Dumfries and Galloway Council

Newton Stewart: Outline Flood Mitigation Options - Addendum

2nd DRAFT

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1 Introduction

1.1 Background

Following the November 2012 flood event, Kaya Consulting Ltd. was commissioned by Dumfries and Galloway Council (DGC) to undertake a detailed flood study for the towns of Newton Stewart and Minnigaff, focusing on flooding risk of urban areas from the River Cree and lower part of Penkiln Burn.

The study demonstrated that during a 200 year flood event up to 134 properties could be at risk of flooding (equally split between residential and non-residential). A number of flood mitigation options were considered and it was found that a flood mitigation scheme to protect all 134 properties during a 200 year event is unlikely to be economically viable (i.e. not producing a positive benefit cost ratio). Subsequently, Kaya Consulting was commissioned by DGC to assess feasibility of a lower level of flood defence which would provide a positive benefit cost ratio. The study was completed and revised final report submitted on November 2015.

In December 2015, there was a second, significantly large flood event on River Cree which caused flooding within Newton Stewart and Minnigaff. The event was of similar magnitude to the 2012 event and highlight the potential risk facing the area.

In response to the second flood event in such quick succession, DGC commissioned a review of the hydrological analysis to update design flows for River Cree and assess the implications of this on the mitigation measures previously considered.

This report summarises the findings of the additional work undertaken since the original flood risk assessment. For ease of reference, findings of the original flood risk assessment are summarised below. However, this report should be read in conjunction with the previous reports (Newton Stewart Flood Study) dated April 2015 and November 2015.

1.2 Scope of Work

- Update hydrological analysis taking cognisance of the December 2015 flood event;
- Run existing mathematical model for the December 15 event and compare predicted and observed flood extent;
- Based on survey data collected, refine existing mathematical model and run model for the December 2015 event and compare against observed flood extent;
- Update flood study and management report, if necessary including review of mitigation options and outline cost-benefit analysis and development of preferred mitigation option;
- Review previously considered flood mitigation options and update cost-benefit analysis;
- Based on the updated modelling work, re-assess flood mitigation options and determine preferred option(s);
- The previously identified practical and economically viable mitigation option will be re-assessed and developed further. This will include conceptual design of flood mitigation measures along the west bank and the requirements for Property Level Protection (PLP) for

each identified property along the east bank, outline costing of the scheme and cost-benefit analysis;

- The original flood study report will be updated to include the above work;
- Present findings of the above work to local residents.

1.3 Summary of Findings of Newton Stewart Flood Study

The original flood study[1] undertook a detailed hydrological assessment for the River Cree and Penkiln Burn to estimate various return period (probability of occurrence) flows in both watercourses at Newton Stewart and developed a linked one-dimensional and two-dimensional (1D/2D) mathematical model of the river system and associated floodplains to predict flood risk through the urban parts of Newton Stewart and Minnigaff. The model was based on 46 surveyed channel cross sections (32 on River Cree and 14 on Penkiln Burn), and dimensional survey of 4 bridges (Road Bridge on Penkiln Burn, Cree Bridge, Metal Footbridge (Sparling) and A75 Bridge) and masonry weir immediately downstream of Cree Bridge. Floodplains were represented by a Digital Terrain Model (DTM) based on LiDAR ground elevation data.

The model requires input of design flows for a range of return periods (probability of occurrences) and these were derived using standard hydrological methods and were agreed with SEPA. The 200 year flow for River Cree in Newton Stewart was predicted as 485 m^3/s (cubic metre per second). This compares with a recorded peak flow of 387 m^3/s for the November 2012 event, which had a return period of around 40 to 85 years. The December 2013 event had a recorded peak flow of the order of 290 m^3/s, with a corresponding return period of the order of 5 years.

The linked 1D/2D mathematical model was calibrated against recorded flood level and flood extent information from the November 2012 event. Calibration is a process which involves adjusting model parameters within acceptable limits to obtain a good match between the model results and observed water levels and flows. This showed that the model predicted flood extent matches well to the flood extent recorded during the 2012 event. This increased confidence in model predictions.

The calibrated model was used to simulate flood inundation for a range of return periods (namely 2, 5, 10, 25, 50, 100, 200, 200 plus climate change, and 1000 year). Flood maps were prepared for each event, showing the areas which would be affected by flooding during each event.

The model predictions showed flooding of properties along Arthur Street, along Millcroft Road, along Victoria Street and Riverside Road, and in the Holmpark area on the opposite bank. Flooding of large areas of undeveloped land on both banks of the river was predicted towards the downstream end of Newton Stewart, including the Scottish Water Sewage Pumping Station. The metal footbridge (Sparling) close to the south end of Riverside Road was predicted to surcharge for flows in excess of the 2 year return period. Surcharging of the bridge was observed during both the 2012 and 2013 events.

The model predicted that 134 properties would be affected during a 200 year flood, equally split between residential and non-residential properties. For a 2 year flood event, 3 residential properties were predicted to be affected by flooding. The number of properties predicted to flood is significantly

[1] Newton Stewart Flood Study – Revised Final Report, Kaya Consulting Limited, April 2015

smaller than indicated in previous studies, due to the improved methods and datasets used in the detailed flood study.

The effect of tides and storm surges in Wigtown Bay on flooding risk at Newton Stewart was investigated. The predicted 200 year sea level (tide+strom surge) at Wigtown Bay was 5.52 m AOD (metres Above Ordnance Datum) based on 2014 data. The predicted 200 year water level in the river at Riverside Road is of the order of 9 m AOD, which is approximately 3.5 m higher than the 200 year extreme sea level at Wigtown Bay. Newton Stewart is some 14 km inland from Wigtown Bay (taken along the centre line of the river) and as tides propagate upstream along this length water level gradually rises due to funnelling effects. The current updated coastal boundary data indicates that approximately 700m downstream of the A75 Bridge the 200 year water level is approximately 6.95 m AOD. This is still some 2 m below the peak water level at Riverside Road. This indicates that should the 200 year tide+storm surge in Wigtown Bay coincide with the 200 year flood in the River Cree, the combined tide and surge would not have a significant effect on peak water levels in the areas upstream of the A75 Bridge (due to level differences). However, 200 year tide+surge would travel upstream of the A75 Bridge during low flows in the river, but this would not cause flooding in Newton Stewart.

A number of flood mitigation options were considered, including the following;

a) flood storage upstream of Newton Stewart;
b) direct defences where flood risk areas could be protected by flood walls and embankments;
c) removal of a gravel berm (island) just downstream of Cree Bridge;
d) dredging;
e) increasing the flow passing capacity of the A75 Road Bridge; and
f) raising the deck level of the metal footbridge (Sparling) near Riverside Road.

Flood Storage Upstream

A potential location for a large upstream flood storage area was identified in the River Cree Valley. The storage area was shown to be able theoretically to reduce peak flows passing downstream by up to 70 m^3/s, resulting in a 200 year flow being reduced to 75 year flow. However, the storage area option was not predicted to be able to reduce 200 year flows sufficiently to prevent widespread flooding in the urban areas of Newton Stewart and Minnigaff, indicating that additional defences (direct or similar) would still be required. In addition, upstream storage option was not considered economically viable (too high a cost for benefit provided) and it would have other environmental and social effects that were not considered in the study. This option, if considered, would need to be combined with direct defences in the urban areas to provide protection against a 200 year flood. Overall, the option was not considered to be practical nor economically viable.

Direct Defences

Direct defences within the urban areas would be able to provide protection to all properties predicted to be at risk. It was calculated that a total of 2.1 km of flood walls and 0.25 km of flood embankments would be required to protect all the flood risk areas in Newton Stewart and Minnigaff from a 200 year flood. Wall heights would generally be up to 2 m high (above existing ground level), except at Reid Terrace where the required height including freeboard would be approximately 2.3 m. Height of the walls from the river bed would be between 3 to 6 m. Options were also considered for defence schemes that provided lower levels of protection. In comparison, a scheme which would provide a 10 year level of protection would require defence heights of up to 1 m on average.

Removal of Gravel Berm, Dredging, Increasing Flow Capacity of A75, and Raising Deck Level of Sparling Footbridge

Modelling work indicated that the removal of the gravel berm, local dredging, increasing the flow capacity of the A75 bridge, and raising the deck level of the metal footbridge all had limited local effects on peak water levels only. Either individually or collectively these mitigation options would not significantly reduce flooding risk to the urban areas of Newton Stewart and Minnigaff. However, they could be considered as part of a wider scheme and combined with other options. It should be noted that historical maps indicate that if removed the gravel berm will likely form again in due course and given likely environmental impacts and limited positive effects, a license to carry out works may be difficult to achieve.

Cost benefit Analysis

An initial cost-benefit analysis was undertaken, based on the model results and conceptual flood alleviation options. A bias factor of 60% was added to cost estimates for the flood defence schemes as per standard practice. This increase in cost estimates aim to cover uncertainties affecting the scheme cost that could be encountered during the later detailed design stage.

Flood damage costs for a range of return periods were estimated using the standard Multi-Coloured Manual 2010. The assessment indicated that flood damage costs from a 200 year flood would be of the order of £3.7M. For a 10 year flood, the corresponding flood damage costs would be of the order of £0.26M.

Costs for construction of flood walls and embankments able to contain a 200 year flood event were estimated to be £16.1M (£25.8M with 60% bias). A scheme with walls able to provide protection up to a 1 in 50 year event was estimated to cost £18M, with 60% bias. A scheme with walls able to provide protection up to a 1 in 10 year event was estimated to cost £5.6M, with 60% bias. In comparison the costs for an upstream flood storage pond were estimated to be between £7.3M and £20.3M (both with 60% bias), with the cost varying depending on the sophistication of the flow control mechanism used, with better and more effective flow control resulting in higher cost.

The costs and benefits of each scheme were assessed and a benefit-cost ratio calculated for each scheme. Benefit-cost ratios need to be greater than unity before they would normally be considered as being economically viable and able to attract grant aid from the Scottish Government. The benefit-cost assessment concluded that;

- The benefit-cost ratios for schemes with flood storage areas and with flood defence walls protecting properties up to the 1 in 200 year would likely be less than unity. If other intangibles such as social and environmental benefits were included the resultant benefit-cost ratio would be higher, but unlikely to be higher than unity.
- The benefit-cost ratio for a scheme with flood walls to provide a 1 in 10 year level of protection was calculated to be greater than unity, even without the addition of intangible benefits.

The conclusion was that a scheme providing 1 in 200 year level of protection is unlikely to be economically viable, whereas a scheme with a lower level of protection could be economically viable and has the potential to attract Scottish Government grant aid.

It should be noted that how the Scottish Government will allocate grants for such schemes in the future is not known at present. If flood mitigation schemes are compared nationally, those with lower benefit-cost ratios may not attract grant until such time other schemes with higher benefit-cost ratios are complete.

It was concluded that, based on the outline cost-benefit analysis undertaken, a scheme consisting of direct defences and providing a lower than 200 year level of protection would appear technically and economically feasible and worth further consideration.

1.4 Aims and Objectives of 2017 Addendum

The findings of the detailed flood study report were presented to Cree Valley Flood Action Group (CVFAG) on 21 January 2014. At that time, due to the low benefit cost ratio, it was agreed at the meeting that a flood mitigation scheme providing protection against one in 200 year flood would unlikely attract funding from Scottish Government, and that a flood mitigation option with a lower level of standard of protection should be considered further. DGC agreed to assess potential practical options which would likely provide an economically viable scheme.

During December 2015, the River Cree experienced the highest water level on record and the second significant flood event in the last couple of years. The event resulted in flooding to many properties within the town and exceeded that of 2012 event. Based on the 2015 event, it was necessary to update the previous hydrological and hydraulic modelling work using new information from the 2015 event.

This Addendum report summarises the work undertaken to date and should be read in conjunction with the previous reports dated April 2015 and November 2015.

2 Update to Hydrological Assessment

2.1 Objective

On 31st December 2015, Newton Stewart experienced the worst flooding on record. As design flow estimates are affected by recorded flows, such an extreme event could have a significant impact on the design flows used to assess flooding risk along the river.

Design flows calculated for the original study were based on the statistical analysis of gauged flow data. Any large flood event will change the flood statistics at a gauged site and as a result, the hydrological calculations undertaken are required to be updated to considering the 2015 event.

2.1.1 Calculation of peak flow during December 2015 event

SEPA operates a flow monitoring station within Newton Stewart which is located towards the southern (downstream) end of the town. The gauge River Cree @ Newton Stewart (station number 81002), is approximately 800 m upstream of the A75 road bridge, which forms the downstream boundary of the study area (with the mathematical model extending significantly further downstream).

Based on the 2016 SEPA rating curve at the gauge, the peak flow during the 2015 event was estimated as 476 m^3/s. Mathematical modelling, presented in Chapter 3, predicted that the peak flow for this event was 427 m^3/s. This was based on extensive calibration work for the December 2015 event, based on observations of flood levels, flood inundation extents and backwatering effects from the Sparling footbridge located downstream of the gauge.

The modelled flow for the 2015 event is considered to be more accurate than the SEPA flow. For this assessment, the peak flow for the December 2015 event is considered to be 427 m^3/s. However, due to potential event specific factors during the 2015 event (i.e., collapse of flood wall and large volumes of debris at Sparling footbridge downstream of the gauge), SEPA data for event prior to 2015 are not revised based on the modelled rating curve.

2.1.2 Summary of AMAX data and Qmed

Discussions were held with SEPA regarding the most appropriate AMAX data to be used to develop a flood frequency curve for the River Cree gauge in Newton Stewart. SEPA have undertaken a number of reviews of the rating curve at the Cree gauge and data provided by SEPA for this model update differed from the data provided for the 2013 study. The SEPA data also differed from the AMAX data stored within the FEH WINFAP dataset.

The agreed approach was;

- WINFAP-FEH (v4.1) AMAX values were used for the period 1963 to 2000.
- SEPA 2016 data was used for the period 2001 to 2014
- The modelled December 2015 flood peak was used for 2015.

The new AMAX (annual Maximum) flows are provided in Figure 1 and Table 1.

Based on this AMAX series the Q_{med} for the River Cree at Newton Stewart is 227 m^3/s.

Figure 1: SEPA 2016 AMAX data

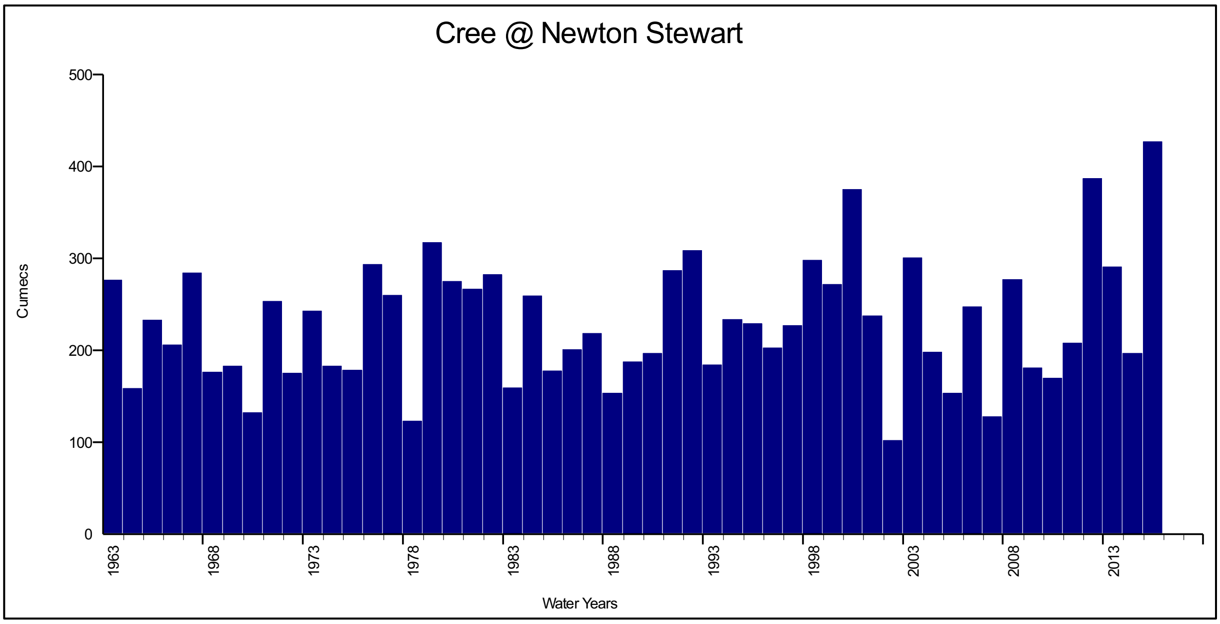


Table 1: AMAX data used in analysis

Year	AMAX (m^3/s)	Year	AMAX (m^3/s)	Year	AMAX (m^3/s)
1963	276.6	**1981**	266.5	**1999**	271.9
1964	159.0	**1982**	282.5	**2000**	375.0
1965	233.1	**1983**	159.5	**2001**	237.7
1966	206.3	**1984**	259.1	**2002**	102.0
1967	284.3	**1985**	177.6	**2003**	300.8
1968	176.6	**1986**	200.6	**2004**	198.2
1969	183.3	**1987**	218.8	**2005**	153.8
1970	132.7	**1988**	153.2	**2006**	247.8
1971	253.6	**1989**	187.9	**2007**	127.8
1972	174.9	**1990**	196.7	**2008**	276.8
1973	243.2	**1991**	286.9	**2009**	180.8
1974	183.3	**1992**	308.8	**2010**	169.8
1975	178.2	**1993**	184.5	**2011**	207.8
1976	293.5	**1994**	234.0	**2012**	386.8
1977	260.0	**1995**	229.1	**2013**	290.8
1978	123.4	**1996**	203.0	**2014**	196.8
1979	317.3	**1997**	226.8	**2015**	426.8
1980	275.3	**1998**	298.4		

2.1.3 Flood Frequency Curve Estimation

Flood frequency curves for the River Cree were calculated based on;

- Single Site Analysis
- Enhanced Single Site Analysis (Pooling Group method)

2.1.3.1 Single Site Analysis

Based on the AMAX data outlined in Table 1, the Single Site flood frequency curves (Generalised Logistics and GEV distributions) for the Newton Stewart gauge site are shown in Figure 2. The Generalised Logistics distribution is used in this assessment and it provides a generally good fit to the observed data.

Return period flow estimates are provided in Table 2 where they have been rounded to the nearest ten cumecs (m^3/s).

Figure 2: Single site analysis flood frequency curve

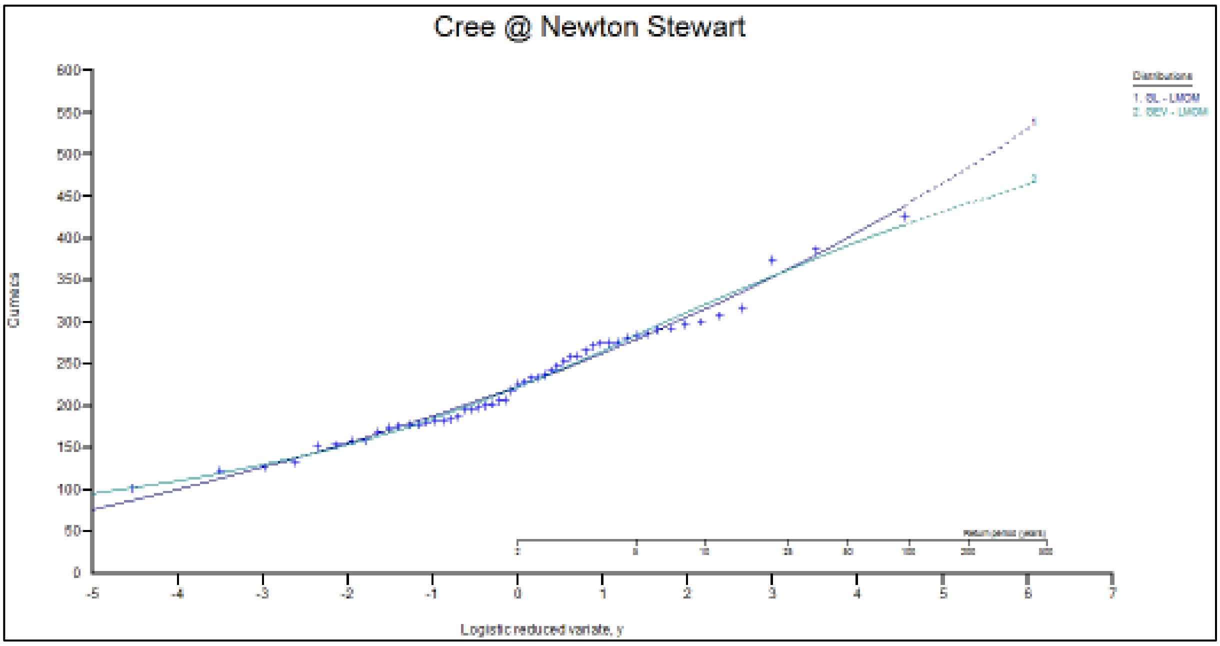


Table 2: Design flows for single site analysis

Return Period (years)	Generalised Logistic (m^3/s)	General Extreme Value (m^3/s)
2	220	220
5	280	280
10	320	320
25	360	360
50	400	390
100	440	420

200	480	440
500	550	470

2.1.3.2 FEH Enhanced Single Site Analysis

An Enhanced Single Site Analysis was undertaken for the Newton Stewart gauge. This is the most appropriate method (WIN-FAP Version 3) for Pooling Group analyses for gauged sites. Return period flow estimates are summarised in Table 3. The Pooling Group developed for the gauged site is provided in Table 4.

Table 3: Design flows for Enhanced Single Site Analysis

Return Period (years)	Generalised Logistic (m^3/s)	General Extreme Value (m^3/s)
2	227	227
5	285	291
10	324	331
25	377	380
50	421	414
100	468	447
200	520	479
500	596	519

It is notable that the design flows produced by the Enhanced Single Site method are similar to those produced using the single site analysis at the gauged site, with the 200 year flow from the Enhanced Single Site Analysis increasing by 7% from the flow predicted using the single site analysis. In addition, the WINFAP goodness-of-fit indicator recommends use of the Generalised Extreme Value statistical distribution; however, based on discussions with SEPA, and allowing for a conservative approach, we have instead used the Generalised Logistic statistical fit which has a flow increase of around 40 m^3/s compared to the Generalised Extreme Value.

Table 4: Pooling group for River Cree

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
81002 (Cree @ Newton Stewart)	0	53	226.806	0.165	0.1	0.302
3003 (Oykel @ Easter Turnaig)	0.326	28	342.057	0.187	0.243	1.565
76003 (Eamont @ Udford)	0.486	53	200.926	0.186	0.136	0.558
71008 (Hodder @ Hodder Place)	0.596	45	222.469	0.159	0.175	1.41
79006 (Nith @ Drumlanrig)	0.679	48	338.607	0.136	0.139	1.347
27043 (Wharfe @ Addingham)	0.694	41	262.267	0.167	0.062	1.568
60002 (Cothi @ Felin Mynachdy)	0.7	53	174.05	0.198	0.208	1.244
71006 (Ribble @ Henthorn)	0.751	46	220.237	0.149	0.156	0.43

25018 (Tees @ Middleton in Teesdale)	0.753	43	214.93	0.184	0.12	0.493
3002 (Carron @ Sgodachail)	0.756	32	190.903	0.167	0.126	0.089
83005 (Irvine @ Shewalton)	0.76	30	200.492	0.143	0.206	1.403
46003 (Dart @ Austins Bridge)	0.767	56	234.524	0.168	0.104	1.591
Total		528				
Weighted Means				0.166	0.136	

2.1.3.3 Final Design Flows for River Cree at Newton Stewart

The Enhanced Single Site Analysis is considered the most appropriate method for estimation of 200 year design flows at the Newton Stewart gauge.

Design flows for the River Cree Newton Stewart are based on the Enhanced Single Site Analysis and GL distribution, i.e., Column 1 of Table 3. This gives a best estimate of the 200 year flow at the gauge of 520 m^3/s.

2.1.4 Comparison to previous design flow estimates

A comparison of the updated design flow estimates to those calculated previously for a range of return periods using the Enhanced Single Site Analysis are presented in Table 5.

The update to the flood hydrology has resulted in an increase to the design flow estimates for the River Cree. This is primarily due to the increase in Q_{med} at the site, resulting from the update to the post-2000 AMAX series by SEPA; this accounts for 4% of the increase in flows. The remaining 3% increase in 200 year flows results from the inclusion of the 2015 peak flow in the River Cree dataset and the inclusion of more recent (2013 to 2015) data for other gauges within the Pooling Group used in the Enhanced Single Site Analysis.

Table 5: A comparison of the design flow estimates based on Enhanced Single Site Analysis using the General Logistic distribution

Return Period (years)	2016 data (m^3/s)	2013 data (m^3/s)	Increase from 2013 to 2016
2	227	219	+4%
5	285	272	+5%
10	324	307	+6%
25	377	356	+6%
50	421	395	+7%
100	468	438	+7%
200	520	485	+7%

2.1.5 Return Period Assessment for 2015 Event

Based on the predicted peak flow of 427 m^3/s for the December 2015 event and the final flood frequency curve at the site, the return period for the 2015 event is estimated to be approximately 1 in 50 to 1 in 55 years. The November 2012 event have a return period of 35 year.

2.2 Joint Probability Analysis

Joint probability describes the likelihood that two events will occur at the same time. In this study, we considered the joint probability of an extreme still sea level occurring at the same time as an extreme flood flow within a river. There has been much research into this issue and the estimation of joint probabilities is covered by many publications including Environment Agency (EA 2005). EA (2005) describes a desk study method that predicts joint probability based on the degree of dependency between the two variables.

2.2.1 Extreme Sea Levels

Following completion of the previous Newton Stewart Flood study, further work on the estimation of coastal boundaries was undertaken on behalf of SEPA. The original; DEFRA, SEPA, and EA ('Coastal boundary conditions for UK mainland and islands', EA 2011), which gives the predicted still water levels (astronomical tides and storm surges) around the UK coastline, has been extended with the new data covering estuaries and sea lochs including data points approximately 0.7 km downstream of the A75.

The updated water levels within estuaries vary compared to the original open sea extreme water levels; local hydraulic effects within estuaries will tend to funnel extreme sea levels as they pass inland, elevating water levels above those predicted for the open coast.

Extreme sea levels (still water levels) for a range of return periods based on DEFRA/EA/SEPA study at the location of the mathematical model downstream boundary, close to Knockdoon are provided in Table 6.

Table 6: SEPA Extreme Sea levels at the location of the mathematical model downstream boundary

Return Period	Extreme Sea level (m AOD)[a]	Confidence Interval (m)
1 year	5.38	±0.2
2 year	5.51	±0.2
5 year	5.67	±0.2
10 year	5.78	±0.2
25 year	5.93	±0.2
50 year	6.03	±0.2
100 year	6.13	±0.3
200 year	6.23	±0.3
1000 year	6.41	±0.4

a. Values for DEFRA/EA Point 1524-12-Main M

2.2.2 Impact of climate change

There are a number of methods for the estimation of the effect of climate change on sea levels.

DEFRA guidance (2006) provides estimates of the likely effect of climate change on sea water levels over the next century for areas around the UK coastline, Table 7. Between 2010 and 2085 the DEFRA guidance would indicate a sea level rise of around 0.55 m for most of Scotland.

Table 7: Adjustments due to climate change, DEFRA (2006)

Component	1990 - 2025	2025 - 2055	2055 - 2085	2085 - 2115
New sea level rise (mm / year)	2.5	7.0	10.0	13.0
Increase in extreme wave height	+ 5 %	+ 5 %	+ 10 %	+ 10 %

SNIFFER (2008) provides a review of available research on the effect of climate change on sea levels, storm surges and wave heights around the Scottish coast. The report does not give guidance on estimates to be used for design, but indicates that sea level rise in this part of the Solway Firth might be expected to be of the order of 1.6 - 35 cm by 2080 depending on the climate change model scenario used.

UKCP09 provide the latest climate change predictions for a range of parameters, including sea level. The UKCP09 provides predictions for a range of emissions scenarios (High, Medium and Low) and provides results as a probability distribution. Predictions nearest to the Cree provided in Table 8. At present, there is no guidance as to the most appropriate emissions scenario and exceedance percentile to use for flood risk assessments in Scotland.

Table 8: UKCP09 sea level rise estimates (m) at the mouth of the Cree (2014 – 2085)

Emissions Scenario	Net Sea Level Rise (m)		
	5% probability	50% probability	95% probability
Low	0.05	0.18	0.31
Medium	0.06	0.23	0.40
High	0.08	0.29	0.51

Based on raw data output from UKCP09 user interface

Based on the available sea level rise estimates, values ranging from 0 – 0.55 m are available from the three methods. This assessment is based on the most recent UKCP09 model results. Based on these results and to take into account the inherent uncertainty involved in estimating sea level rise, this assessment considers:

- 0.23 m is likely to be the 'best estimate' of sea level rise due to climate change (UKCP09, Medium Emissions, 50%ile) i.e. the value appropriate for derivation of the 1 in 200 year + climate change flood water level.

2.2.3 Joint Probability Analysis

An extreme, 1 in 200 year high tide level has a 0.5 % chance of occurring once during any year and when it occurs it will have a duration of only a couple of hours or so. In a similar way, a 1 in 200 year fluvial flow also has a 0.5 % chance of occurring once during any year and will also have a duration of a few hours only. Hence, the likelihood that both events will occur at the same time is very small.

Calculations in this report were undertaken using methods outlined in EA (2005). Fluvial flows and extreme still water levels between the Cree (81002) are 'strongly correlated' and given a dependence measure (χ factor) of 0.11 (from Figure 2 in FD2308 TR2 and from Table 4.7 of FD2308 TR1). Using the methods outlined in EA (2005) different combinations of fluvial flows and still water level return periods are found to have a 200 year probability of occurring together. In this report, each of these combinations of fluvial flow and sea level are considered and the combination(s) giving the highest peak water level(s) at points along the Cree is determined.

Joint probability extremes of sea levels at the model boundary and fluvial flow in the Cree are provided in Table 9.

Seven different combinations of design still water levels are selected and matched with return period flows that would produce 200 year risk (0.5% risk) within the study area.

Model scenarios are considered for different combinations of sea level and river flow to assess the worst case 200 year conditions at the site.

Table 9: 200 year Joint Probability assessment for the River Cree

Scenario	Respective return periods (years)		Extreme values for present day (2012)		Extreme values for future scenario (2085)	
	Sea Level (m AOD)	River Flow (m^3/s)	Sea Level (m AOD)	River Flow (m^3/s)	Sea Level (m AOD)	River flow (m^3/s)
1	2	200	5.51	520	5.83	260
2	5	97	5.67	470	6.00	228
3	10	48	5.78	420	6.14	201
4	20	24	5.88	380	6.26	183
5	50	10	6.03	320	6.43	148
6	100	5	6.13	280	6.56	130
7	200	2	6.23	230	6.68	110

The above 7 scenarios were modelled using the mathematical model; maximum water levels were noted to occur during scenario 1, which indicated that extreme flooding in Newton Stewart is fluvially dominated. Therefore, the assessment has been undertaken using scenario 1 arrangement to assess peak flood events in the Cree. To be conservative a 2 year extreme sea level was used in all model runs (i.e. 5 year flow occurring with a 2 year sea level etc.)

3 Updated Mathematical Modelling

Following the December 2015 flood event there were several factors which could significantly affect the modelling results previously produced. These include:

a) Changes taken place within the main channel of the river, particularly downstream of Cree Bridge;
b) Removal of Sparling footbridge; and
c) Increased design flows.

Design flows were updated as outlined in the previous section. A topographical survey was carried out of the main channel of River Cree through Newton Stewart to capture changes taken place during the December 2015 flood event.

3.1 New Information and Model Updates

As part of the update, 11 new cross sections have been re-surveyed and compared against the original survey. Comparing the post and pre-December 2015 surveys indicated that there are no significant differences in the bed level and channel shape both upstream and downstream of Cree Bridge, with the exception of some changes in bed and channel shape immediately downstream of the weir. Small changes noted in the channel bed level would not have a significant effect on flooding risk along the river.

The model has been updated using the new survey information.

The following main updates have been included in the model:

- Additional cross sections taken at the metal footbridge (upstream of confluence with Penkiln Burn);
- Metal footbridge structure (upstream of confluence);
- Five new cross sections included upstream of the Main Cree Bridge;
- Cross section downstream of the weir has been updated;
- Six new cross sections included downstream of the masonry weir;
- Three new cross sections added to extend the downstream boundary to the south.

It should be noted that most of the above cross sections replaced previous sections, although there were no significant differences between the two sets.

Following the updates to the 1D model, the associated 2D model references have also been updated, i.e. to link new cross sections to 2D domain etc.

3.2 Simulation of 2015 Event

The updated model was then calibrated against the December 2015 flood event. The 2015 event was unique in that the event was not only the worst recorded event, a wall collapsed on Riverside Road which weakened the defences and resulted in significantly more flow passing along Victoria Street than may have been envisaged.

In addition, a significant volume of debris was noted on the Sparling footbridge and within hedges along the left bank of the channel in the vicinity of the bridge. Bed level and shape of the channel immediately downstream of the masonry weir were also altered by scouring.

The Sparling bridge has been removed and is due to be located 100m downstream at a level above 1:200 + Climate Change event. Given heightened levels on west bank, only the east side will require a ramp access.

Based on the above outlined specific factors associated with the December 2015 flood event, not all the aspects of the updated model to represent this event would be relevant to the river at other times (past and future). For example, the collapsed wall has since been repaired and Sparling footbridge, which was present during the event, has been removed. Therefore, simulation of the December 2015 event and any modifications made to the model would largely apply to this event only and cannot be extrapolated to other events and times.

3.2.1 2015 event data

Data available for the 2015 event has been obtained from a number of sources including:

- SEPA Gauge;
- Local news reports;
- Local news photographs;
- Social media photos;
- Local professional photographer photos; and
- Site observations immediately after the event.

Minimum flood depths and water levels have been estimated using known topographical data and the information collated from the above sources. Table 10 shows the predicted water levels at various locations along the river. The available photographs showing flooding in these areas are provided in Appendix A.

3.2.2 Model run and results

Peak flow representing the December 2015 flood event was determined from gauge data and refined hydrological analysis summarised in Section 2. The estimated peak flow was then split between River Cree and Penkiln Burn based on the proportion of their catchment areas.

For the downstream boundary of the model, recorded tide levels at Kirkudbright Bay tide gauge was obtained and this level was adjusted by the level difference between Kirkudbright and River Cree based on SEPA Coastal Boundary conditions for a return period similar to the recorded tide level at Kirkudbright. For the December 2015 event, this difference was calculated to be approximately 0.2m.

Both boundaries were run for their recorded time periods, i.e. boundary peaks were not set to match.

The wall which collapsed during the event was removed from the model and flood waters were freely able to spill on to Riverside Road at this point and then flow to Victoria Street.

Comparison of predicted and observed water levels at a number locations along the river is shown in Table 10.

Table 10: 2015 model calibration points

Location	2015 Flood Level (m AOD)	Predicted Water Level (m AOD)
Meal Mill	At least 11.25	11.1
Hazelbank House	At least 10.7	10.9
Reid Terrace	At least 10.5	10.5
Riverside Cottage	At least 10.2	10.5
Rosebank Cottage	At least 9.9	10.1
Riverside Road	At least 9.7	9.8
Creebridge Road	At least 9.6	9.6
Morton's Entry	At least 9.3	9.4
Victoria Street	At least 9.3	9.4
Penkiln Terrace	At least 12.4	N/A
SEPA Gauge	8.961	8.99

As can be seen from Table 10, the predicted peak water levels correlate well with the observed water levels at most locations, including at the SEPA gauge where water levels were found to be within an acceptable range.

One area where the model underpredicted water levels was on the left bank of the Penkiln Burn, upstream of the confluence with the River Cree. Flood waters were recorded overtopping the left bank and inundating high ground; however, this flooding mechanism was not predicted. There may be a few reasons why this may have occurred; however, most likely reason is the proportioning of flows between River Cree and Penkiln Burn based on their catchment areas. It is likely that, depending on the propagation of the storm, the proportion of peak flows in each watercourse could change. The other reason could be timing of the peak flows in each watercourse. It is therefore possible to increase flows in Penkiln Burn and adjust Cree flows accordingly so that combined flow passing downstream is the same as at present. This would result in higher water level along Penkiln Burn and no change to water levels downstream of the confluence.

For the purposes of this assessment, correlation between the predicted and observed water levels presented in Table 10 was considered reasonable.

3.3 Design Flow Runs

The model was then adjusted by reinstating the collapsed section of the wall at Riverside Road. The adjusted model was then run for a range of design flows as listed in Table 11. The predicted peak water levels for 5, 10, 25, 50, 100, 200, and 500 year rerun periods are shown in Table 12. The correspond flood extent maps are provided in Appendix B.

Table 11: Modelled scenarios

Run No.	Scenario	Peak flow in River Cree (m^3/s)	Peak Flow in Penkiln Burn (m^3/s)	Downstream Water Level (m AOD)
1	Q200+CCT2	539	91	5.51
2	Q500T2	444	76	5.51
3	Q200T2	449	76	5.51

4	Q100T2	400	68	5.51
5	Q50T2	359	60	5.51
6	Q25T2	319	54	5.51
7	Q10T2	272	46	5.51
8	Q5T2	238	40	5.51

Table 12: Updated model results

Location	5 year	10 year	25 year	50 year	100 year	200 year	500 year
CR022	12.90	13.04	13.29	13.44	13.62	13.80	14.07
CR021	12.79	12.92	13.17	13.31	13.48	13.66	13.93
CR020	12.50	12.62	12.86	13.00	13.15	13.32	13.60
CR019	10.89	11.02	11.33	11.58	11.88	12.14	12.47
CR018	10.45	10.63	11.03	11.33	11.65	11.99	12.44
CR017	9.98	10.11	10.38	10.54	10.73	10.98	11.28
CR016	9.95	10.08	10.35	10.51	10.71	10.95	11.24
CR015	9.79	9.93	10.21	10.38	10.60	10.86	11.13
CR014	9.69	9.83	10.13	10.31	10.53	10.80	11.08
CR013	9.50	9.64	9.91	10.08	10.27	10.50	10.71
S3_US	9.38	9.53	9.81	9.98	10.18	10.42	10.62
CR012	9.16	9.31	9.59	9.75	9.95	10.20	10.38
CR011	8.85	8.98	9.22	9.36	9.56	9.88	9.98
CR010	8.52	8.64	8.87	9.02	9.22	9.55	9.63
CR009	8.41	8.50	8.68	8.78	8.95	9.34	9.26
CR008	8.33	8.42	8.60	8.70	8.86	9.28	9.18
CR008A	8.26	8.38	8.60	8.71	8.86	9.28	8.96
CR007	7.70	7.78	7.95	8.06	8.22	8.40	8.72
CR006	7.33	7.44	7.71	7.90	8.13	8.33	8.69
CR007	7.70	7.78	7.95	8.06	8.22	8.40	8.72
CR005	7.01	7.17	7.49	7.69	7.94	8.17	8.52
CR004	6.89	7.06	7.39	7.59	7.83	8.07	8.42
CR003	6.46	6.56	6.77	6.90	7.05	7.21	7.42

4 Possible Flood Mitigation Option

The assessment carried out previously indicated that a flood mitigation scheme consisting of flood walls/earth embankments and Property Level Protection (PLP) may be able to provide a practical option with a positive benefit-cost ratio.

Walls: These would be engineered flood walls capable of containing flood waters up to the design water level above which flood waters would be able to overtop the walls. At this stage only standard walls have been considered and no consideration has been given to type of wall or wall finish which will be assessed during the next stage.

Embankments: These would consist of earth bunds and would be made of suitable soil, compacted and landscaped to suit local conditions. At this stage limited areas at the car park on Riverside Road may be considered suitable for such defences. Other possible areas for use might be the bank opposite the car park and along Arthur Street if defences are placed away from the bank of the river and adjacent to the road.

Property Level of Protection: These would include, but not necessarily limited to:

a) Manual/Automatic door guards;
b) Manual/Self-closing airbricks and covers;
c) Non-return valves on sewer pipes;
d) Re-pointing external walls (up to 0.6m above ground level with water resistant mortar);
e) Silicone gel sealant around service and cable entry points;
f) Sump pump;
g) Resilient plaster (up to 1m); resilient doors; windows and frames; resilient kitchen; raised electrics and appliances; and concrete/sealed floors.

A recent study commissioned by DEFRA[2] showed the benefits of such defences where a wider flood mitigation scheme is not technically feasible or financially viable. This followed by a study for Scottish Government[3] which aims to quantify how many properties and businesses might benefit from property level protection (PLP), now and in 2035, and what the costs and benefits of providing PLP within Scotland may be. The results have been presented at both a national level (to inform policy decisions) and at a regional level (to assist local authority decisions). However, the analysis is based on SEPA indicative flood mapping and more detailed analysis will need to be carried out for specific watercourses.

[2] Establishing the Cost Effectiveness of Property Flood Protection: FD2657, August 2012, JBA.
[3] Assessing the Flood Risk Management Benefits of Property Level Protection: Technical and Economic Appraisal Report - Final Report v2.0 November 2014

4.1 Mitigation Measures Considered

Initial mitigation measures considered showed that raising of the Sparling footbridge at Riverside Road will need to be part of any options considered as it affects local water levels upstream. However, the bridge was damaged during the December 2015 flood and has since been removed. It was shown in the original study report that raising the deck of the footbridge above flood level reduces peak water levels by approximately 0.45m immediate upstream of the bridge. This gradually reduces to nil at the weir downstream of Cree Bridge.

Removal of the gravel berm (island) downstream of Cree Bridge and dredging could also provide a small local benefit which would not have a significant effect on flooding risk, however, historical maps suggest that sediment will likely continue to deposit in this area and the island will likely form again. Therefore, these measures are not considered as viable long term measures. It is suggested that a visual assessment is made of the size of the island from time to time and if a continues and sustained increase in the size of the island occurs then consideration should be given to removing excessive sediment from the area.

Some sediment has also deposited immediately upstream of Cree Bridge. It is not expected that sediment accumulation in this area would continue to increase as flow velocities increase approaching the bridge and the weir, and sediment accumulated there during normal flows would be washed down during the next flood.

Based on the above and observations made during a number of walkover surveys, a combination of the following flood mitigation measures are considered practical and may be able to provide an acceptable level of protection.

- Raising of existing flood walls where appropriate;
- Construction of new flood walls and embankments where appropriate; and
- Property Level Protection (PLP);

In order to provide up to, say, 100 year level of protection, all properties within the 100 year flood extent shown in Figure 6 were considered.

In broad terms, the areas where flood defences would be required can be split into four sections. These are:

Reach 1: West bank downstream (south) of Cree Bridge;
Reach 2: West bank upstream (north) of Cree Bridge;
Reach 3: East bank upstream (north) of Cree Bridge; and
Reach 4: East bank downstream (south) of Cree Bridge

Potential mitigation measures for each of these reaches have been considered below.

4.1.1 West bank downstream (south) of Cree Bridge

This section extends between Cree Bridge and south side of the car park adjacent to the former Sparling footbridge and runs along Riverside Road. Along this section, direct defences in the form of flood walls and raised ground levels (or earth bunds) at the car park are proposed.

Consideration was given to raising of existing wall along Riverside Road. On average existing defences would need to be raised by 0.4m (given a total wall height above pavement of the order of 1.2m). However, although the existing wall appears in reasonable condition, raising the wall require either replacing it with a new wall from river bed or constructing a new wall on the roadside of the existing wall. Replacing the entire wall is likely to be more expensive, therefore consideration was given to constructing a new wall on the roadside of the existing wall. Possible line of defence along the road is shown in Figure 3.

As existing pavement along the riverside is narrow (see photo below), constructing a new wall along the pavement would mean that there would be no pavement left along the riverside. An alternative option may be to make Riverside Road a 'One-Way' street which would allow a new wall being constructed on the roadside of the existing wall and still leave sufficient room for a standard pavement along the river. This would not only provide flood protection, but would enhance the amenity of a riverside walk, improve safety and enable the incorporation of rationalised surface water drainage.

Within the existing car park, sufficient width exists to allow for some reduction in the surfaced area of the car park, to create additional width within which a heightened earthwork bund could be created, raising the level of the existing riverside path, and thereby enhancing flood protection accordingly.

Figure 3: Possible defences for Riverside Road

If the former Sparling footbridge were to be constructed within this reach of the river, its deck level will need to be above the flood level and its impact on peak water levels minimised as much as possible. However, it is understood that most likely location for the new bridge may be immediately downstream of this reach.

4.1.2 West bank upstream (north) of Cree Bridge

Along this section direct defences in the form of flood walls and an earth bund are proposed.

Possible flood mitigation options considered include:

- Option 1: Raising and repairing existing walls, utilising a similar detail to that proposed at Riverside Road;
- Option 2: Construction of new low flood wall with flood gate access alongside the road/rear of footway.

Both options are considered in combination with PLP where appropriate.

There are uncertainties with Option 1 as the structural integrity of existing walls is not known in detail. It was reported that during the 2012 flood event, these walls were not overtopped, but flood waters were able to go through the walls (presumably through cracks, and other gaps) and cause flooding.

For Option 1, there are significant challenges to protect the single property at No. 55 Arthur Street. A significant amount of work may be required to protect this property and this may not be cost effective.

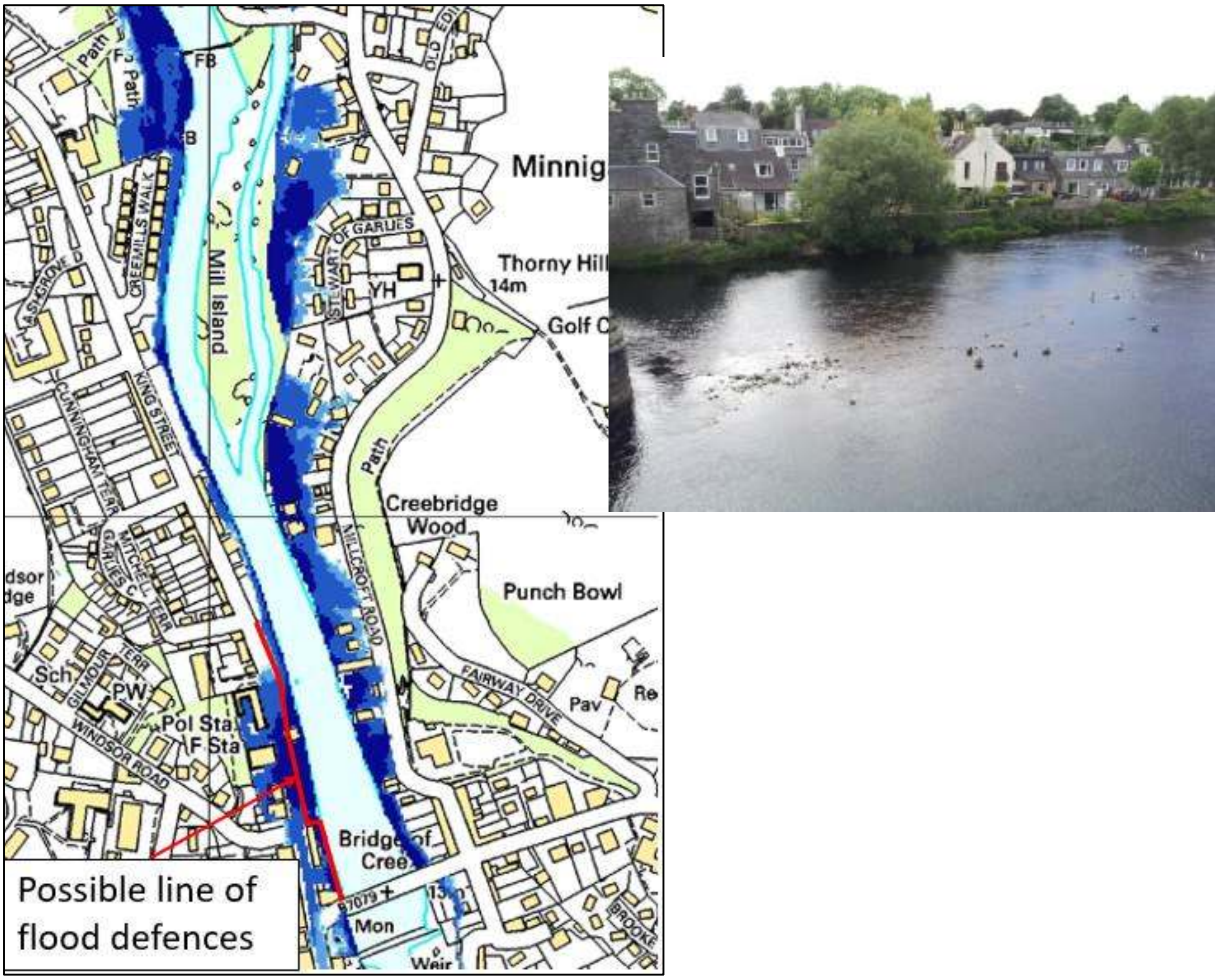
Option 2 would be simpler, and therefore less costly. However, existing flood defences along the river bank protecting properties between the bridge and Windsor Road junction may have to be repaired and raised where necessary. Upstream, north of Windsor Road, the property at 55 Arthur Street is at risk and there does not appear to be simple ways of protecting this property. Even if it was surrounded by walls on all three land sides, flood waters could either enter the building from the riverside window or come up the floorboard. As no practical mitigation measures could be developed for this property, it has been left within the floodplain and without protection. However, it provides a flow path to Arthur Street and without any measures Arthur Street would still flood through this property even if all the other areas were protected.

Option 2 would also have the advantage of maintaining some of the existing floodplain of the river, upstream (north) of Windsor Road. It would, however, be necessary to carry out some work on the existing wall to stabilise it. With flood defences set back from the edge of the river, consideration could be given to lowering existing defences to increase conveyance and minimise the impact of the defences on peak water levels on the opposite bank.

It appears that Option 2 would not be tenable unless the existing property at 55 Arthur Street was demolished or made water-proof, with the latter likely to be extremely difficult and impractical. As indicated above, leaving it in in-situ could compromise the effectiveness of the flood defences which could jeopardise the scheme attracting grant aid from the Scottish Government.

Possible line of flood defences is shown in Figure 4.

Figure 4: Possible line of defences



4.1.3 East bank upstream (north) of Cree Bridge

Along this section of the river there are a number of properties which are at risk of flooding on the riverside of Millcroft Road, see Figure 5. At Reid Terrace, flood depths up to 1.3m have been predicted. In order to protect these properties a flood wall of the order of 0.5km long may be required.

The construction of a flood wall will be extremely difficult in places like Reid Terrace (Photo 1) due to:

- Severe access difficulties to enable construction of the wall and need for construction plant to be established on the riverside of the wall, with resulting environmental impacts and short term increased flooding risks on the properties opposite.
- Limited space for wall construction relative to front of riverside properties.
- Impact of heightened wall on outlook from properties, and visual appearance from west bank of river.
- Multiple ownership of properties to be protected leading to potential difficulties in achieving agreements/legal issues.

Notwithstanding the above, as the cost of such a wall would be very expensive, it makes the whole mitigation scheme economically unviable.

Photo 1: Reid Terrace from west bank

At this stage, the only practical option for the properties on the east bank of the river upstream of Cree Bridge appears to be PLP. It should be noted that PLP's are only effective for flood depths up to 0.8-1.0m. For those properties predicted to be at risk of flooding in excess of this, PLP's would still provide significant protection, but full 100 year level of protection may not be provided. However, protecting this area will need to be considered further in the next stage of the scheme.

In addition to PLP, making the properties resilient would help in future clean-ups, should floodwater inundate internally. With the recent launch of a Flood Warning System, PLP is more effective given warning times in excess of 3 hours.

4.1.4 East bank downstream (south) of Cree Bridge

Along this section, a limited number of properties are predicted to be at risk during a 100 year flood. It is possible to protect these properties either by a low flood wall/embankment between the river and the road (Figure 5) or by PLP.

Figure 5: Possible line of defences

5 Modelling of Proposed Mitigation Option

The flood mitigation options outlined in Section 4 indicate that most practical mitigation option appears to be:

1) Construction of a new flood wall along Riverside Road;
2) Repairing and where necessary raising existing wall between Cree Bridge and Windsor Road;
3) Construction of a wall/earth bund along the riverside of Arthur Street upstream (north) of Windsor Road;
4) Construction of a low flood wall/embankment between the former Sparling footbridge and the weir on the east bank; or protecting properties affected along this reach by PLP; and
5) Providing PLP for properties at risk of flooding along east bank of the river upstream (north) of Cree Bridge (where appropriate).

The above would provide protection to all properties on the west bank up to 100 year level of protection, except the property at 55 Arthur Street, which is left within the floodplain undefended.

The defence levels along the west bank were set to the predicted 100 year water level + 300mm freeboard. It should be noted that this level defence accounts for increases in water level should the properties along the east bank be protected by a flood wall in future, resulting in a similar level of protection along both banks.

No hard defences along the east bank of the river, upstream (north) of Cree Bridge are proposed. However, PLP and improvements to property to make resilient to ingress of water are considered for all properties at risk of flooding along this length of the river. Downstream of Cree Bridge, whether a hard defence (wall of embankment) will be used or PLP will be determined at the next stage.

The mathematical model was amended to include the mitigation option outlined above and the model results for the 100 year flood are shown in Figure 6. This assumes no hard defences along the east bank.

Model results indicated that, with the defences in place, there is no significant increase in peak water level throughout the modelled reach. Flood level increases in the region of up to 30-40mm are predicted.

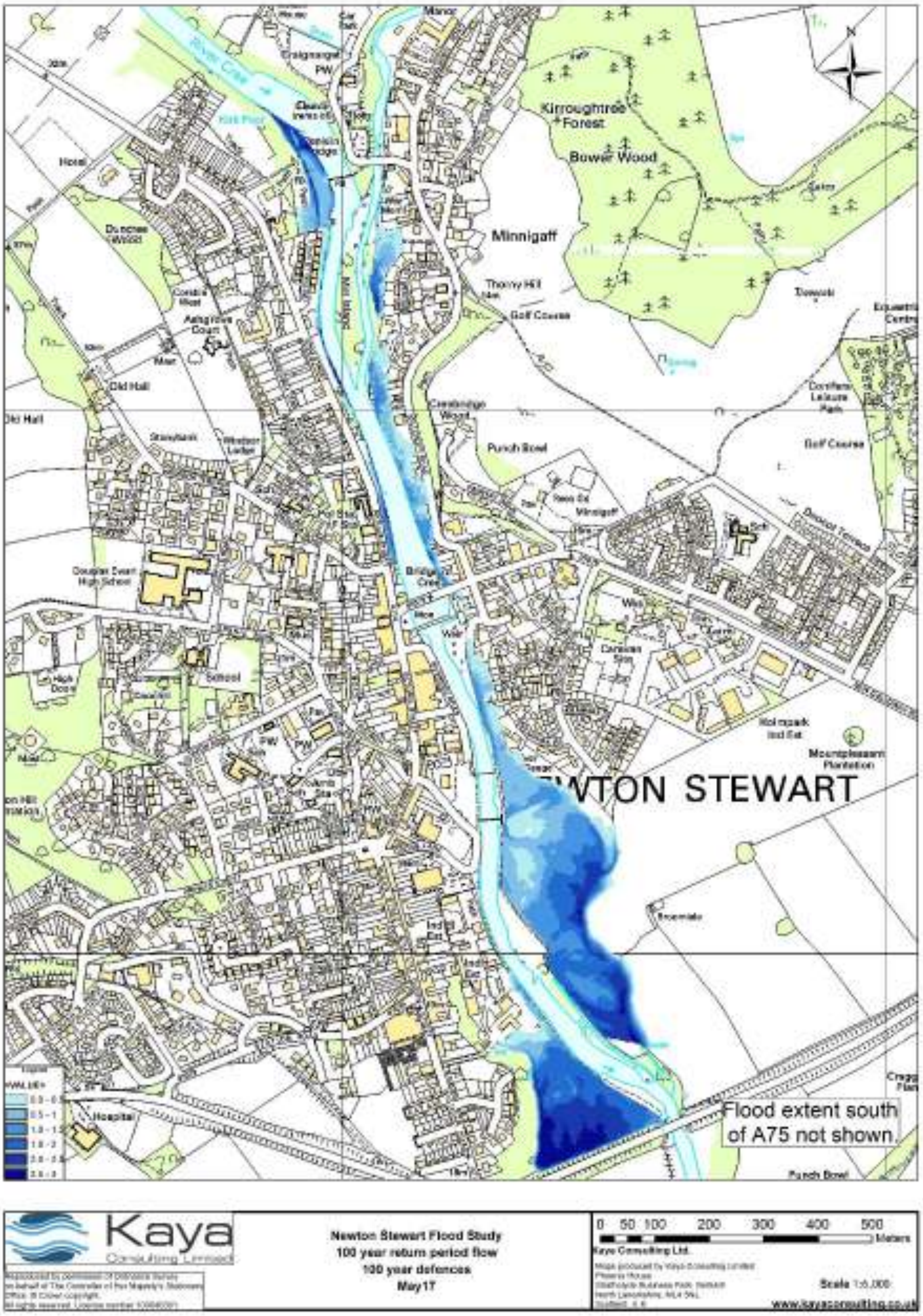
Although the proposed hard defences along the west bank raises water level in the river, this is largely negated by removed Sparling footbridge which lowered water level upstream of the footbridge.

Table 13 shows that the increase in water level upstream of Cree Bridge is up to approximately 30-40mm as a result of proposed defences.

Table 13: Comparison of water level with and without defences (downstream of Cree Bridge)

Location	100 year		200 year	
	Existing (m AOD)	Change in water level	Existing (m AOD)	Change in water level
Section 18	11.65	-0.05	11.99	-0.09
Section 17	10.73	0.04	10.98	0.03
Section 16	10.71	0.03	10.94	0.03
Section 15	10.60	0.03	10.86	0.01
u/s Bridge of Cree	10.48	0.04	10.75	0.01
d/s Bridge of Cree	10.27	0.04	10.50	0.09
Downstream of weir	10.01	0.06	10.26	0.01
Section 12	9.95	0.05	10.20	0.00
Section 11	9.56	0.03	9.84	-0.07
Section 10	9.22	-0.11	9.53	-0.27
Section 9	8.95	-0.07	9.34	-0.34
Section 8	8.86	-0.12	9.28	-0.40
Section 8A	8.86	-0.10	9.27	-0.37

Figure 6: Predicted flood extent for 100 year flood with proposed defences in place



6 Outline Cost Benefit Analysis

An initial cost-benefit analysis was undertaken as part of the original flood study in 2015, based on the model results at that time. A bias factor of 60% was added to cost estimates for the flood defence schemes as per standard practice. This increase in cost estimates aims to cover uncertainties affecting the scheme cost that could be encountered during the later detailed design stage, although an allowance is included in the capital cost for factors like utility diversion, preliminaries, etc. The bias factor is reduced as the design progresses and uncertainties are progressively eliminated.

Flood damage costs for a range of return periods were estimated using the standard Multi-Coloured Manual 2010. The assessment indicated that flood damage costs from a 200 year flood would be of the order of £3.7M. For a 10 year flood, the corresponding flood damage costs would be of the order of £0.26M.

Costs for construction of flood walls and embankments able to contain a 200 year flood event were estimated to be £16.1M which is equivalent to £25.8M, with 60% bias. A scheme with walls able to provide protection up to a 1 in 50 year event was estimated to cost £18M, with 60% bias.

The conclusion was that a scheme providing 1 in 200 year level of protection is unlikely to be economically viable (i.e. resulting in a benefit-cost ratio less than unity), whereas a scheme with a lower level of protection could be economically viable and has the potential to attract Scottish Government grant aid.

Subsequently, it was agreed at a meeting with local residents that flood mitigation options with a lower level of standard of protection should be considered. DGC has then commissioned additional studies to assess the feasibility of practical flood mitigation measures that would provide a lower level of protection and a positive benefit-cost ratio.

Initially, a level of protection of 75 years was considered. For such a scheme to be economically viable, the cost of mitigation measures will need to be lowered substantially, possibly through the use of Property Level Protection (PLP). A significant proportion of the cost of mitigation scheme is associated with protecting the properties on the east bank of the river upstream of Cree Bridge (i.e. on the Minnigaff side). If the properties in this area could be protected by PLP (where possible), this would significantly reduce the cost of the mitigation scheme and increase the benefit-cost ratio.

In view of the above, the outline cost-benefit analysis undertaken during the original study was refined assuming:

- Hard defences are provided along the west bank of the river (Arthur Street) with top of defences set at 75 year water level + 0.3m freeboard;
- The property at 55 Arthur Street is not protected and written off;
- £75,000 for buying out the property at 55 Arthur Street;
- Average cost of PLP per property of £10,000 plus £300 per property per annum for maintenance;
- All affected properties on the east bank with depth of flooding less than 0.8m were protected using PLP up to 75 year of risk.

This gives a benefit cost ratio of just over 2, indicating that such a scheme would be economically viable. This analysis included direct costs and benefits only and the final benefit-cost ratio will likely be higher if intangibles, social and environmental benefits are also included.

Manual PLP measures puts the onus on the occupiers to act before and during flooding to mitigate flood damage. However, automatic measures can be implemented where possible and practical. If not all at risk properties on the east bank were to be protected by PLP and some of these properties were flooded as at present, this would reduce the benefit-cost ratio. Assuming only half of such properties on the east bank use PLP, this would reduce the benefit-cost ratio to approximately 1.5.

Following the highest ever recorded December 2015 flood, a review of hydrological analysis indicated that the design flows for River Cree were increased as a result. This resulted in higher water levels along the river. Although the resulting extent of inundation and number of properties affected have not changed significantly, increased water levels resulted in higher flood damage costs, indicating that this would result in a higher benefit-cost ratio or alternatively a scheme with a higher level of protection may now be economically viable.

Using the updated design flows, the estimated flood damage cost during a 200 year flood increased from £3.7M to £4.7M. The properties at risk of flooding are summarised in Table 14.

Table 14: Estimated number of properties at risk of flooding

Level of protection (year)	Residential	Non-residential	Total
100	53	43	96
200	67	67	134

For 200 year level of protection with a scheme costing of the order of £16.1M (£25.8M with 60% optimism bias), the resulting benefit-cost ratio is still less than unity. This indicates that although increased design flows resulted in increased flood damage costs, these were not sufficient to offset the cost of the scheme over an assumed lifetime of 100 years. In order to achieve a positive benefit-cost ratio, a scheme costing no more than say of the order of £9M (£14.4M with 60% optimism bias) would be required. However, intangibles and other environmental benefits will need to be included at the next stage in order to achieve a better estimate.

6.1 Cost-Benefit Analysis of Mitigation Scheme Considered

An outline cost-benefit analysis was carried out for a scheme as summarised in Sections 4 and 5 and providing both 1 in 100 year and 1 in 200 year level of protection. This include the following:

- Construction of a new flood wall along Riverside Road;
- Repairing and where necessary raising existing wall between Cree Bridge and Windsor Road;
- Construction of a wall/earth bund along the riverside of Arthur Street upstream (north) of Windsor Road;
- The property at 55 Arthur Street is not protected and written off;
- £75,000 for buying out the property at 55 Arthur Street;
- Construction of a low flood wall/embankment between the former Sparling footbridge and the weir on the east bank; or protecting properties affected along this reach by PLP; and

- Providing PLP for properties at risk of flooding along east bank of the river upstream (north) of Cree Bridge (where appropriate).

Estimated capital cost of the scheme is £4.1M (£6.56M with 60% optimism bias) for the 100 year and £4.9M (£7.8M with 60% optimism bias) for the 200 year level of protection, Table 15.

Table 15: Estimated capital and maintenance costs

Level of protection (year)	Capital Cost (£M)	Maintenance over 100 years (£M)
100	4.1	1.3
200	4.9	1.3

Estimated benefit-cost ratio is 1.8 for the 100 year level of protection, assuming no properties on the east bank are protected, Table 16. This increases to 1.9 if half of the properties at risk along the east bank are protected by PLP. Similarly, for a 200 year level of protection, the corresponding benefit-cost ratios are 1.6 and 1.7.

Table 16: Estimated average benefit-cost ratios

Level of protection (year)	Benefit/cost ratio	
	No PLP	With 50% PLP
100	1.8	1.9
200	1.6	1.7

The above indicates that hard defences to protect all affected properties along the west bank (except 55 Arthur Street) and all affected properties along the east bank downstream (south) of Cree Bridge up to 200 year level with 0.3m freeboard and all those affected properties suitable for PLP on the east bank upstream (north) of Cree Bridge appears to be economically viable. The benefit-cost ratio will likely to increase with the addition of intangibles, environmental and social benefits.

At this stage, the above figures are based on broad assumptions. For example, there is uncertainty about the conditions of existing walls on the west bank immediately upstream of Cree Bridge and it is assumed that these walls can be repaired and made sufficiently good to operate satisfactorily during the lifetime of the scheme. The works along Riverside Road could potentially be combined with a public realm project to improve amenity value.

There is also uncertainty about the future of the property at 55 Arthur Street. At present, it is assumed to be left unprotected and flow path through it blocked.

The uncertainties associated with the above scheme will be reduced at the next stage and a better assessment will be made of the scheme costs. As a result, cost-benefit analysis will be refined as and when sufficient information n becomes availbale.

7 Conclusions and Recommendations

This addendum report updates the hydrological analysis undertaken previously prior to the December 2015 flood event, re-assesses flooding risk from updated design flows, and re-assesses economic viability of a practical flood mitigation scheme.

The highest ever recorded December 2015 flood at Newton Stewart resulted in increased design flows for the River Cree. Increased design flows result in increased water level along the river. Although this does not significantly change the extent of inundation previously predicted and number of properties affected by flooding, it increases the flood damage costs.

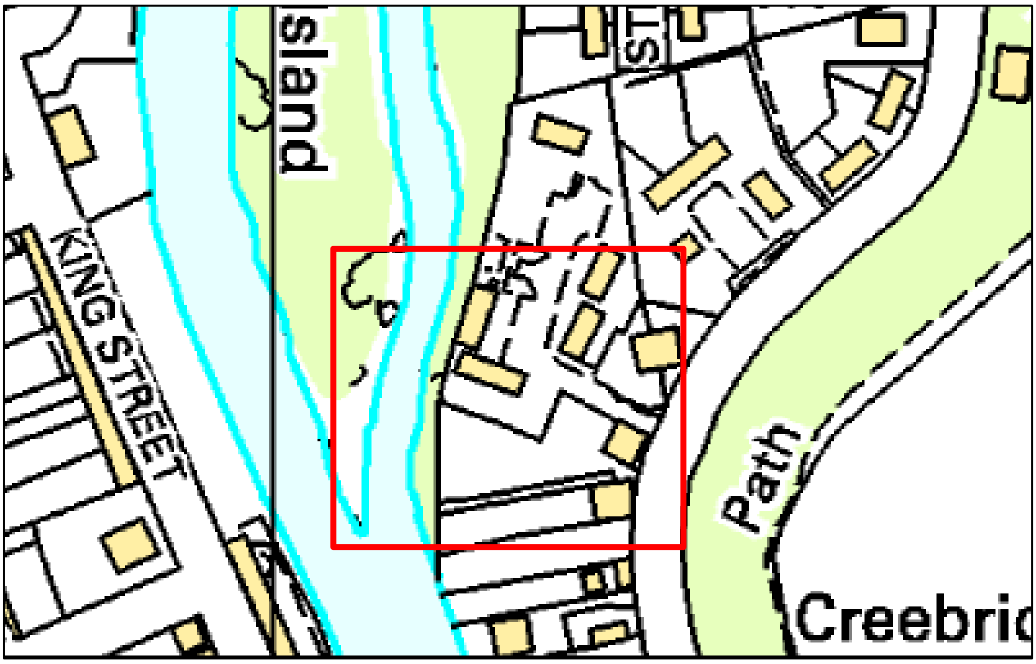
The re-assessment indicated that it may now be economically viable to protect all affected properties along the west bank of the river by hard defences and protect all affected properties along the east bank of the river downstream of Cree Bridge by either hard defences or Property Level Protection (PLP) and those affected properties suitable for PLP along the east bank upstream (north) of Cree Bridge. The level of defence considered is up to 1 in 200 year. Some properties along the east bank upstream of Cree Bridge will not be able to be protected as either protecting these areas by hard defences are disproportionally expensive or depth of flooding in these areas exceeds the effective height for PLP. However, PLP would still provide some benefits to these properties, albeit for flood events smaller than the design event.

Economic viability of a scheme to provide 200 year level of protection along both banks of the river should be further investigated at the next stage.

The above proposals will be progressed further at the next stage of the scheme, which Dumfries and Galloway Council has already commissioned for others to undertake.

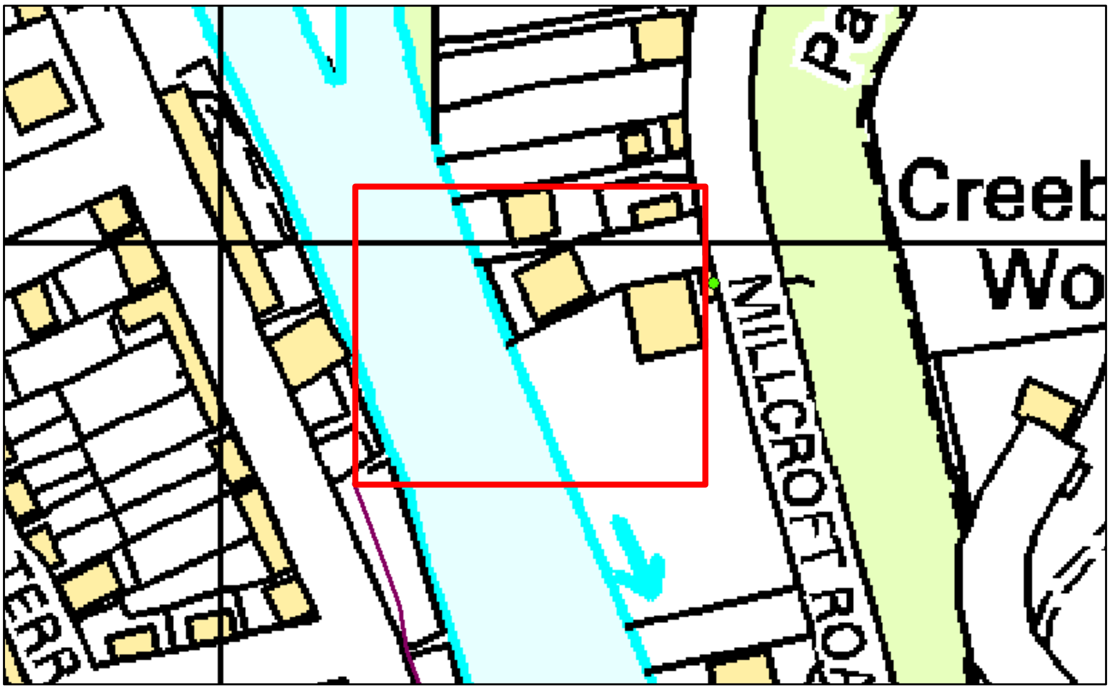
Appendix A: Flood Photos (December 2015)

Mealmill flooding, at least 11.25 m AOD. Credit Stephen Jolly -Source: Facebook



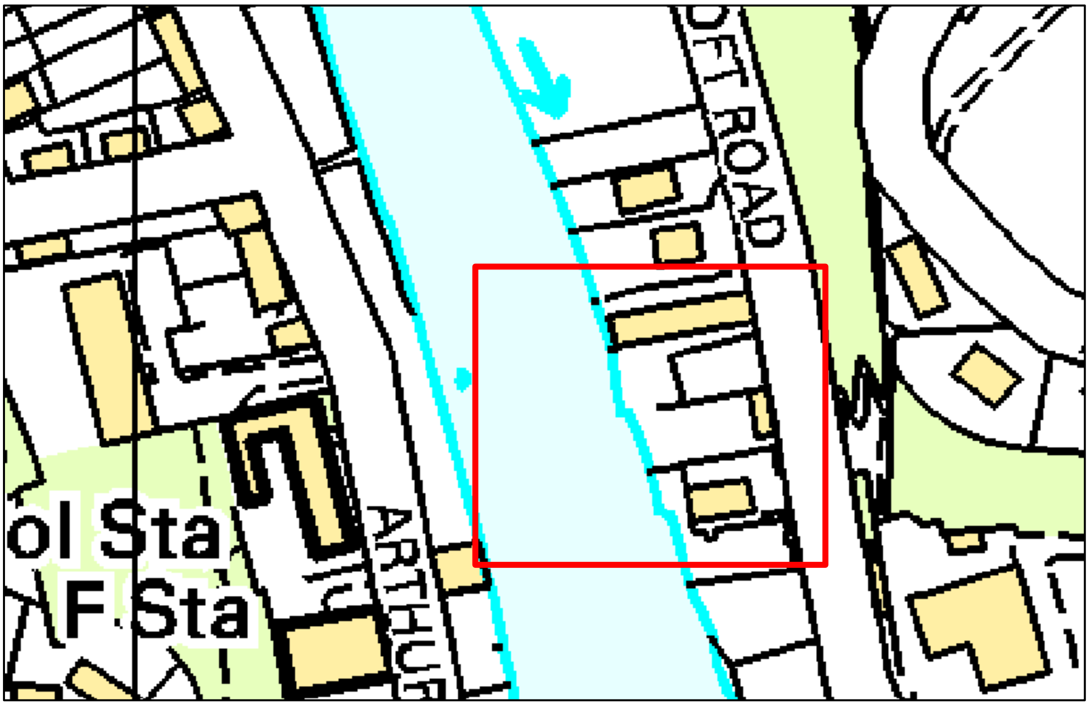
Penkiln Burn – Upstream of river confluence

Hazelbank flooding, at least 10.7 m AOD. Credit Stephen Jolly -Source: Facebook



River Cree – Downstream of river confluence

Reid Terrace flooding, at least 10.50 m AOD. Credit Stephen Jolly -Source: Facebook

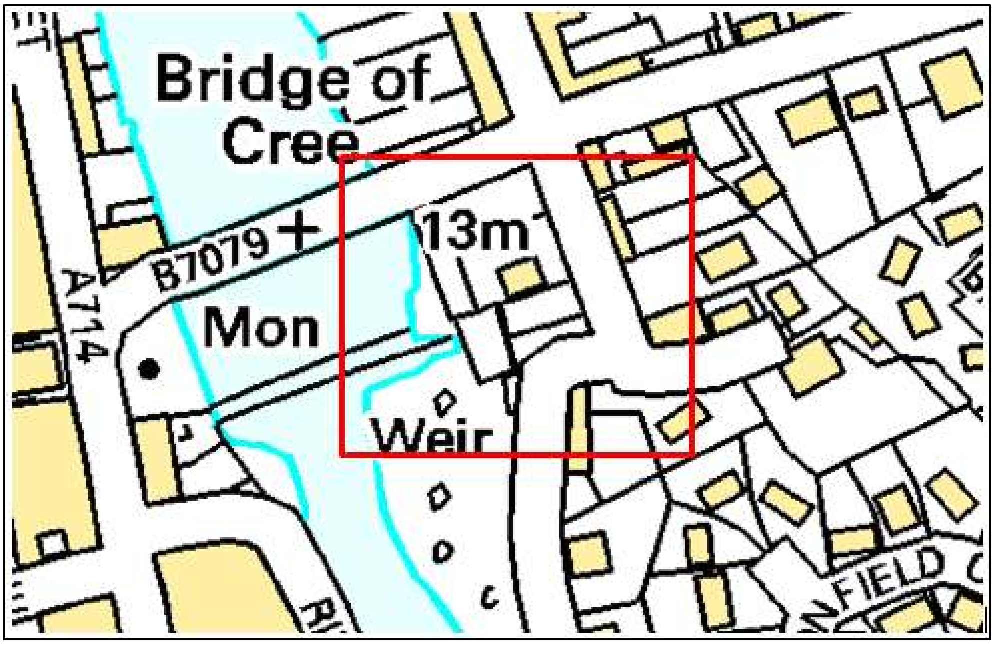


Reid Terrace on east bank of the channel.

Riverside Cottage flooding, at least 10.2 m AOD. Credit Stephen Jolly -Source: Facebook

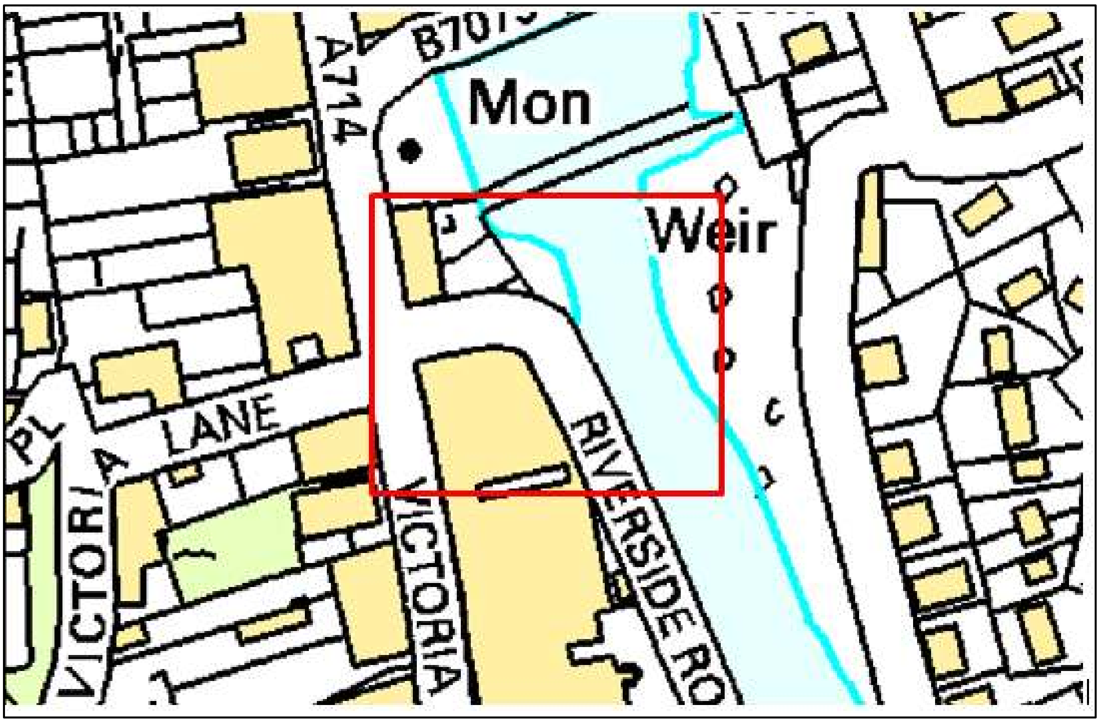
River Cree – Downstream of Reid Terrace

Rosebank Cottage flooding, at least 9.9 m AOD. Credit Stephen Jolly -Source: Facebook



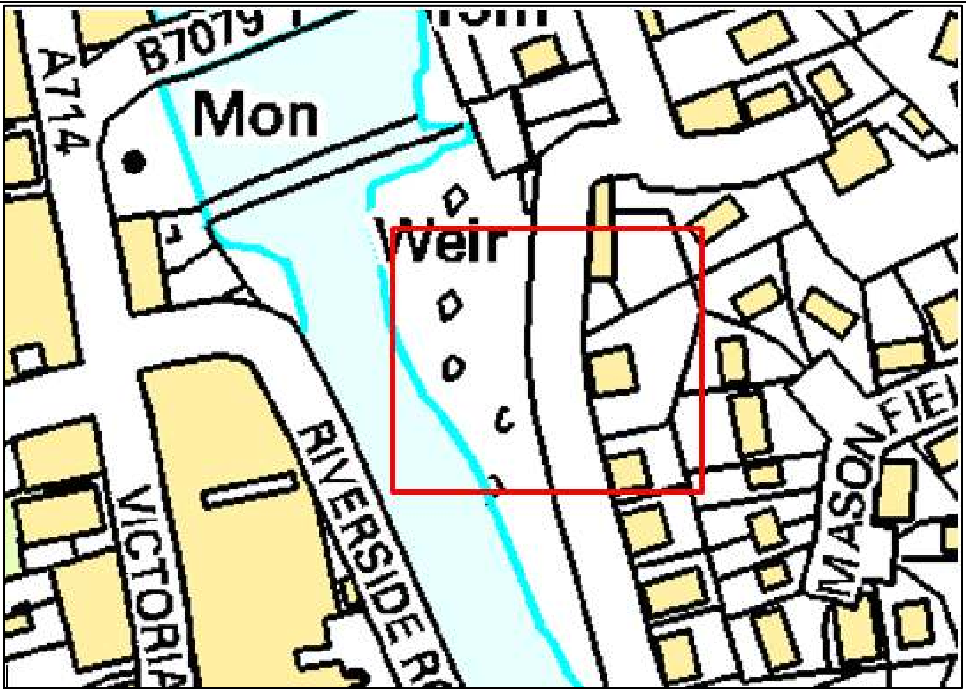
River Cree – Downstream of main River Cree bridge

Riverside Road flooding, at least 9.7 m AOD. Credit Stephen Jolly -Source: Facebook

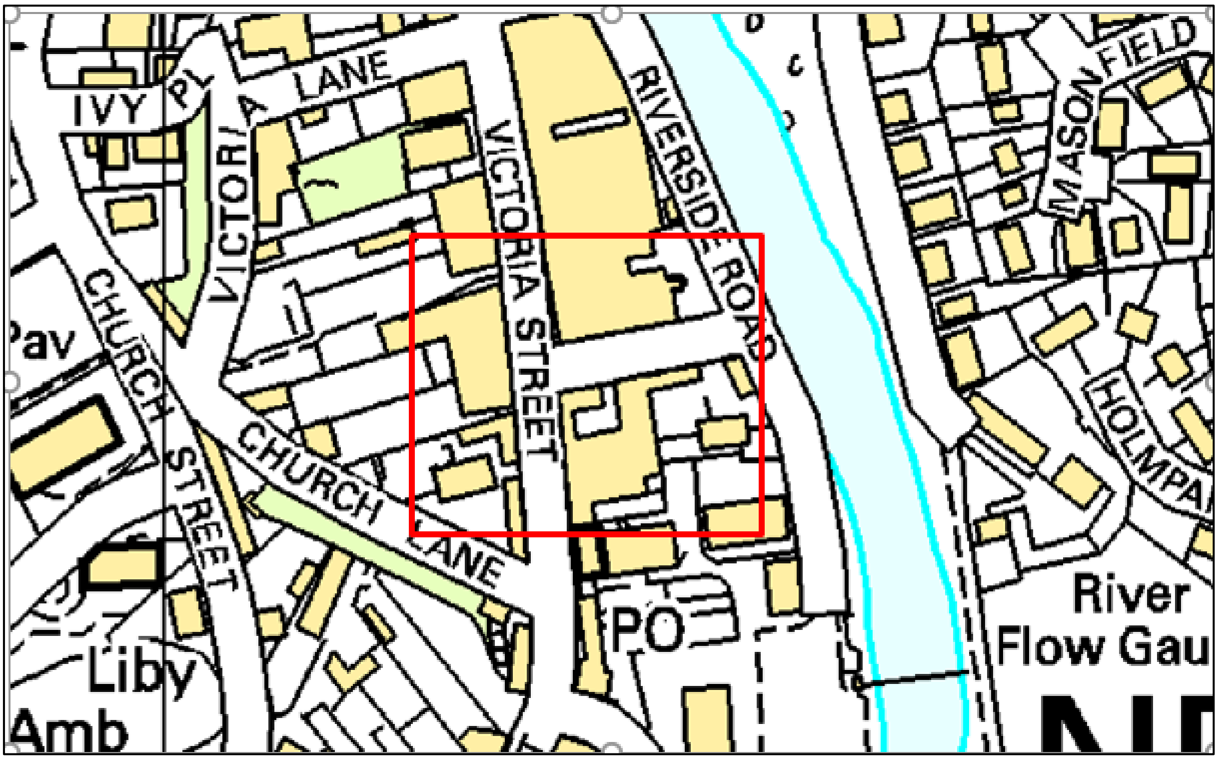


River Cree – West bank, downstream of weir

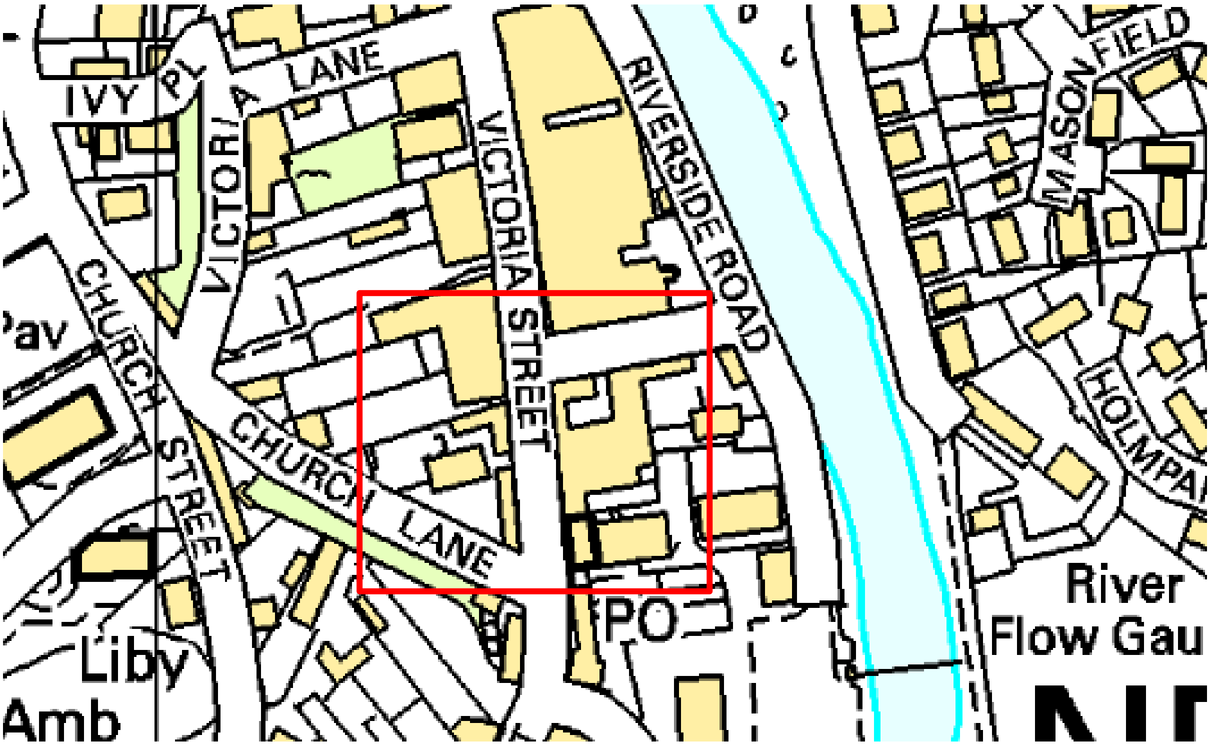
Creebridge Road, at least 9.6 m AOD. Credit Newton Stewart flooding and Helping Page -Source: Facebook



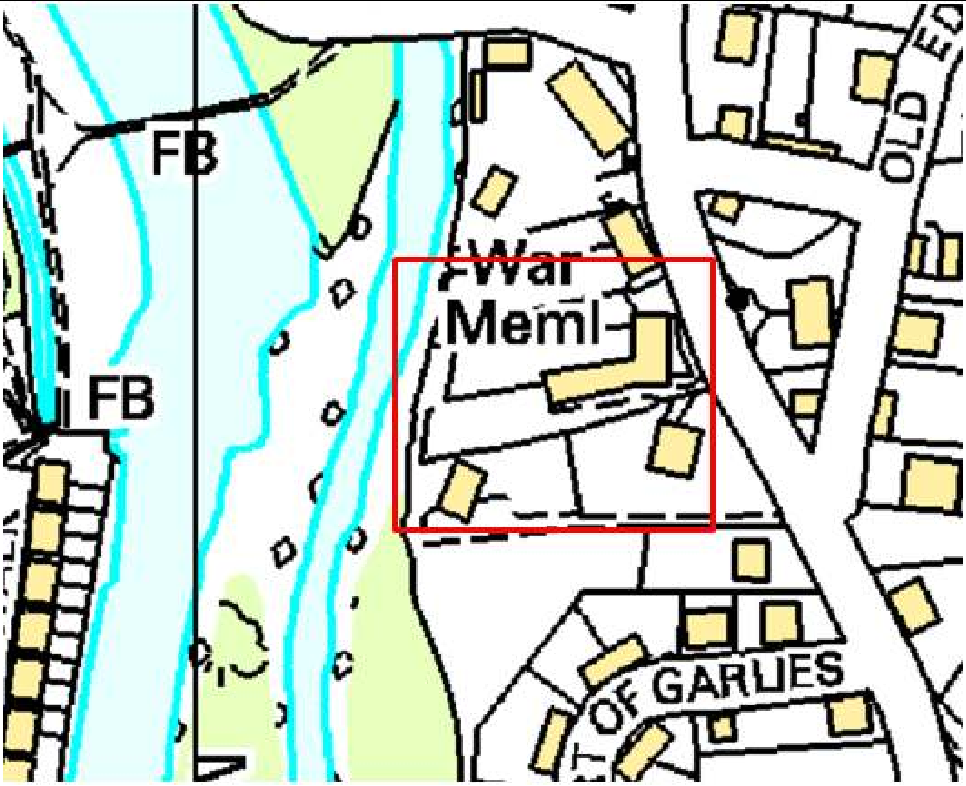
River Cree – Opposite Riverside Road, downstream of weir


Morton's Entry flooding, at least 9.3 m AOD. Credit Eric Sloan -Source: Galloway Gazette website

River Cree – Victoria Street

Victoria Street flooding, at least 9.3 m AOD. Credit Eric Sloan -Source: Galloway Gazette website



River Cree – Victoria Street

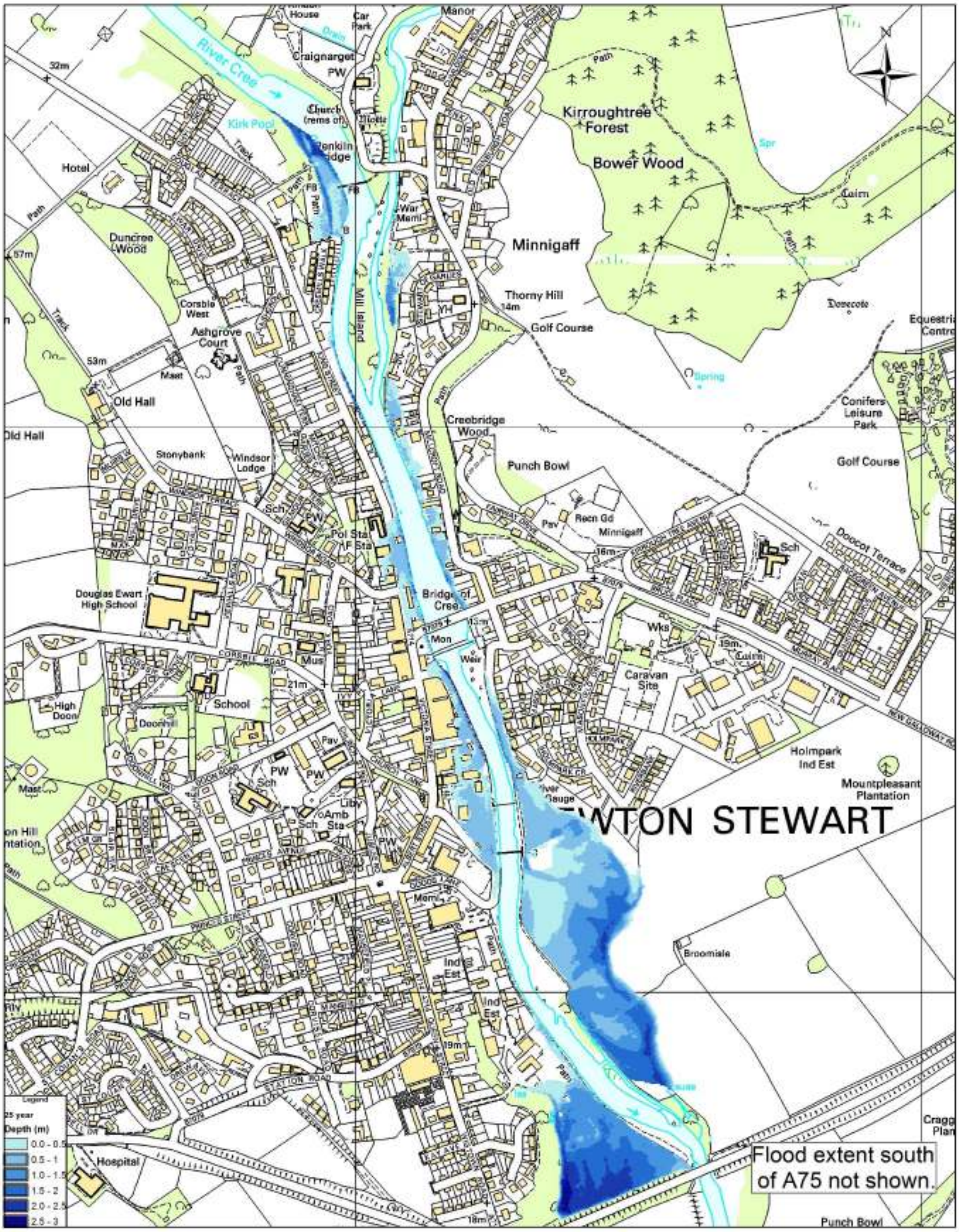

Penkiln Terrace flooding, at least 12.3 m AOD. Credit Stephen Jolley

Penkiln Burn – Upstream of confluence

Appendix B: Flood Maps

Figure 7: 5 year Flood Map

Figure 8: 10 year Flood Map

Figure 9: 25 year Flood Map



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Newton Stewart Flood Study
25 year return period flow
May 17

0 50 100 200 300 400 500 Meters

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North Lanarkshire, ML4 3NJ,
Scotland, U.K.

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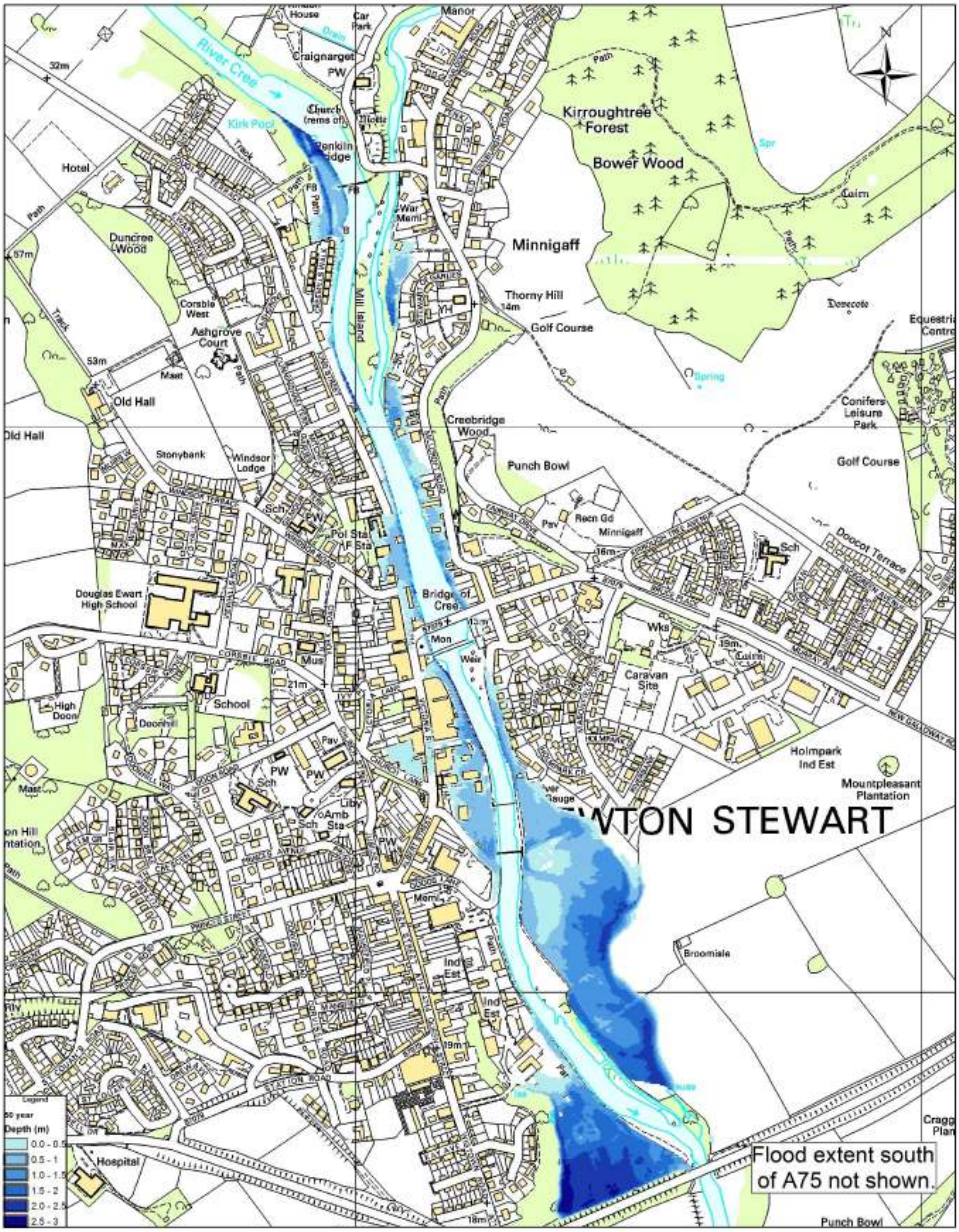
Figure 10: 50 year Flood Map



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Newton Stewart Flood Study
50 year return period flow
May 17

0 50 100 200 300 400 500 Meters

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Figure 11: 100 year Flood Map

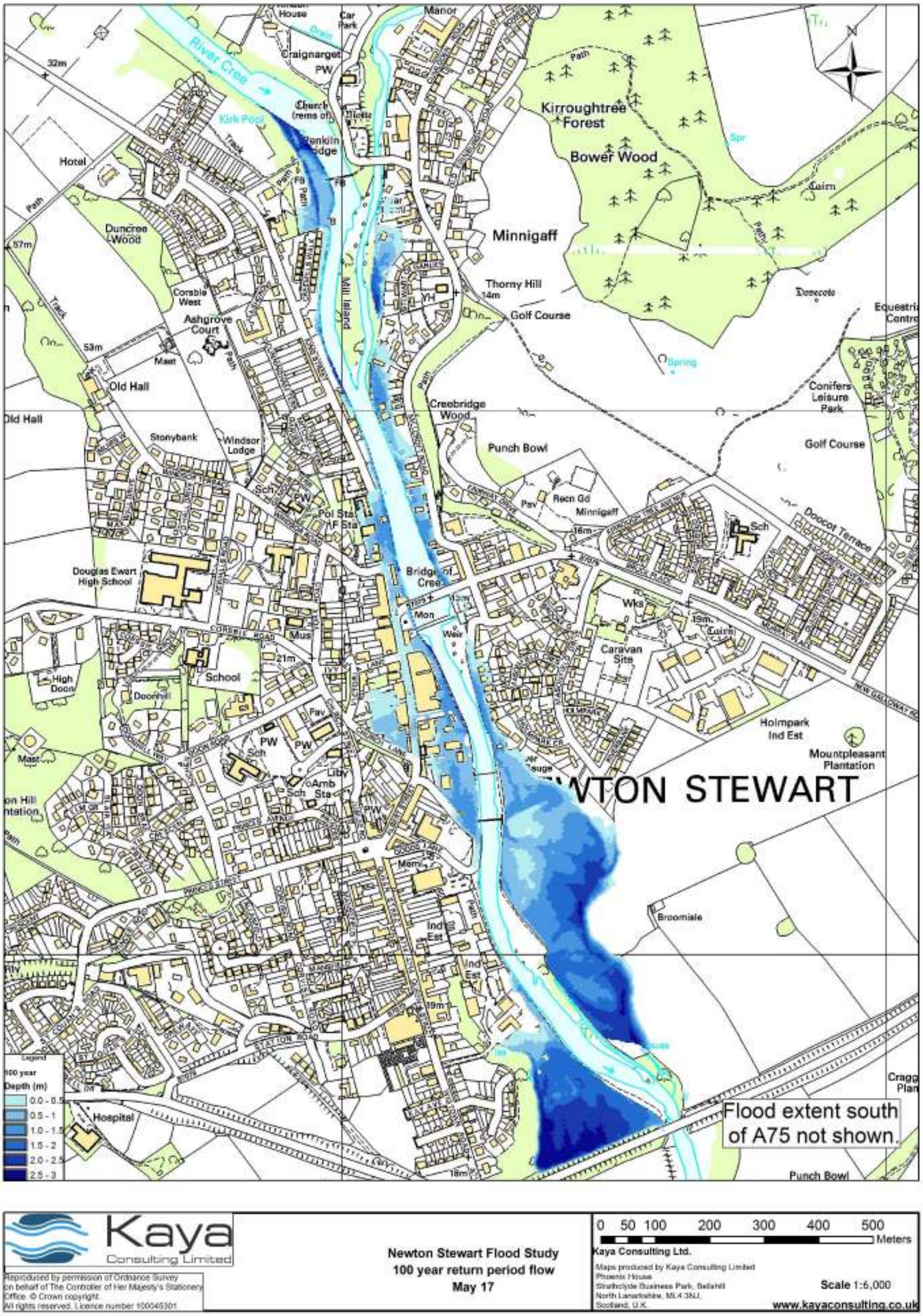
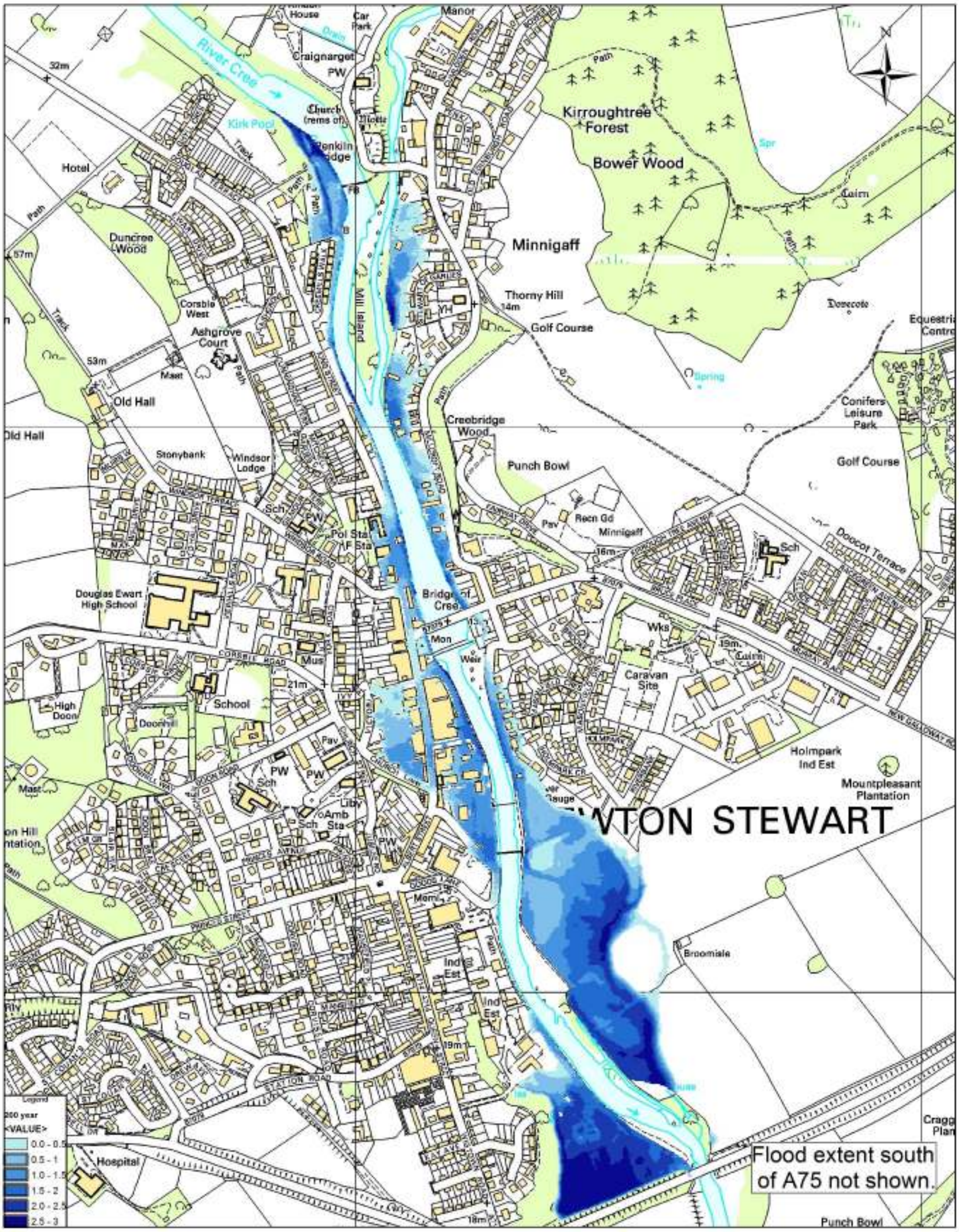


Figure 12: 200 year Flood Map



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