Dumfries and Galloway Council

Newton Stewart Flood Protection Scheme

Hydraulic Modelling Summary Report

Final

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1 Introduction

Following extensive flooding experienced in Newtown Stewart in 2012, 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 the lower part of the Penkiln Burn.

The assessment was progressed post 2012 and DGC subsequently commissioned SWECO consulting engineers to take the scheme forward, including design of the scheme and preparation of a flood order (a process required under the Flood Risk Management (Scotland) Act 2009, for Local Authorities to promote a flood protection scheme in their areas). DGC retained Kaya Consulting Ltd. to provide mathematical modelling support to SWECO during the process.

The modelling work has been undertaken in stages, with individual reports provided at phases in the project. This report seeks to summarise and consolidate the hydraulic modelling work undertaken to support the scheme development.

1.1 Background

As part of the original study in 2013, Kaya Consulting undertook a detailed hydrological assessment to calculate the likely flow experienced during the 2012 event, and also derive a range of return period flows to be used in the assessment. This was followed by detailed mathematical modelling of the River Cree and lower part of Penkiln Burn. The model was then used to predict the risk of flooding along both watercourses. The assessment required topographic survey of the channel and relevant hydraulic structures within the study area and this was used to setup the mathematical model.

Model results of the original 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).

In December 2015, a significant flood event occurred on the River Cree and Penkiln Burn which caused flooding within Newton Stewart and Minnigaff. The event was of a relatively similar magnitude to the 2012 event and highlighted the potential risk facing the area.

In response to a second severe flood event occurring in such quick succession, DGC commissioned a review of the hydrological analysis to update design flows for the River Cree and assess the implications on the mitigation measures considered previously. Additional topographical survey was commissioned to capture post event channel conditions and the model was updated accordingly. Model calibration was checked and refined against the data collected during the 2015 event. The findings of this additional work were reported in an Addendum in 2017 (Newton Stewart Flood Study – Addendum, May 2017).

Subsequently, DGC commissioned SWECO consulting engineers to progress a flood defence scheme for Newton Stewart and Minnigaff. On commencement of the project, SWECO reviewed the mathematical model of the River Cree, constructed by Kaya Consulting Ltd, and suggested modifications and improvements to make the model suitable for use in the design of the scheme. Following this work an agreed baseline model was established for use for the flood protection scheme project. The model was then used to consider a range of flood management options, proposed by SWECO.

An abundance of model runs were carried out to assess the effectiveness of a series of mitigation options, and although these options are listed in the report, model results for each option are not presented, primarily due to the size of output and relevance of such large volume of data to the reader. However, those results were made available to SWECO who analysed and used them for option appraisal process. In this summary report, model results are provided for the Preferred Scheme only.

As part of the sensitivity testing of the proposed scheme, it was required to assess the effect of future climate change uplifts taking into account the latest climate change predictions. This required design flows to be increased by 28% and 44% as well as increasing the water levels at the downstream boundary which is tidally affected. A full suite of model runs was required, ranging from 2 year to 1000-year return periods.

Initial modelling of the extreme flows such as the 1000-year plus 44% showed some numerical instabilities. As a result, and following a further internal review, the baseline model was further refined (April/May 2019) to resolve such instabilities which only occurred during extreme flow conditions in excess of design conditions. This was achieved by replacing some level boundary spill units by weir type, and refining grid resolution locally. Further model runs indicated that this has not significantly affected the baseline model and that the baseline model was suitable for the simulation of the flows ranging from 2 year to 1000-year plus 44%, for both the existing case and with the proposed defences in place. This model was then used for all subsequent model runs.

A summary of the model development is provided in Table 1 below – elements of each update are detailed in the corresponding report.

Table 1: Hydraulic model development summary

Item	Model statue	Reporting	Date
Draft flood study report prepared	Initial construction of 1D-2D linked model	Newton Stewart Draft 26Nov13	Nov 2013
Final report issued	Model finalised	Newton Stewart Revised Final April15	April 2015
Mitigation options report prepared	Model re-run with series of mitigation measures	Newton Stewart Flood Mitigation Options (Draft)Nov15	Nov 2015
Preparation of VM1 and long list	Model was to re-run to enable assessment of possible flood mitigation measures.	NSFPS Technical Note (July 2017).docx	July 2017
VM2 + SWECO Review of model	Model was updated based on survey information and review comments	(Oct 2017) Batch 2.docx”	Oct 2017
Optioneering following long list outputs	Model updated to additional data at Penkiln Burn	NSFPS Hydraulic Modelling Summary Report).docx	Oct 2018
Climate change outputs	Model updated to facilitate climate change flows +28%/+44%	NSFPS Hydraulic Modelling Summary Report - Addendum Nov19	Nov 2019

2 Summary of Hydrological Analysis

A detailed hydrological assessment was undertaken as part of the original study in 2013. An update was subsequently undertaken following the 2015 flood event. Details of the assessment can be found in the associated reports; however, a summary is provided below.

2.1.1 Calculation of Peak Flow during November 2012 event

On Monday 19th November 2012, Newton Stewart and Minnigaff were subjected to severe flooding from the River Cree and Penkiln Burn.

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. Results of the gauge data indicated that, at that time, the 2012 event was the highest ever recorded flood event on record.

During the event, the peak observed water level was 3.82 m OD, which is converted to a flow of 387 m^3/s, based on the rating curve derived at that time.

2.1.2 Calculation of Peak Flow during December 2015 event

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 undertaken predicted that the peak flow for this event was likely 427 m^3/s. This was based on extensive calibration work for the December 2015 event, including observations of flood levels, flood inundation extents and backwatering effects from the Sparling footbridge located downstream of the gauge (which was significantly impacted by debris during the event and subsequently removed).

The modelled flow for the 2015 event is considered to be more accurate than the SEPA flow, as it takes into account hydraulic effects at high flows that are not considered in the SEPA rating curve at the gauge (which is based on extrapolation of flow measurements taken under lower flows than observed at the peak of the 2015 event) and due to particular observed effects during the 2015 event (i.e., collapse of flood wall at Riverside and large volumes of debris at Sparling footbridge downstream of the gauge). For this assessment, the peak flow for the December 2015 event is considered to be 427 m^3/s. However, due to the specific influencing factors experienced during the 2015 event, SEPA data for events prior to 2015 were not revised based on the modelled rating curve.

2.1.3 Summary of AMAX Data and Qmed

Discussions were held with SEPA regarding the most appropriate AMAX (Annual Maximum Flow) 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.
- Updated SEPA data was used for the period 2001 to 2014.

- The modelled December 2015 flood peak was used for 2015.

The new AMAX flows are provided in Figure 1 and Table 2.

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

Figure 1: SEPA 2016 AMAX data

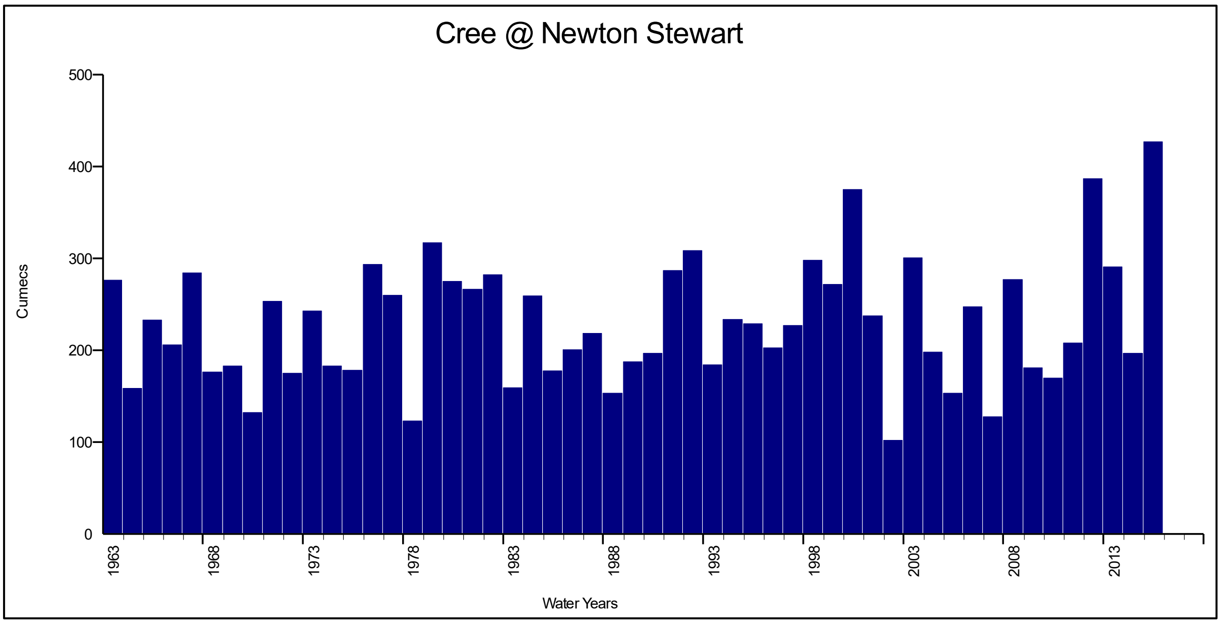


Table 2: AMAX data used in analysis

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		

2.1.4 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)

2.1.4.1 Single Site Analysis

Based on the AMAX data outlined in Table 1, the Single Site flood frequency curves (Generalised Logistics and Generalised Extreme Value 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 3 where they have been rounded to the nearest ten cumecs (m^3/s).

Figure 2: Single Site Analysis flood frequency curve

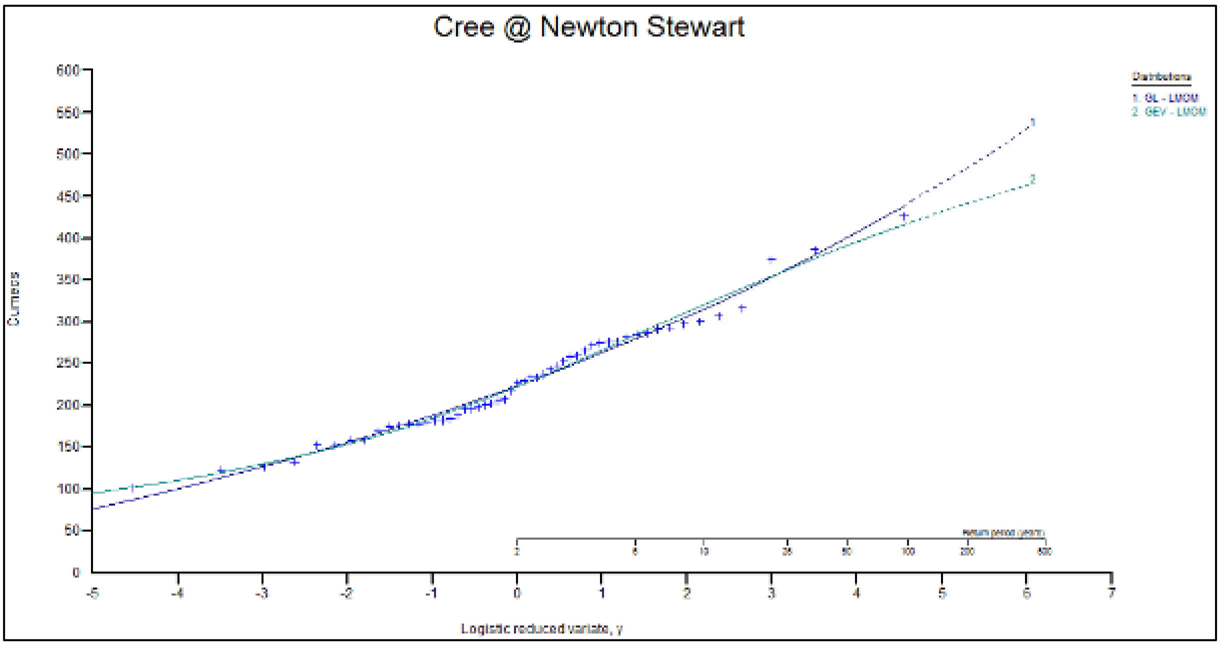


Table 3: Design flows for Single Site Analysis

Return Period (years)	Generalised Logistic (m^3/s)	Generalised 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

2.1.4.2 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 4. The Pooling Group developed for the gauged site is provided in Table 5.

Table 4: Design flows for Enhanced Single Site Analysis

Return Period (years)	Generalised Logistic (m^3/s)	Generalised 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 up to 1 in 50 year return period, with the 200-year flow from the Enhanced Single Site Analysis increasing by 7% from the flow predicted using the Single Site analysis. It is noted that the WINFAP goodness-of-fit indicator recommends the 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. The Flood Estimation Handbook also advises that Generalised Logistic distribution is considered to perform better than Generalised Extreme Value statistical distribution for pooled growth curve derivation.

Table 5: Pooling Group for River Cree

Station	Distance (km)	Years of data	QMED AM (m^3/s)	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	

2.1.4.3 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 at Newton Stewart used for the assessment are based on the Enhanced Single Site Analysis and Generalised Logistics distribution, i.e., Column 2 of Table 4. This gives a best estimate of the 200-year flow at the gauge of 520 m^3/s.

2.1.5 Comparison to Previous Design Flow Estimates

A comparison of the updated design flow estimates to those calculated previously are presented in Table 6.

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 6: A comparison of the design flow estimates based on Enhanced Single Site Analysis using the Generalised 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%

2.1.6 Climate Change

SEPA's fluvial hazard maps use the 2080 high emissions scenario 67th percentile (i.e. uplifts in peak flow that are "unlikely to be exceed"). The model was run with this approach using the percentage change in flood peak value of 44% for the Solway river basin region. Based on discussions with

SWECO, the 2080 medium emissions scenario 67th percentile value of 28% was also run as a sensitivity.

2.1.7 Return Period Assessment for 2012 and 2015 Events

As part of the original study, the return period of the 2012 event was estimated at around 50 years (44 years). However, for comparison statistical analysis of peak water levels at the gauge were undertaken and this gave a return period for the 2012 event of around 85 years. Such a discrepancy between flow and water level data is not unexpected, especially at sites where water goes out of bank at high flows. Hence, based on available data at that time the 2012 event would appear to have a return period of between 85 and 50 years, with the likelihood of the return period being closer to the upper end of the scale.

Return periods based on most up-to-date analysis
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 had a return period of approximately 1 in 35 years, which is lower than the original estimate. This indicates that the 2015 event was larger event than the 2012 event.

3 Base Model

The mathematical model constructed to represent the River Cree and lower part of Penkiln Burn is based on:

- Main channel of both watercourses represented in a 1D model, constructed using surveyed channel cross section and structure data; and
- Floodplains on both banks of the watercourses were represented using a 2D model constructed using LiDAR DTM and topographical survey undertaken during the study.

The 1D and 2D models are linked together dynamically to allow free flow of water between the two domains. This is a standard approach used for modelling river and floodplain systems.

The model is based on Flood Modeller Pro (formerly known as ISIS) and is widely used and accepted by SEPA and Local Authorities for the modelling of this type of river system.

Details of the modelling system, data used, model calibrations, etc. can be found in the previous study reports.

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

3.1 Model Updates

As part of the flood protection scheme project, and in line with model review undertaken by SWECO, the following additional work was carried out to refine the mathematical modelling system.

3.1.1 1D Updates

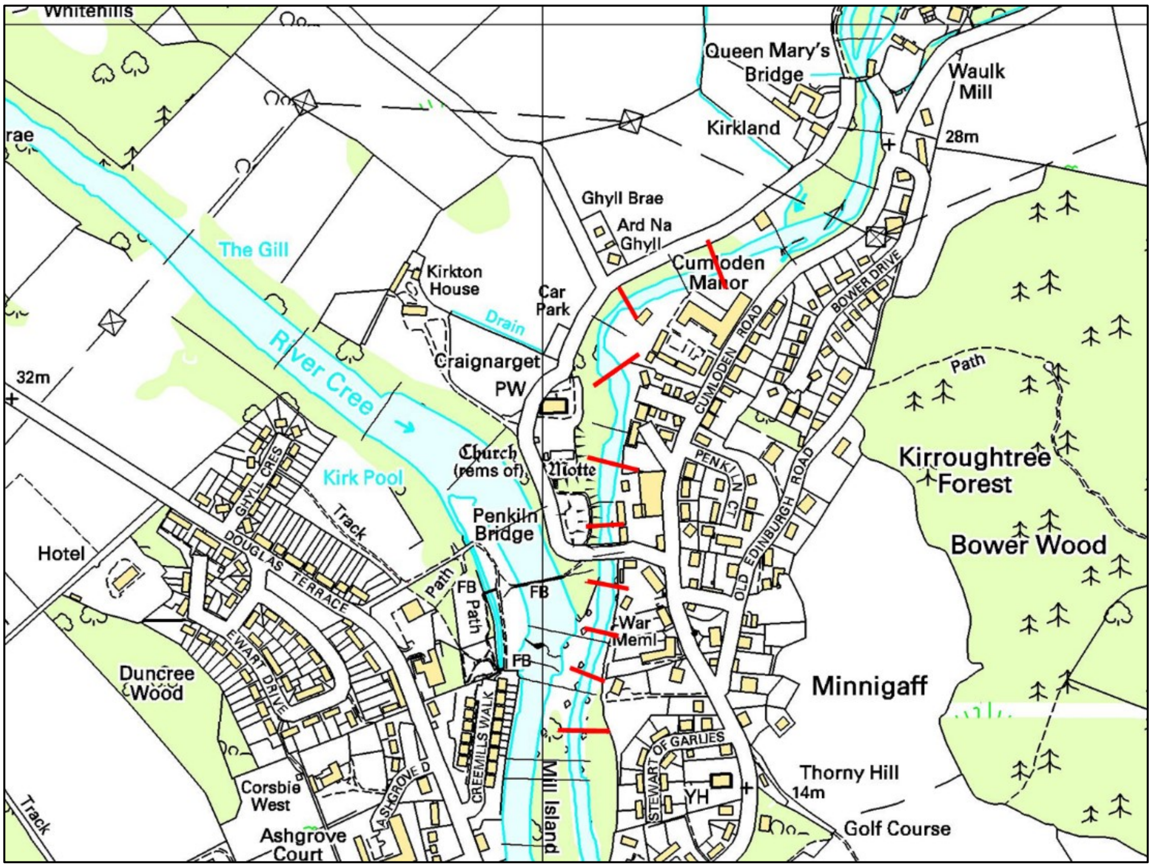
3.1.1.1 Additional River Sections

New model cross sections have been added to the model which have either replaced old cross sections or added at new locations. Notable areas where the model has been updated from the 2013/14 study include:

- Sections on Penkiln Burn upstream of the confluence, see Figure 3;
- Sparling Bridge removed (as it was damaged during the 2015 flood event and was subsequently removed);
- All existing sections downstream of the A75 bridge have been replaced by surveyed channel sections and the model extended further downstream into the tidal reach. The model was run for higher flows and where glass walling occurs along this section cross sections have been extended to higher ground.

Water level predictions at the new downstream location were extracted from SEPA Coastal Flood Boundary dataset and applied as downstream boundary conditions.

Figure 3: Location of new cross sections surveyed on Penkiln Burn



3.1.1.2 Spill Units

Throughout the study area there are a number of walled defence structures, especially on the right bank of the channel looking downstream. The defences were surveyed and represented in the model using 1D lateral spill units which provided an accurate representation of overtopping levels. Flows leaving the 1D domain were linked to the 2D floodplain domain using "Q" link lines accept flows from the 1D spill units and pass them into 2D model. Although these worked satisfactorily for the range of flows considered at that time, they showed some numerical instabilities when defences were significantly overtopped during flows involving climate change increases up to 44%. These units were subsequently replaced by level link lines in the 2D. This resolved the numerical instability issues.

3.1.1.3 Storage Areas SA to SA9

The right bank area downstream of the A75, previously modelled as a 1D storage area, has been converted and included in the 2D domain.

3.1.1.4 Flood Relief culverts

Four flood relief culverts have been inserted into the model under the A75 embankment. The culverts have been represented each as an orifice unit (nested in the 2D domain) with each having a 1.5m diameter. To increase model stability a flap was added to restrict backflow (reverse flow) up the culvert. The inlet and outlet levels have been set to tie into the DTM.

3.1.1.5 Interpolates

In order to increase model stability further, a few interpolated cross sections were introduced in some areas.

3.1.1.6 Downstream Boundary

The original model extended 9km downstream from the study area, adjacent to the Solway Firth. The Environment Agency (2011) Coastal Flood Boundary Dataset was used to define the downstream boundary (Point 1524).

As the likelihood that a 200-year flow event occurring at the same time as a 200-year extreme sea level is extremely low, a joint probability assessment was undertaken. However, following a model sensitivity assessment, it was noted that flood levels in the study area were not sensitive to water levels in the Solway.

Following completion of the original modelling and reporting, SEPA commissioned a study to ascertain extreme sea levels within estuaries in Scotland (an update to the EA Coastal Flood Boundary Dataset) which provided extreme water levels within the Cree much closer to the study area.

Following a review of the model by SWECO, it was requested that the downstream boundary is set closer to the study area using updated Coastal Flood Boundary data. The joint probability was revised using results from the updated SEPA extreme water level data. Using the methods outlined in EA (2005) joint probability methodology, the dependence classification of river flows and extreme sea levels fall into the “Strongly Correlated” dependence category (from Figure 2 in FD2308 TR2 and from Table 4.7 of FD2308 TR1). A dependence measure value of $\chi = 0.095$ was selected based on interpolation of values between Portpatrick and Heysham. Results of the different combinations of river flows and extreme sea level return periods have been derived for the 200-year joint exceedance return period (refer to Table 7 below). Each of the scenarios of river flow and extreme sea level were modelled, which indicated that peak water levels in the study area are a result of high fluvial flows which result in higher water levels in the area of interest than those corresponding to high sea levels (i.e. scenario 1 in Table 7).

Table 7: Joint Probability – River flow and Extreme Sea Level return period combinations for a 200-year return period

Scenario	Extreme sea level (RP)	Peak flow in River Cree (RP)
1	1	200
2	2	181
3	5	72
4	10	36
5	20	18
6	50	7
7	100	4
8	200	2

Based on the joint probably results, return period events less than the 200-year would require an extreme sea level of less than a 1-year level; however, to be conservative all design runs for such scenarios have been undertaken with a 1-year extreme sea level. As the scheme is designed against the 200-year event, a 1-year sea level was deemed suitable for the 1000 and 500-year events.

A further sensitivity analysis was undertaken to assess the sensitivity of water levels at the study area based on changes to the downstream boundary. It was noted that there was no change to water levels in the area of interest by increasing the downstream boundary level to a 2-year sea level.

3.1.2 2D Updates

3.1.2.1 Link Lines

The overtopping levels of the existing defences were surveyed as part of the original assessment. These levels were used to create “Z-Lines” which were superimposed on the underlaying topography. As a result, the model picks the right overtopping level from the combined DTM for the level type link lines used to transfer water between the 1D and 2D domains.

The lengths of the new link lines were adjusted to fit new interpolated channel cross sections. Small changes to overtopping spill coefficients were made to improve the accuracy of model predictions.

3.1.2.2 Active Area

The Active Areas representing the 2D domain were adjusted in the vicinity of the park area (240963, 566387 – Creemills Walk) which is located on the right bank of the River Cree immediately upstream of the junction with the Penkiln Burn. The area was adjusted to match local high points on the bank and reduce and double counting of flows in the 1D and 2D domains.

3.1.2.3 Updated 2D zone

Aspect Surveys undertook a detailed survey of river banks and adjacent floodplain areas an ASCII grid was also generated and was provided via SWECO. This data was used to replace the original levels from the LiDAR data. Extreme values within the DTM have been filtered out as well as link line adjustments to aid stability. The model has been run with a 2.5m resampled grid within the town and a 5m grid downstream of the A75.

3.1.2.4 Ground Model Refinements

A roughness grid is included in the base case model and the DTM has been updated so that the area under each building footprint is raised to the surveyed threshold level. This allows flood waters to flow round the building rather than going through it, up to the threshold level.

3.2 Model Calibration Check

The original model was successfully calibrated against the 2012 and 2015 flood events. Following the model improvements outlined above, a check was undertaken to assess whether the refined model represents historical flood events with reasonable accuracy expected from such models.

The model was assessed against the following:

- Known flood *extents* based on historical evidence;

- Known flood *depths* based on historical evidence; and
- Recorded water level and flow data from SEPA's manual gauging.

Examples of model calibration are summarised below (list is not exhaustive).

3.2.1 Flood Extent

Known flood extents are available for many areas of Newton Stewart for the 2015 event. Figures 4 and 5 show how the model predicts overtopping of the left bank of the Penkiln Burn and River Cree; this has been compared to photos provided at the peak of the event.

Associated flood photos indicate that the model matches well with the recorded flood extent.

Figure 4: Known flood extents compared against modelled water levels

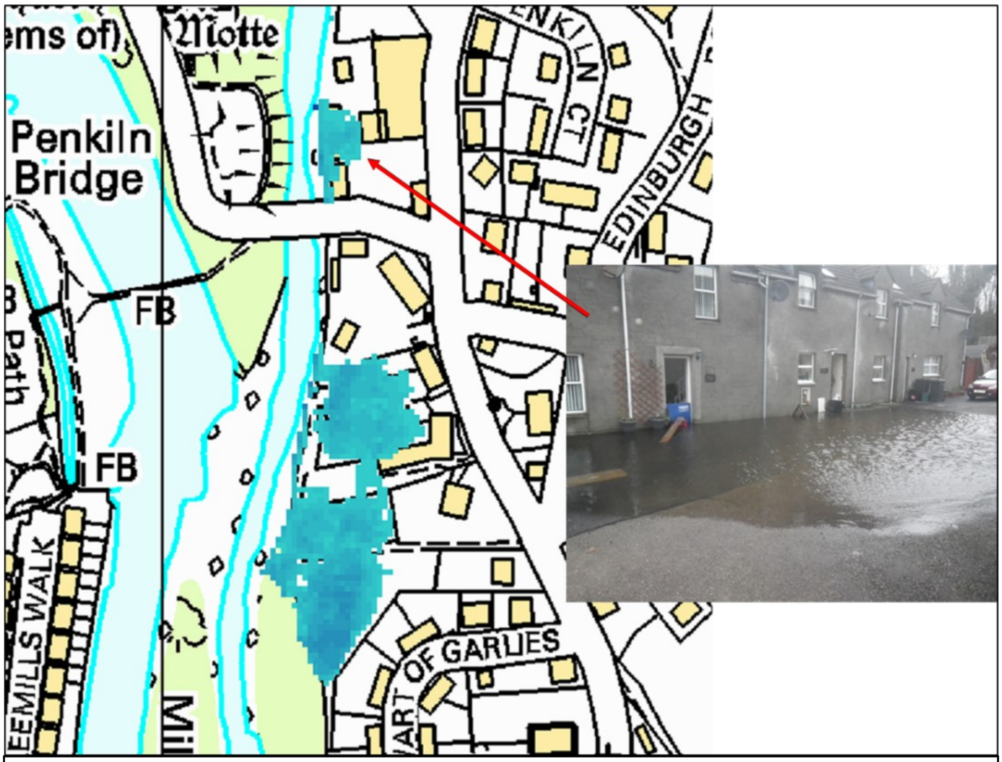


Figure 5: Known flood extents compared against modelled water levels

3.2.2 Flood Level

Comparison of recorded and predicted flows and water levels at the SEPA gauge Newton Stewart are shown in Table 8.

Table 8: Known flood levels compared against modelled water levels (nearest 0.1 m)

Location	2015 Flood Level (m AOD)	Predicted Water Level (m AOD)
Meal Mill	At least 11.25	11.2
Hazelbank House	At least 10.7	10.8
Reid Terrace	At least 10.5	10.7
Riverside Cottage	At least 10.2	10.7
Rosebank Cottage	At least 9.9	10.3
Riverside Road	At least 9.7	9.9
Creebridge Road	At least 9.6	9.7
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

Gauging data was also collected from SEPA. Results of a manual gauge indicated that, for a flow of approximately 170 m^3/s, a water level of 7.7m AOD was recorded. Results indicated that the model calibrates well with a manual SEPA gauge rating, see Table 9 below. The updated model is within approximately 10 mm of the maximum water level recorded at the SEPA gauge during the 2015 event. This comparison is treated with caution as recordings from the gauge flat lined during the event and the level of 9.0m AOD is given as an estimate by SEPA.

Table 9: Comparison of model stage and flow results at SEPA gauge

	Manual gauging		2015 event	
	SEPA	Updated model	SEPA	Updated model
Flow (m^3/s)	170	170	427	427
Stage (m AOD)	7.70	7.68	9.0	9.01

For the purposes of this assessment, it was concluded that the refined model provides sufficiently good correlation with observed water levels and therefore it is considered suitable for use for the flood protection scheme project.

3.3 Baseline Re-run

The updated base model was re-run using the inflows from the updated hydrological analysis described above.

3.3.1 Design Flow Runs

The updated baseline model was re-run for the full suite (11 return period events listed in Table 10) of present day design events; i.e. ranging from 2-year to 1000-year. In addition, full suites for the plus 28% and 44% climate change uplifts were also undertaken. In total, 33 runs were modelled for the base case run.

It should be noted that the effect of climate change on the downstream boundary was also considered. A 2-year future sea level of 6.72 m AOD was selected based on recent sea level uplifts recommended in recent guidance published by SEPA[1]. This uplift was applied for both the +28% and +44% model runs.

The baseline modelled inflows and downstream boundary water levels are provided in Table 10.

Selected model results for the 200-year/+28%/+44% are presented in Table 11 (cross section locations are illustrated in Figures 6-8). A complete package of results for all return periods were provided to SWECO.

The predicted 200-year flood map is also provided in Figure 9.

[1] https://www.sepa.org.uk/media/426913/lups_cc1.pdf SEPA Climate Change guidance document

Table 10: Base case model boundaries

Run No.	Scenario (Q-Flow, T-Water level)	Peak flow in River Cree (m^3/s)	Peak Flow in Penkiln Burn (m^3/s)	Downstream Water Level (m AOD)[b]
1	Q1000T1	416	215	5.81 (6.72[b])
2	Q500T1	414	182	5.81 (6.72[b])
3	[a]Q200T1	369	151	5.81 (6.72[b])
4	Q100T1	337	131	5.81 (6.72[b])
5	Q75T1	329	124	5.81 (6.72[b])
6	Q50T1	306	114	5.81 (6.72[b])
7	Q30T1	290	102	5.81 (6.72[b])
8	Q25T1	282	98	5.81 (6.72[b])
9	Q10T1	246	78	5.81 (6.72[b])
10	Q5T1	220	64	5.81 (6.72[b])
11	Q2T1	172	55	5.81 (6.72[b])

[a]Q200T1, refers to model run with river inflows set to the 1 in 200-year flood level, with model downstream boundary set to a 1-year extreme coastal level.
[b]The current 1-year coastal water level was selected as 5.81m AOD based on the SEPA Coastal Flood Boundary Dataset Point 1524-20-Main-M. A future 2-year future sea level of 6.72 m AOD was selected based on recent sea level uplifts recommended in recent guidance published by SEPA.

Table 11: Model results for 200-year events including climate change uplifts

Model Cross Section Label (See Figures 6-8)	Predicted Water Level (m AOD)		
	200-year	200-year + 28%	200-year + 44%
PN030	23.31	23.53	23.65
PN029	21.07	21.37	21.52
PN028	19.91	20.21	20.37
PN027	18.49	18.86	19.00
PN027_I5	17.48	17.82	17.97
PN026	17.21	17.49	17.67
PN026_I7	16.02	16.33	16.48
PN025	15.28	15.57	15.71
PN025_I5	14.67	15.10	15.30
PN024	14.26	14.69	14.89
PN024_I	13.86	14.23	14.38
PN023	13.33	13.72	13.95
PN023_I	13.17	13.60	13.84
PN023A	12.98	13.43	13.67
PN_S5_US	12.95	13.38	13.63
PN_S5_DS	12.99	13.40	13.63
PN019A	12.82	13.17	13.35
PN019A_N	12.71	13.14	13.36
PN019A_N2	12.52	12.96	13.15
PN019B	12.52	13.01	13.23
PN019B_I2	12.13	12.65	12.92
PN019C	12.04	12.53	12.79
PN019C_IN	11.89	12.41	12.68

PN019C_3	11.77	12.28	12.54
PN019	11.78	12.27	12.53
PN_AP_002	11.64	12.13	12.38
PN018	11.49	11.98	12.23
PN018_I1	11.37	11.83	12.07
PN_AP003US	11.39	11.87	12.11
CR022	13.41	13.81	14.01
CR021	13.25	13.63	13.82
CR021_2	13.19	13.60	13.81
CR020	12.96	13.36	13.57
FB_US	12.71	13.12	13.34
FB_DS	12.71	13.12	13.33
FB_DS_2	12.57	13.02	13.25
S4_CR_US	12.61	13.11	13.37
S4_CR_DS	12.42	12.93	13.19
S4_DS	12.07	12.63	12.91
SEC12	12.07	12.55	12.81
CR019	11.80	12.30	12.57
CR019_I2	11.61	12.16	12.42
CR_AP_002	11.70	12.21	12.47
CR018	11.52	12.00	12.25
SEC11	10.90	11.28	11.49
CR_AP003US	11.39	11.87	12.11
CR_AP_003	11.39	11.87	12.11
AP_003_I1	11.28	11.75	12.00
CR017	10.98	11.42	11.72
CR016	10.96	11.40	11.71
CR_AP_004	10.96	11.40	11.70
AP_004_I1	10.93	11.37	11.65
CR015	10.88	11.38	11.65
CR015_I2	10.85	11.35	11.61
CR014	10.83	11.37	11.65
CR_AP_005	10.78	11.32	11.61
S3.5_US	10.78	11.31	11.60
S3.5_DS	10.56	10.95	11.15
CR013	10.53	10.93	11.14
S3_US	10.46	10.86	11.05
S3_DS	10.30	10.67	10.86
S3_DS_2	10.33	10.71	10.90
CR012	10.23	10.59	10.77
CR012_2	10.10	10.45	10.62
CR011	9.88	10.21	10.37
CR011_1	9.76	10.07	10.22
CR011_I3	9.68	9.99	10.15
CR010	9.46	9.76	9.93
CR009	9.33	9.62	9.78
CR008	9.23	9.53	9.70
CR008A	9.15	9.47	9.66

CR008A_U	9.05	9.34	9.52
S2_BR	9.05	9.33	9.51
CR007A	9.01	9.31	9.50
CR007A_WU	9.05	9.41	9.63
CR007A_WD	8.78	9.13	9.36
CR007	8.39	8.88	9.14
CR006	8.28	8.86	9.14
CR005	8.06	8.70	8.99
CR004	7.95	8.61	8.91
CR004A	7.15	7.73	7.95
S1_US[a]	7.00	7.58	7.79

[a]S1_US is the last cross section presented in the results table and Figure 8; however, the model extends more than +3km downstream of the study area.

Figure 6: Cross section locations 1/3

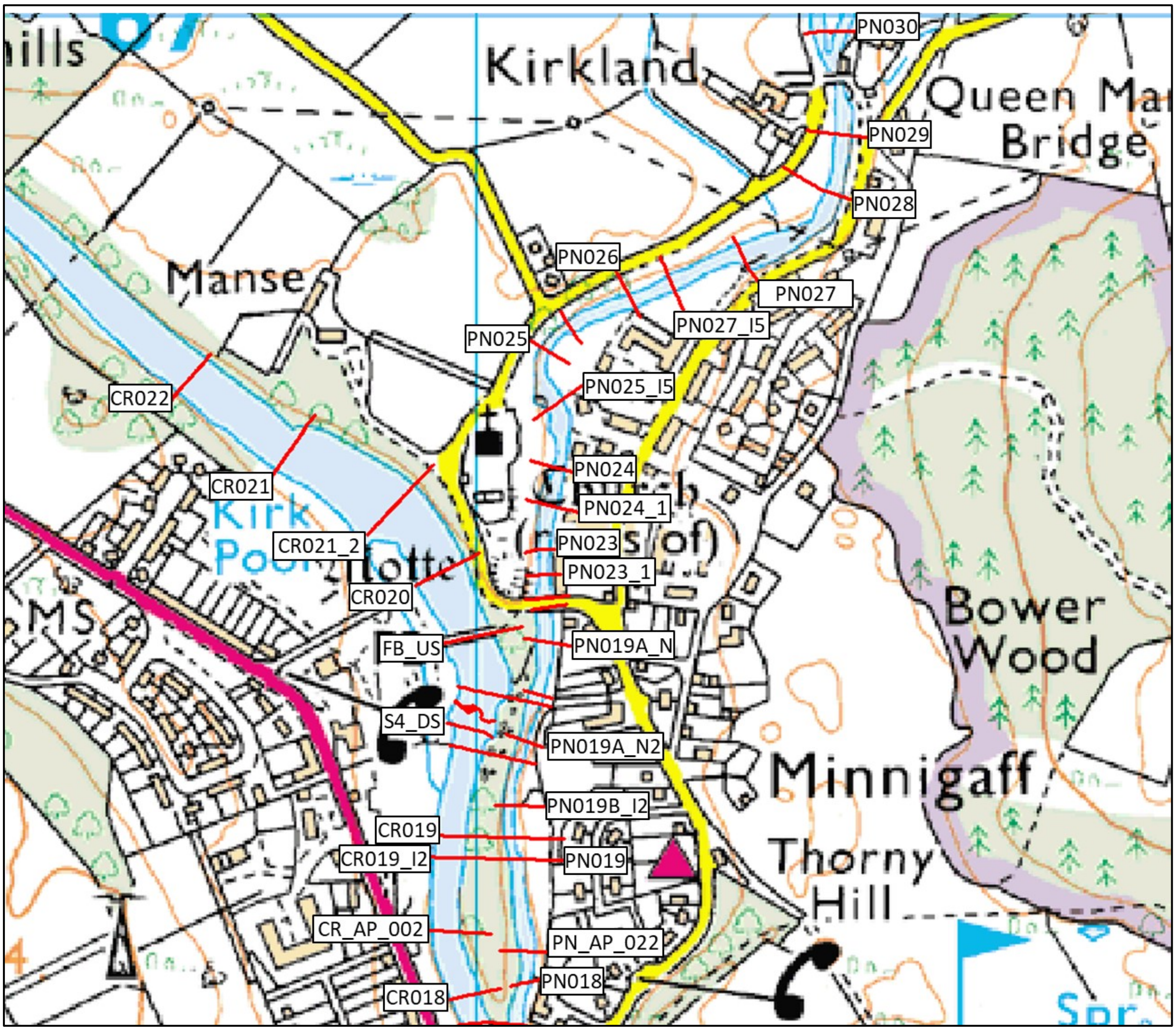


Figure 7: Cross section locations 2/3

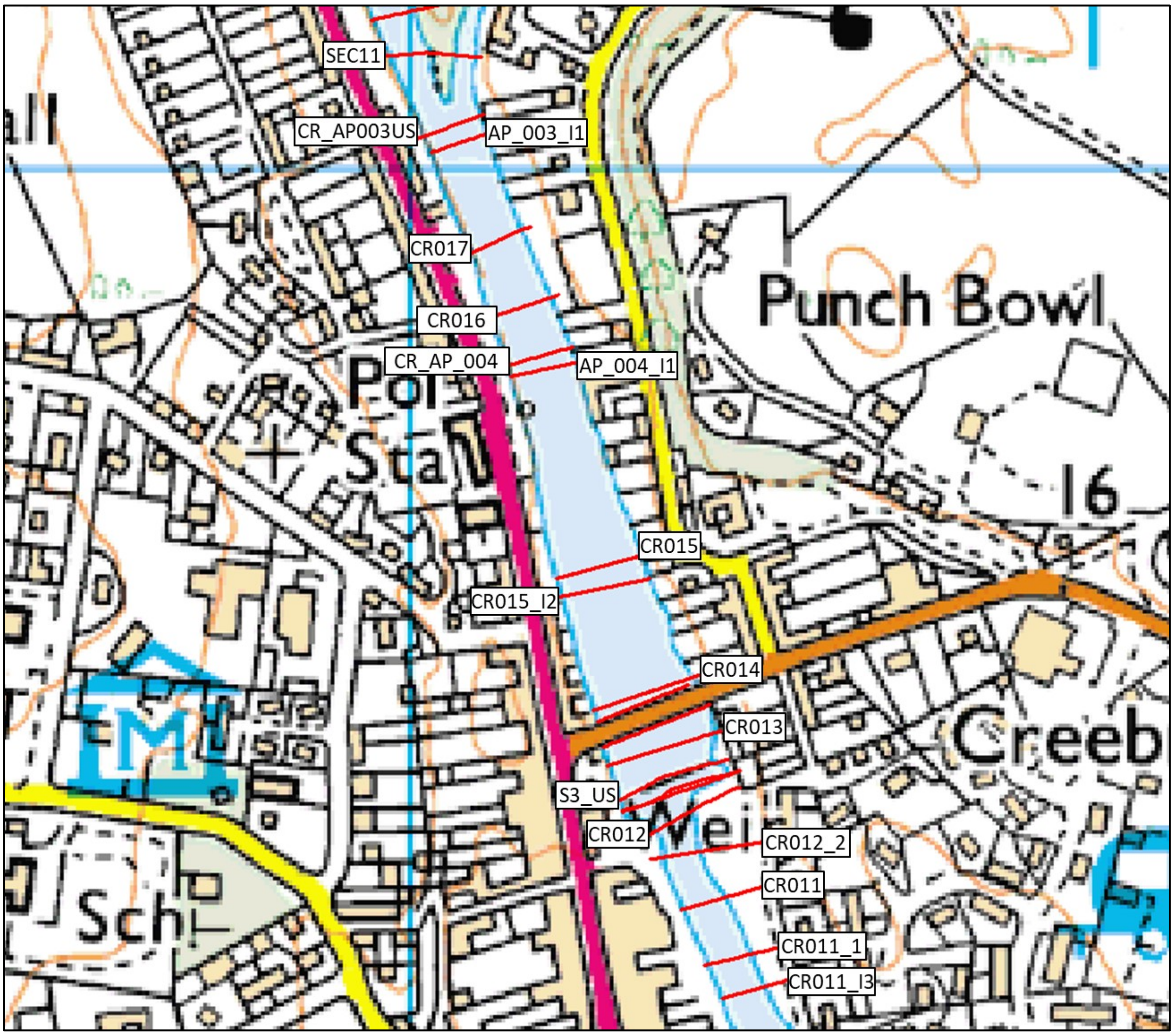


Figure 8: Cross section locations 3/3

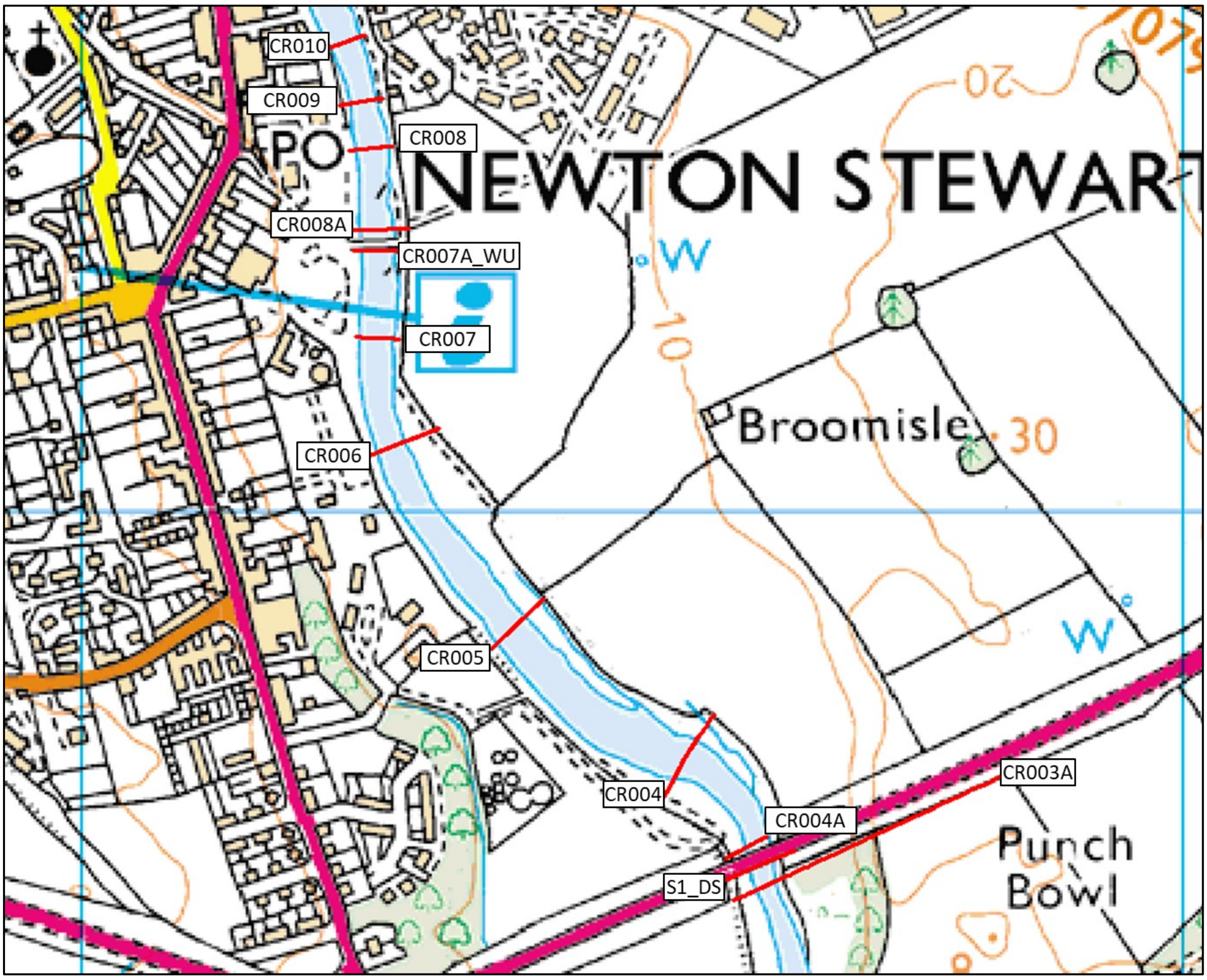


Figure 9: Predicted 200-year flood extent

4 Modelling for Optioneering

The optioneering process and choice of flood protection options to be considered was undertaken by SWECO. The selected options were then modelled by Kaya Consulting and the model results provided to SWECO for their analysis and assessment of mitigation options. A separate report has been prepared by SWECO which gives details of the optioneering process and reference should be made to this report (Newton Stewart Flood Management Optioneering Report, SWECO).

A long list of mitigation options was prepared by SWECO. This included 24 options outlined in Table 12. In order to allow an initial assessment of these options, the following work was carried out:

- Setting up a hydrological model of the upper catchment (i.e., upstream of Minnigaff and Newton Stewart) using Flood Modeller software and assessing the impact of each upstream option on the peak flow at the upstream edge of the town.
- Using the updated mathematical model to assess efficacy of identified possible mitigation options.

The assessment of the options was carried out at a Value Management (VM) meeting attended by stakeholders. Following the first VM, those selected for further consideration are outlined in Table 12 (i.e. marked as "Selected for further consideration").

Table 12: Long list of options identified by SWECO

Option Number	Option Description	VM1 Assessment
1	Storage of water in the Glenhapple area	Discounted
2	Storage of water in the Linloskin Bridge area	Selected for further consideration
3	Storage of water in the Frankie Hill area	Discounted
4	Construction of upstream obstruction on the River Cree	Selected for further consideration
5	Construction of an upstream obstruction on the Penkiln Burn	Discounted
6	Construction of walls to provide protection and convey flood waters downstream	Selected for further consideration
7	Increase flow area beneath A75 bridge	Selected for further consideration
8	Removal of A75 embankment	Discounted
9	Increase number and size of culverts beneath the A75 embankment	Selected for further consideration
10	Removal of gravel berm downstream of Cree Bridge	Discounted
11	Removal of weir upstream of Cree Bridge	Discounted
12	Removal of weir upstream of Newton Stewart	Discounted
13	Move River Cree and Penkiln Burn confluence upstream to historical location	Discounted
14	Removing of Mill Island	Discounted
15	Removal of sediment at key structures	Discounted
16	Diversion of Penkiln Burn	Discounted
17	Removal sediment build up from the river bed	Discounted
18	Disconnecting of the former Mill Lade from the River Cree	Discounted

19	Reprofiling land in the Broomisle area	Selected for further consideration
20	Reinstate redundant flood storage area at the Water of Minnoch	Selected for further consideration
21	Use of Ghyll area for additional flood storage	Selected for further consideration
22	Storage in the River Cree tributaries	Selected for further consideration
23	Forrest management in the upper catchment	Discounted
24	Reprofiling of land around Scottish Water pumping station	Selected for further consideration

Additional model runs were carried out for the ten options selected for further consideration. This involved amending the existing model for each option and running the model. Model results were provided to SWECO for their assessment.

The model results were discussed at a second VM meeting and a shortlist of options was selected for further consideration. These included the following:

Table 13: Table of additional model runs

Option Number	Option Description
1	Combination of Options 7 & 9
2	Combination of Options 7 & 19
3	Combination of Options 7 & 24
4	Combination of Options 7,9 & 19
5	Combination of Options 9 & 19
6	Combination of Options 9 & 24
7	Combination of Options 19 & 24
8	Combination of Options 6 & 7
9	Combination of Options 6 & 9
10	Combination of Options 6 & 19
11	Combination of Options 6 & 24
12	Combination of Options 6,7 & 9
13	Combination of Options 6,7 & 19
14	Combination of Options 6,7,9 & 9

In total, over 200 scenarios were modelled and assessed as part of the optioneering process.

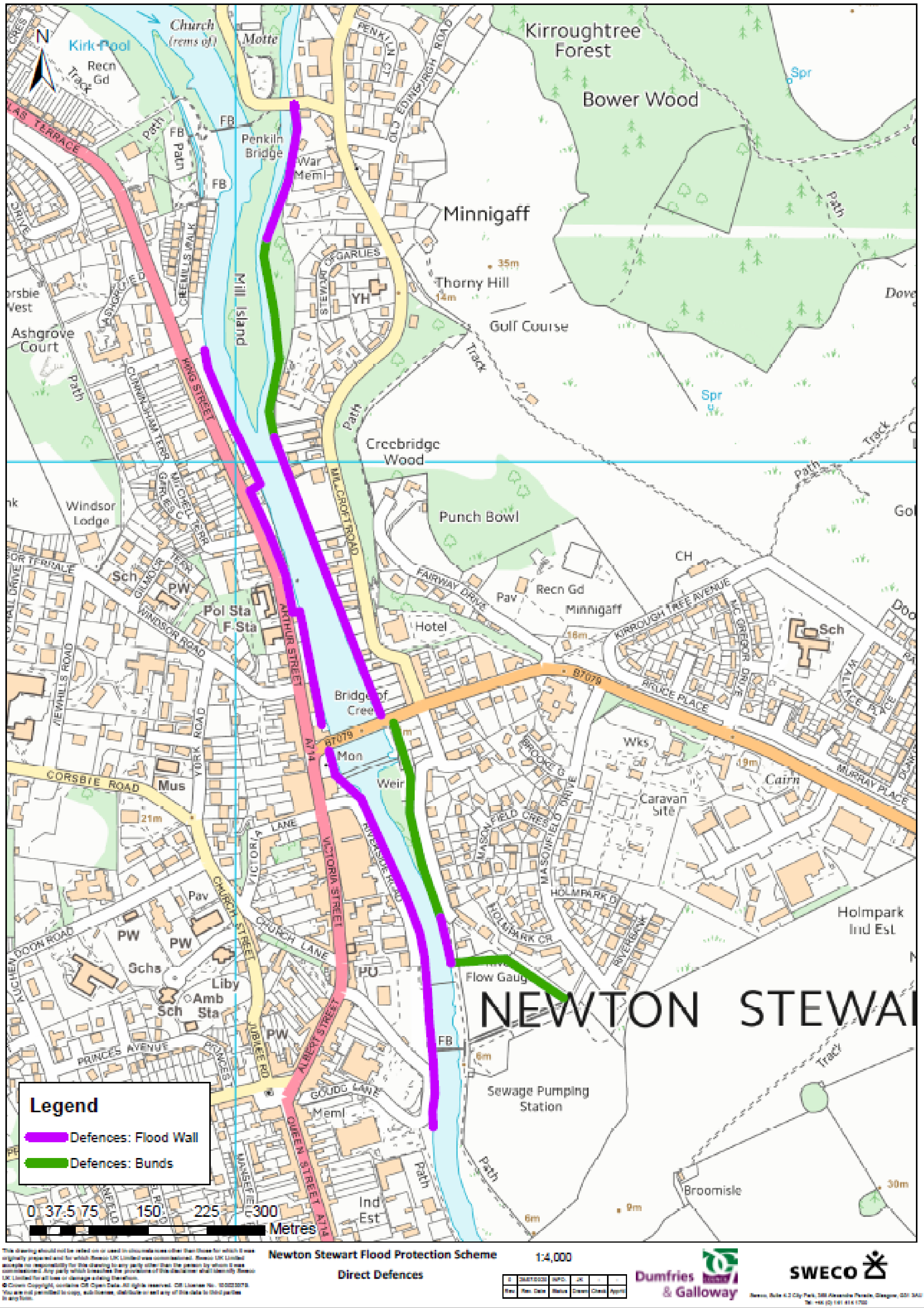
5 Preferred Scheme

Following the optioneering process, a preferred scheme was identified by SWECO. The outline design for the flood protection scheme comprised the following:

- A new, re-located Sparling Bridge – see Figure 10 for location;
- Direct defences along both banks of the river constructed either as earth bunds or flood walls – see Figure 11;
- Lowering of ground (out-of-bank) beneath the A75 bridge. The ground levels on the west side of the river section representing the bridge to be lowered to 6.27 m AOD. Note final level may change at detailed design due to site constraints etc.

Figure 10: Location of new Sparling Bridge

Figure 11: Location of direct defences



5.1.1 Preferred Scheme Results

As with the base case scenarios, full suite of model results for the eleven cases listed in Table 13 has been provided to SWECO and the DGC for review. Only the predicted 200-year cases for the preferred scheme, including climate change, are provided in Table 14 below.

Table 14: Model results for 200-year defended scenario

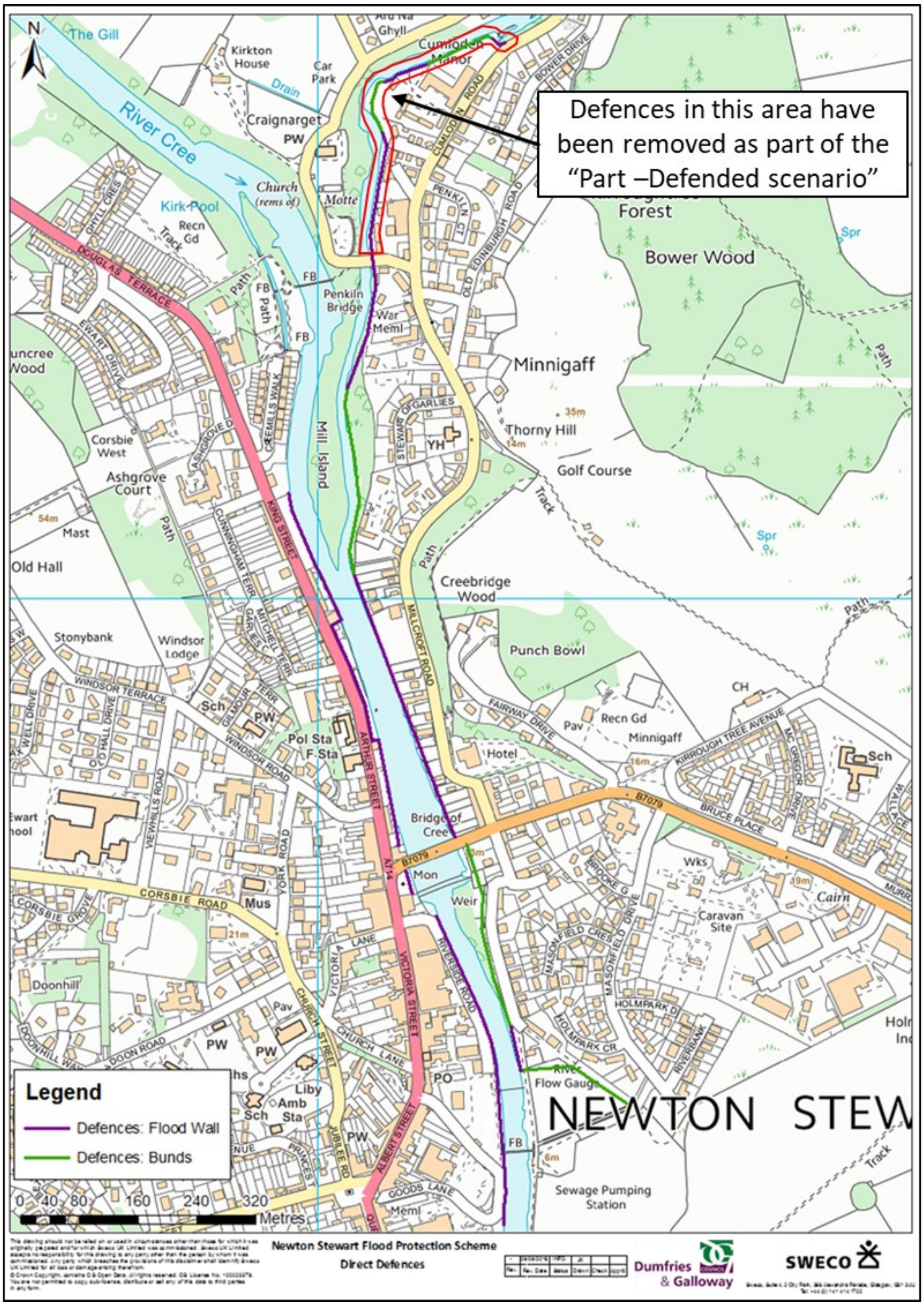
Model Cross Section Label (See Figures 1-3)	200-year defended (m AOD)	200-year +28% (m AOD)	200-year +44% (m AOD)
PN030	23.31	23.53	23.65
PN029	21.07	21.37	21.52
PN028	19.91	20.21	20.37
PN027	18.49	18.86	19.01
PN027_I5	17.48	17.81	17.95
PN026	17.20	17.45	17.58
PN026_I7	16.02	16.37	16.53
PN025	15.28	15.59	15.76
PN025_I5	14.68	15.12	15.33
PN024	14.29	14.74	14.95
PN024_I	13.90	14.32	14.50
PN023	13.38	13.78	14.01
PN023_I	13.15	13.58	13.83
PN023A	13.00	13.43	13.66
PN_S5_US	12.97	13.38	13.61
PN_S5_DS	13.01	13.40	13.61
PN019A	12.86	13.23	13.44
PN019A_N	12.77	13.21	13.45
PN019A_N2	12.59	13.04	13.28
PN019B	12.59	13.08	13.31
PN019B_I2	12.22	12.75	13.03
PN019C	12.10	12.61	12.88
PN019C_IN	11.90	12.46	12.75
PN019C_3	11.84	12.39	12.67
PN019	11.84	12.38	12.65
PN_AP_002	11.72	12.26	12.53
PN018	11.58	12.12	12.38
PN018_I1	11.49	12.01	12.25
PN_AP003US	11.51	12.06	12.31
CR022	13.42	13.83	14.04
CR021	13.27	13.67	13.86
CR021_2	13.21	13.64	13.85
CR020	12.99	13.41	13.62
FB_US	12.76	13.19	13.42
FB_DS	12.76	13.19	13.41
FB_DS_2	12.62	13.09	13.32
S4_CR_US	12.67	13.18	13.44
S4_CR_DS	12.49	13.01	13.27

S4_DS	12.14	12.73	13.02
SEC12	12.11	12.64	12.90
CR019	11.86	12.41	12.69
CR019_I2	11.71	12.29	12.56
CR_AP_002	11.78	12.34	12.60
CR018	11.62	12.15	12.41
SEC11	11.06	11.49	11.67
CR_AP003US	11.51	12.06	12.31
CR_AP_003	11.51	12.06	12.31
AP_003_I1	11.31	11.81	12.08
CR017	11.11	11.55	11.75
CR016	11.12	11.54	11.75
CR_AP_004	11.11	11.55	11.76
AP_004_I1	11.09	11.52	11.74
CR015	11.03	11.50	11.72
CR015_I2	11.01	11.48	11.69
CR014	10.99	11.52	11.78
CR_AP_005	10.96	11.48	11.76
S3.5_US	10.95	11.48	11.75
S3.5_DS	10.74	11.14	11.33
CR013	10.72	11.12	11.31
S3_US	10.66	11.06	11.25
S3_DS	10.53	10.91	11.10
S3_DS_2	10.55	10.94	11.13
CR012	10.47	10.85	11.04
CR012_2	10.36	10.73	10.92
CR011	10.16	10.53	10.72
CR011_1	10.03	10.41	10.59
CR011_I3	9.91	10.33	10.52
CR010	9.55	9.96	10.18
CR009	9.42	9.78	9.95
CR008	9.26	9.67	9.86
CR008A	9.13	9.58	9.79
CR008A_U	9.01	9.42	9.60
S2_BR	9.00	9.41	9.59
CR007A	8.97	9.43	9.66
CR007A_WU	9.06	9.52	9.78
CR007A_WD	8.73	9.20	9.50
CR007	8.36	8.99	9.33
CR006	8.26	8.98	9.32
CR005	8.05	8.83	9.18
CR004	7.95	8.79	9.08
CR004A	7.15	7.83	8.07
S1_US	7.05	7.72	7.95

6 Part-Defended Option

In addition to the above, a Part-Defended scenario was also requested to be assessed. This scenario removed all proposed flood defences north of the Penkiln Bridge, see Figure 12.

Figure 12: 200-year part defended scenario



6.1.1 Part Defended Results

A Part Defended scenario was also requested to be modelled, and this also involved the simulation of full suite of scenarios for the eleven cases listed in Table 13. Only the results for the 200-year cases, including climate change, are provided in Table 15 below.

Table 15: Model results for 200-year Part Defended

Model Cross Section Label (See Figures 1-3)	200-year Part Defended (m AOD)	200-year +28% (m AOD)	200-year +44% (m AOD)
PN030	23.31	23.53	23.65
PN029	21.07	21.37	21.52
PN028	19.91	20.21	20.37
PN027	18.49	18.87	19.02
PN027_I5	17.48	17.82	17.97
PN026	17.21	17.49	17.67
PN026_I7	16.02	16.33	16.49
PN025	15.28	15.57	15.72
PN025_I5	14.67	15.11	15.33
PN024	14.27	14.71	14.93
PN024_I	13.87	14.26	14.47
PN023	13.36	13.77	14.00
PN023_I	13.19	13.65	13.90
PN023A	13.00	13.43	13.65
PN_S5_US	12.97	13.38	13.60
PN_S5_DS	13.01	13.40	13.60
PN019A	12.86	13.23	13.43
PN019A_N	12.77	13.22	13.44
PN019A_N2	12.59	13.04	13.27
PN019B	12.59	13.09	13.30
PN019B_I2	12.22	12.77	13.01
PN019C	12.10	12.63	12.87
PN019C_IN	11.90	12.49	12.74
PN019C_3	11.84	12.41	12.66
PN019	11.84	12.41	12.64
PN_AP_002	11.72	12.29	12.51
PN018	11.58	12.15	12.37
PN018_I1	11.49	12.04	12.23
PN_AP003US	11.51	12.09	12.30
CR022	13.42	13.84	14.03
CR021	13.27	13.67	13.86
CR021_2	13.20	13.64	13.85
CR020	12.99	13.42	13.62
FB_US	12.76	13.20	13.42
FB_DS	12.76	13.20	13.41
FB_DS_2	12.62	13.10	13.32
S4_CR_US	12.67	13.19	13.43
S4_CR_DS	12.49	13.02	13.26
S4_DS	12.14	12.75	13.01

SEC12	12.11	12.65	12.90
CR019	11.86	12.43	12.68
CR019_I2	11.71	12.31	12.55
CR_AP_002	11.78	12.36	12.59
CR018	11.62	12.18	12.40
SEC11	11.06	11.53	11.64
CR_AP003US	11.51	12.09	12.30
CR_AP_003	11.51	12.09	12.30
AP_003_I1	11.31	11.86	12.05
CR017	11.11	11.60	11.76
CR016	11.12	11.61	11.76
CR_AP_004	11.11	11.60	11.75
AP_004_I1	11.09	11.57	11.71
CR015	11.03	11.54	11.69
CR015_I2	11.01	11.52	11.67
CR014	10.99	11.55	11.77
CR_AP_005	10.96	11.52	11.74
S3.5_US	10.95	11.52	11.73
S3.5_DS	10.74	11.17	11.31
CR013	10.72	11.15	11.30
S3_US	10.66	11.09	11.23
S3_DS	10.53	10.94	11.08
S3_DS_2	10.55	10.97	11.11
CR012	10.47	10.88	11.02
CR012_2	10.36	10.77	10.89
CR011	10.16	10.57	10.69
CR011_1	10.03	10.45	10.56
CR011_I3	9.91	10.37	10.50
CR010	9.55	9.99	10.14
CR009	9.42	9.80	9.93
CR008	9.26	9.70	9.84
CR008A	9.13	9.60	9.77
CR008A_U	9.01	9.43	9.57
S2_BR	9.00	9.42	9.57
CR007A	8.97	9.46	9.64
CR007A_WU	9.06	9.56	9.76
CR007A_WD	8.73	9.25	9.47
CR007	8.37	9.05	9.30
CR006	8.27	9.05	9.28
CR005	8.05	8.88	9.13
CR004	7.95	8.84	9.04
CR004A	7.15	7.87	8.04
S1_US	7.05	7.76	7.92

7 Conclusion

This report summarises detailed mathematical modelling work undertaken to develop a flood protection scheme for Newton Stewart and Minnigaff. The mathematical model of the River Cree and Penkiln Burn, developed for the 2013-2015 flood study, was refined before it was used as a tool to assess a range of flood management options.

Over 200 model runs were carried out and used in the assessment of flood options by SWECO. Model results from the base case and preferred options are presented in this report, but all model results were communicated to SWECO, who analysed and developed the preferred option.

Final model results for only the 200 year/+28%/+44% scenarios for the proposed Newton Stewart Flood Prevention Scheme are provided in the report, whilst a full suite of model results was provided to SWECO for the development of the scheme.

This report summaries the mathematical modelling which was undertaken and should be read in conjunction with the previous study report (2015) and its addendum (2017) and Newton Stewart Flood Protection Scheme – Flood Management Optioneering Report (SWECO).

Appendix

Ref:1293/CA/MS

Your Ref:

17th May 2023

Dumfries & Galloway Council
Cargen Tower
Garroch Business Centre
Cargenbridge
Dumfries
DG2 8PN

By email to: Smith, Michael <Michael.Smith@dumgal.gov.uk>

For the attention of Michael Smith

Dear Sir,

Dumfries and Galloway Council
Newton Stewart Flood Prevention Scheme
Review of Flood Scheme Updates Against Previously Modelled Options

Following a comprehensive flood study conducted by Kaya Consulting in 2015, with subsequent updates in 2017, Dumfries and Galloway Council commissioned SWECO to advance a flood defence scheme for Newton Stewart and Minnigaff.

Proposed defence scenarios were modelled in April / May 2019 and a hydraulic modelling report was prepared in August 2020, which summarised the previous work and presented results for two main defence options, (i) 'full' defended and (ii) 'part defended' schemes. The full defended scheme refers to the defences extending upstream of the Penkiln Bridge and the part defended scheme refers to the defences starting from just downstream of the bridge.

The part defended scheme has been selected as the preferred option and designs have been progressed by SWECO. Dumfries and Galloway Council has asked that Kaya Consulting review the final defence layout against the options modelled in 2019.

The drawings reviewed are:

- 118908-400-101/2
- 118908-400-111/2/3/4/5/6/7
- 118908-400-150/4/5

Compared to the layout proposed in 2019 there have been minor adjustments to the defences, such as the inclusion of a low wall at the monument on Victoria and additional defences on Good's Lane. However, these changes will not impact the model predictions provided in 2019 and reported in "*NSFPS Hydraulic Modelling Summary Report, Aug20*".

This review has focussed on an assessment as to whether the final defence layout would impact previous model predictions.

We trust this information is sufficient at such time. If you wish to discuss any parts of the above, please do not hesitate to contact the undersigned.

Yours faithfully,

Callum Anderson
Technical Director