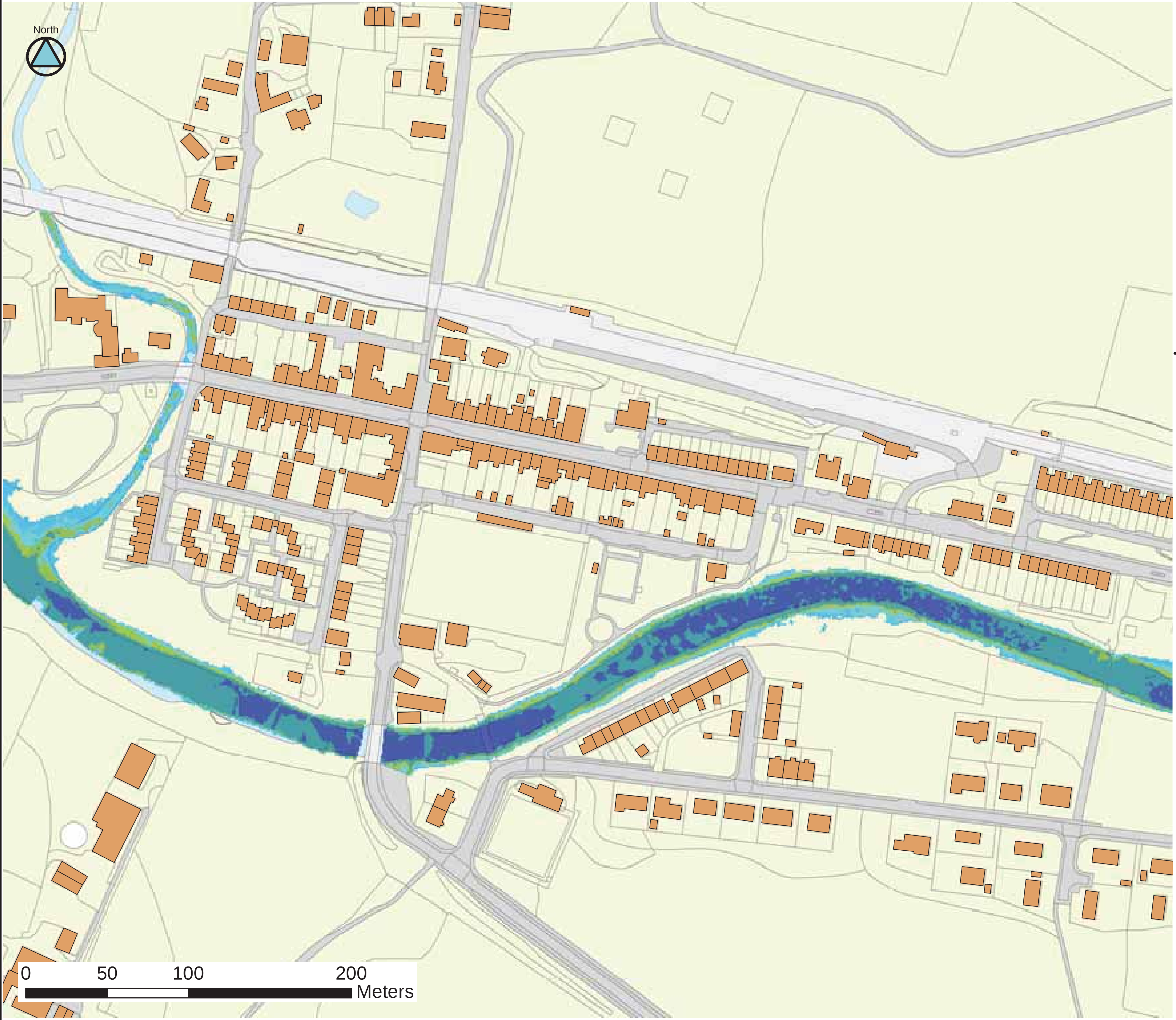
NOTE
THIS FIGURE DISPLAYS THE PROPERTY REFERENCE (TH XX) FOLLOWED BY THE DIFFERENCE IN PREDICTED FLOOD LEVEL

Legend

- Properties with flood data

December 2013 flood extent

MODEL CALIBRATION FOR THE DECEMBER 2013 FLOOD EVENT

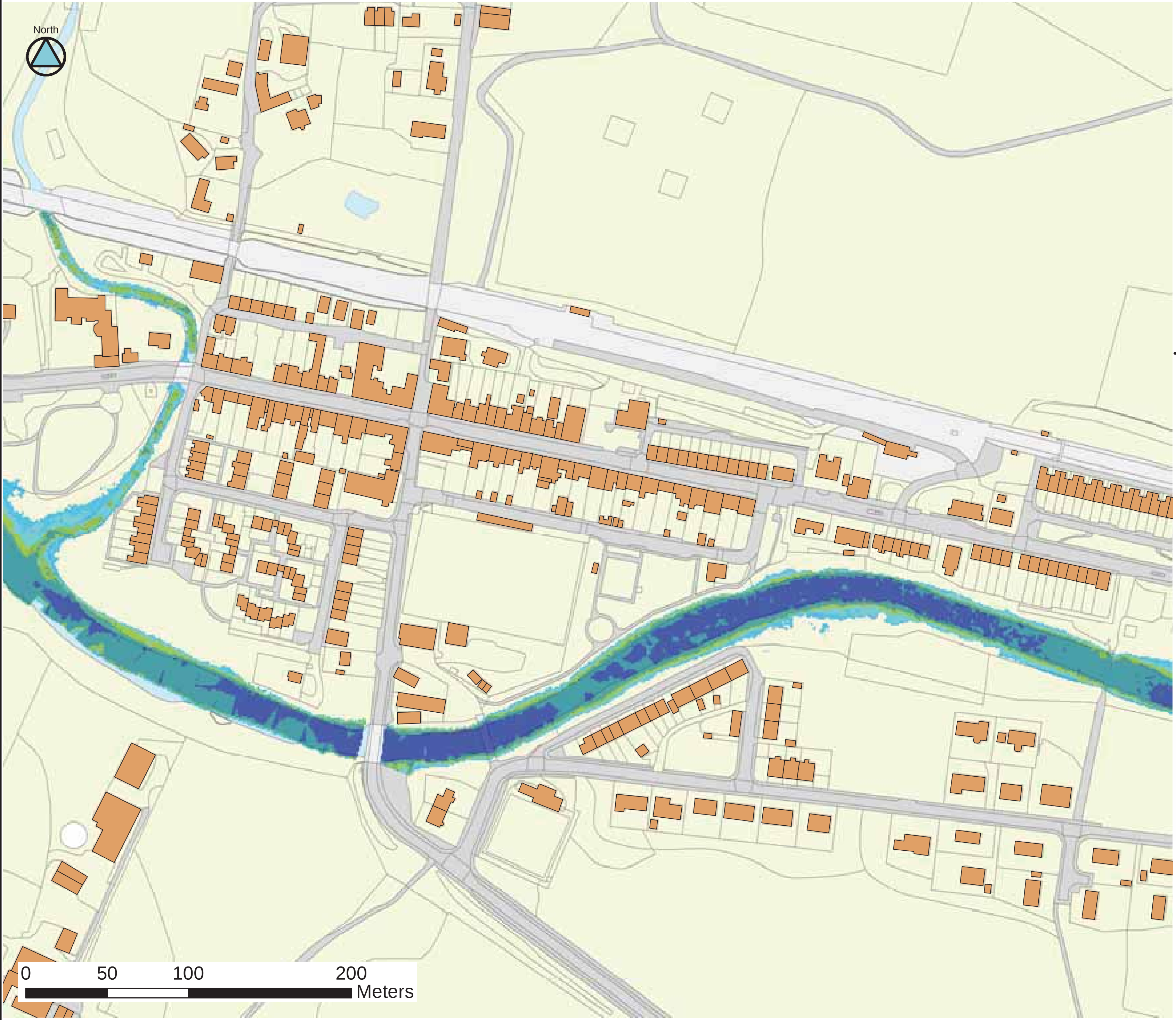


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 1
FLOOD DEPTH MAP FOR THE 2 YEAR (50% AP) FLOW EVENT ON THE POLBOWER BURN

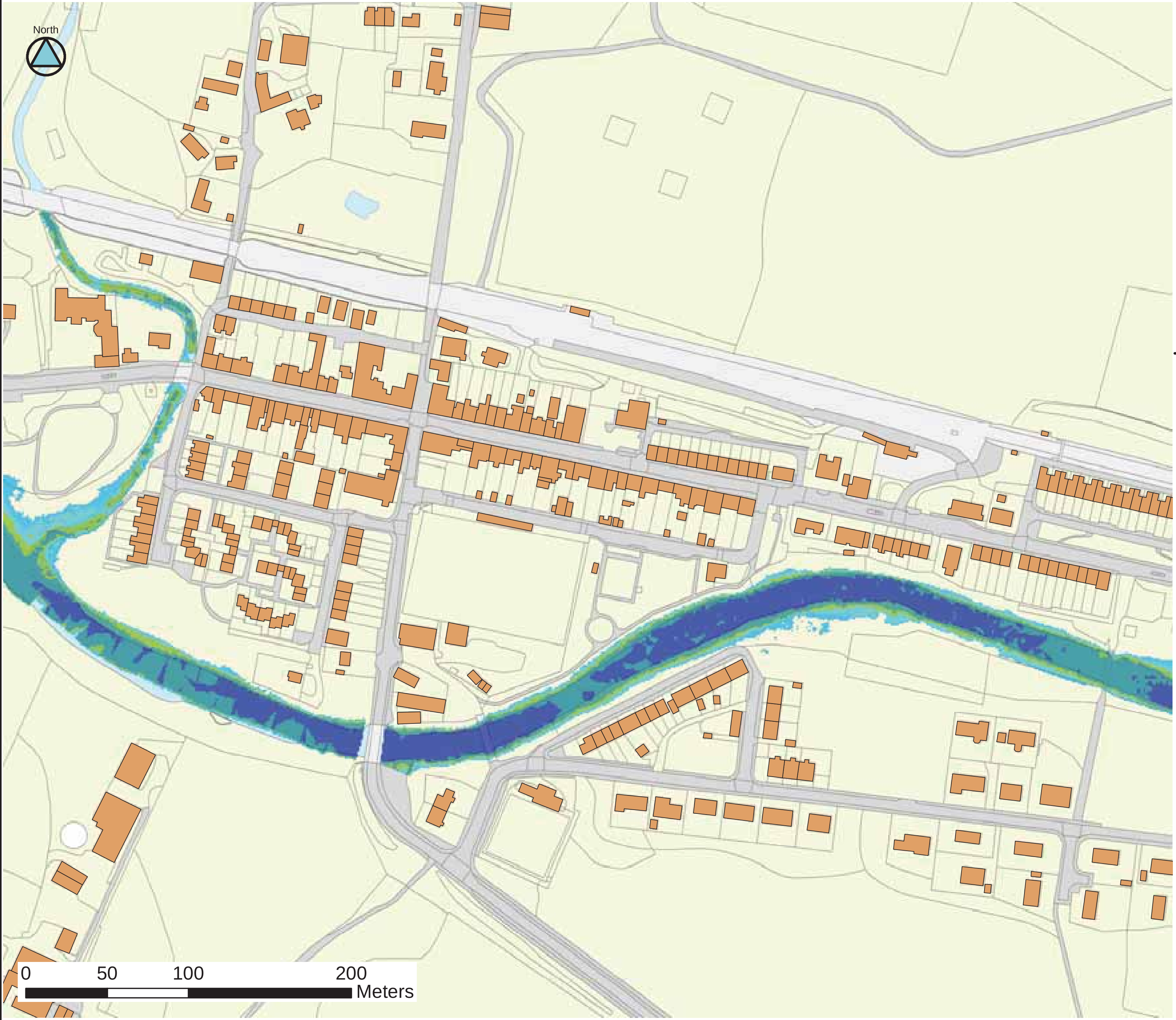


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 2
FLOOD DEPTH MAP FOR THE 5 YEAR (20% AP) FLOW EVENT ON THE POLBOWER BURN



Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

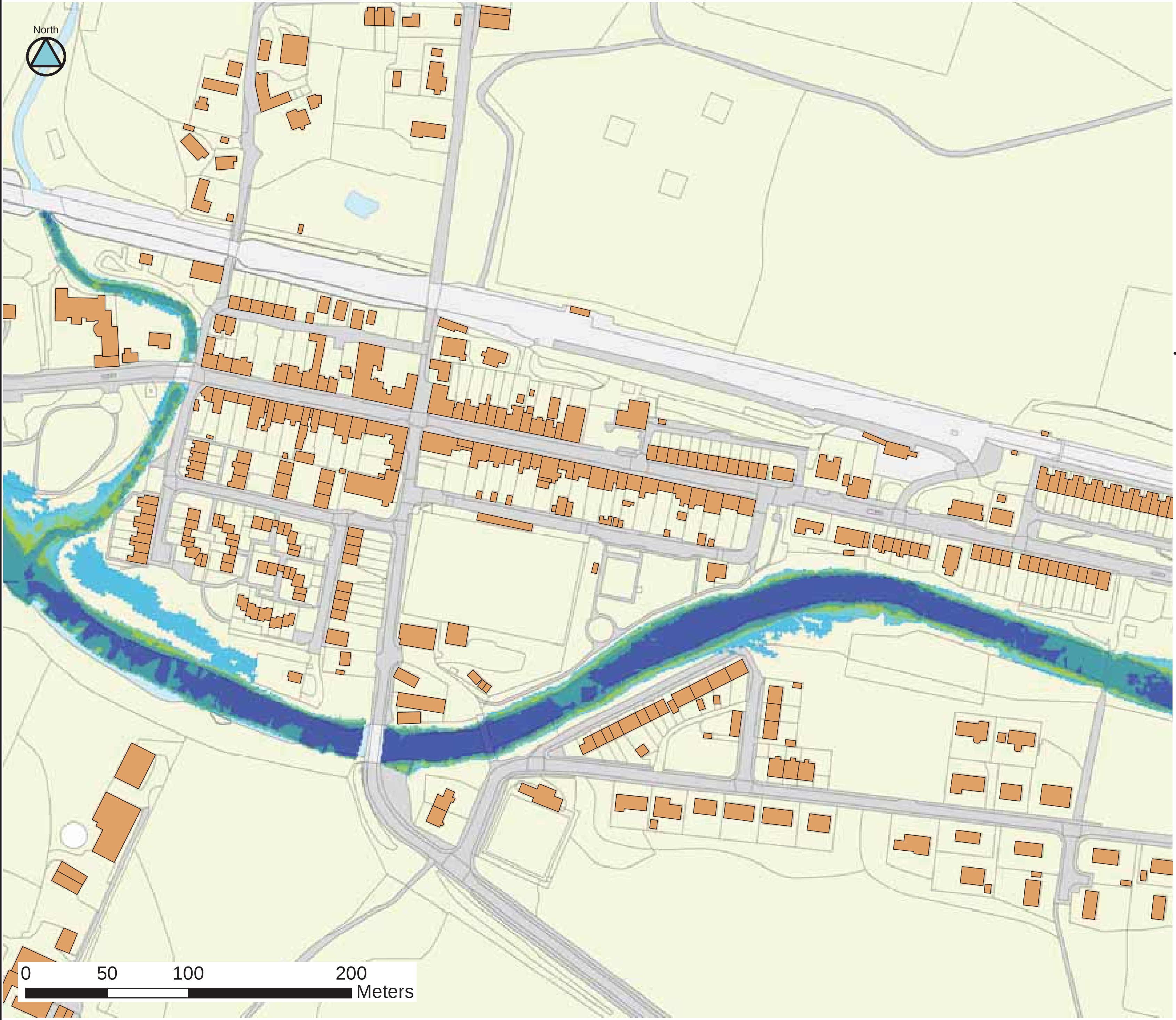
FIGURE 3
FLOOD DEPTH MAP FOR THE 10 YEAR (10% AP) FLOW EVENT ON THE POLBOWER BURN

Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 4
FLOOD DEPTH MAP FOR THE 25 YEAR (4% AP) FLOW EVENT ON THE POLBOWER BURN

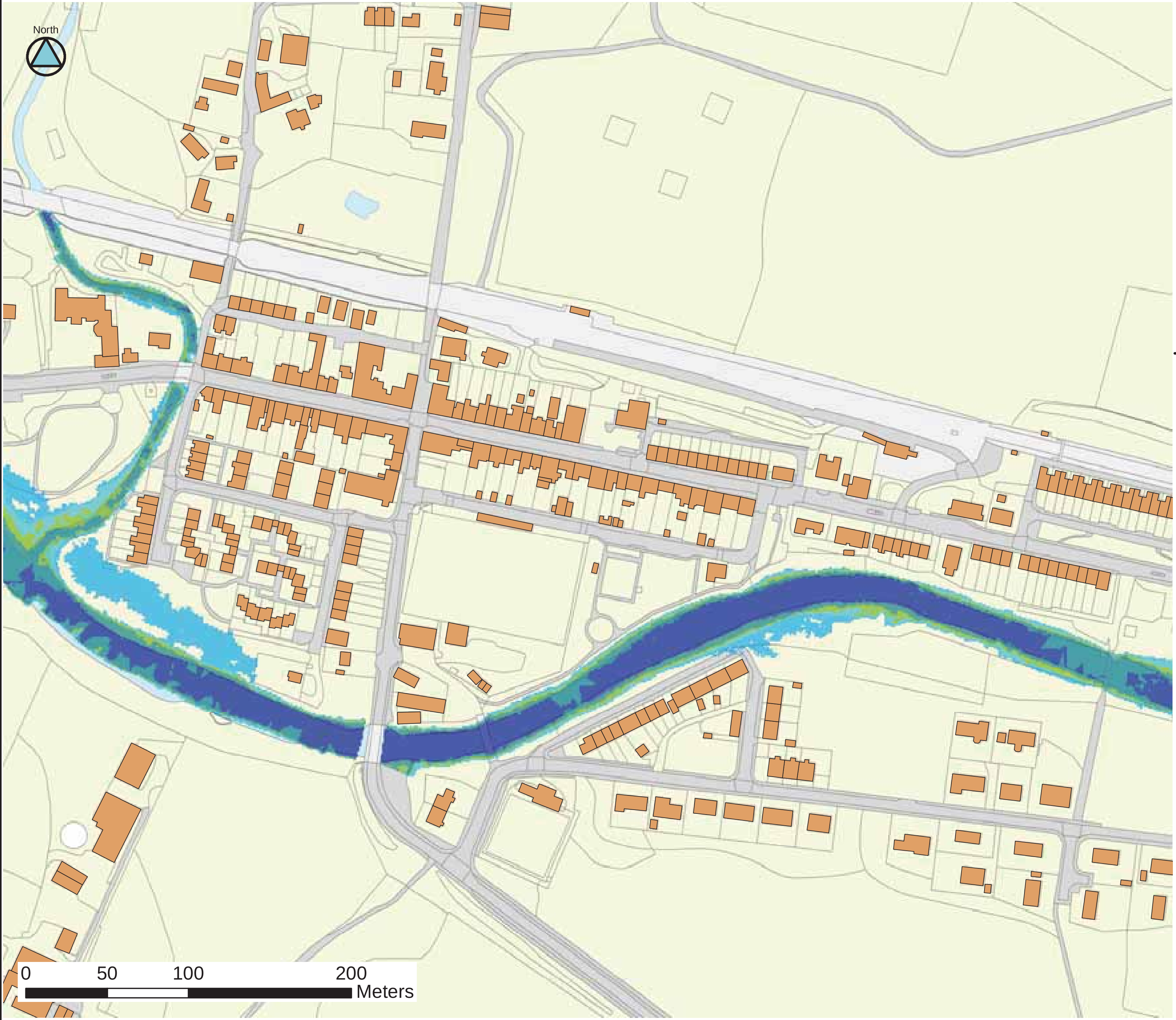


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 5
FLOOD DEPTH MAP FOR THE 50 YEAR (2% AP) FLOW EVENT ON THE POLBOWER BURN

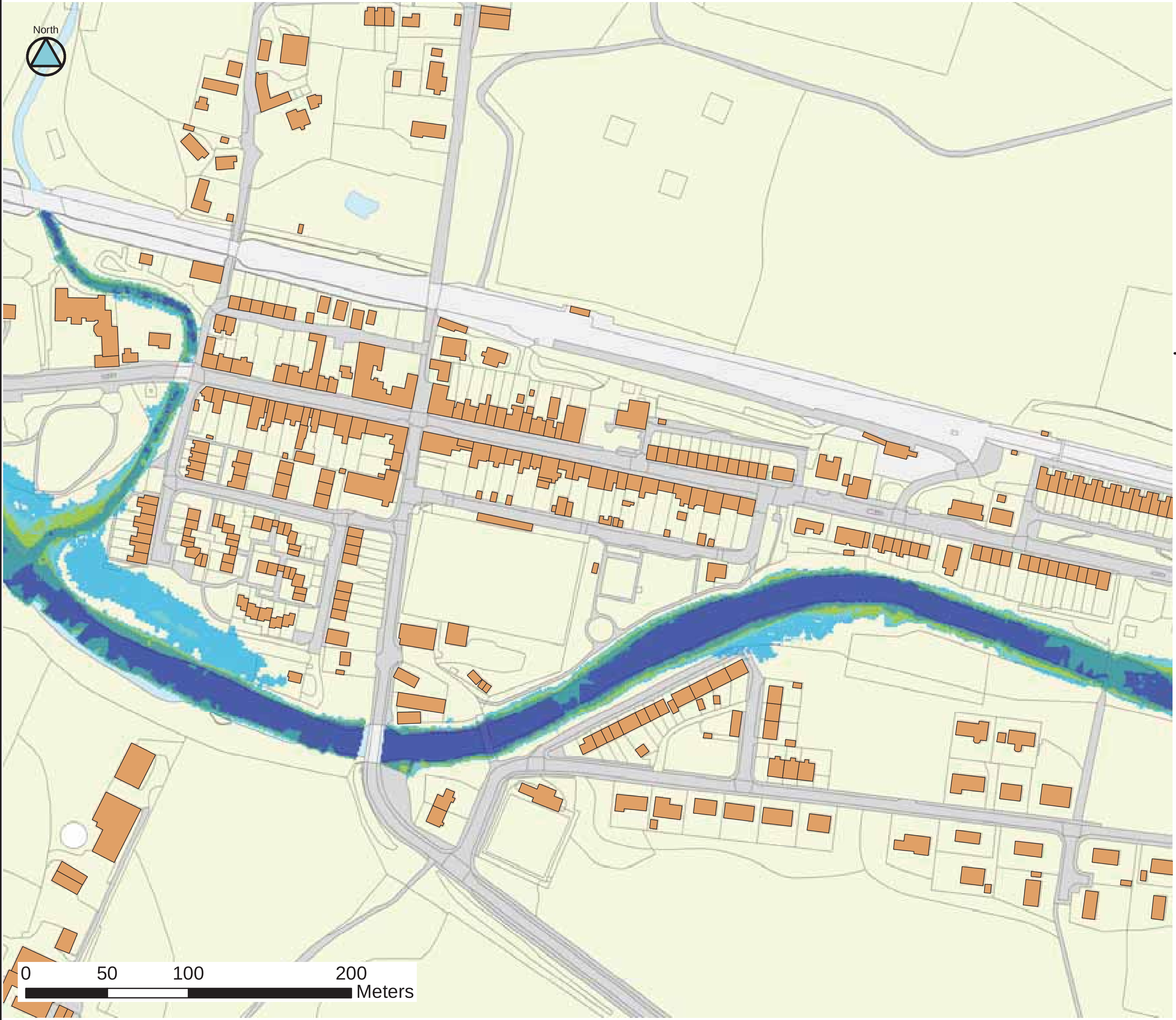


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 6
FLOOD DEPTH MAP FOR THE 100 YEAR (1% AP) FLOW EVENT ON THE POLBOWER BURN



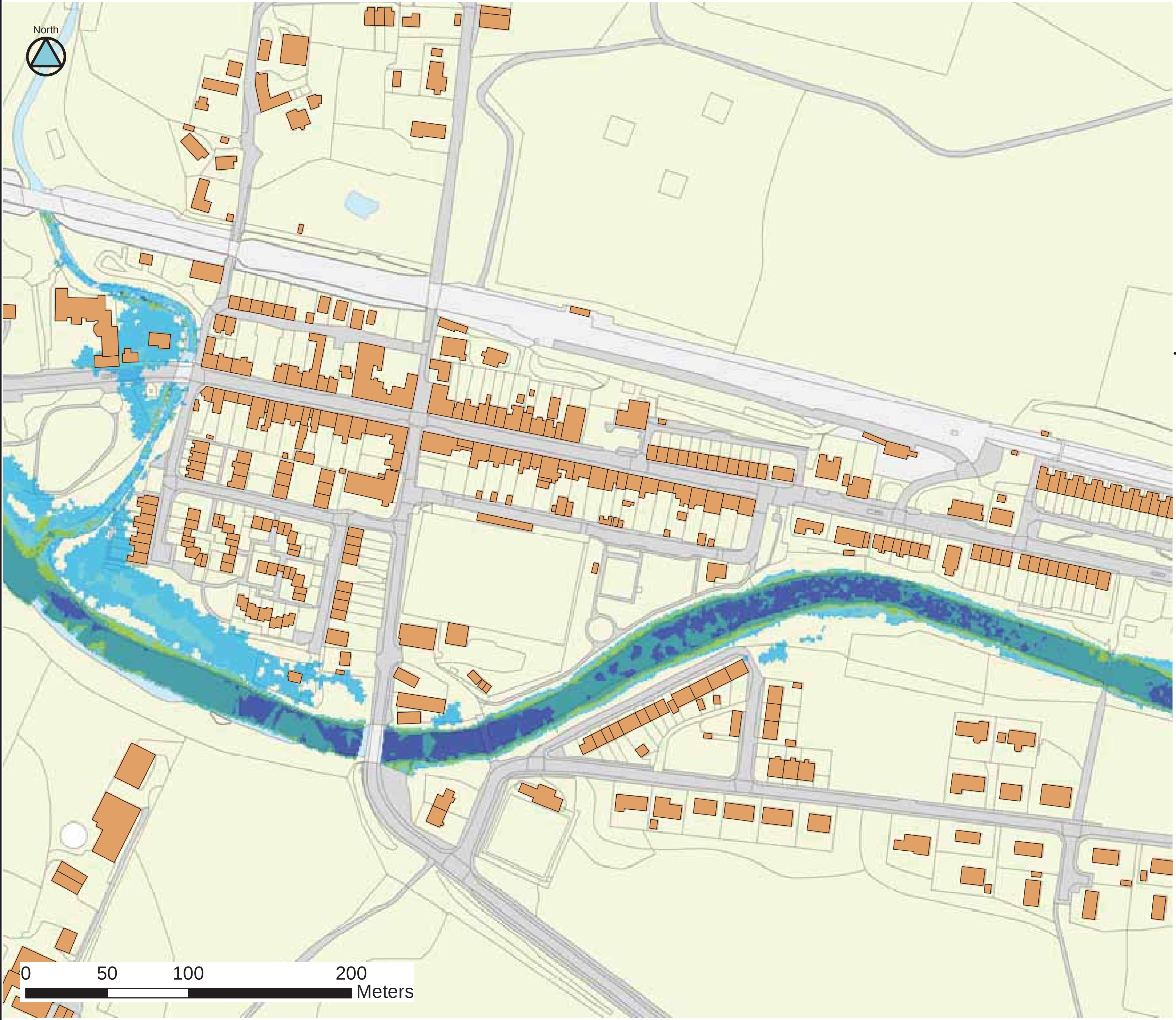
Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

JBA consulting

FIGURE 7
FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP) FLOW EVENT ON THE POLBOWER BURN

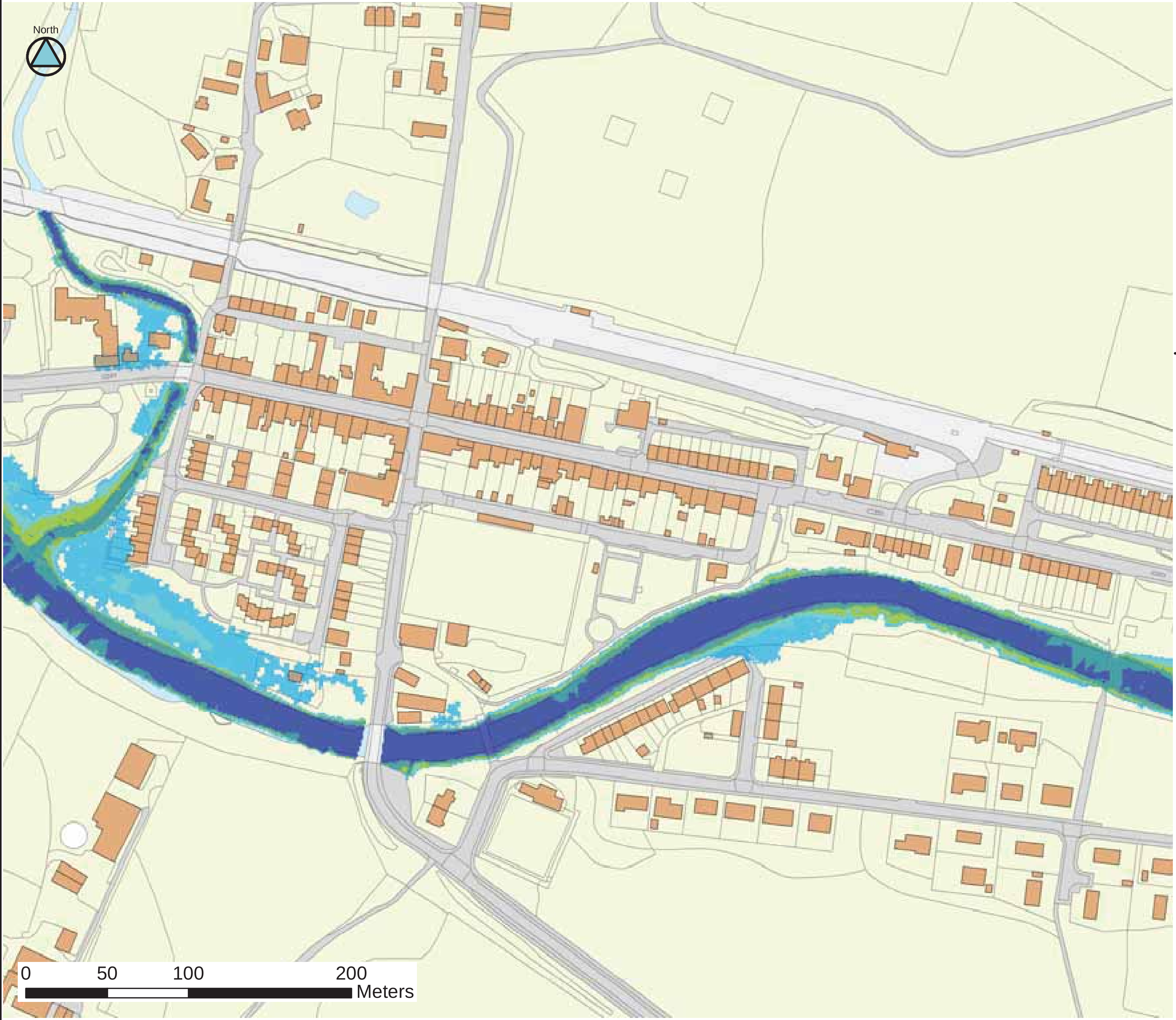


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 8
FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP + CC) FLOW EVENT ACCOUNTING FOR CLIMATE CHANGE ON THE POLBOWER BURN

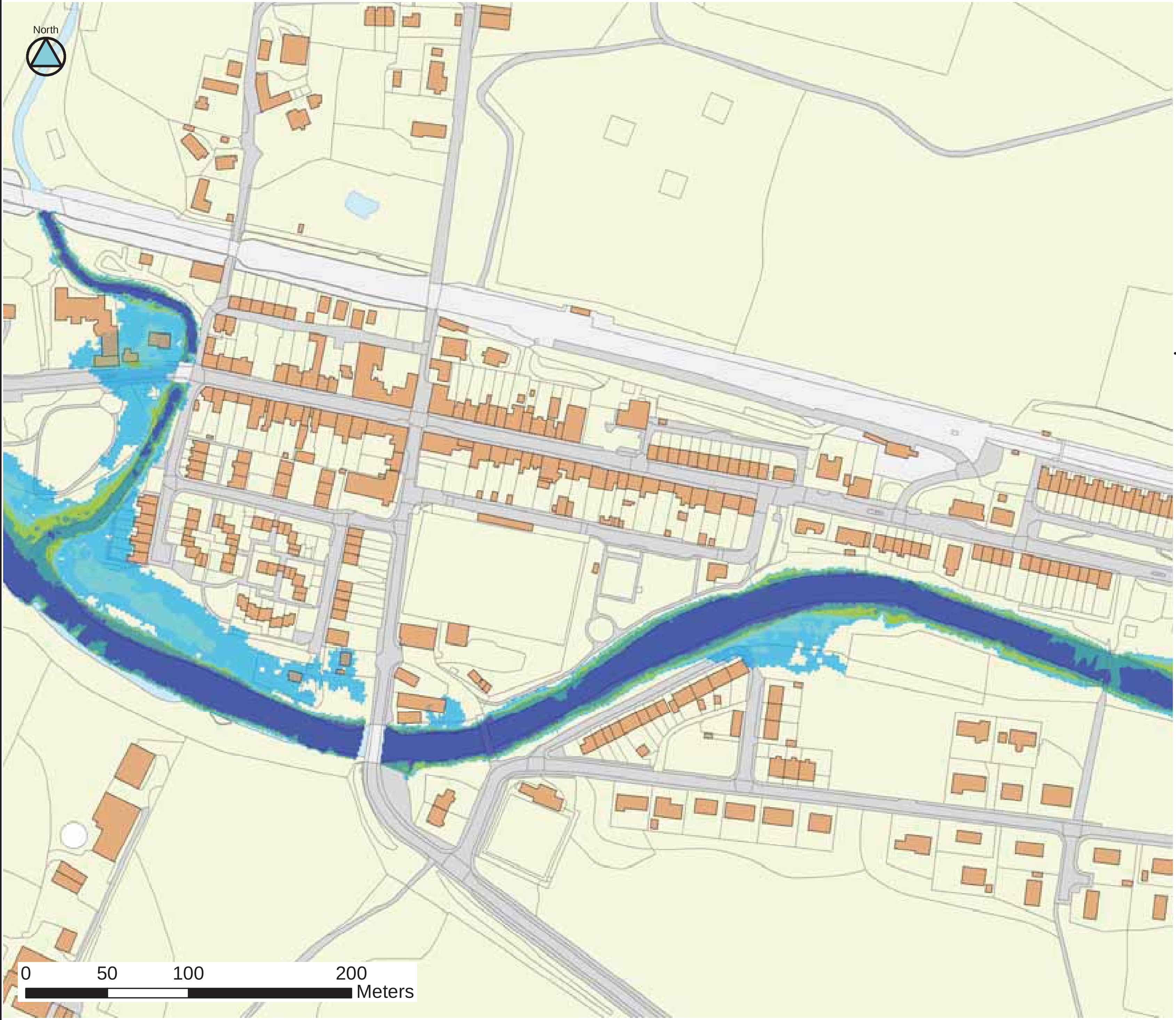


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 9
FLOOD DEPTH MAP FOR THE 500 YEAR (0.2% AP) FLOW EVENT ON THE POLBOWER BURN

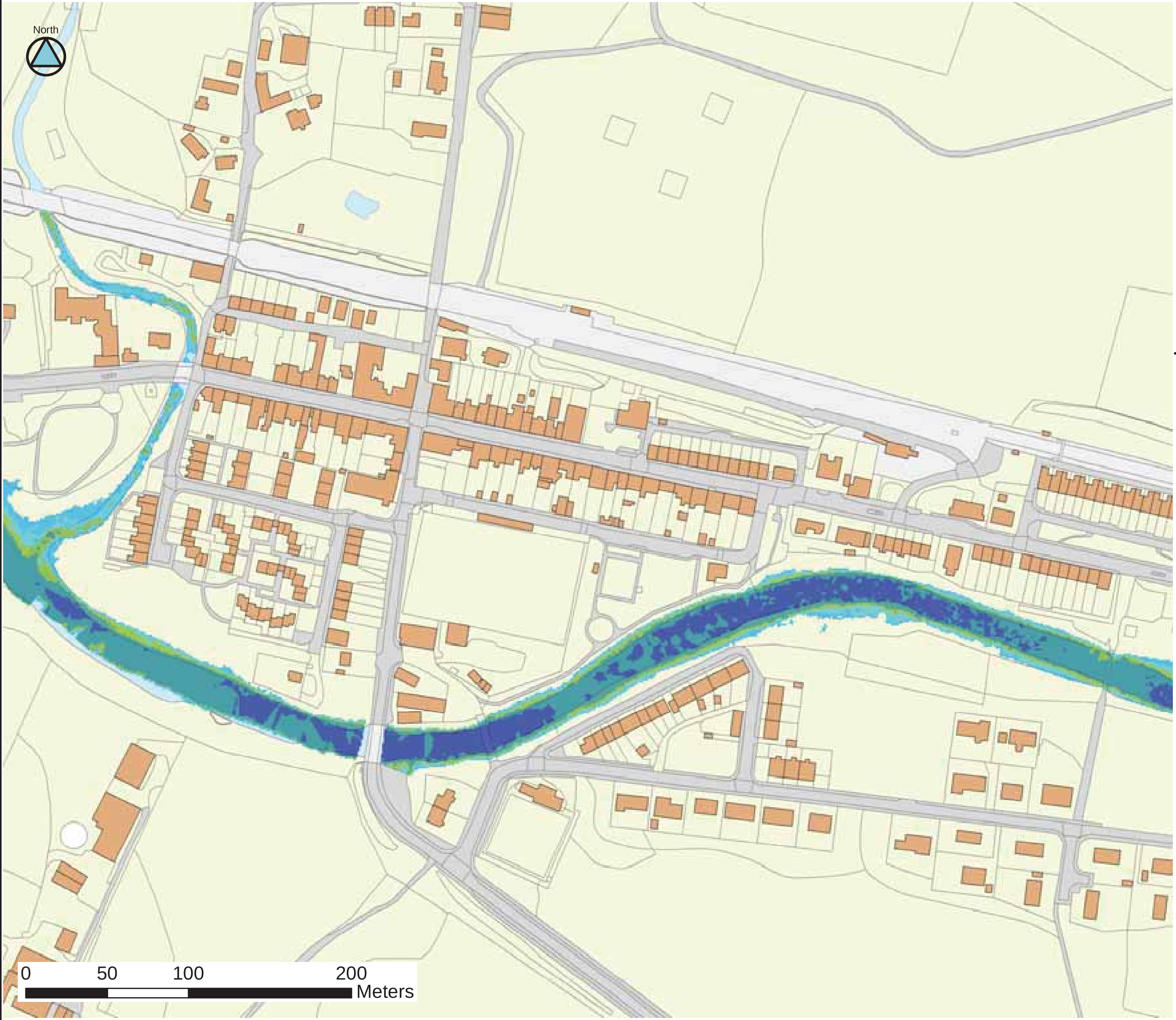


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 10
FLOOD DEPTH MAP FOR THE 1000 YEAR (0.1% AP) FLOW EVENT ON THE POLBOWER BURN

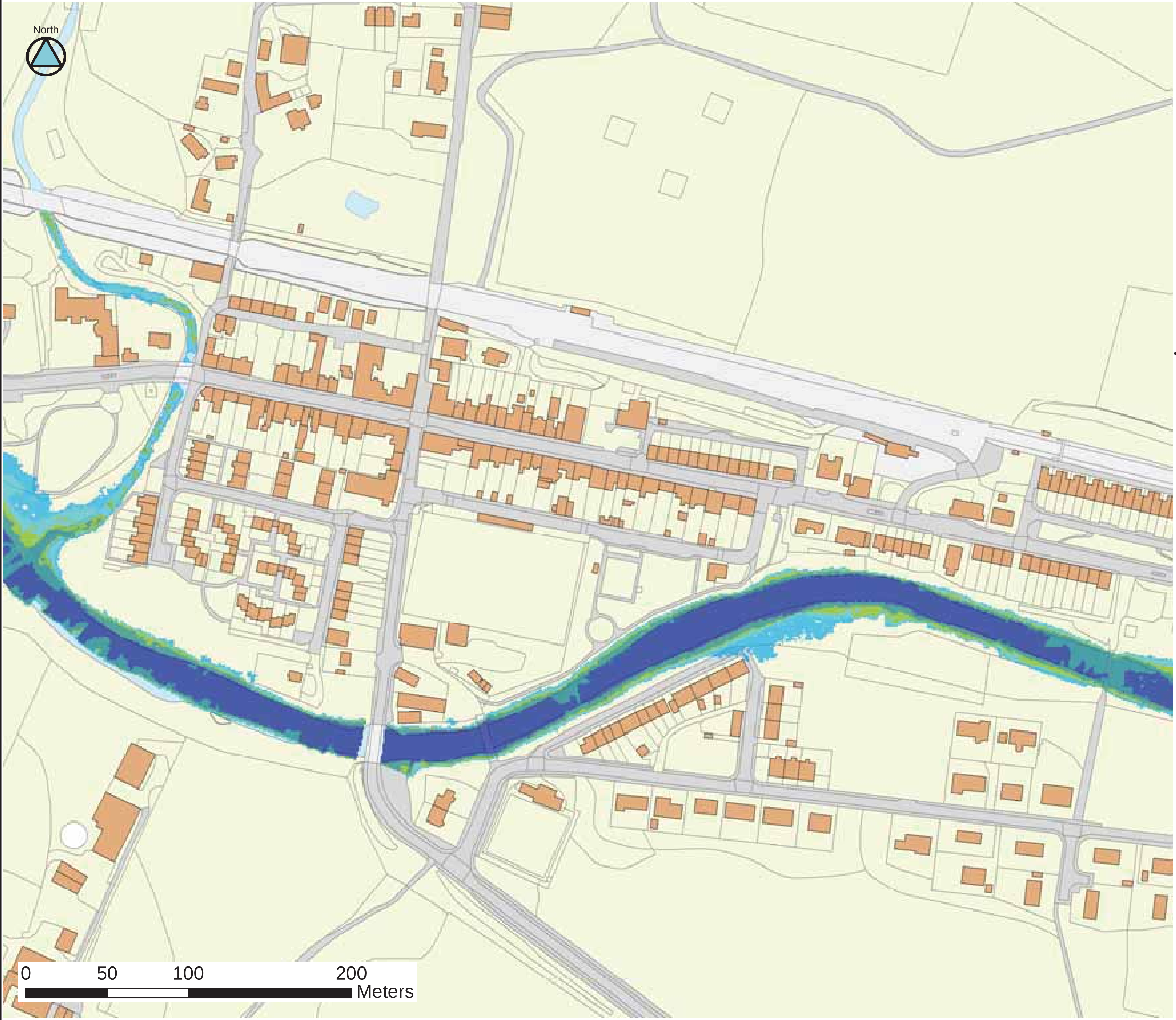


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 11
FLOOD DEPTH MAP FOR THE 2 YEAR (50% AP) FLOW EVENT ON THE RIVER NITH

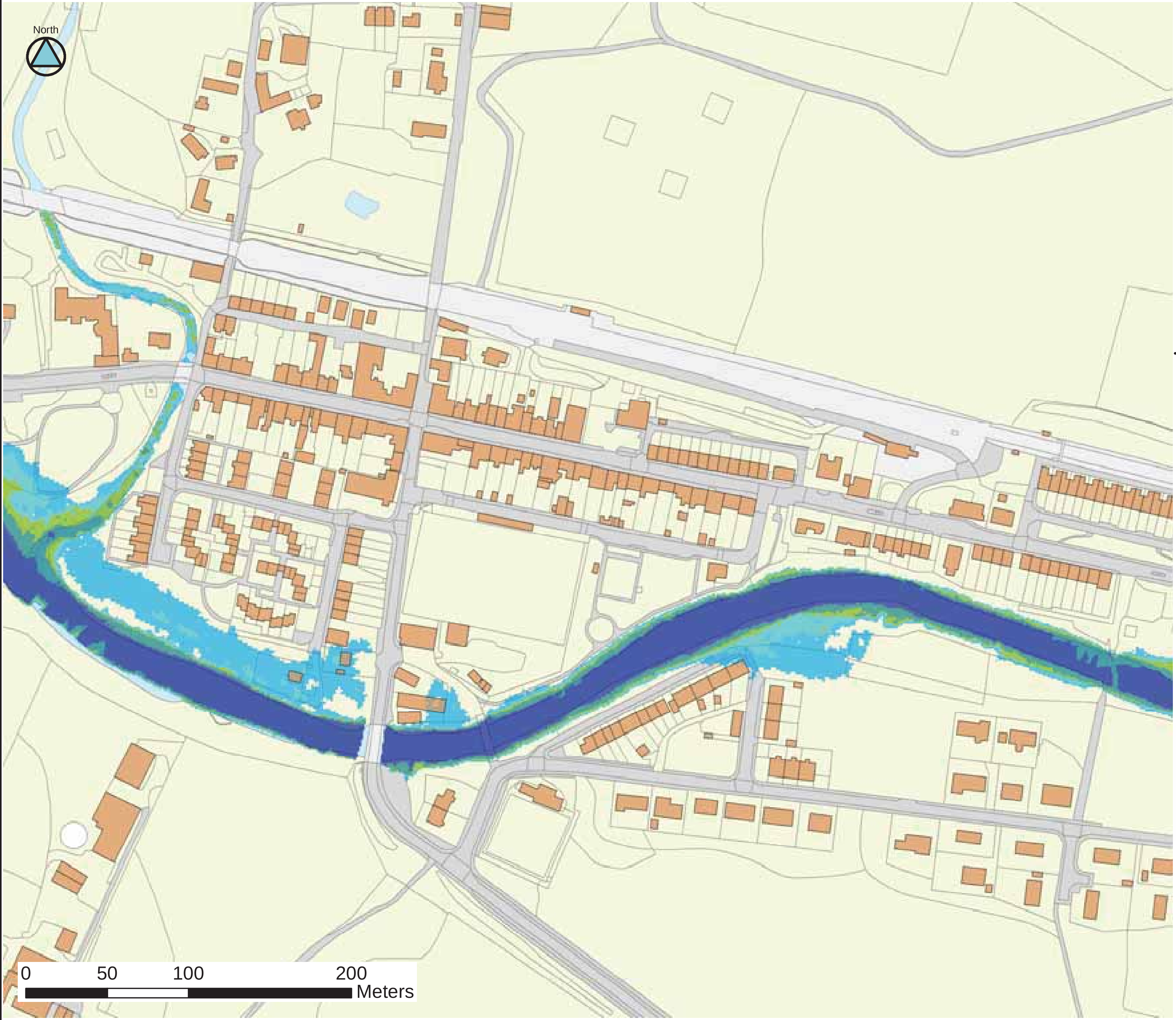


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 12
FLOOD DEPTH MAP FOR THE 5 YEAR (20% AP) FLOW EVENT ON THE RIVER NITH

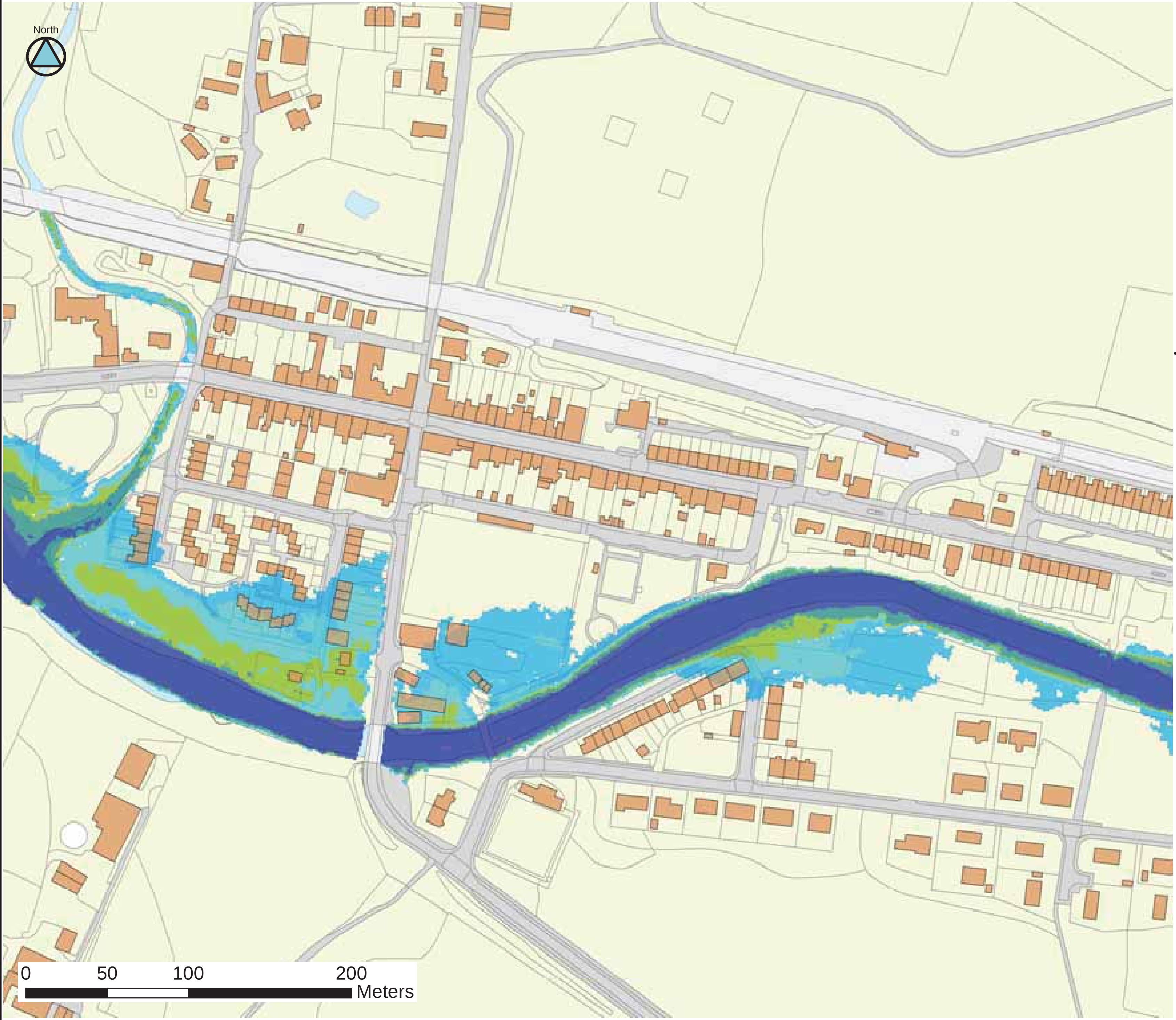


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 13
FLOOD DEPTH MAP FOR THE 10 YEAR (10% AP) FLOW EVENT ON THE RIVER NITH

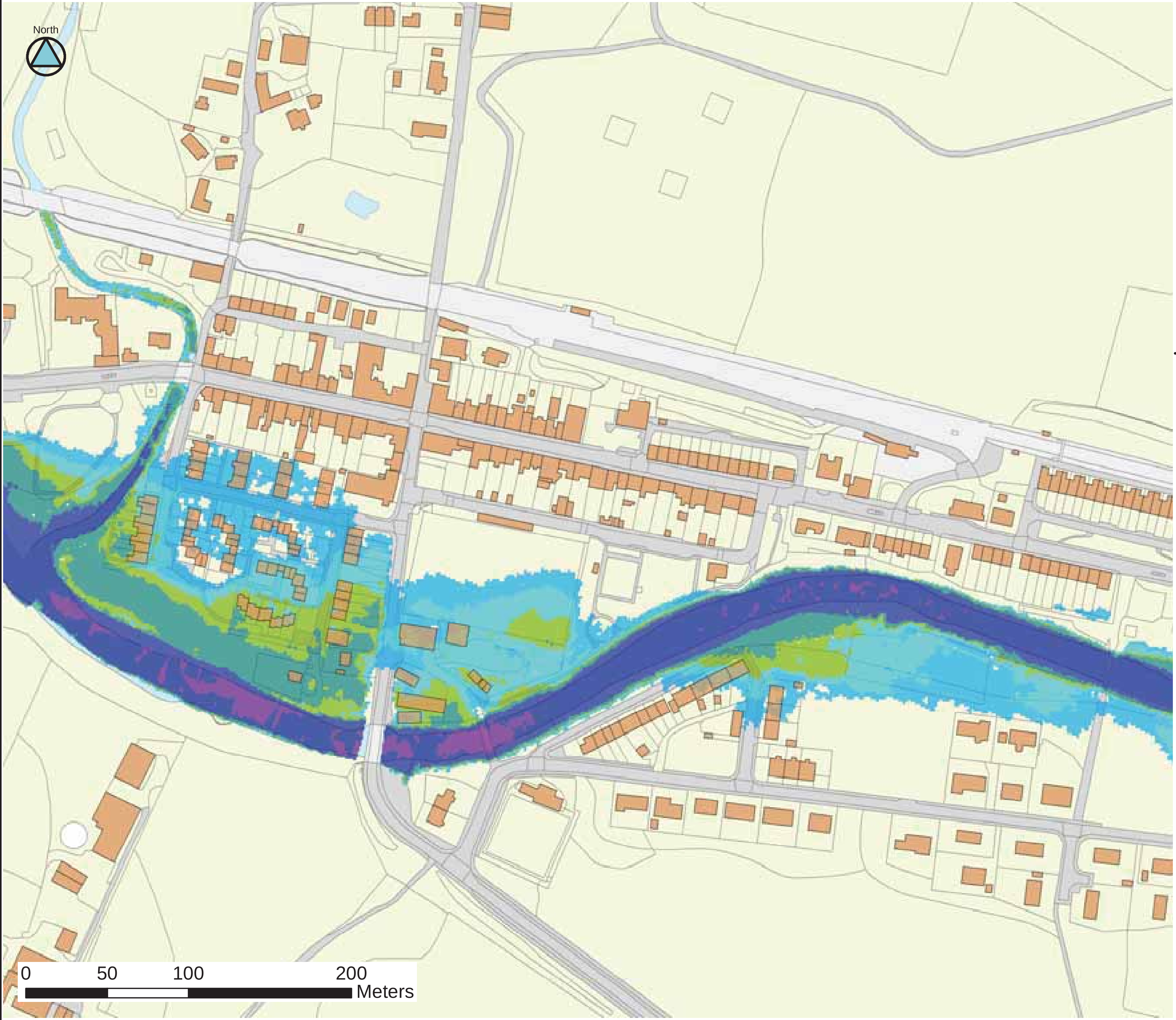


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 14
FLOOD DEPTH MAP FOR THE 25 YEAR (4% AP) FLOW EVENT ON THE RIVER NITH

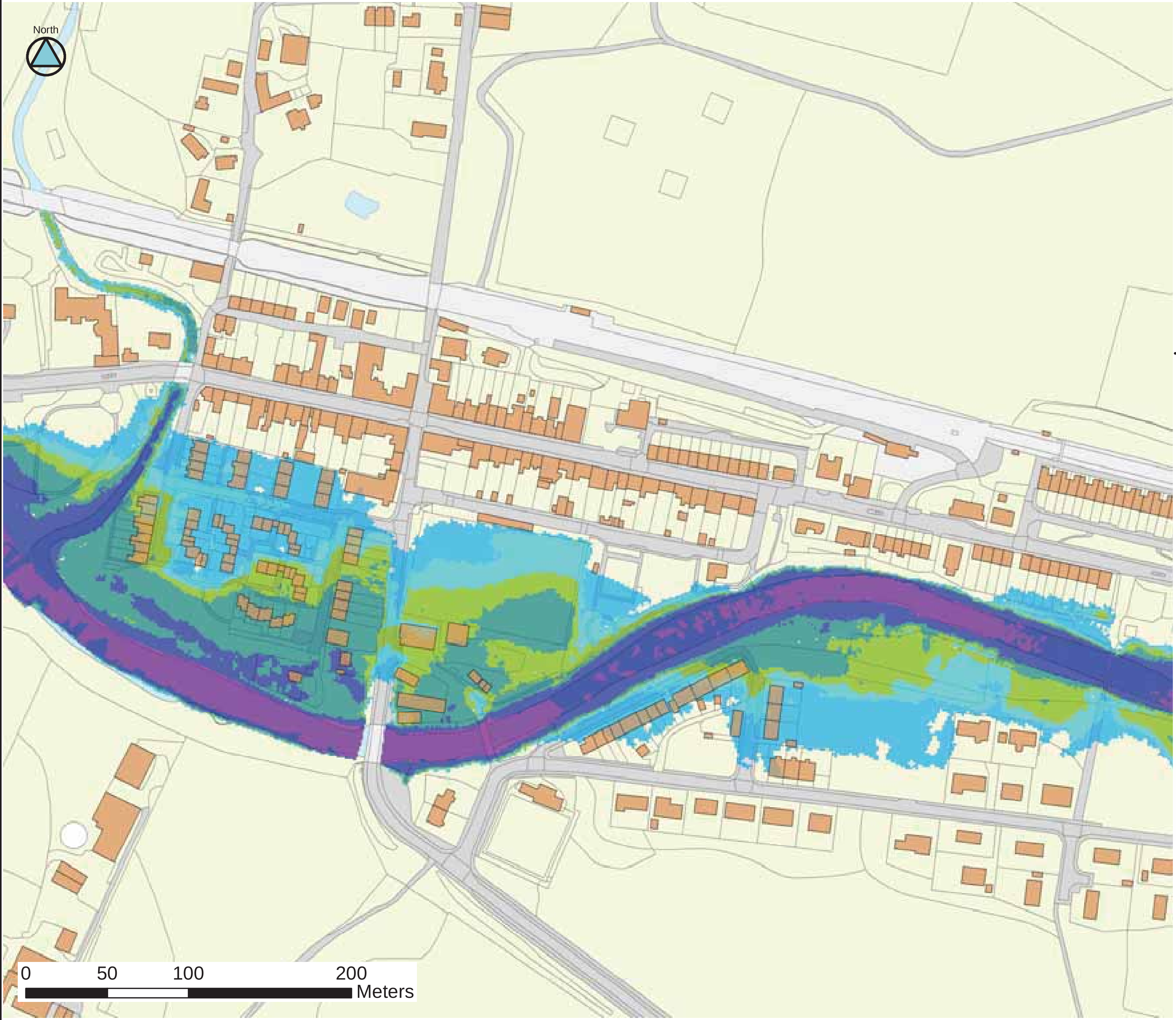


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 15
FLOOD DEPTH MAP FOR THE 50 YEAR (2% AP) FLOW EVENT ON THE RIVER NITH



Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 16
FLOOD DEPTH MAP FOR THE 100 YEAR (1% AP) FLOW EVENT ON THE RIVER NITH

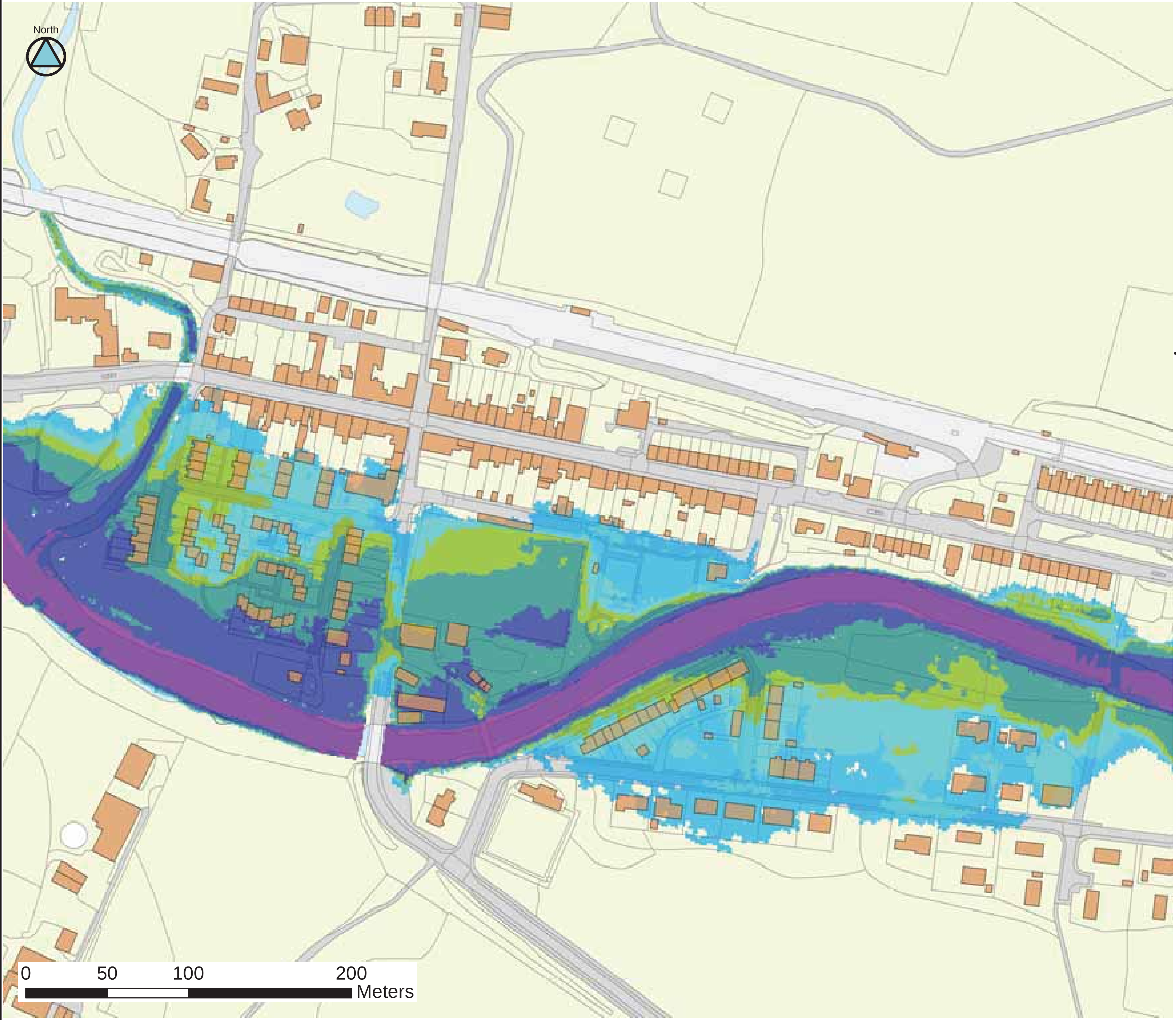
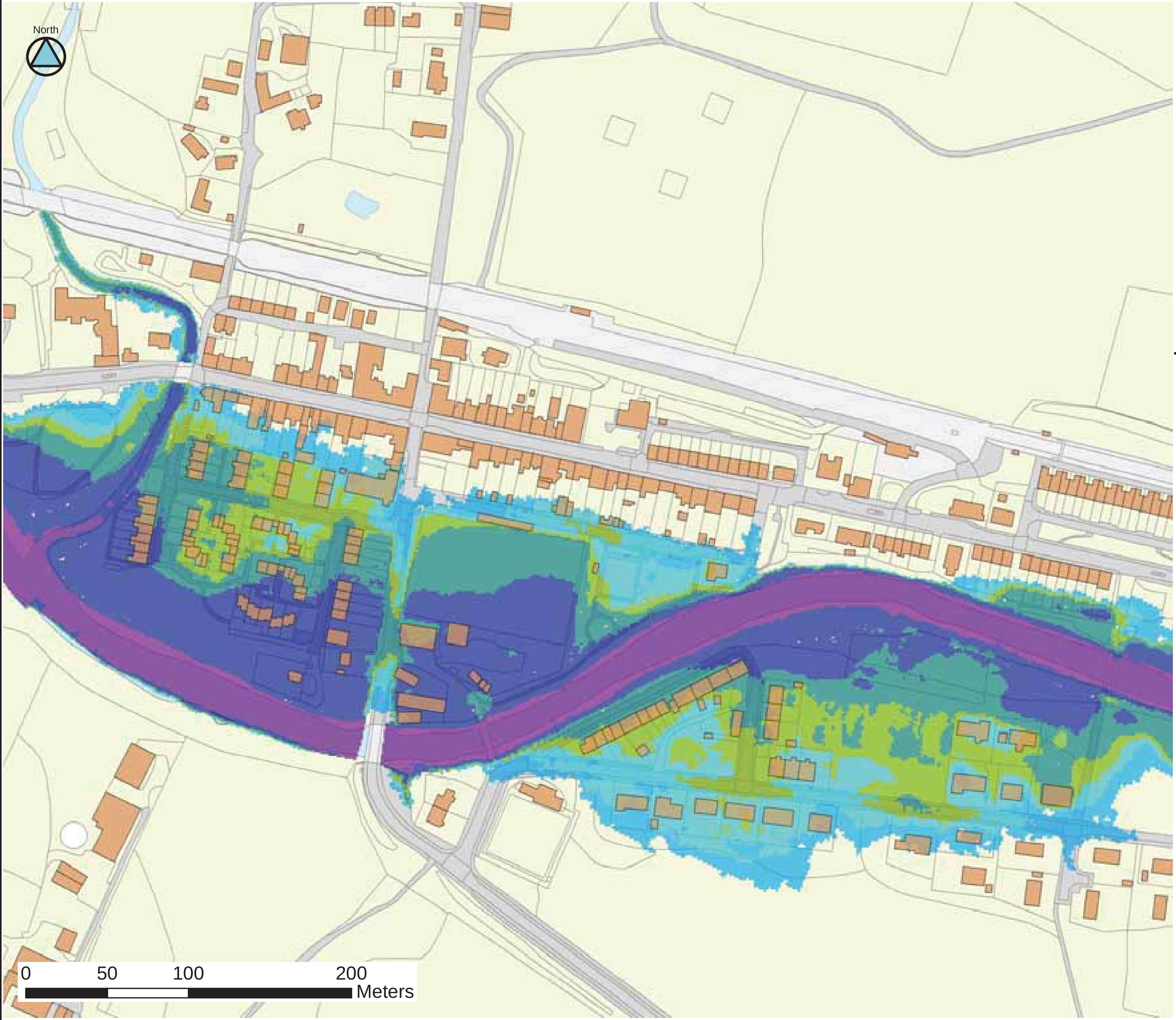


FIGURE 17
FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP) FLOW EVENT ON THE RIVER NITH

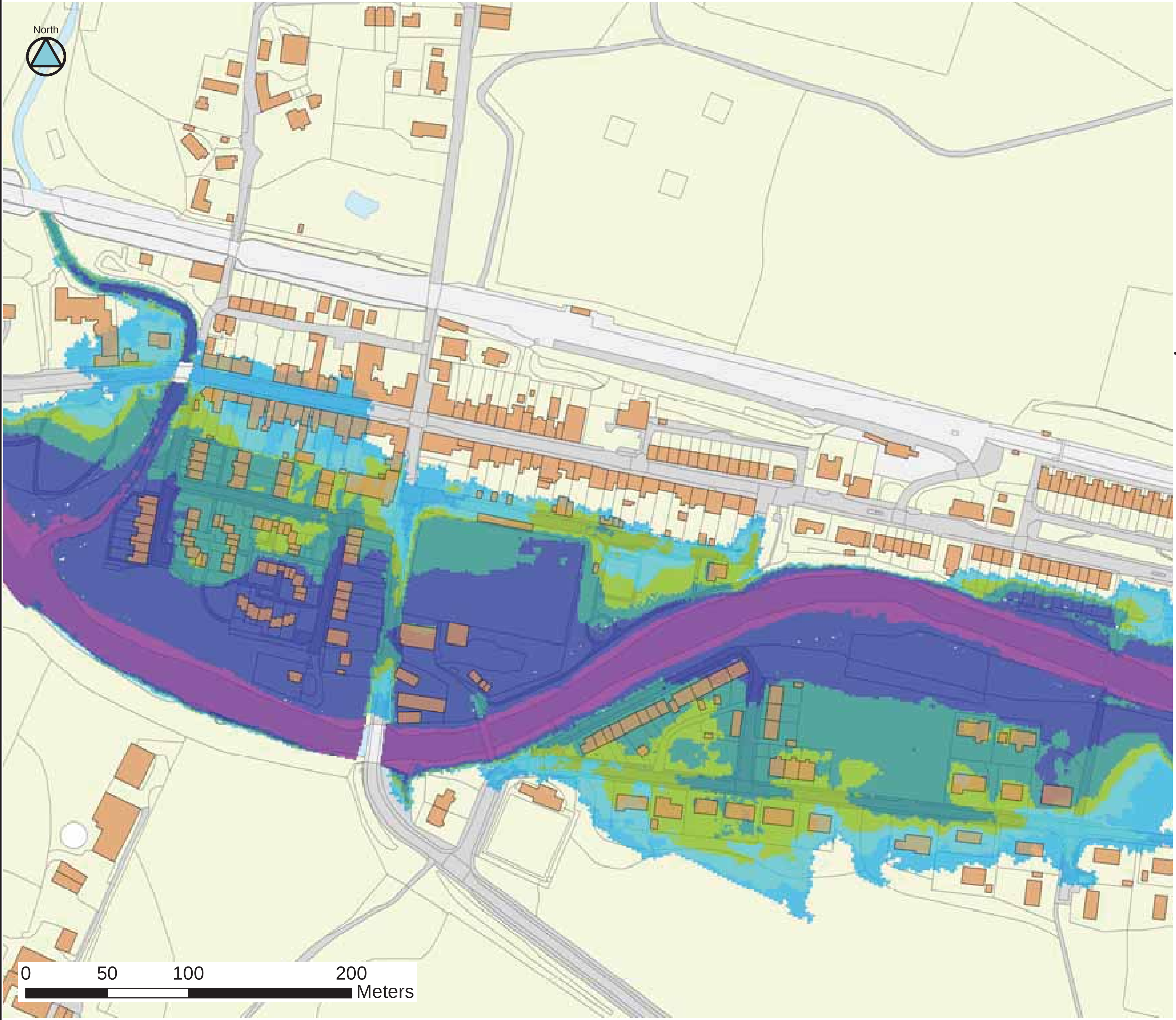


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 18
FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP+CC) FLOW EVENT ACCOUNTING FOR CLIMATE CHANGE ON THE RIVER NITH



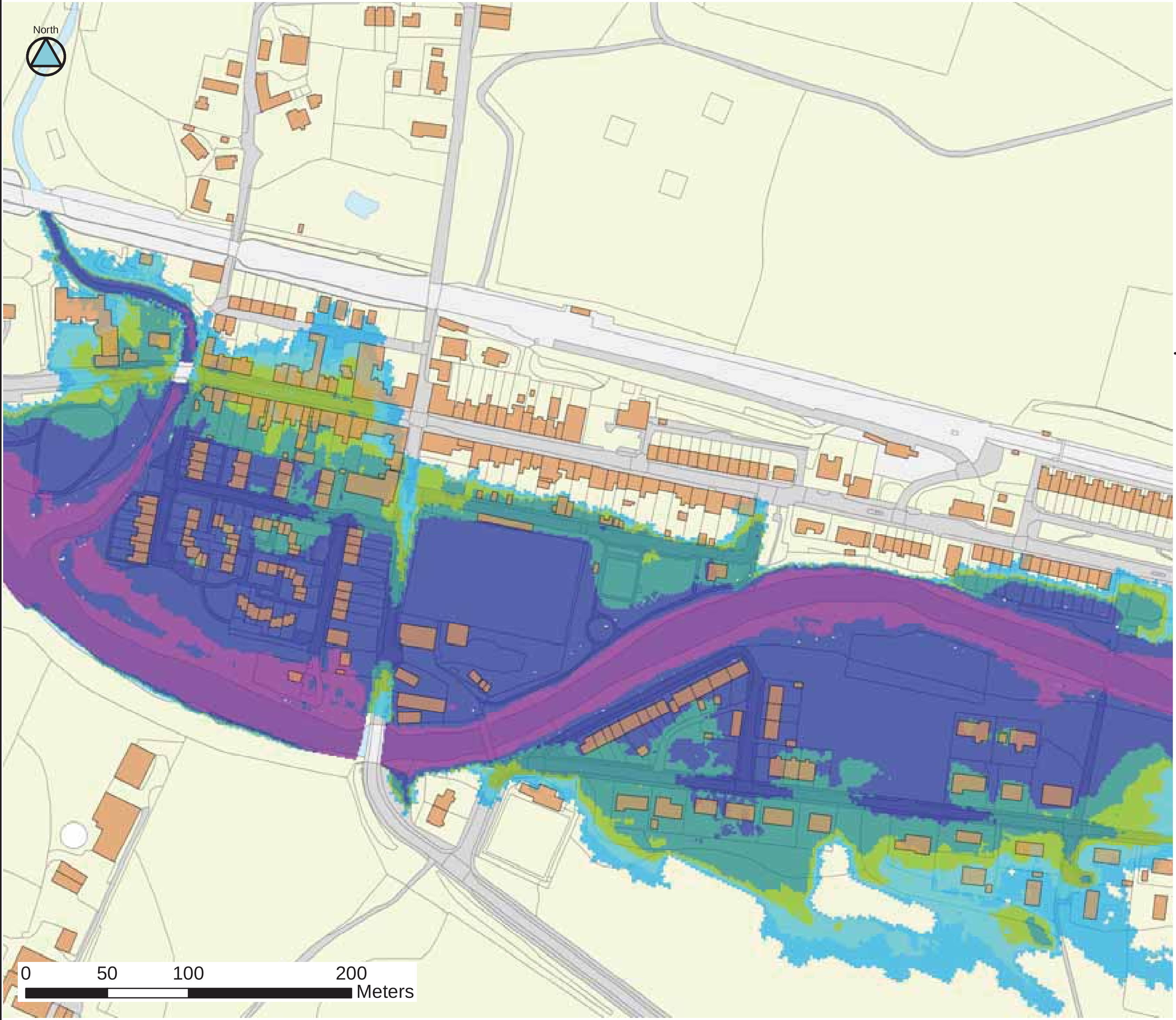
Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

JBA consulting

FIGURE 19
FLOOD DEPTH MAP FOR THE 500 YEAR (0.2% AP+CC) FLOW EVENT ACCOUNTING FOR CLIMATE CHANGE ON THE RIVER NITH



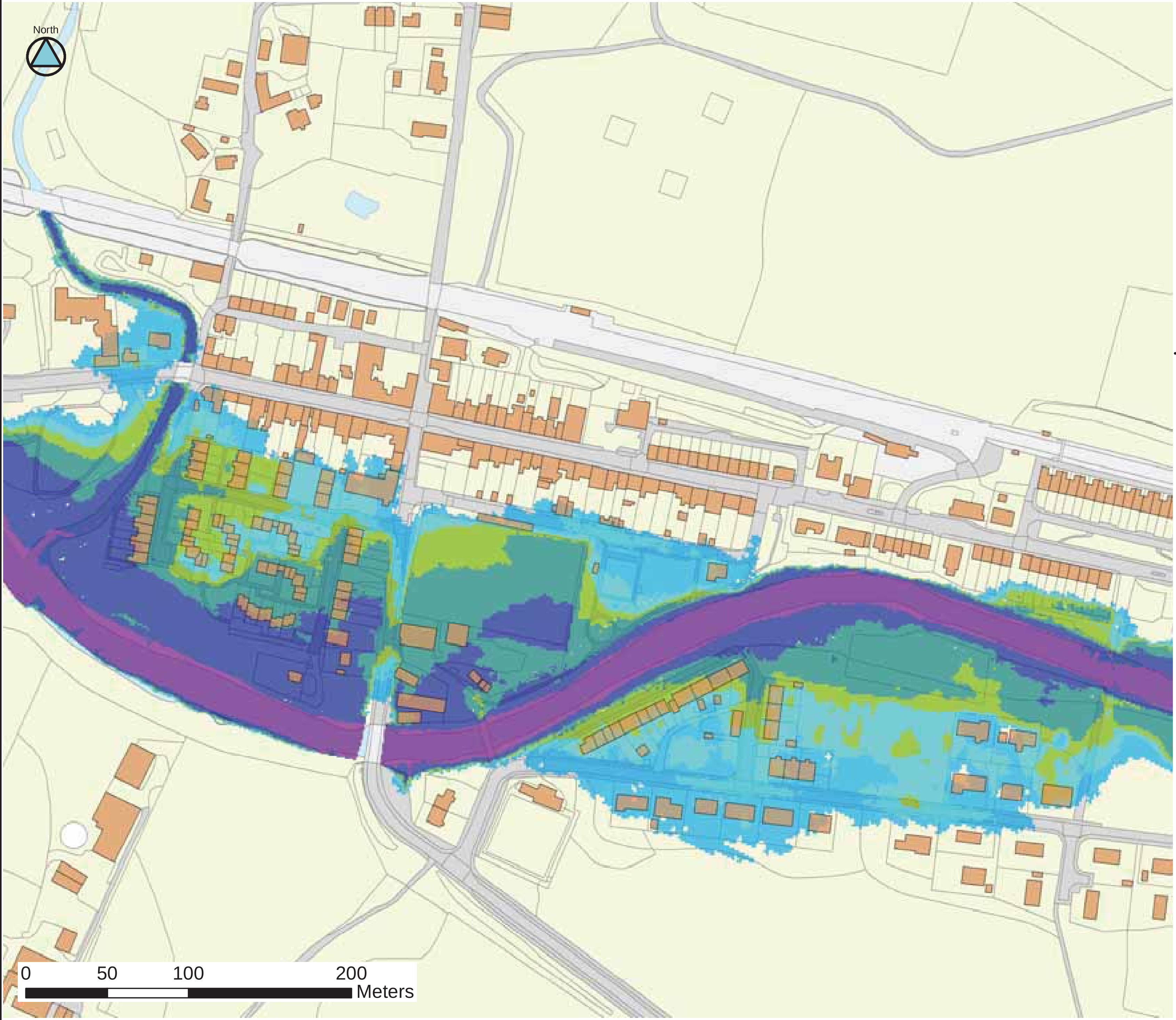
Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 20

FLOOD DEPTH MAP FOR THE 1000 YEAR (0.1% AP+CC) FLOW EVENT ACCOUNTING FOR CLIMATE CHANGE ON THE RIVER NITH

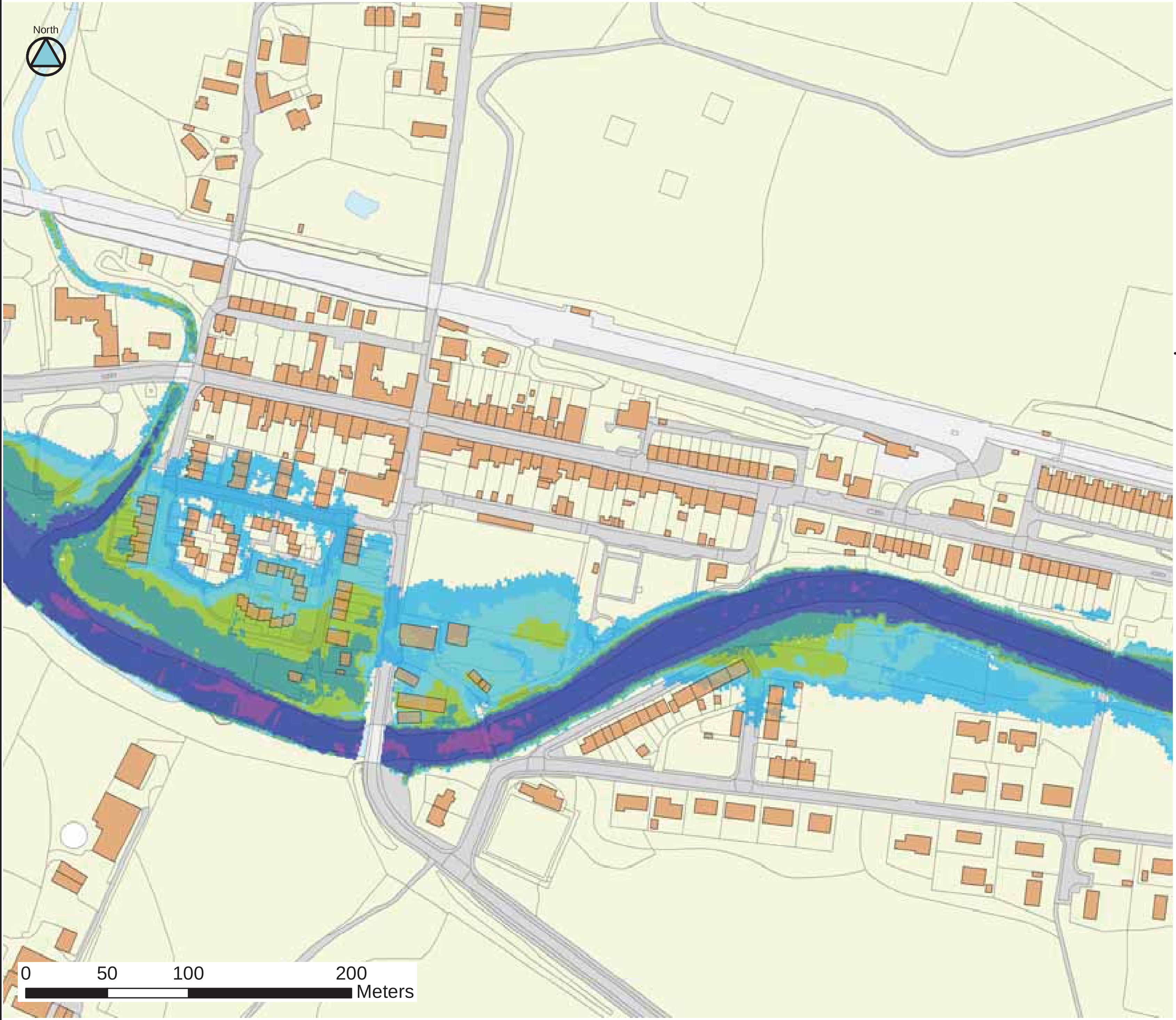


Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 21
FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP) FLOW EVENT ON BOTH THE POLBOWER BURN AND THE RIVER NITH



Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

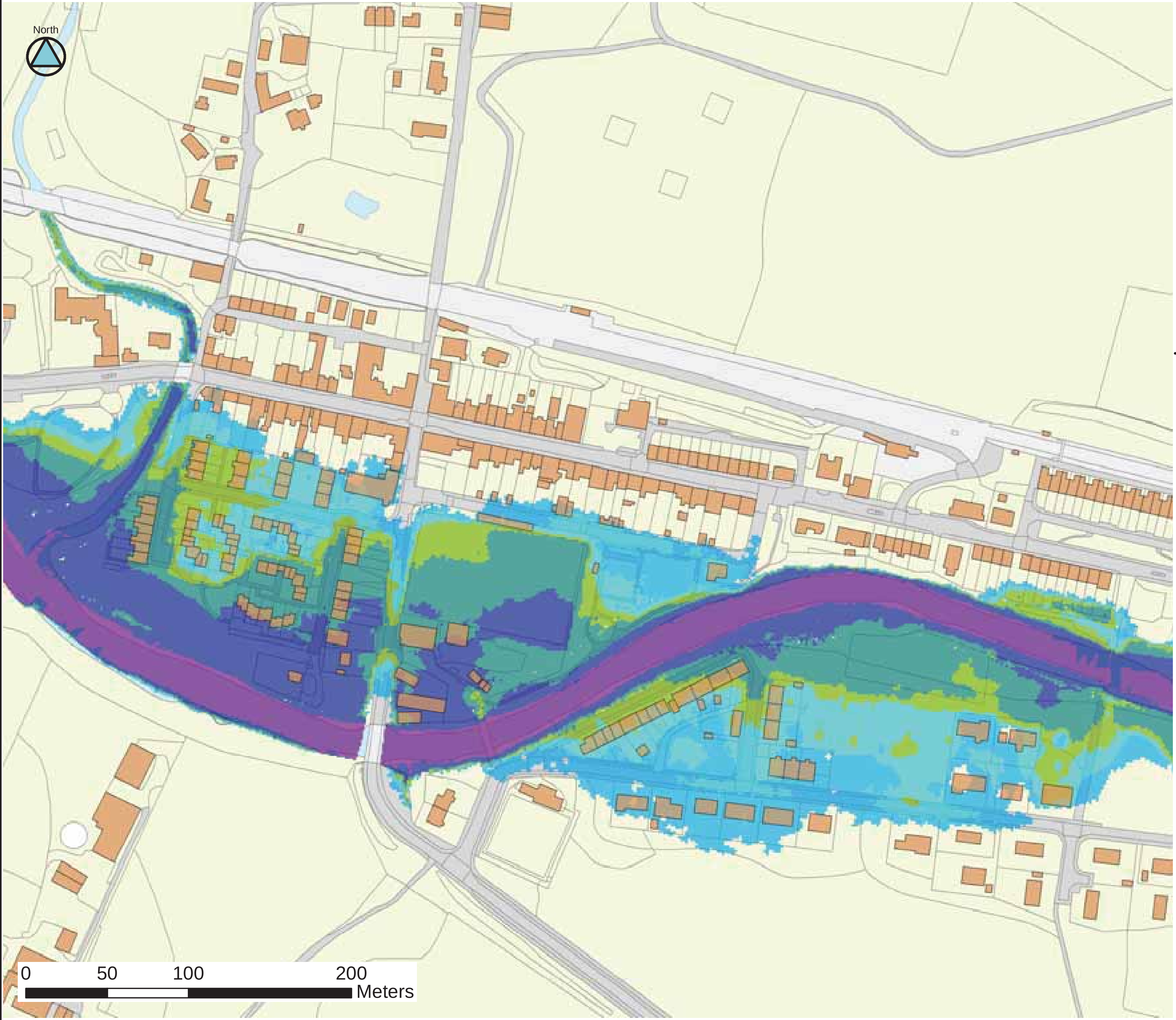
FIGURE 22
FLOOD DEPTH MAP FOR THE DECEMBER 2013 FLOOD EVENT

Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 23
BRIDGE BLOCKAGE SCENARIO FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP) FLOW EVENT ON THE POLBOWER BURN



Legend

Flood depth (m)

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.5
- 1.5 - 3.0
- 3.0 - 4.7

FIGURE 24
BRIDGE BLOCKAGE SCENARIO FLOOD DEPTH MAP FOR THE 200 YEAR (0.5% AP) FLOW EVENT ON THE RIVER NITH