BALLATER ADDITONAL FLOOD STUDY

Feasibility Report- Technical Report

IBE1982
D04
June 2023

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
D01	Draft	DM/JB	DM	AJ	Nov 2022
D02	Draft	DM/JB	DM	AJ	April 2023
D03	Draft final	DM/JB	DM	AJ	May 2023
D04	Final	DM/JB	DM	AJ	June 2023

Approval for issue

Andrew Jackson	7 June 2023

Prepared by:

RPS

Diane McGinnis
Senior Associate - Water Environment and Flood Risk Management

Elmwood House
74 Boucher Road, Belfast
Co. Antrim BT12 6RZ

T +44 2890 667 914
E diane.mcginnis@rpsgroup.com

Prepared for:

Aberdeenshire Council

Lee Watson
Principal Engineer

Flood Risk & Coastal Protection
Infrastructure Services
Aberdeenshire Council,
Stonehaven, AB39 2QP

T
E

Contents

Figures

Tables

Appendices

1 INTRODUCTION

1.1 Background

The River Dee is the main river in Ballater, flowing in an easterly direction and draining to the North Sea at Aberdeen. The Rivers Gairn and Muick are tributaries of the Dee which pass through the Cairngorms National Park and have confluences located in Ballater, where there is a mix of residential and commercial properties and social amenities such as a Golf Course and Caravan Park. The location of Ballater is shown in Figure 1.1

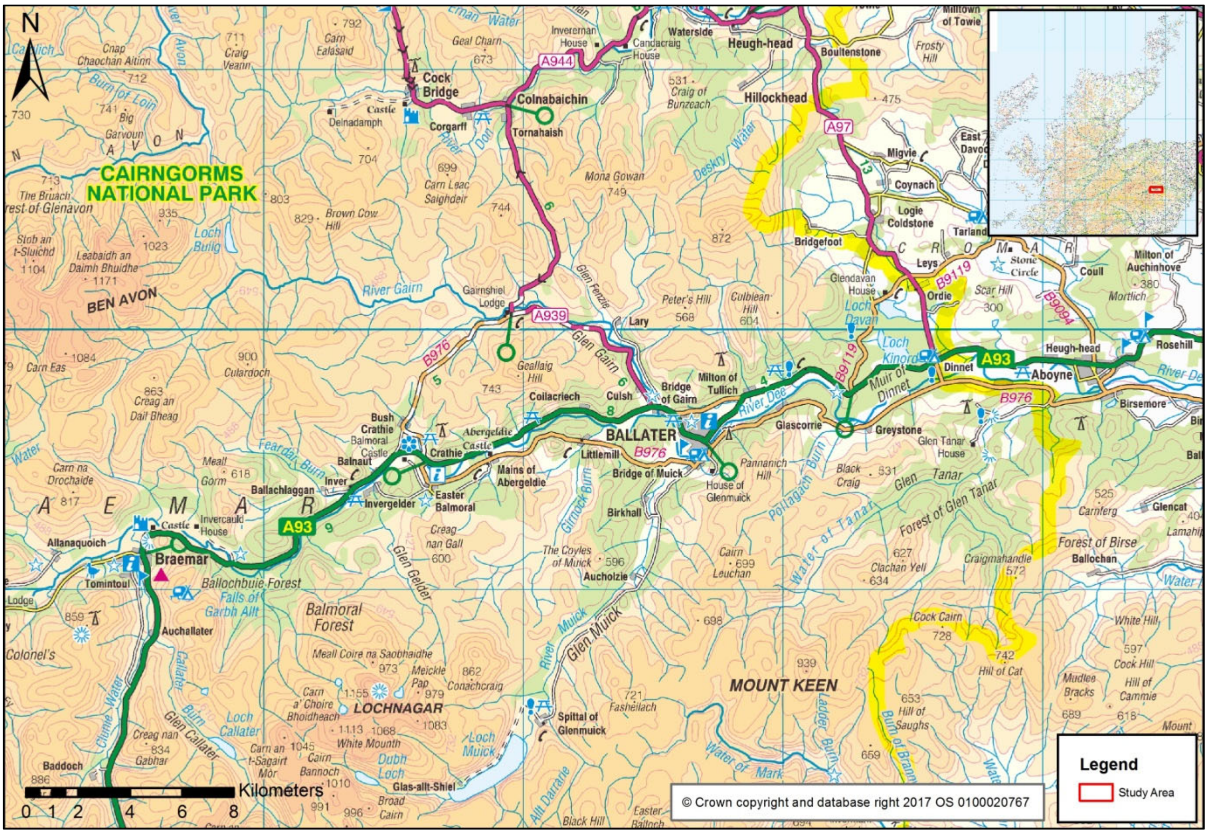


Figure 1.1: Location of Ballater

Ballater has experienced significant flooding from the River Dee in the past. In December 2015, heavy rainfall during Storm Frank caused the River Dee to burst its banks, flooding over 300 properties. Following a further event in February 2021, the course of the River Dee changed, most notably in the vicinity of Ballater Golf Course. During this event, erosion to rock armour protection occurred and sections of informal flood defence bund along the left bank of the River Dee at the Golf Course were washed away.

A further flood event occurred in November 2022, with a SEPA-estimated return period of 6-7 years. Prior warning was given for this event, and a range of measures were quickly deployed to provide a degree of protection to the at-risk properties within Ballater. For this reason, along with the hydrological complexity in ascertaining the contributions from each catchment involved (Gairn, Muick and Dee) a much lower impact on receptors was caused by this event than would have been expected based on comparable modelling simulations from both the 2018 and 2022 models. Given the lack of a detailed and thorough hydrological analysis, this event has not been considered within this study.

1.2 Ballater Flood Protection Study

In 2018, Aberdeenshire Council commissioned RPS to carry out a feasibility study to identify flood risk associated with the Rivers Dee, Gairn and Muick in Ballater and assess options (including economic viability) for the alleviation of future flooding. As part of this, RPS undertook comprehensive review of existing information including historical flood event data, survey information, existing hydraulic models and reports in addition to procuring additional topographical survey information. A new 2-D hydraulic model of the River Dee, Gairn and Muick was constructed, within the bounds of the study area. This model was fully reviewed and approved by SEPA. A preferred flood protection option for Ballater was subsequently identified, comprising direct defences (permanent and glass walls), pumping stations, relocation, property level protection and resilience measures.

1.3 Objectives of Additional Study

The aim of the Ballater Additional Flood Study is to identify any changes to flood risk resulting from significant morphological changes to the River Dee, and to assess the potential for minor works to manage the flood risk to Ballater until such time that a decision is made to implement the proposed main scheme as described above.

Minor works have been suggested by members of the local community and these will be further investigated as part of this study:

1. Removal of dead trees from river channel and reuse in bank reinforcement.
2. Clearance of deposited gravel from main river channel on Glenmuick side.
3. Clearance of outlet channel for watercourse across Golf Course.
4. Build new bund across rough ground at southern end of Golf Course.

2 SITE VISIT

2.1 Defence Condition Inspection

A site visit was completed in March 2022, with the objective of revisiting the site to determine any change in the structural condition of the existing flood risk management assets following the last inspection in 2018. Following this visit, a 'Defence Condition Inspection' report was completed and issued to Aberdeenshire Council (see Appendix A).

2.2 Appraisal of Benefit of Minor Works

A secondary function of the RPS site visit in March 2022 was to evaluate the practicality of, and potentially inform a subsequent appraisal of the benefit of, implementing the minor works measures as described in Section 1.3.

2.2.1 Option 1: Removal of dead trees/ debris

Removal/ clearance of this debris should increase conveyance along this section of the flood plain, however the impact of this would need to be assessed using the hydraulic model to determine if it would make any significant difference to water levels adjacent to the Golf Course even during low return period flood events. Consideration would also need to be given the potential for the enhanced conveyance resulting from the removal of this material to increase flood risk at the Caravan Park, something that again would be best quantified by use of the hydraulic model before any extensive clearance is undertaken.

Assuming that the modelling does identify a beneficial impact of removing this material, it is entirely reasonable that the material extracted could be used to enhance the erosion resistance of existing defence structure or any new defence. However, if this approach is adopted it will be imperative that the material is adequately secured to prevent it from being washed away and further contributing to potential blockage of flow downstream.

2.2.2 Option 2: Clearance of Channel on Glenmuick side

It was obvious from the 2022 site visit that the main flow channel of the River Dee had migrated from the Glenmuick side to the Ballater side in the area around the confluence with the River Muick. This change in flow path has been associated with infilling of the former flow channel with riverine gravel and sand, to the extent that the feature formerly known as the Manse Pool on the Glenmuick side no longer exists. The change in flow path of the River Dee is such that the flow approaching the former channel on the Glenmuick side of the river is now deflected to the east, towards Ballater which is probably what has contributed to the bypassing of the former Glenmuick channel. The exact reason for this change in flow path is uncertain, however from what could be observed on site and derived from a review of online historic mapping, it appears that the left-hand bend upstream has become more pronounced, which combined with potentially more resistant bank material on the Glenmuick side has resulted in the change in flow direction. Thus, while it may appear desirable to excavate the deposited material from the former channel on the Glenmuick side, it is very doubtful that alone would result in the River Dee returning to its former path. It was also observed that the quantity of material to be moved in such an operation would not be insignificant for potentially limited benefit.

While complete removal of the deposited material from the former channel on the Glenmuick side of the River Dee channel is unlikely to be an achievable solution, there may be merit in the removal or redistribution of some material from the northern end of the cobble bank that has become established to try to encourage the River Dee to take a more southerly trajectory. It is unlikely that this would make any significant direct contribution to the management of flood risk at Ballater, however it may reduce the potential threat of further erosion along the left bank of the river and hence the risk of further section of the informal flood embankment/ footpath being lost.

2.2.3 Option 3: Clearance of Outlet channel at Golf Course

The minor watercourse that flows through/ under the Golf Course discharges to the River Dee just upstream of the Caravan Park. Whilst the channel within the Golf Course is well maintained and free of debris, once it passes beyond the actual playing course it flows through an area of tress and scrub on the inside of the bend of the river at the confluence of the River Dee and River Muick and this section is heavily choked with debris from previous flood event on the River Dee.

Clearance of this channel would increase its conveyance potential, which should assist in draining flood waters from the area of the Golf Course and hence might to some degree reduce the flood risk to the developed area of Ballater particularly during more frequent flood events. However, as with the general clearance of flood debris from the floodplain the effect of clearing this channel would need to be examined via the hydraulic model to ascertain what benefit would accrue. Whilst it is unlikely, there is also a possibility that clearance of this channel could allow any backed-up flood water from the area immediately upstream of the Royal Bridge to flow back on to the Golf Course potentially increasing the flood risk to the developed area on Ballater. Thus, before any decision can be made on the effectiveness of this measure the updated hydraulic model simulations would need to be completed.

2.2.4 Option 4: New bund at Southern End of Golf Course

At the time of the 2018 site inspections there was a river side bund present at the south end of the Golf Course, which is understood to have been washed away during the flood event of February 2021. Anecdotal reports from locals on the February 2021 event suggest that this structure held back flood water for some time, before succumbing to erosion and therefore may have reduced the extent of flooding experienced. Consequently, there is concern locally that the lack of this structure may represent an increased flood risk to Ballater even during relatively frequent flood events. One of the tasks associated with the Ballater Additional Flood Study is to update the previously developed hydraulic model to reflect the post February 2021 channel geometry and establish how this has affected the flood risk to Ballater. This task will confirm if there is indeed an increased flood risk to Ballater and hence the potential need for remedial works to maintain the previous standard of flood protection.

Irrespective of the outcome of the modelling, it was clear from the site inspection that the re-establishment of a flood defence along the present riverbank is unlikely to be sustainable due to the change in orientation of the

River Dee. Visual examination of the topography within the area of rough ground belonging to the golf Club at the south end of the course identified a potential alternative line making use of generally raised ground levels extending in a more or less straight line that might represent a more sustainable alignment for any future flood embankment. Construction of an embankment along this alignment would involve crossing the watercourse draining the Golf Course, which flows through a low point in the topography, however culverting of this short stretch should not be a significant challenge, there are already numerous culverts and crossing throughout the Golf Course and where the existing riverside pathway crosses a short distance to the south of the identified alignment.

3 ADDITIONAL SURVEY INFORMATION

3.1 Topographical Survey

A topographical survey completed by Aspect Surveys during July and August 2017 was used in the 2018 study. Since this period, several large magnitude flood events have been recorded and as such considerable morphological change has occurred to the River Dee in the vicinity of Ballater. To ensure accuracy of the hydraulic model, RPS procured a revised topographical survey of the River Dee from the northern extent of the Golf Course to the Royal Bridge. This was again undertaken by Aspect Surveys and completed during March and April 2022, resulting in the delivery of 45 new cross-sections (see Figure 3.1 for locations). The additional topographic survey is shown in Appendix B.

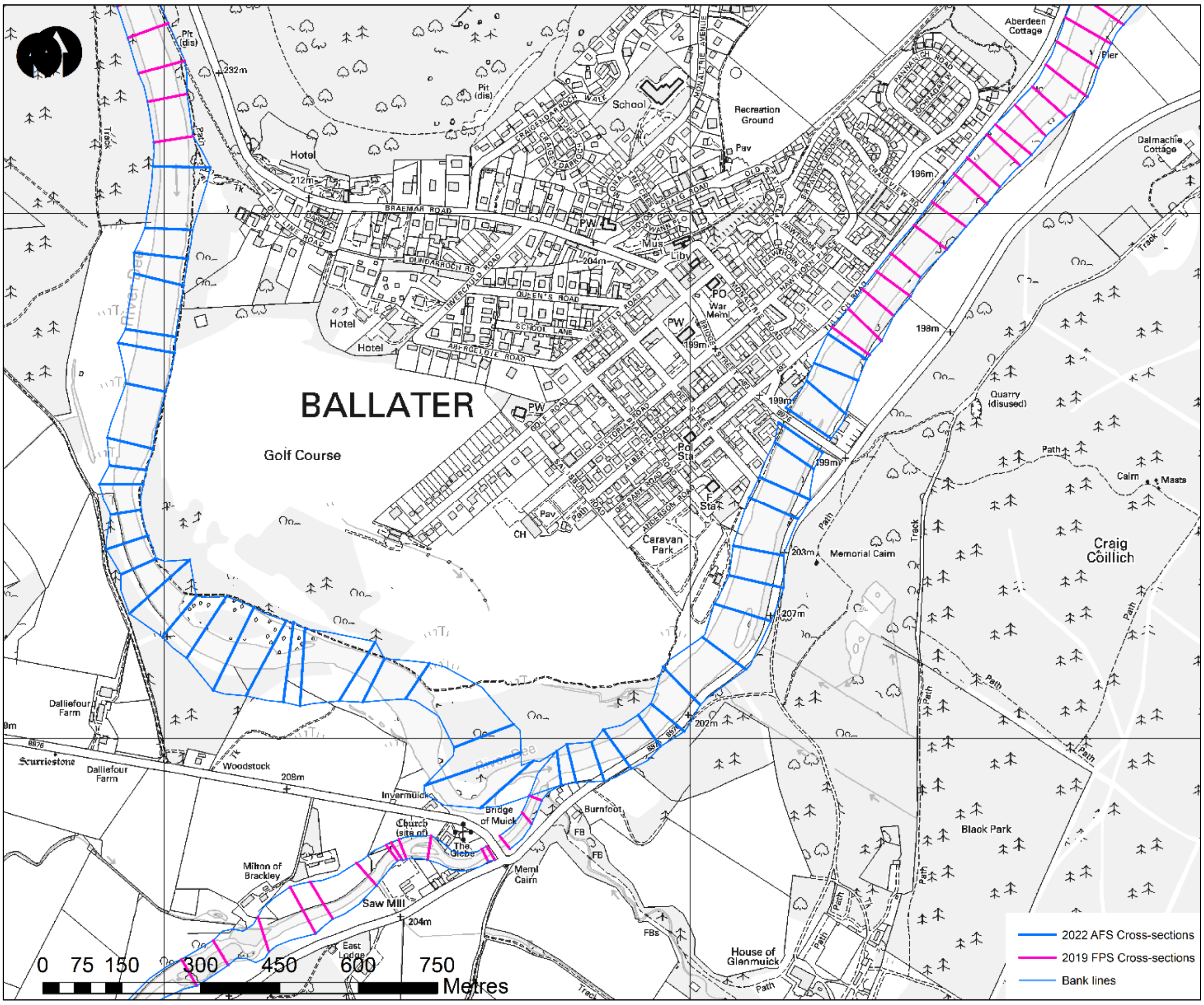


Figure 3.1: Existing and newly surveyed cross-sections for use in the Ballater Additional Flood Study

3.2 Surface and Terrain Models

Owing to notable changes in channel morphology post 2018, new high-resolution LiDAR was procured for the River Dee in the vicinity of Ballater Golf Course (see Figure 3.2), and was used to supplement the existing ground model which formed the basis of the 2018 model.

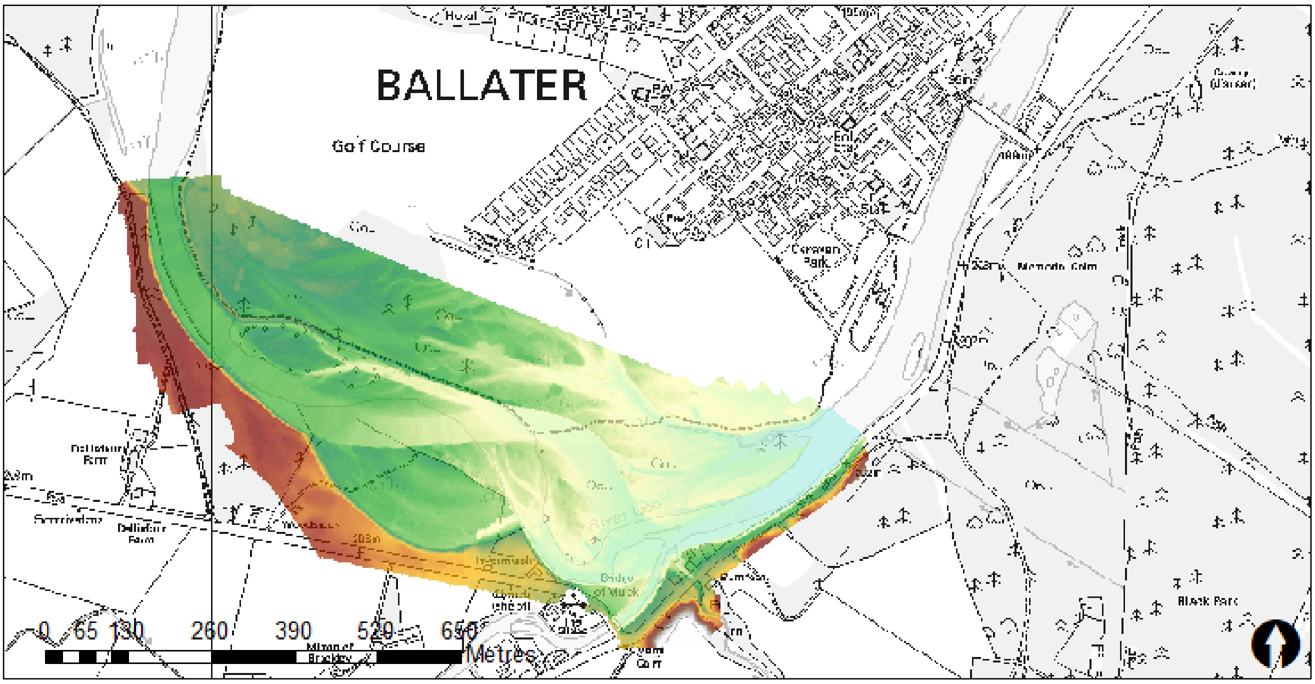


Figure 3.2: Newly procured LiDAR of the left and right bank of the River Dee, south of Ballater Golf Course

4 MORPHOLOGICAL ASSESSMENT

4.1 Repeat Fluvial Audit

An initial fluvial audit of the River Dee was undertaken as part of the original study by Cbec, who were commissioned to undertake a repeat fluvial audit as part of this study (see Appendix C). The fluvial audit, which was completed in June 2022, confirmed the trajectory and magnitude of geomorphological change previously predicted in 2018 and as anticipated, included significant planform adjustment (see Figure 4.1) specifically:

- the sediment 'pulse' generated through Storm Frank significantly altered channel configuration in the vicinity of Ballater Golf Course, leading to migration of the main stem of the River Dee.
- where Storm Frank had locally increased cross-sectional area and lowered transport capacity (such as the area immediately upstream of the confluence with the Muick), large alluvial deposits have developed between fluvial audits.
- the sediment 'pulse' generated through Storm Frank significantly altered channel configuration in the vicinity of Ballater Golf Course, leading to migration of the main stem of the River Dee change in cross-sectional profile and channel hydraulics exacerbated erosional forces along the left bank of the River Dee in the lower section of the embankment protecting the Golf Course and Ballater.

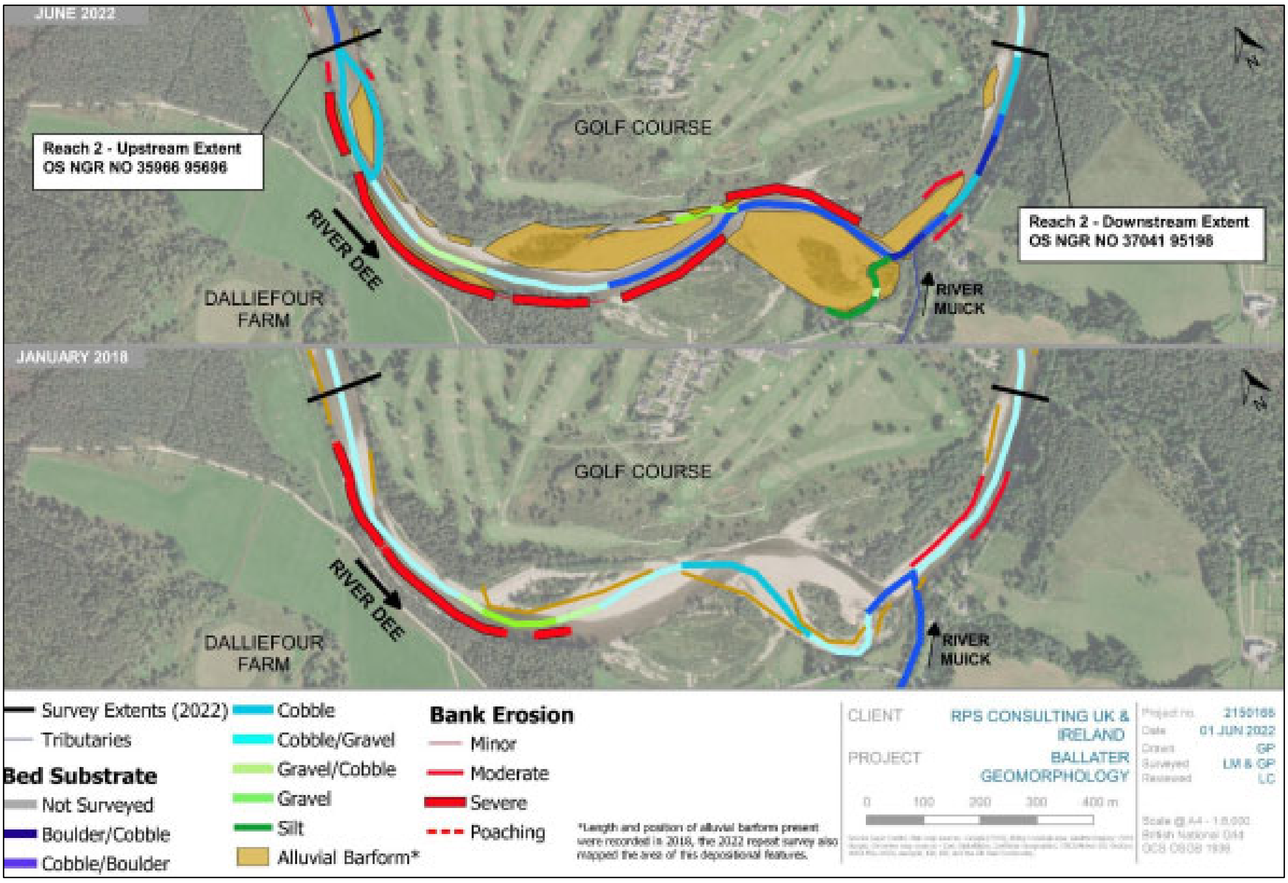


Figure 4.1: Geomorphological assessment of the River Dee in the vicinity of Ballater

4.2 Assessment of Minor Works Options

Additionally, Cbec were asked to provide a preliminary qualitative assessment of the adequacy of the four minor works options being proposed.

4.2.1 Option 1: Removal of Dead Trees/Debris

Option 1 could contribute towards the natural reactivation of the previous primary low route of the River Dee as well as limiting the excessive recruitment of large wood that could further decrease conveyance during high flow events.

4.2.2 Option 2: Clearance of Channel on Glenmuick side

Option 2 would require a robust detailed design process to provide evidence that newly dug main channel can be self-sustainable and will not perform as a sediment “sink” in the next high flow events.

4.2.3 Option 3: Clearance of Outlet Channel at Golf Course

There are some likely limitations to the long-term effectiveness of Option 3. Considering the grain diameter of sediment recently deposited in the area of woodland closer to the Golf Course it appears that, within the current channel configuration, relatively small events can deposit substantial volumes of fine material in these side channels. Therefore, the depositional character of this area can significantly limit the long-term effectiveness of this option.

4.2.4 Option 4: New Bund at Southern End of Golf Course

Option 4 may provide a positive contribution to the desired 1 in 10 year standard of protection, with minimal impact to geomorphic processes. However, careful consideration will be necessary to ensure that final barrier configuration does not produce the following negative impacts:

- Barriers deflecting hydraulic forces during a high flow event and increasing shear stress and erosive potential in the River Dee.
- Potential for changes in nearby flood levels in proximity to Golf Course and Caravan Park. In particular, it is recommended that barrier installation is not completed prior to undergoing hydraulic modelling updates.

5 REVIEW OF FEBRUARY 2021 EVENT HYDROLOGY

As described previously, a significant event occurred on 21st February 2021 in Ballater. Aberdeenshire Council requested that RPS evaluate how this event compared to the previous high event in August 2014. The results are presented in Appendix D.

The analysis showed varied responses and magnitude across the three contributing catchments (Dee, Gairn and Muick), with both the Gairn and Muick catchments showing significantly greater flows and subsequently return periods for the February 2021 event compared to the August 2014 event. However, during this period the River Dee recorded only its fifth greatest flow, some 20% lower than that of the August 2014 event. The differences between the three catchments are largely attributed to differences in scale and response to rainfall. Given the scale of the River Dee and its consequent contributions, by proportion, to flow facing Ballater, the return period of the February 2021 event observed at Polhollick flow gauging station on the River Dee of 5 to 10 years, is assumed representative for Ballater at this time.

6 UPDATED HYDRAULIC MODELLING

6.1 Model Construction

6.1.1 Model Conceptualisation

Building upon the 2018 hydraulic model, the Rivers Dee, Gairn and Muick catchments were conceptualised as shown in Figure 6.1, and the model developed with the following updates:

- Ground model updated with LiDAR procured for the Additional Flood Study.
- Terrain Sensitive Meshing (TSM) enabled to represent variation in micro-topography within the 2-D zone. Maximum and minimum cell size retained.
- Finished Floor Levels, mesh zones, mesh level zones and porous polygons utilised by the Flood Protection Study retained.
- 1-D network updated with newly surveyed cross-sections.

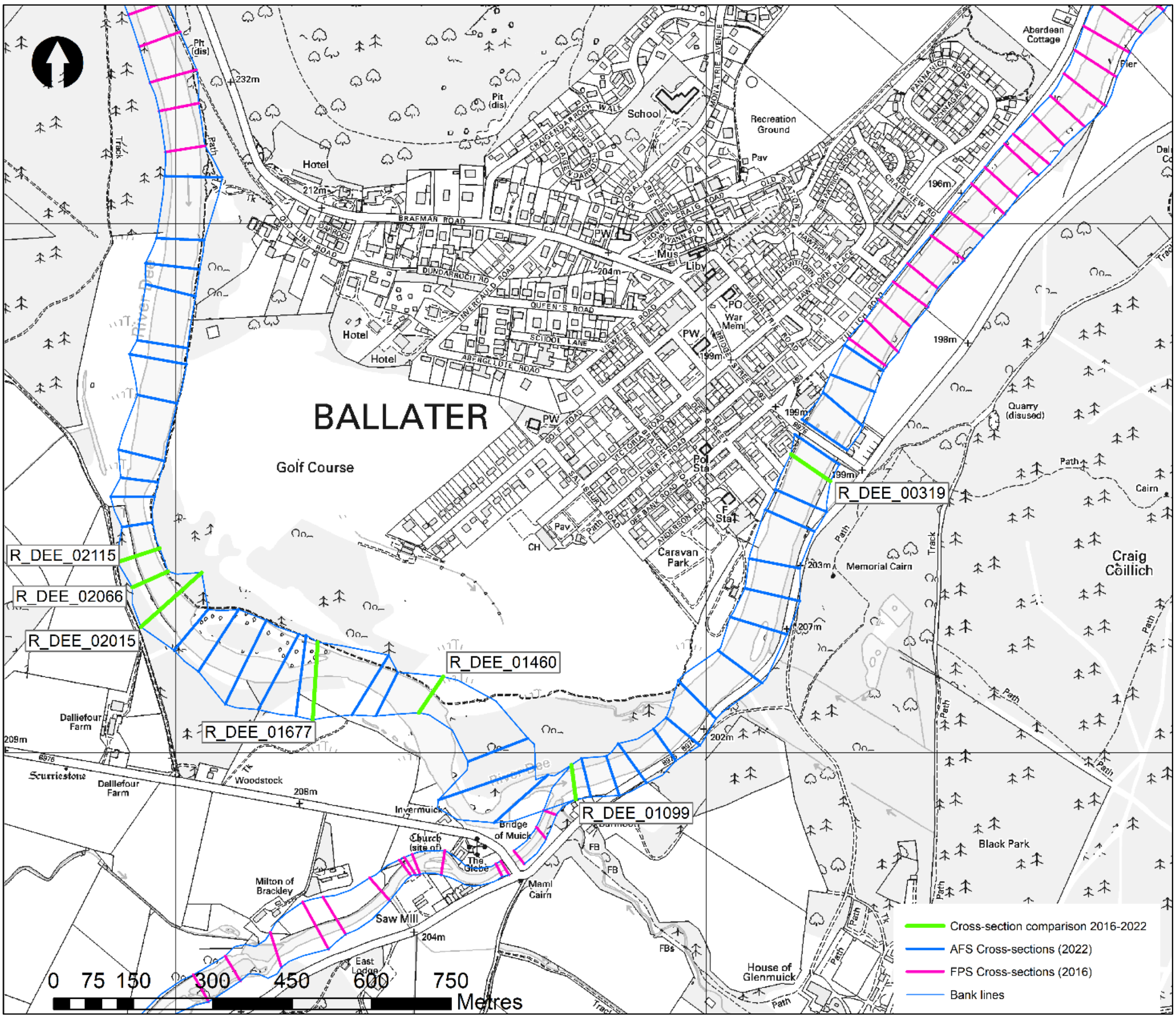


Figure 6.1: Ballater Additional Flood Study model extents

6.1.2 Modelling Software

As with the existing 2018 Study model, InfoWorks ICM was used to undertake numerical modelling, in this instance version 2021.5. As an integrated modelling package, ICM includes full solution modelling of open channels, floodplains, embankments, and structures. 2-D areas are modelled as flexible triangular mesh which allows high resolution in specific areas (i.e. riverbanks and around buildings) and lower resolution in others (i.e. open floodplains).

6.1.3 1-D Model Domain

6.1.3.1 Survey Data

45 new cross sections were surveyed in the Additional Flood Study, with 13 sections overlapping with the 2018 survey. The overlapping cross-sections were compared between the two surveys to assess the scale of change – seven sections revealed significant change (Figure 6.2 to 6.8), and six sections showed no significant change (see Appendix E).

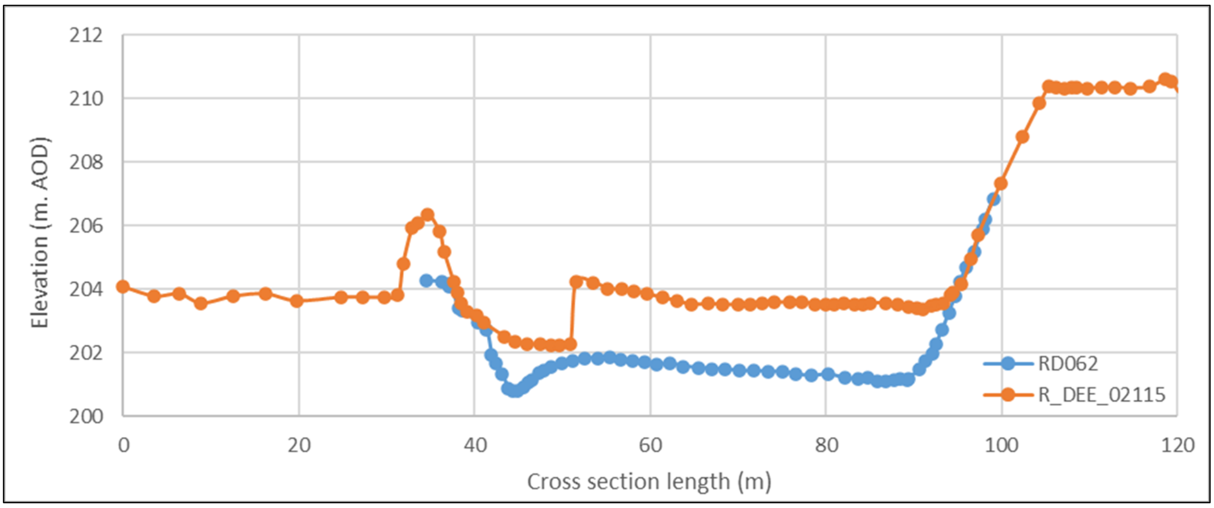


Figure 6.2: RD062 (2016) Vs. R_DEE_02115 (2022)

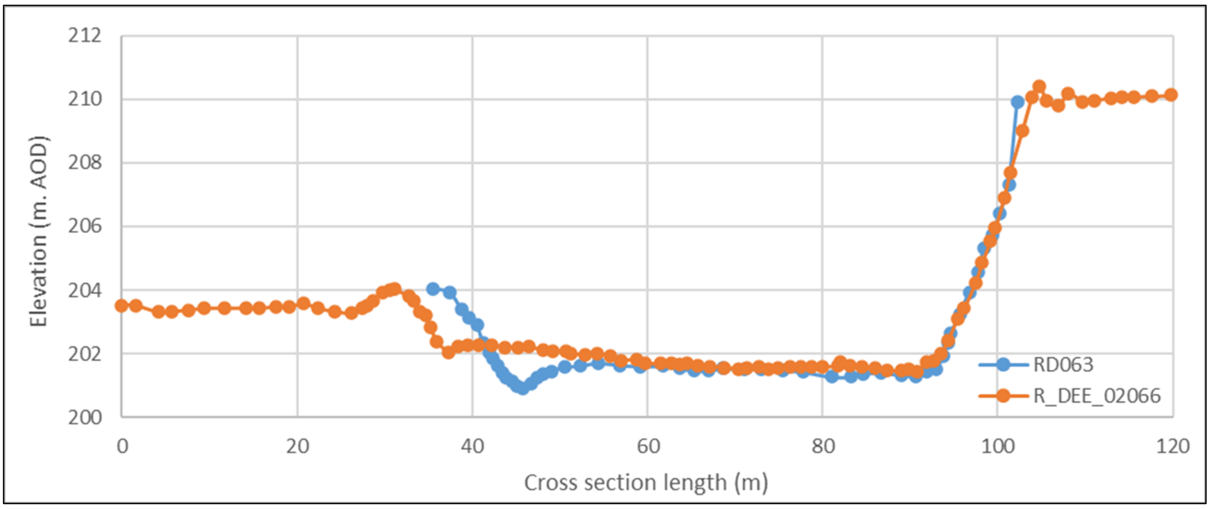


Figure 6.3: RD063 (2016) Vs. R_DEE_02066 (2022)

Figure 6.2 shows significant deposition across the channel, raising bed level to near that of the left floodplain – reducing conveyance capacity. A large embankment is also now present. Figure 6.3 shows deposition on the left of the channel. In Figure 6.4 deposition is evident in the centre of the channel, along with the removal of a high point on the left bank – the 2022 section now extends 20m further before reaching the same elevation observed in 2016. Across Figure 6.2 – Figure 6.4 the constrained nature of the channel is evident, anchored by a high right bank, thus making the lower left bank more accessible to overbank flow. Figure 6.5 shows deposition across the channel, with good agreement between bank high points in both surveys.

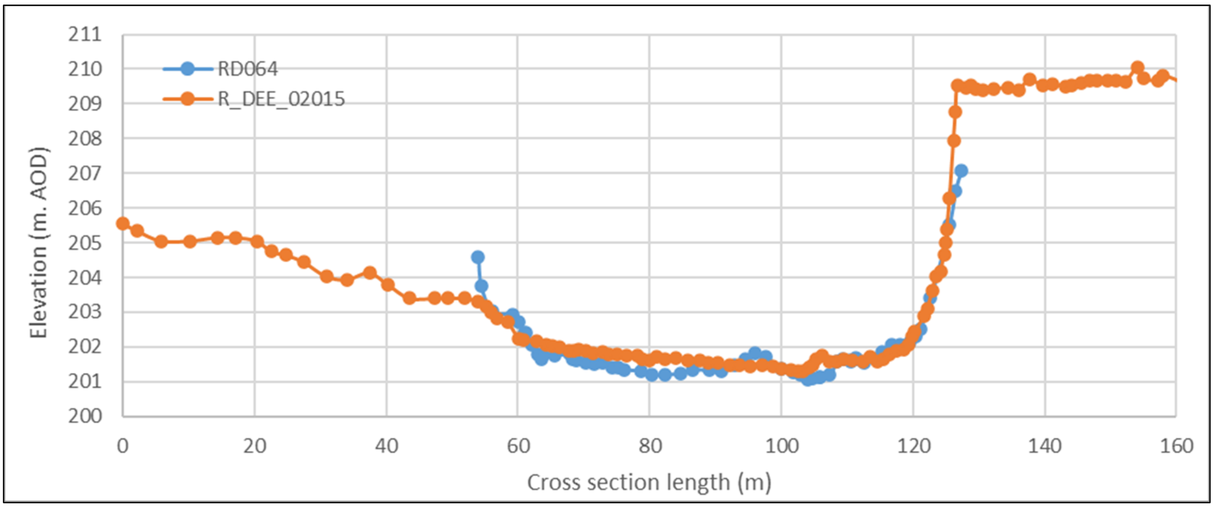


Figure 6.4: RD064 (2016) Vs. R_DEE_02015 (2022)

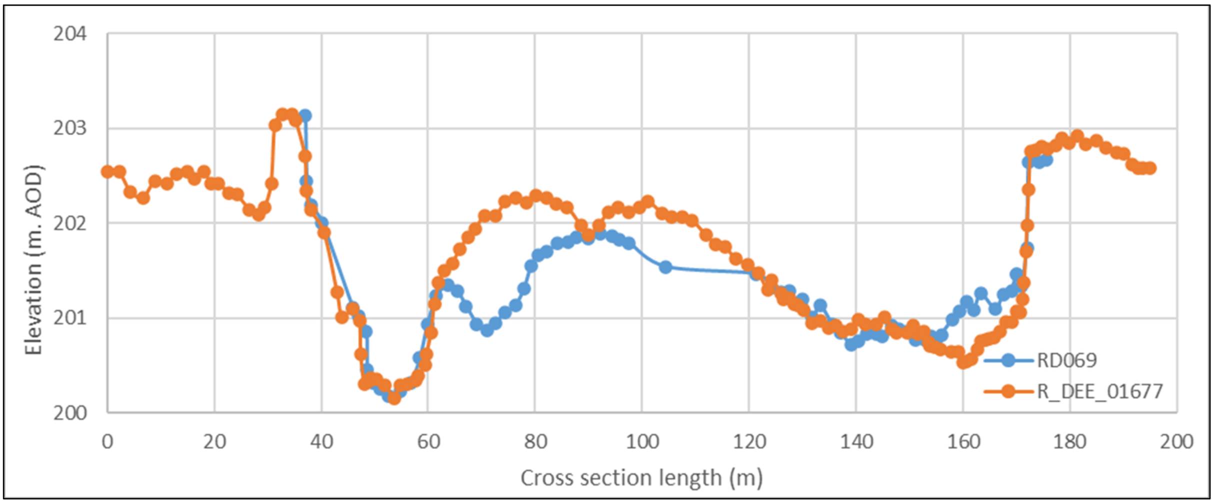


Figure 6.5: RD069 (2016) Vs. R_DEE_01677 (2022)

Figure 6.6 shows good agreement between the different periods, with two notable observations – the low point in RD073 is a poor representation of the bed and secondly, the left bank high point is significantly lower than in 2016. R_DEE_01099 shares a common right bank with RD080 (Figure 6.7) and exhibits good agreement between high points, however R_DEE_01099 is canted relative to RD080 by 17m at the left bank section ends. Whilst preventing direct comparison of the left banks, indicative assessment of channel shape is possible –

showing erosion on the right side of the channel and deposition on the left. This suggests reduced conveyance capacity and with a well-defined high right bank would make left bank spilling more probable. Figure 6.8 shows good agreement between survey periods, with a high wall now present on the left bank, general deposition across the bed and incision on the right side of the bed where the new channel is now routed.

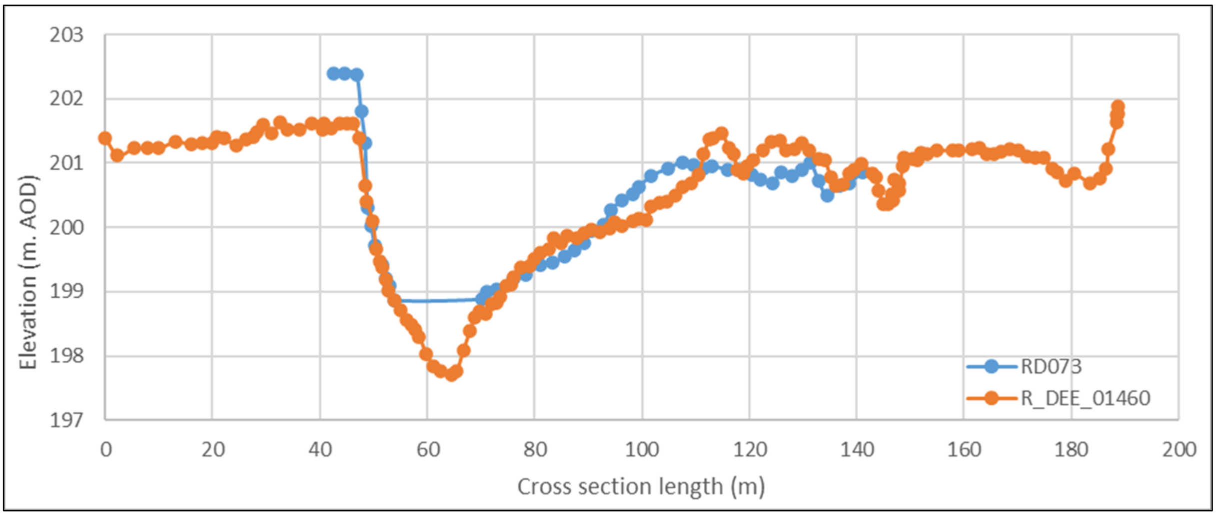


Figure 6.6: RD073 (2016) Vs. R_DEE_01460 (2022)

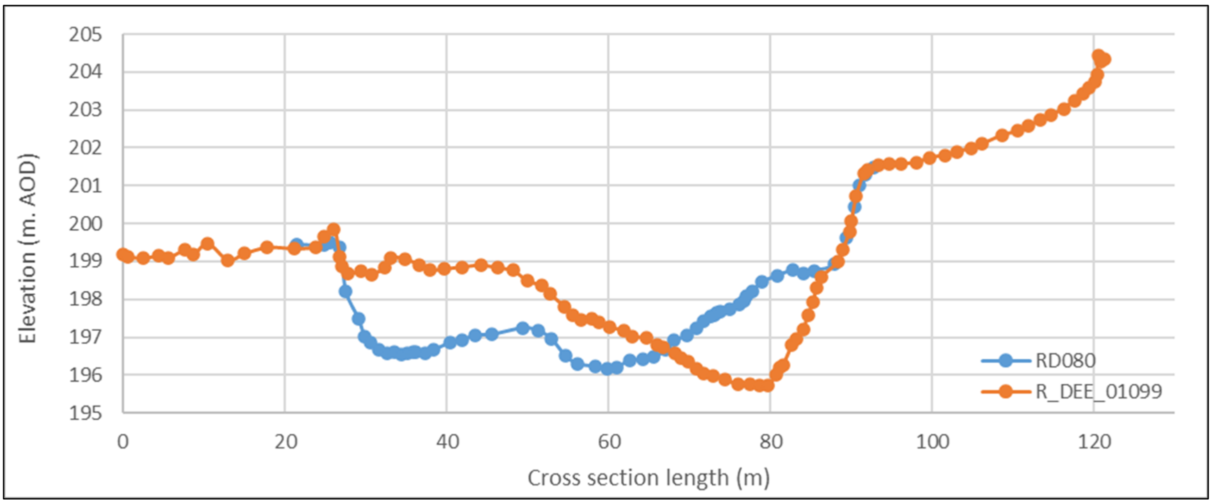


Figure 6.7: RD080 (2016) Vs. R_DEE_01099 (2022)

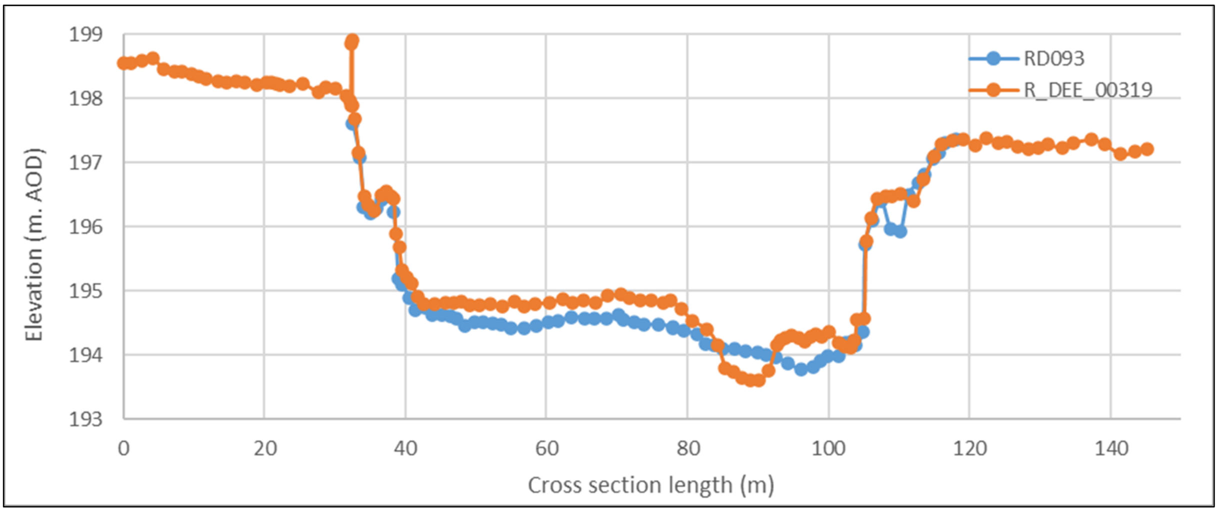


Figure 6.8: RD064 (2016) Vs. R_DEE_00319 (2022)

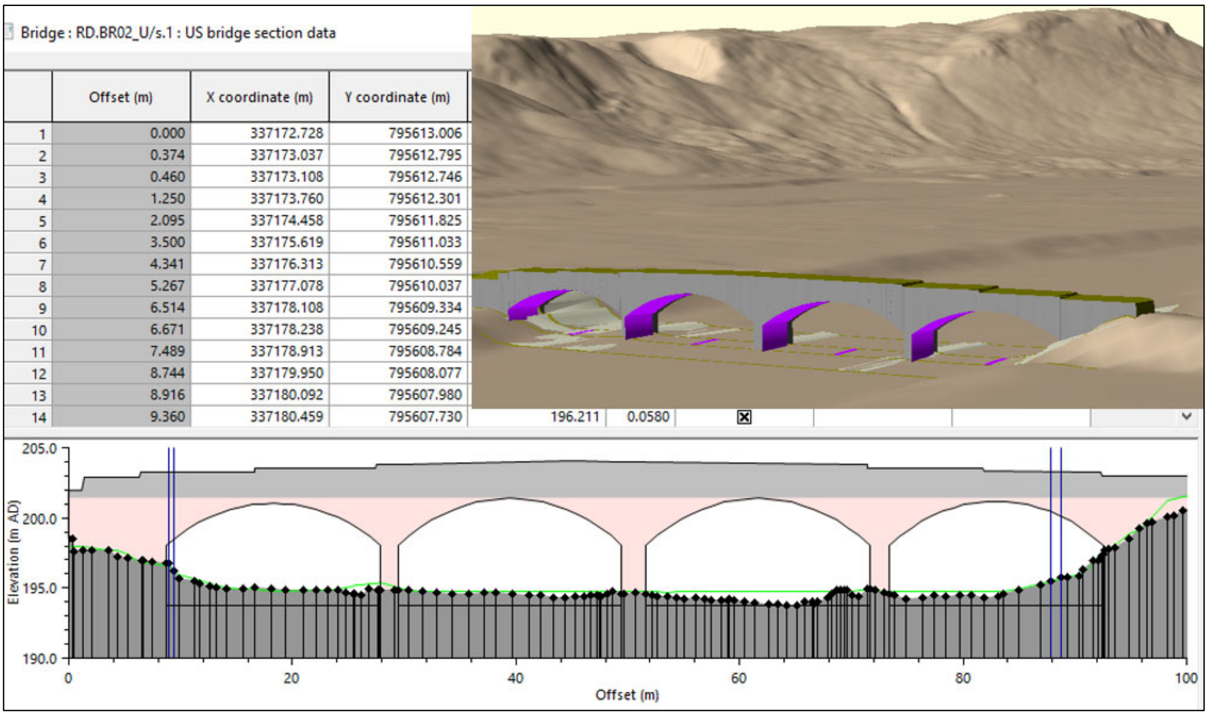
6.1.3.2 Roughness

Manning's coefficient of roughness (*n*) values (Chow, 1959[1]) were individually assigned to the new channel cross sections of the 1-D network based on surveyors' photographs.

6.1.3.3 Structures

The in-bank portion of the model (1-D) was created using the geometry of a mixture of cross sections surveyed in 2016 and used for the 2018 Study, supplemented by additional survey undertaken in 2022. All structures built during the 2018 Study remain unchanged, except for the Royal Bridge in Ballater, which was rebuilt using the 2022 survey data (Figure 6.9), providing accurate representation of current channel bed and banks across the footprint of the bridge.

[1] Chow, V.T., 1959, Open-channel hydraulics: New York, McGraw Hill, 680 p.



	Offset (m)	X coordinate (m)	Y coordinate (m)
1	0.000	337172.728	795613.006
2	0.374	337173.037	795612.795
3	0.460	337173.108	795612.746
4	1.250	337173.760	795612.301
5	2.095	337174.458	795611.825
6	3.500	337175.619	795611.033
7	4.341	337176.313	795610.559
8	5.267	337177.078	795610.037
9	6.514	337178.108	795609.334
10	6.671	337178.238	795609.245
11	7.489	337178.913	795608.784
12	8.744	337179.950	795608.077
13	8.916	337180.092	795607.980
14	9.360	337180.459	795607.730

Figure 6.9: 2022 ICM representation of Royal Bridge

6.1.3.4 Bank Lines

River channels are modelled as a 1-D network, connected to the 2-D floodplain by bank lines. Bank lines use levels at the extremities of surveyed cross sections to generate topographic representations of the riverbank, validated by LiDAR levels. Modular limit and discharge co-efficient represent the flow condition between bank and floodplain (2-D), applied in line with recommendations by Innovyze, unless otherwise stated.

6.1.4 2-D Model Domain

6.1.4.1 Comparison of LiDAR

The 2018 model utilised a DTM combining 2016 LiDAR provided by the Hutton Institute for the Ballater area, with Aberdeenshire Council 2011/2012 LiDAR used for the upper reaches of the Muick and Gairn. The Aberdeenshire Council dataset had a 1m horizontal resolution and a vertical accuracy of +/- 150mm (RMSE) whilst the Hutton Institute data had a 0.25m horizontal resolution and an average difference between LiDAR and ground control points of -190mm. 2022 LiDAR survey was found to exhibit +/- 50mm on short grass and +/- 100-250mm RMSE in densely vegetated areas when assessed against RTK survey.

Assessing the 2022 LiDAR against the existing combined DTM used in the 2018 Study (Figure 6.10) supported observations of extensive erosion and alluvial barform formation identified by CBEC during geomorphological assessment (Appendix C), showing significant change in ground surface level. The totality of such observations is limited, owing to the efficacy of LiDAR across the wetted portion of the channel and across densely vegetated areas, and as such may not be used for an absolute measure of ground surface change, but rather as an indicative measure.

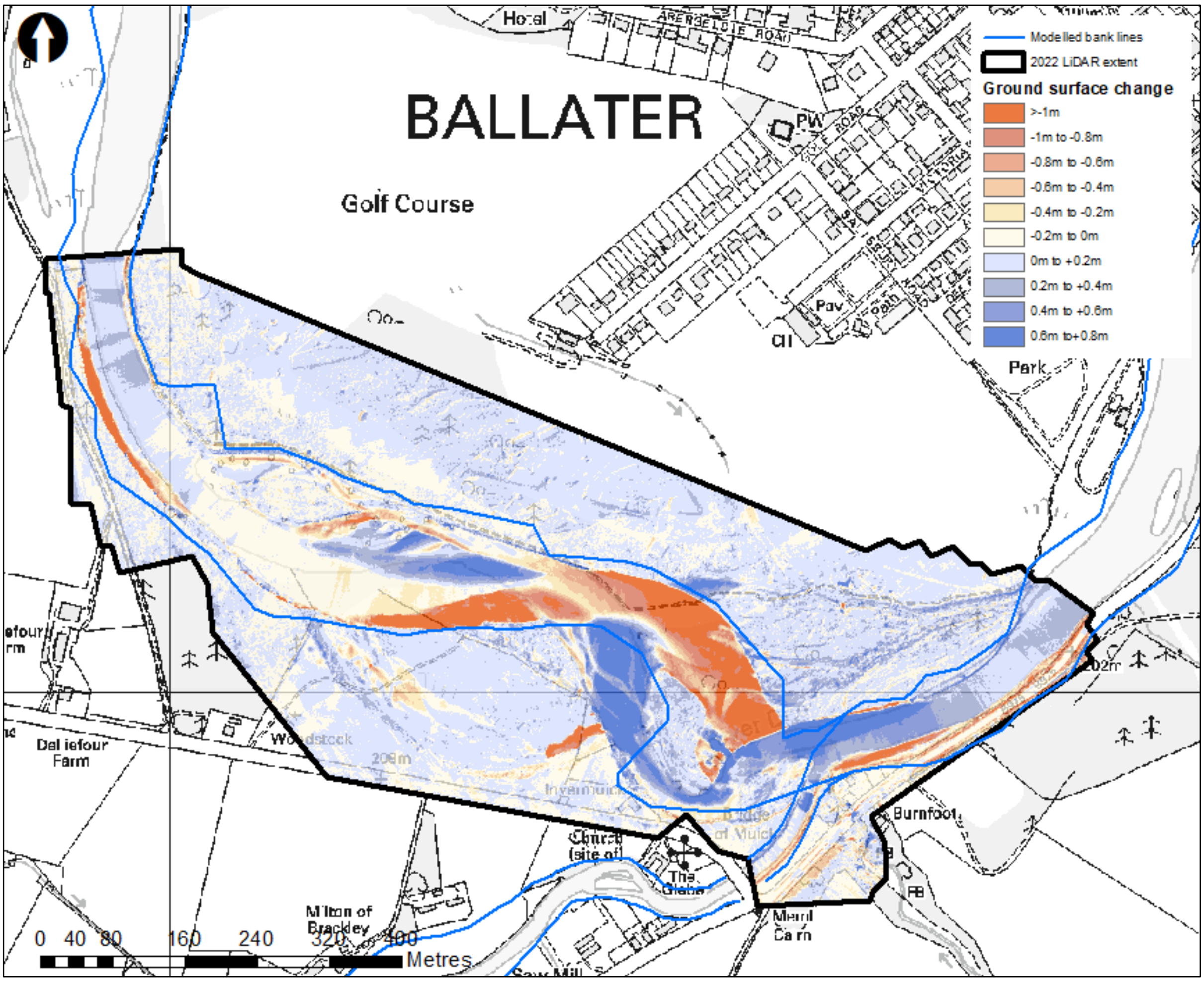


Figure 6.10: Comparison of 2011/2012 LiDAR and 2022 LiDAR

6.1.4.2 Mesh

To enable accurate assessment of 2-D flow paths, a composite Digital Terrain Model (DTM) composed of LiDAR utilised in the 2018 Study and supplemented by LiDAR captured in 2022 for the Additional Flood Study was mosaicked and clipped to generate a 2-D computational mesh of appropriate extent for the study. Finished Floor Levels (FFLs) and porous polygons utilised by the 2018 study were applied to represent buildings, walls and openings. The extent of the 2-D mesh zone, along with visible porous polygons is shown in Figure 6.11. In line with Innovyze guidance, a minimum element area of 25m^2 and a maximum element area of 100m^2 was applied to the 2-D mesh.

Figure 6.11: Ballater Additional Flood Study model 2-D mesh extent

6.1.4.3 Mesh Zone

To enable more accurate modelling of flood mechanisms and extent within the urban area, a mesh zone of much higher resolution (using a maximum and minimum element area of 5 and 1m^2, respectively) was applied to the urban area of Ballater, using the same extent as applied by the 2018 Study (Figure 6.12).

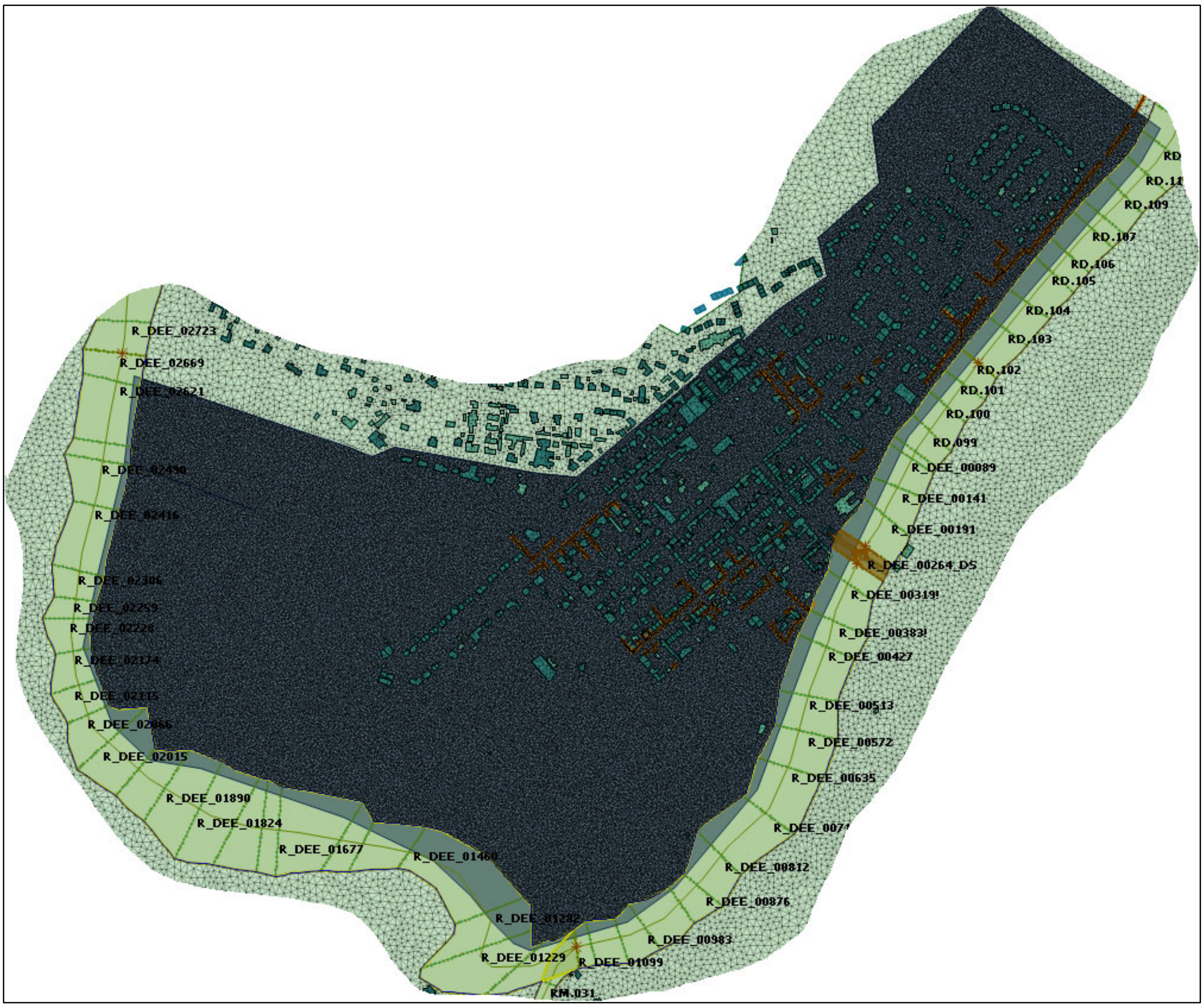


Figure 6.12: Ballater urban mesh zone

6.1.4.4 Roughness

In the 2-D domain, roughness values are used to numerically represent different materials and the subsequent impact on flow conditions. Roughness zones and associated roughness values utilised by the 2018 Flood Protection Study model were also applied to the 2022 Additional Flood Study model.

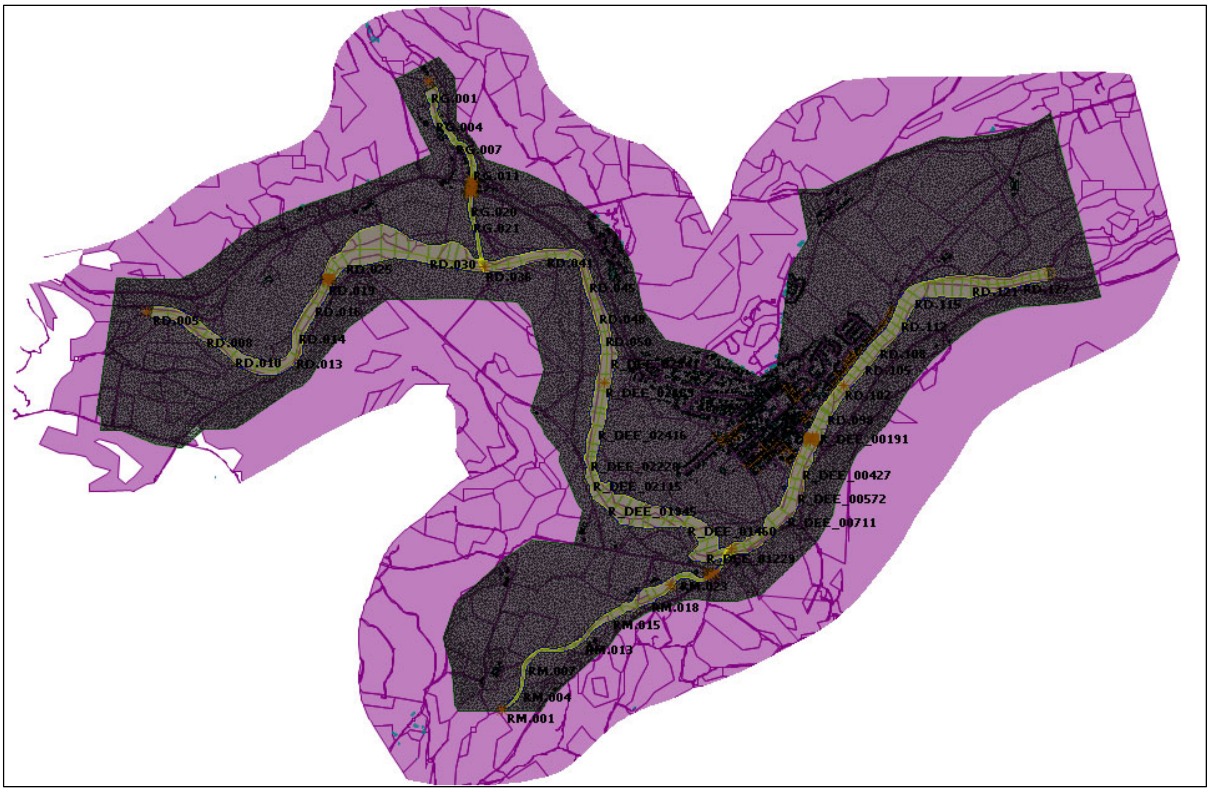


Figure 6.13: Modelled 2-D roughness zones applied to the Additional Flood Study model

6.1.5 Boundary Conditions

Upstream boundary conditions generated by hydrological assessment for the 2018 Study model were retained and introduced as point and lateral inflows to the 1-D domain. Lateral flow hydrographs between Hydrological Estimation Point (HEP) inflows were disaggregated for the appropriate river reaches based on length.

The downstream extent of the model is not impacted by coastal flows. Therefore, a normal boundary condition was applied to the 2-D zone, with no water level applied to the downstream outfall node. This approach enabled direct anchoring of the model to the hydrological analysis.

6.1.6 Simulation Parameters

Table 6.1 presents the key simulation parameters used during all modelled simulations. Internal checks confirmed the maximum space step is not greater than 1/(2S) where S is the river slope and not greater than 0.2D/S where D is the typical depth of flow (50% AEP event).

Table 6.1: Simulation parameters applied to the Additional Flood Study model

1D Domain	
Timestep (seconds)	1
Min / Max space step	0.5m / 100m
Max Timestep Halvings	10
Drowned bank linearisation threshold (m)	0.1
2D Domain	
Timestep (seconds)	Dynamic
Timestep Stability Control	0.95
Maximum Velocity	10
Theta	0.9
Inundation Mapping Depth Threshold	0.001m
Link 1D and 2D calculations at minor timestep	Yes

6.2 Model Performance

A mass balance check on the 1% AEP draft model has been carried out to ensure that the total volume of water entering and leaving the model at the upstream and downstream boundaries balances the quantity of water remaining in the model domain at the end of a simulation. This is a further indication of how the draft model is performing and to allow finalisation of the model. As a rule of thumb, mass balance errors should be less than 2%. If the mass balance error is greater than 2%, the cause and location of the mass balance error within the model schematisation should be identified and the consequence of this error assessed and improvements to the model considered. If the mass error is greater than 5%, then it suggests that the model schematisation is not robust and needs to be reviewed (Environment Agency, 2010). With a mass balance error of 0.002% the Ballater Additional Flood Study model is deemed robust.

6.3 Results of Updated Model

The updated model network was used to simulate a range of return periods as per the previous study. Flood event probabilities are referred to in terms of a percentage Annual Exceedance Probability (AEP). This represents the probability of an event of this, or greater, severity occurring in any given year. They are also commonly referred to in terms of a Return Period which is the time, typically in years, in which we would expect an event of a certain magnitude to occur. Table 6.2 sets out the range of flood event probabilities for which the updated model was run, expressed in terms of Annual Exceedance Probability (AEP), and Return Period.

Table 6.2: AEP and equivalent return periods

Annual Exceedance Probability (AEP)	Return Period (Years)
50%	2
20%	5
10%	10
3.33%	30
1%	100

The full range of flood extent depth maps are shown in Appendix F. It should be noted that the extents are representative of the river channel at the time of survey (April 2022), and that any further alterations to the channel could alter the modelled extents.

6.3.1 Comparisons with 2018 study

Extents produced for the 2022 study have been compared against those produced for the 2018 study, with changes to extent and number of buildings within the flood extent noted. Note that in the comparison maps the flood extents from the 2018 study are shown in red, the flood extents from the 2022 study are shown in blue, and any areas where the 2018 and 2022 flood extents overlap are shown in purple.

6.3.1.1 50% Annual Exceedance Probability

Comparison of the 2018 and 2022 50% AEP extents (Figure 6.14) shows significant increase in flood extent on both the left and right banks (blue areas). On the left bank, new extents are now shown encroaching upon Ballater Golf Course, Caravan Park and properties within the town to the south-west of Royal Bridge, resulting in an additional 22 properties at risk (Table 6.3). On the right bank of the River Dee to the north-west of Ballater Golf Course, an increased extent is noted to impact previously unaffected agricultural land, however no new properties are shown to be at risk. Conversely, decreases in flood extent are shown in two locations (red areas), one to the south of Ballater Golf Course and west of the Glen Muick confluence, where the previous channel routing is now not shown to be encroached upon by the 50% AEP extent, and another on the right bank of the River Dee, impacting agricultural land north-east of Royal Bridge.

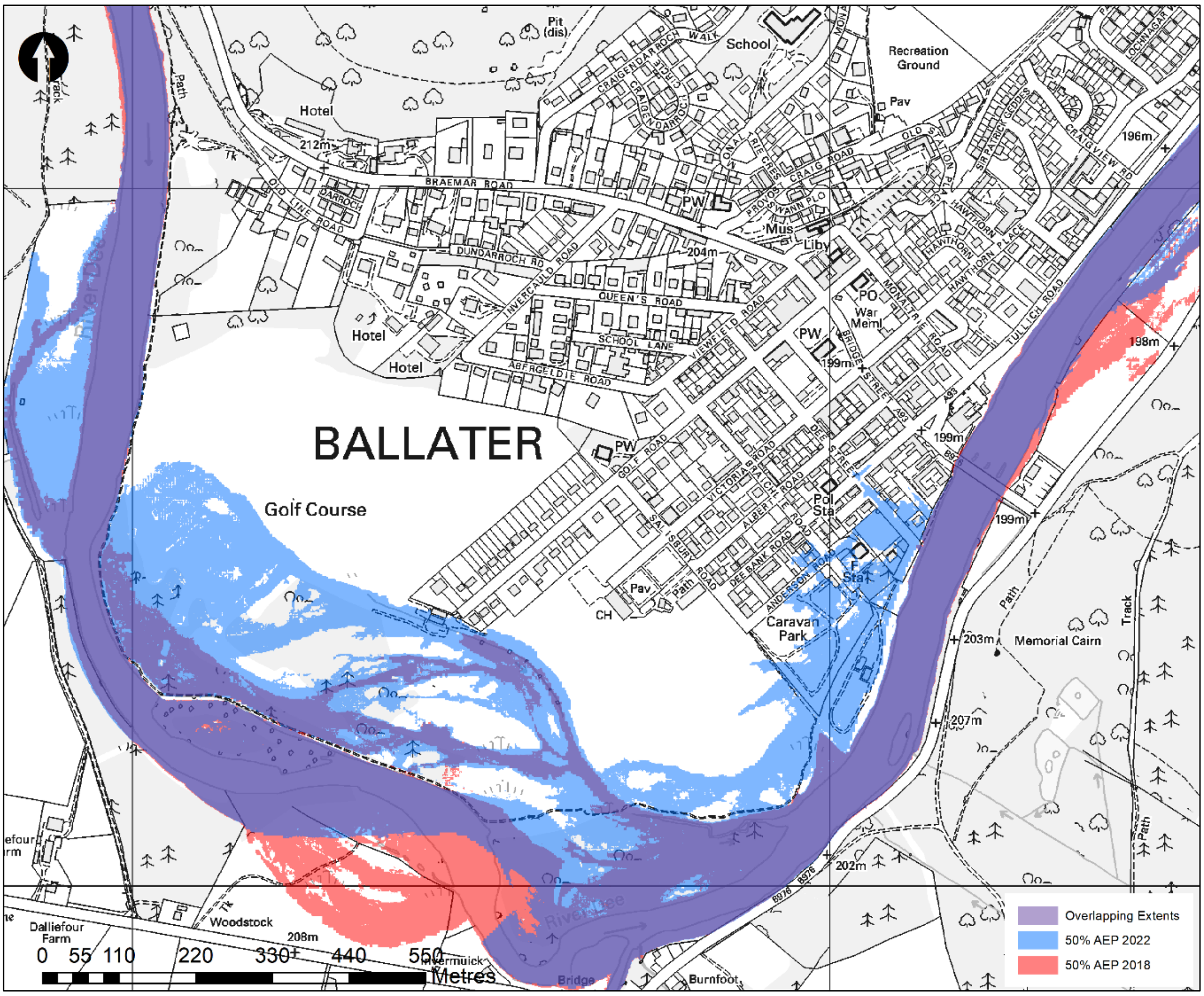


Figure 6.14: 2018 vs. 2022 50% AEP flood extents

6.3.1.2 20% Annual Exceedance Probability

Comparison of 2018 and 2022 extents shows a general increase in the 2022 extent, primarily on the left bank and encroaching upon Ballater Golf Course, Caravan Park and properties south-west of Royal Bridge (blue areas in Figure 6.15), resulting in an additional 79 properties across the scheme area at risk in the 2022 extent (Table 6.3). An additional increase in extent between 2018 and 2022 is noted on the right bank to the north-west of Ballater Golf Course. Decreases in flood extent are again observed west of the Glen Muick confluence and immediately north and south of Royal bridge on the right bank of the River Dee (red areas).

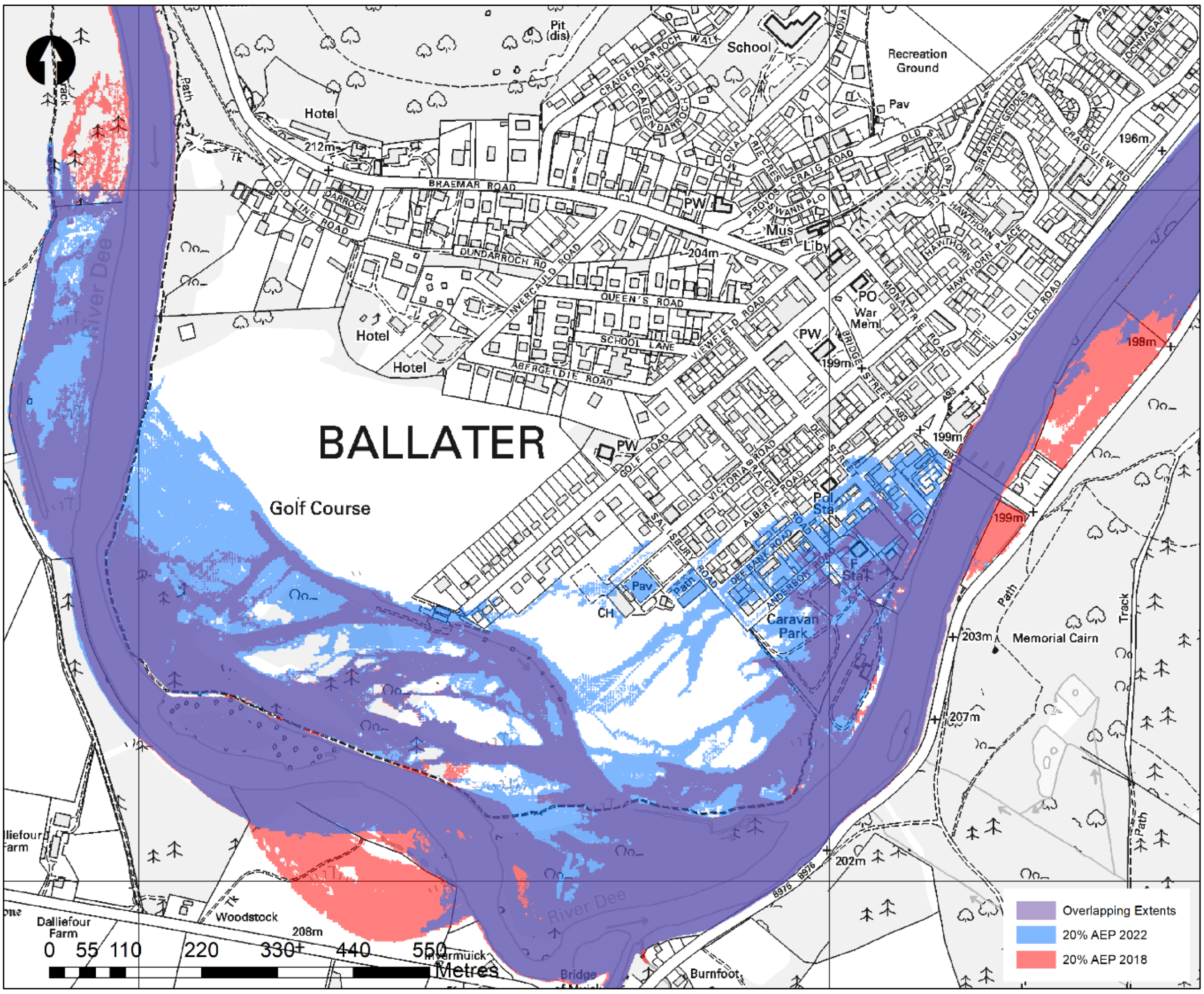


Figure 6.15: 2018 vs. 2022 20% AEP flood extents

6.3.1.3 10% Annual Exceedance Probability

In the 10% AEP event, the 2022 extents show an additional 72 properties are at risk compared to the 2018 extent (Table 6.3), predominantly in the south and south-east of Ballater, where flows spilling from the Golf Course drainage channel meet overbank flows from the River Dee upstream of the Royal Bridge. Additionally, a preferential flow path across the Golf Course from the west, previously not present at this magnitude, is shown to be developing, although not encroaching upon any properties (Figure 6.16).

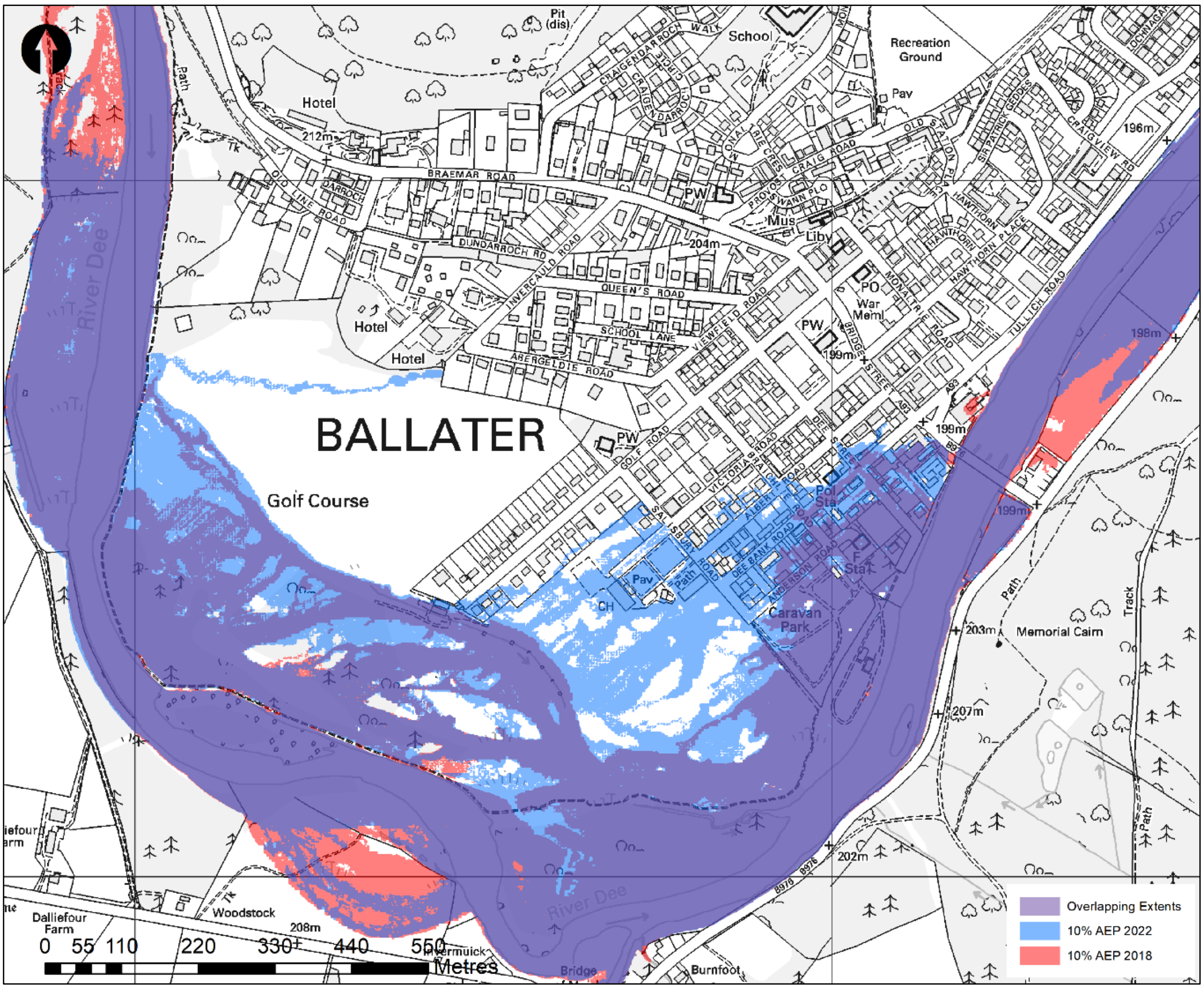


Figure 6.16: 2018 vs. 2022 10% AEP flood extents

6.3.1.4 3.33% Annual Exceedance Probability

In the 3.33% AEP event, an additional 195 properties across the scheme area are shown to be at risk (Table 6.3) in the 2022 extent compared to the 2018 extent (Figure 6.17), with the bulk of these properties on the left bank of the River Dee adjacent to and downstream of the Royal Bridge (blue areas). A previously identified flood mechanism emanating from the left bank of the River Dee in the west of the Golf Course is shown to be more significant than represented in the 2018 extents, along with the extent of flooding impacting the Golf Course to the east of the Golf Course drainage channel.

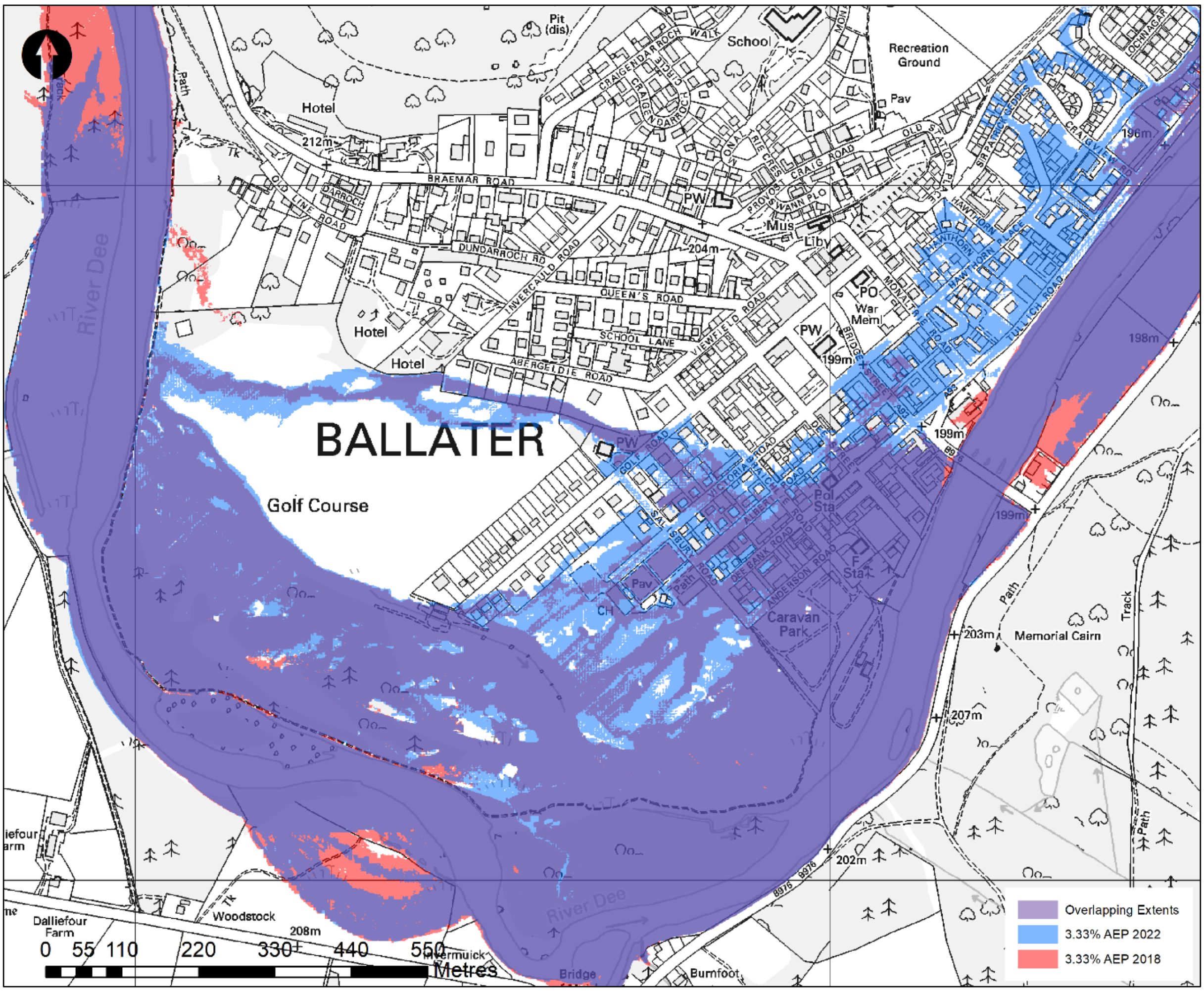


Figure 6.17: 2018 vs. 2022 3.33% AEP flood extents

6.3.1.5 1% Annual Exceedance Probability

The 1% AEP extents produced in 2022 are comparable to those produced in 2018 (Figure 6.18). No significant increases in extent are shown to impact Ballater town, however minor increases to the north-west of Royal Bridge are noted (blue areas). A previous mechanism of overbank flow onto the Golf Course from the north-west, shown in 2018 extents, is no longer present at this magnitude (red areas). Across the scheme area an additional 10 properties are shown to be at risk in the 2022 extents.

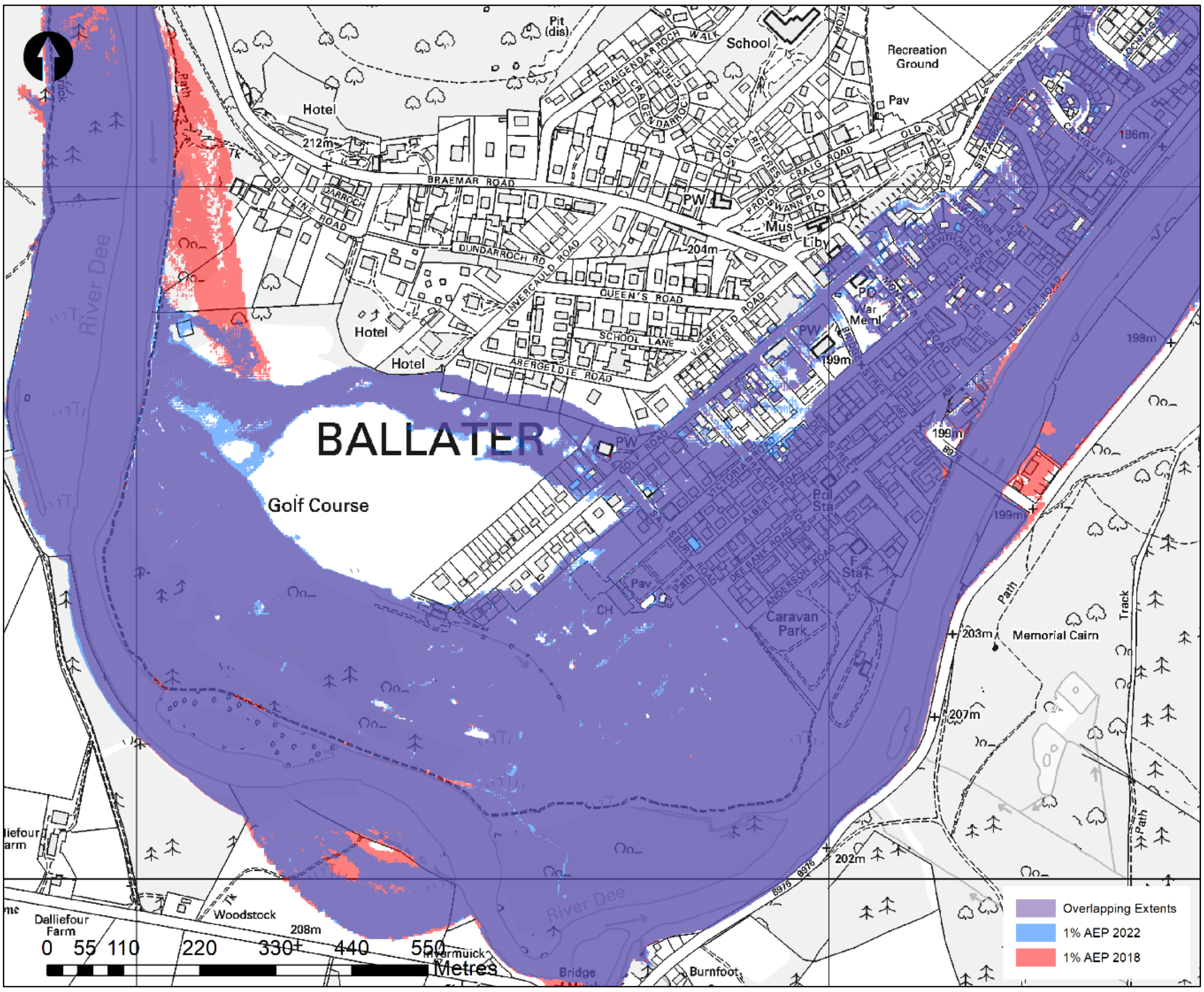


Figure 6.18: 2018 vs. 2022 1% AEP flood extents

6.3.2 Number of buildings at risk

Table 6.3 identifies the number of buildings affected in both the 2018 and 2022 models, and the difference between these figures. The table shows increases in the number of buildings affected by flooding in all return periods, with the largest increase in a 3.33% AEP event.

Table 6.3: Buildings within flood extent 2018 vs. 2022

Annual Exceedance Probability (%)	No. of buildings affected 2018	No. of buildings affected 2022	Difference
50	0	22	+22
20	18	97	+79
10	71	143	+72
3.33	204	399	+195
1	522	562	+40

For the 3.33% AEP event, the depths of flooding at the properties affected in the 2022 model have been determined and summarised in Table 6.4. Appendix G shows the locations of these properties.

Table 6.4: Depths of flooding from 2022 model (3.33% AEP)

Depth of flooding (m)	Number of properties
< 0.3	303
0.3 to 0.6	51
0.6 +	45

6.3.3 Identification of Ballater Golf Course Flood Mechanisms

An assessment of the means by which flood flows associated with a 3.33% AEP event (1 in 30 year return period) access the left bank floodplain in the vicinity of Ballater Golf Course has been undertaken.

Initially, the left bank is overtopped at a low point west of the course and south of the area noted in the previous study as having breached in the 2015 event. These flows find a side channel in the topography on the Golf Course which runs roughly parallel to the left bank of the River Dee, before entering the Golf Course drainage channel west of the confluence with the River Dee (Figure 6.19). Flows continue to build along this preferential flow path and are supplemented by backwatering pressures from the River Dee confluence. Increasing flow across this pathway results in further spilling towards and eventually entering the Golf Course drainage channel along the entirety of its course (Figure 6.20).

Once inundated along its course, the topography limits further spilling across the left bank of the Golf Course drainage channel to the north-east and instead flows accumulate in topographic low points at the mouth and head of the Golf Course drainage channel. Flows accumulated to the north of the mouth of the Golf Course drainage channel then exploit the topography in establishing a preferential flow path north-east, parallel to the left bank of the River Dee and toward and through the Caravan Park, resulting in flooding south of Bridge Street. No further spilling is observed across the left bank of the River Dee in this vicinity at this time (Figure 6.21).

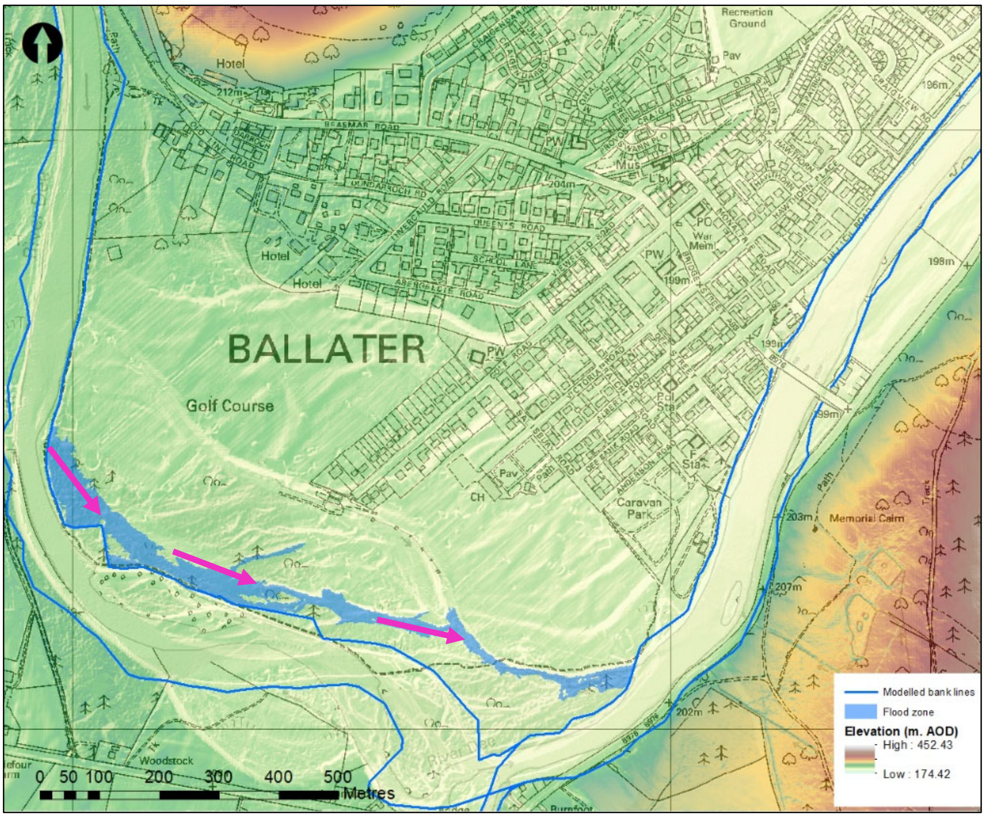


Figure 6.19: Ballater Golf Course flood mechanism 1

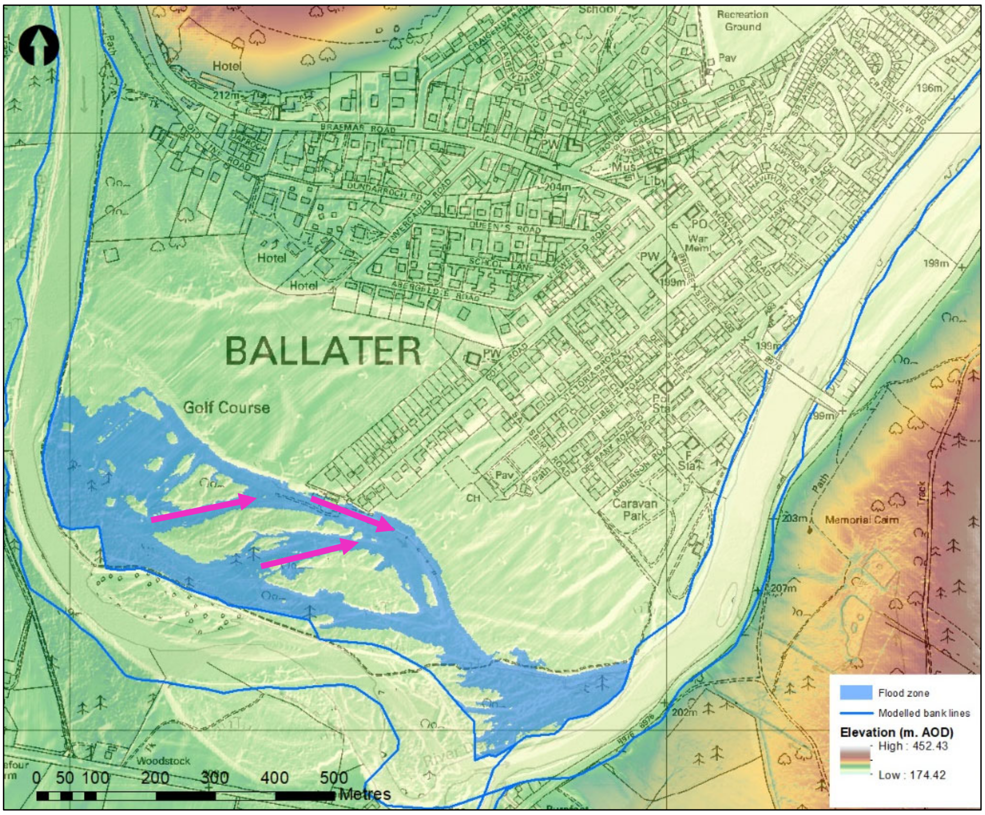


Figure 6.20: Ballater Golf Course flood mechanism 2

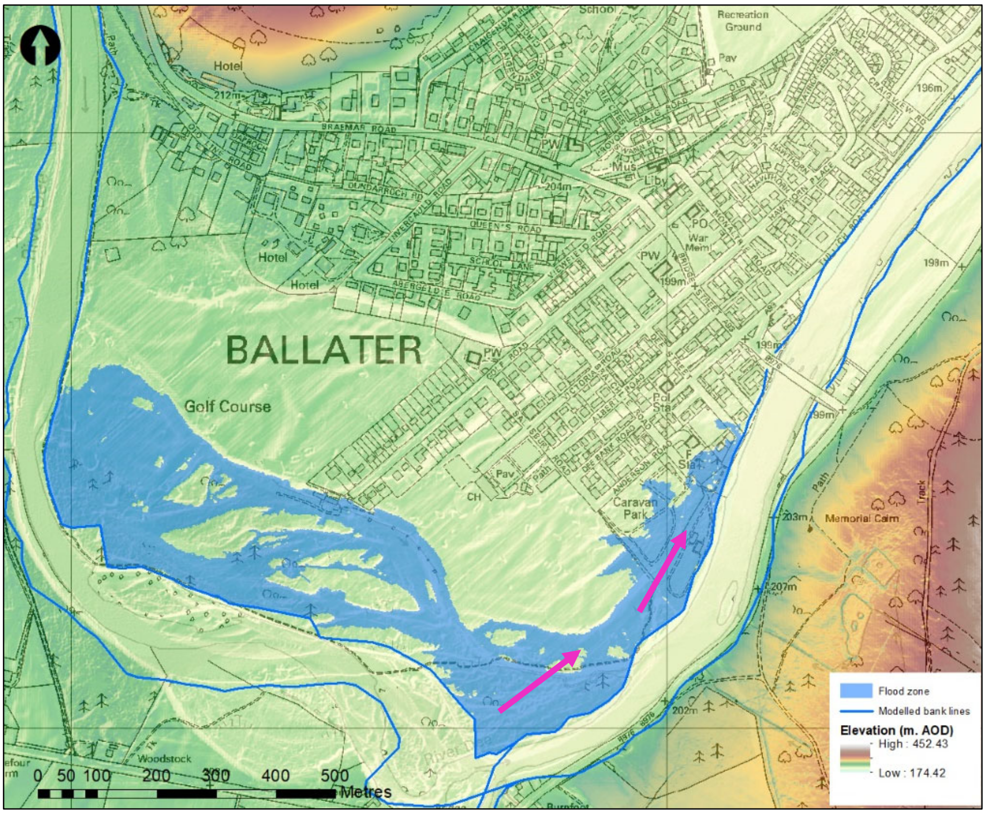


Figure 6.21: Ballater Golf Course flood mechanism 3

Flow from the River Dee then exits over the left bank to the immediate south-east of the Caravan Park, contributing to and exacerbating flooding in the south-east of Ballater town, south of Bridge Street (Figure 6.22). Between the peak of the 10% and 3.33% AEP events, spilling occurs across the left bank of the River Dee to the west of the Golf Course (Figure 6.23). Establishing a preferential flow path in an historic channel evident in the topography along the garden boundaries of properties on Abergeldie Road, flows move east across the Golf Course, passing through properties in the Golf Road/ Salisbury Road junction area. This flow exacerbates flooding south of Bridge Street and contributes to flooding throughout the town along the left bank of the River Dee.

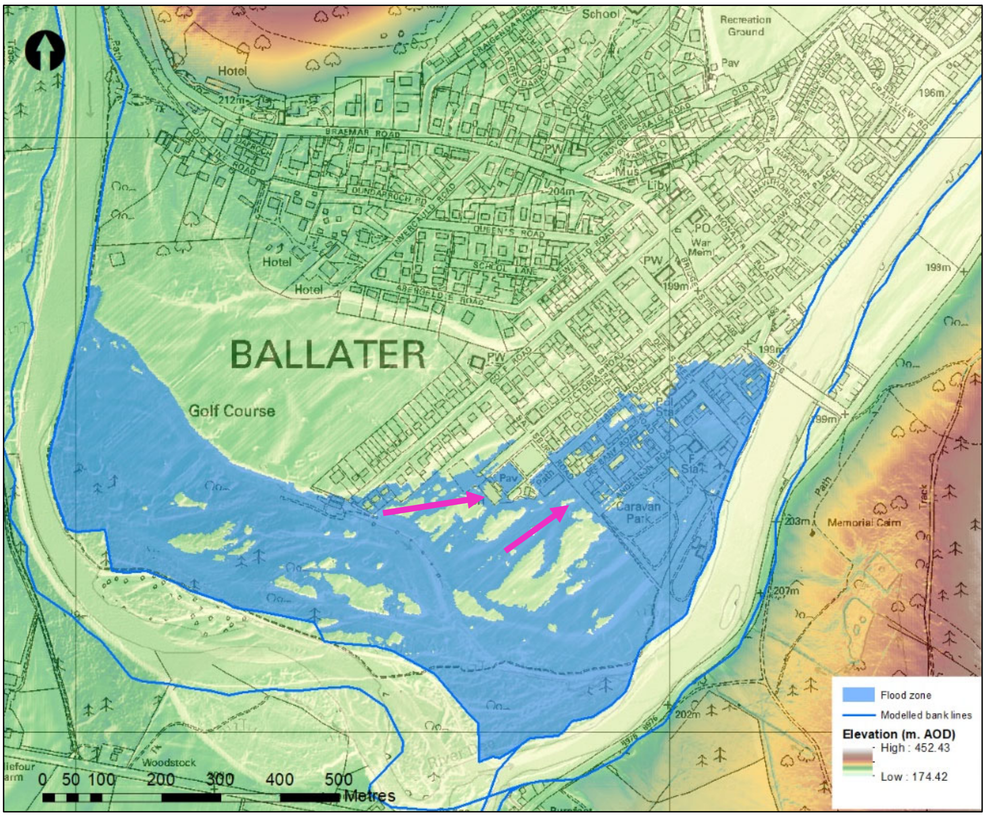


Figure 6.22: Ballater Golf Course flood mechanism 4

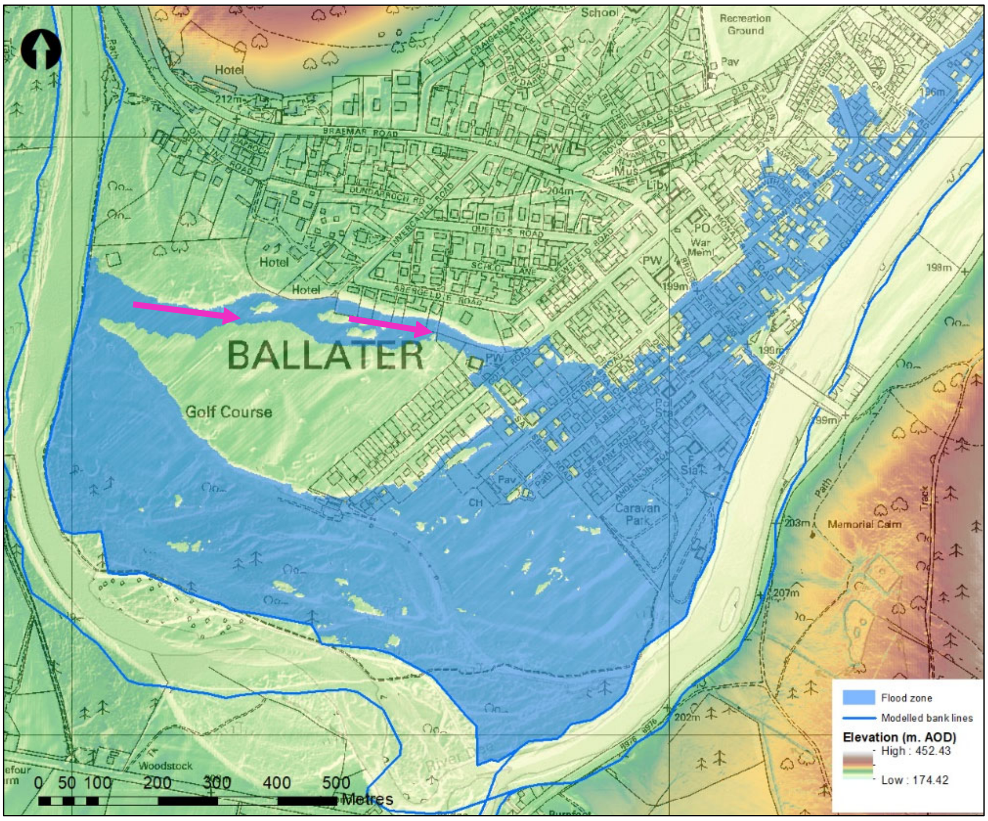


Figure 6.23: Ballater Golf Course flood mechanism 5

Table 6.5: Summary of flood mechanisms impacting Ballater

Flood mechanism	Description	Activation
1	Left bank spilling parallel to the south of, but not yet entering the Golf Course drainage channel.	~50% AEP
2	Back watering of Golf Course drainage channel outlet by River Dee causes north-easterly spilling, entering and activating the Golf Course drainage channel.	~50% AEP
3	Back watering of Golf Course drainage channel outlet by the River Dee reduces capacity in Golf Course drainage channel and causes flow to spill further east across the Golf Course towards Ballater Caravan Park.	~50% AEP
4	Golf Course drainage channel overwhelmed, flows spill across the Golf Course, moving north-easterly towards the Golf Club and entering Ballater north-west of the Caravan Park. Mixes with mechanism #3 and extends into Ballater.	Between 50-10% AEP
5	Left bank of the Dee overtopped in the north-west of the Golf Course, activating historic topographic channel to the rear of properties on Abergeldie Road. Crosses Golf Road north of St Nathalan's Catholic Church and enters Ballater to mix with flows from mechanism 3 & 4.	Between 10-3.33% AEP

6.4 Updated Damage Assessment

As part of the previous study, a damage assessment was completed based on the previous flood extents. One of the tasks of the Additional Flood Study was to update the damage assessment to assess the baseline and potential increases in flood damage. As significant changes have been made to flood extents, there will be an increase in properties at risk. Additional analysis was therefore required to determine the change in damages. The updated 2022 damage assessment is presented in Appendix H.

7 MODELLING OF MINOR WORKS OPTIONS

The updated hydraulic model has been used to simulate the impact of the four proposed minor works options on flood extents generated by events with AEP of 50%, 20%, 10% and 3.33%. Where the hydraulic model does not explicitly allow representation of the existing scenario, RPS have endeavoured to achieve accurate representation by modifying model parameters as required. A description of how the four options have been represented is described in the following sections.

The flood extents from the updated model as described in Section 6 form the baseline for the assessment of the impact of the minor works options. Note that in the comparison maps the baseline flood extents from the 2022 study are shown in red, the extents from the minor works option are shown in blue, and any areas where the flood extents overlap are shown in purple.

The estimated number of properties at risk in each minor works extent has been included. These figures have been calculated based on a simple selection of buildings which intersect the flood extents. Estimates of the number of properties at risk may only be used to compare the effect on flood extent of each minor works option against one another, and not against the updated damage assessment. The findings of the detailed damage assessment which was undertaken separately are included in Appendix H.

7.1 Option 1: Removal of Dead Trees/ Debris

The clearance of obstructive dead trees and other debris was simulated in the area of the confluence of the Golf Course drainage channel with the River Dee. Given the representation of this area is exclusively in the 2-D domain, a 2-D roughness zone change was applied such that a more efficient flow condition was represented for overbank flows crossing the floodplain into this area. This entailed localised reduction of roughness on the floodplain from n=0.0765 and n=0.085 to n=0.025, typically indicative of a change from a flood plain comprised of thick brush to one comprised of short grass (Figure 7.1).

Figure 7.1: Option 1 roughness zone changes

Model simulations show Option 1 to have a limited effect in reducing the extent of flooding in the vicinity of the Caravan Park in the instance of the 50% AEP event, however some minor increase is noted immediately north of the Caravan Park (Figure 7.2). Both the 20% (Figure 7.3) and 10% AEP events (Figure 7.4) show limited reductions in flood extents on the Golf Course to the south of the Caravan Park, whilst significant increase in extent is noted elsewhere on the Golf Course in the case of the 20% AEP event, and leading to earlier development of the Abergeldie Road preferential flow path in the case of the 10% AEP event. In the case of the 3.33% AEP event (Figure 7.5), both minor increases and decreases are noted. This option showed increases in the number of buildings within the flood extent in the 50, 20 and 3.33% AEP events than shown in the 2022 baseline scenario (Table 7.1).

Table 7.1: Buildings within Option 1 flood extent

Annual Exceedance Probability (%)	2022 Baseline	Option 1	Difference
50	22	26	+4
20	97	113	+16
10	143	137	-6
3.33	399	412	+13

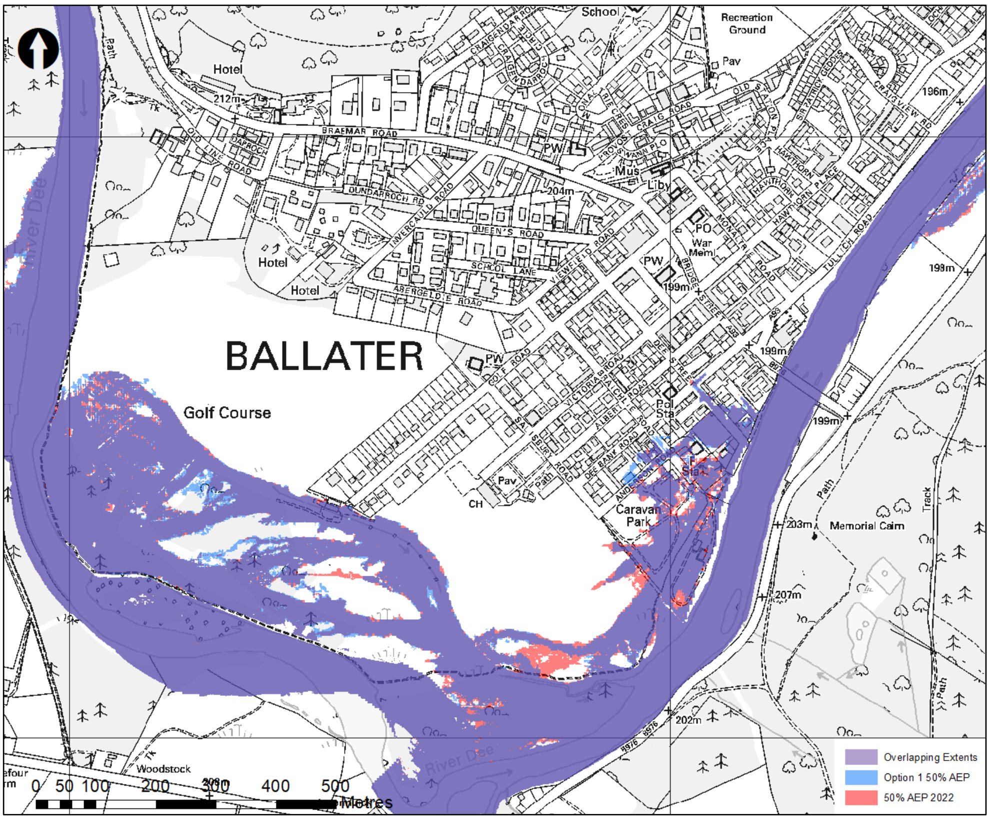


Figure 7.2: Option 1 50% AEP extent

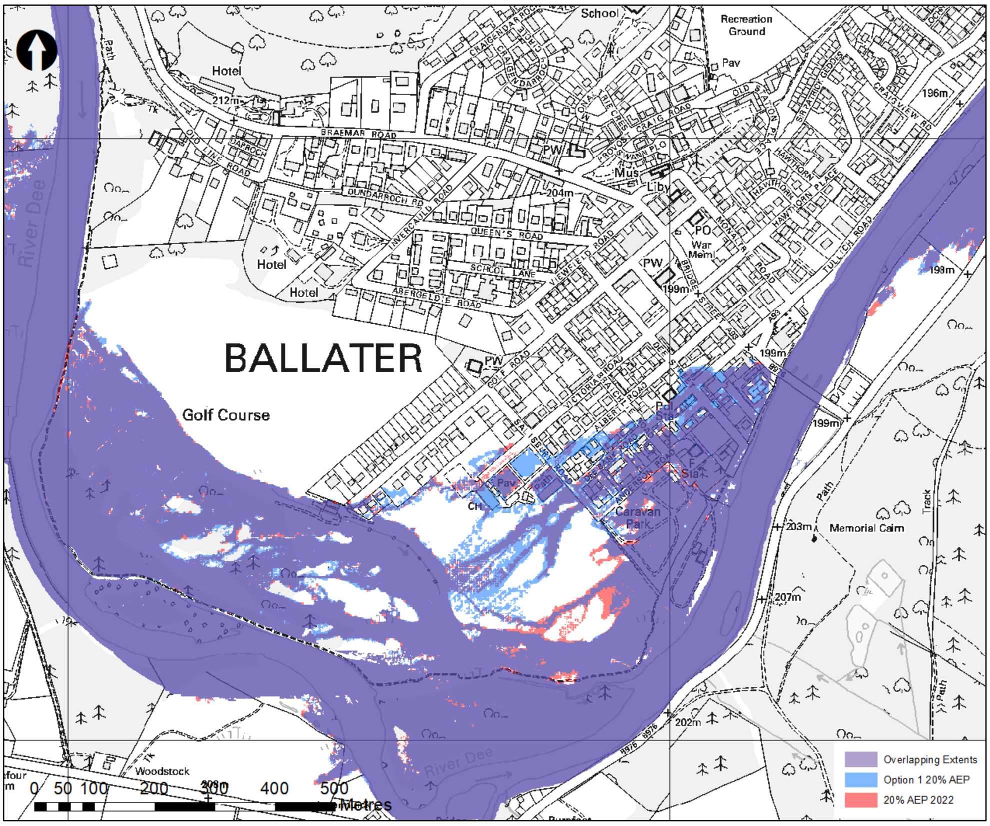


Figure 7.3: Option 1 20% AEP extent

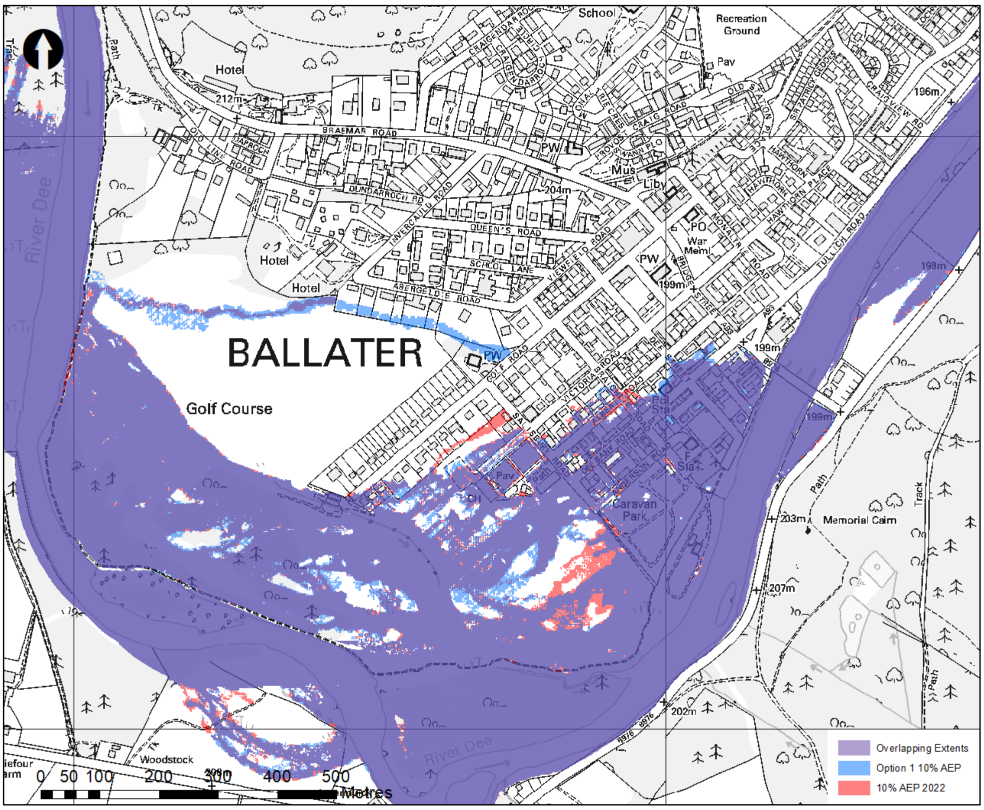


Figure 7.4: Option 1 10% AEP extent

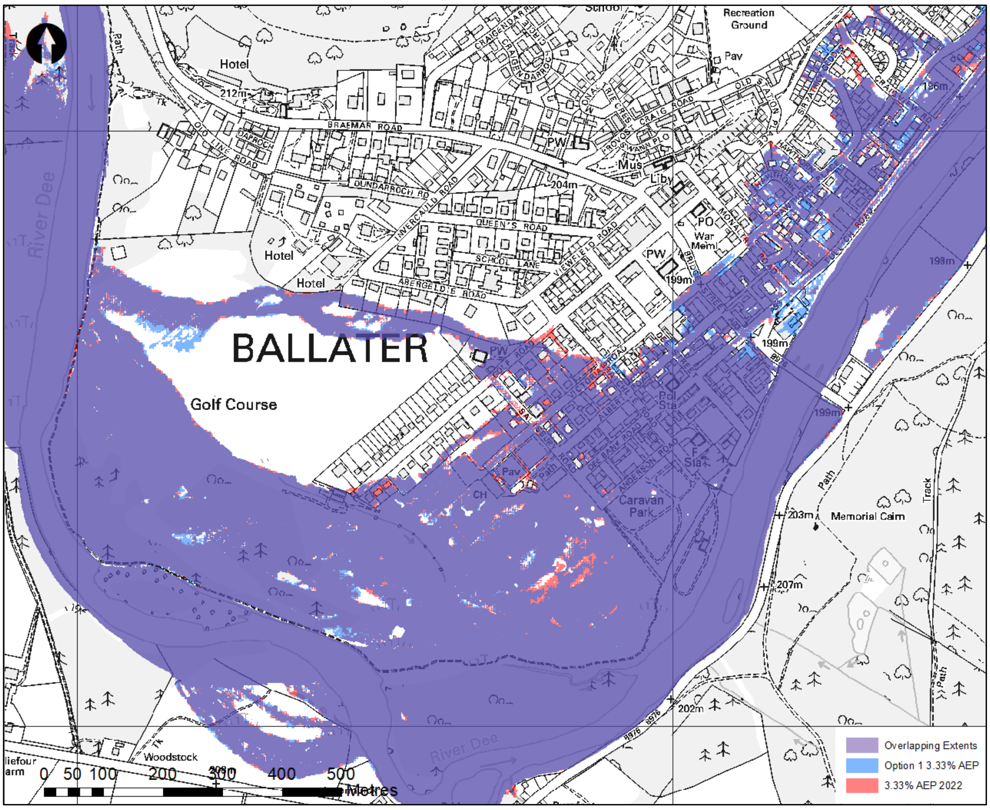


Figure 7.5: Option 1 3.33% AEP extent

7.2 Option 2: Clearance of Channel on Glenmuick side

Whilst it is noted by RPS (Section 2.2.2) that complete removal of deposited material on the right side of the channel is unlikely to make any direct contribution to flood risk management in Ballater, there may exist an opportunity to deflect erosive potential away from the informal defence embankment on the left side of the channel by encouraging the River Dee to take a more southerly alignment, similar to that observed before the recent large magnitude events.

Historical ortho imagery was consulted to apply the 2010 channel alignment to an approximate 480m reach of the River Dee in the vicinity of the Glenmuick confluence (Figure 7.6 and Figure 7.7). This utilised the creation of synthetic cross-sections constructed from the 2022 Drone LiDAR – derived Digital Terrain Model. Re-profiling was undertaken to mirror the current (March/ April 2022) bed profile, adjusted to suit the historic channel alignment and with enhanced conveyance capacity simulated by deepening of the bed (Figure 7.8). To prevent in-channel flows from exploiting the current low left bank to by-pass channel modifications across the 2-D domain, a mesh zone was applied to artificially raise the left bank adjacent to the Glenmuick confluence, similar to the 2010 arrangement before the river cut a new course through this area.

Figure 7.6: 2010 alignment of the River Dee at the Glenmuick confluence

Figure 7.7: 2022 and 2010 (yellow) alignment of the River Dee at the Glenmuick confluence

Figure 7.8: Option 2 Bank line adjustments and mesh level zone placement

Option 2 simulations show significant change across all four return periods, with both significant increase and decrease in each flood extent (Figure 7.9 to Figure 7.12). In each instance, flooding emanating from the left bank of the River Dee in the west of the Golf Course via the Golf Course drainage channel is significantly reduced, including the elimination of the Abergeldie Road preferential flow path in the 3.33% AEP event (Figure 7.12). However, significant increase in flood extent results in an increased number of buildings within the flood extent in the Option 2 simulation than in the 2022 baseline simulation for all four tested flood events (Table 7.2).

Table 7.2: Buildings within Option 2 flood extent

Annual Exceedance Probability (%)	2022 Baseline	Option 2	Difference
50	22	67	+45
20	97	102	+5
10	143	192	+49
3.33	399	417	+18

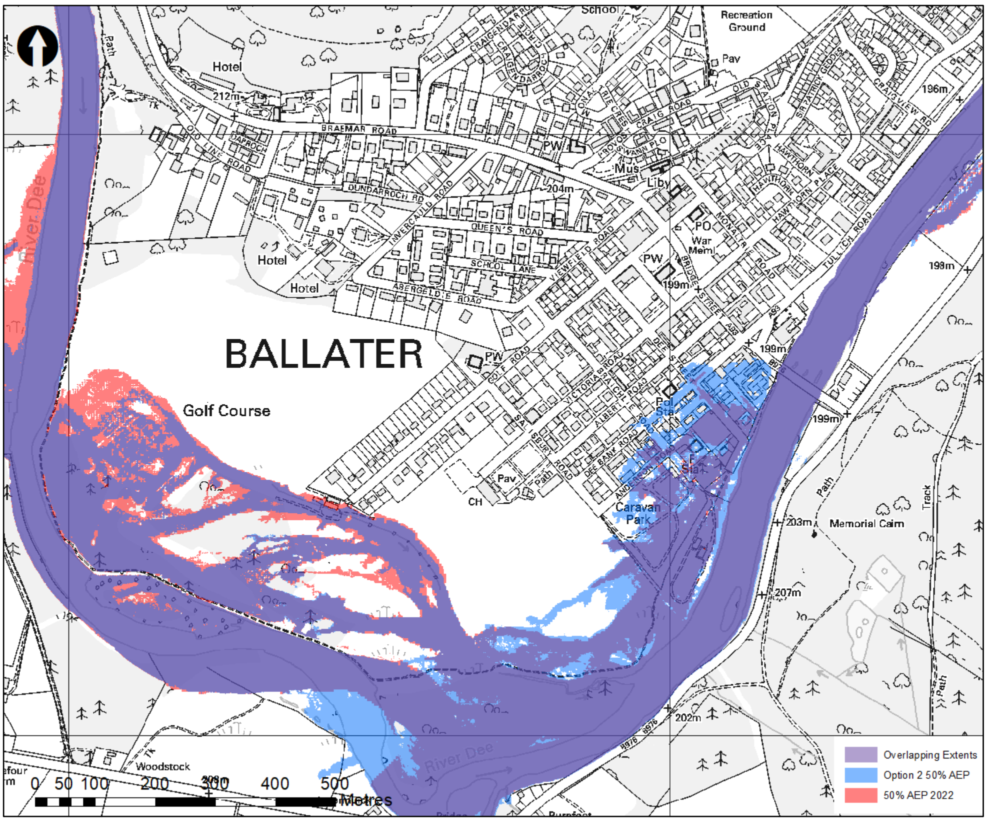


Figure 7.9: Option 2 50% AEP extent

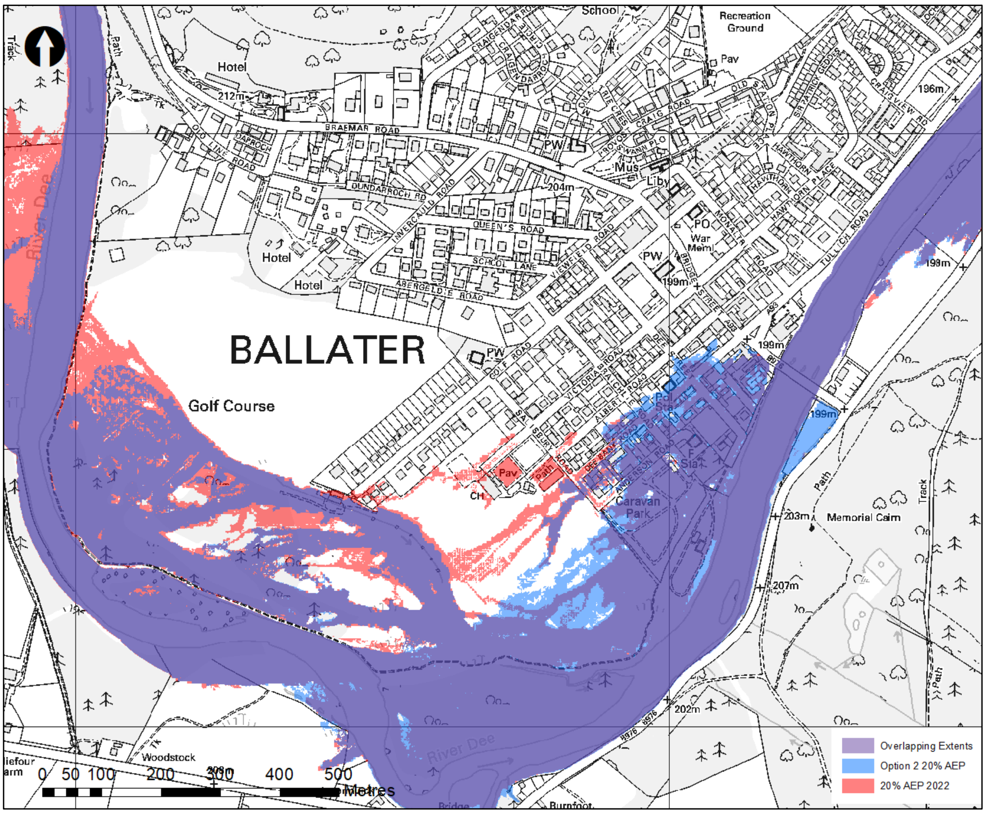


Figure 7.10: Option 2 20% AEP extent

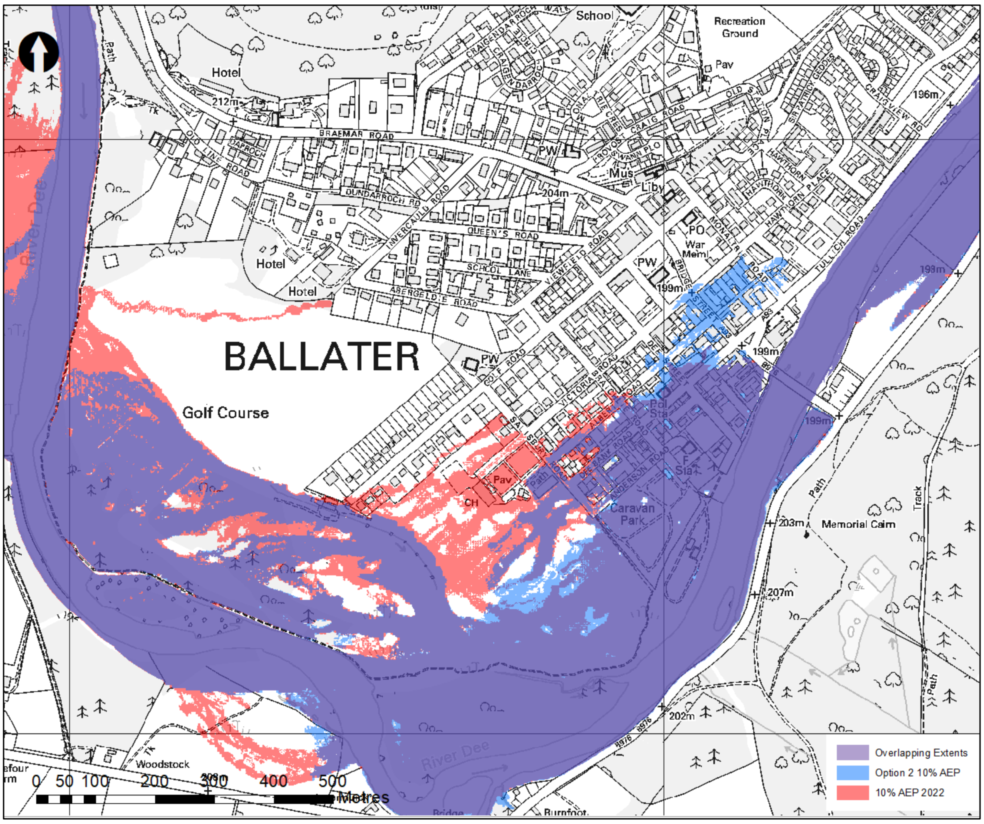


Figure 7.11: Option 2 10% AEP extent

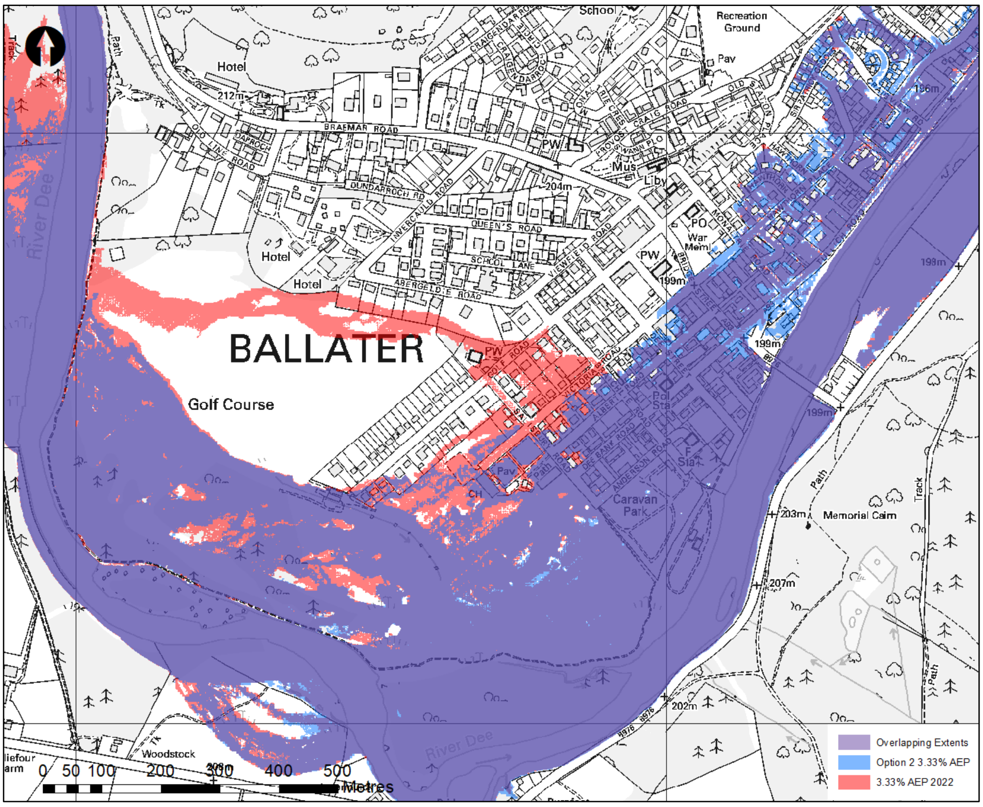


Figure 7.12: Option 2 3.33% AEP extent

7.3 Option 3: Clearance of Outlet Channel at Golf Course

Similar to Option 1, Option 3 aims to reduce resistance to flow and improve conveyance capacity of the Golf Course drainage channel. Unlike Option 1 which simulated a more efficient flow condition through the area of the drainage channel outlet, Option 3 utilises a targeted approach to improve the conveyance capacity of just the channel through the same area. In the hydraulic model, the channel is not represented in the 1-D domain as with the Rivers Dee, Gairn and Muick, but on account of its relatively small size is instead represented in the 2-D domain. As mentioned in Section 6.1.4, the 2-D domain is a mesh comprised of triangles of various sizes, each containing a ground elevation inferred from the digital terrain model. The use of Terrain-Sensitive Meshing (TSM) allows flexibility of the mesh to dynamically change triangle size to ensure topographic changes are accurately represented, such as drainage channels. To simulate greater conveyance capacity, a mesh level zone was applied to artificially increase the depth of the Golf Course drainage channel along approximately 190m of its confluence with the River Dee (Figure 7.13).

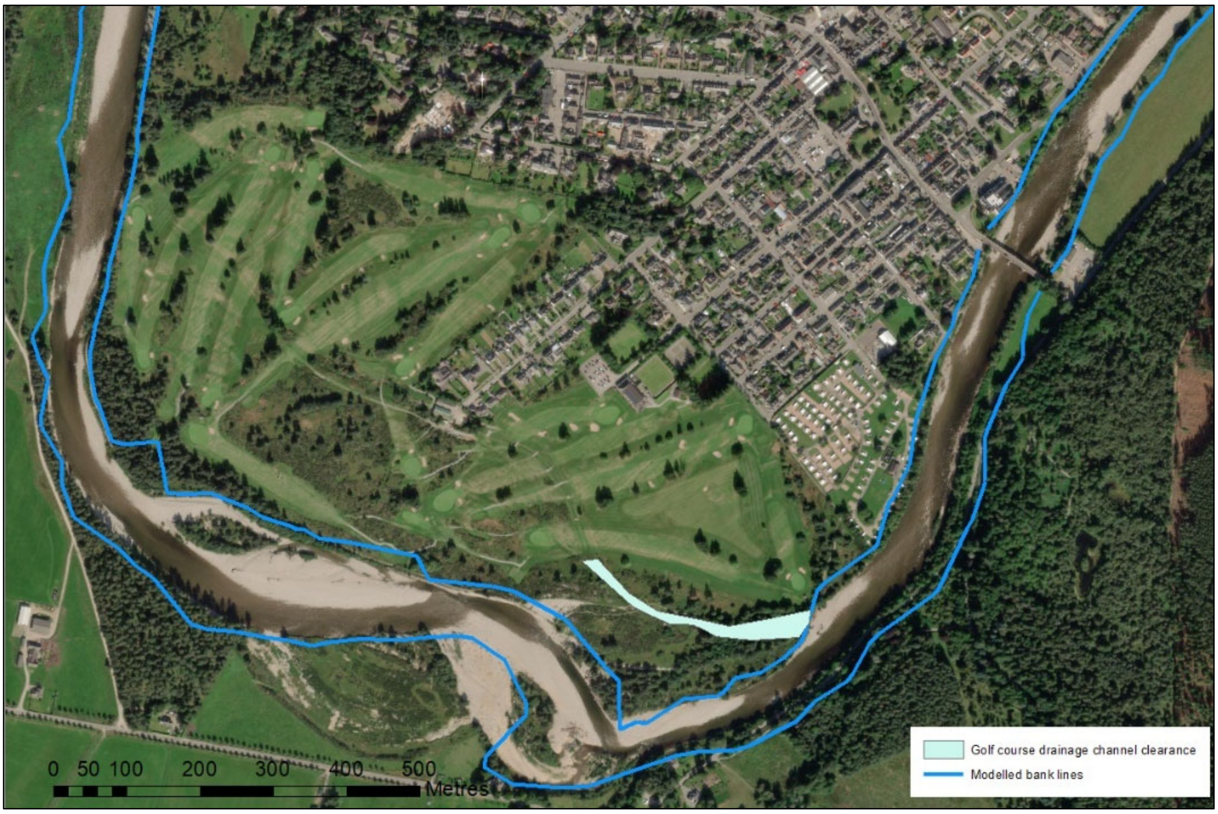


Figure 7.13: Option 3 Golf Course drainage channel clearance

Simulation of Option 3 shows a reduction in flood extent for events with AEP 50, 20, 10 and 3.33% (Figure 7.14 to Figure 7.17). The largest reductions in flood extent are for the 50 and 20% AEP events (Figure 7.14 and Figure 7.15), with greatest effect shown to properties immediately north east of the Caravan site in the 50% AEP event and north of the caravan site in the 20% AEP event. Of the four minor works options, Option 3 is the only option that reduces the number of buildings within the flood extent produced by all four modelled events (50, 20, 10 and 3.33% AEP) (Table 7.3).

Table 7.3: Buildings within Option 3 flood extent

Annual Exceedance Probability (%)	2022 Baseline	Option 3	Difference
50	22	15	-7
20	97	81	-16
10	143	138	-5
3.33	399	392	-7

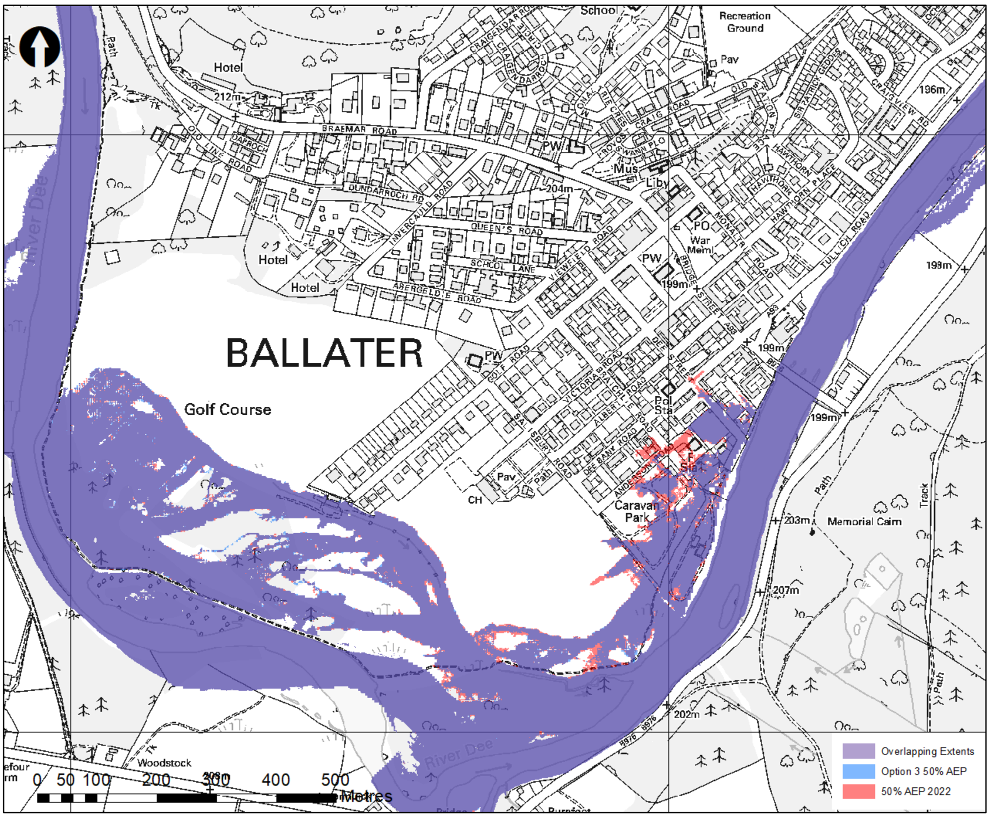


Figure 7.14: Option 3 50% AEP extent

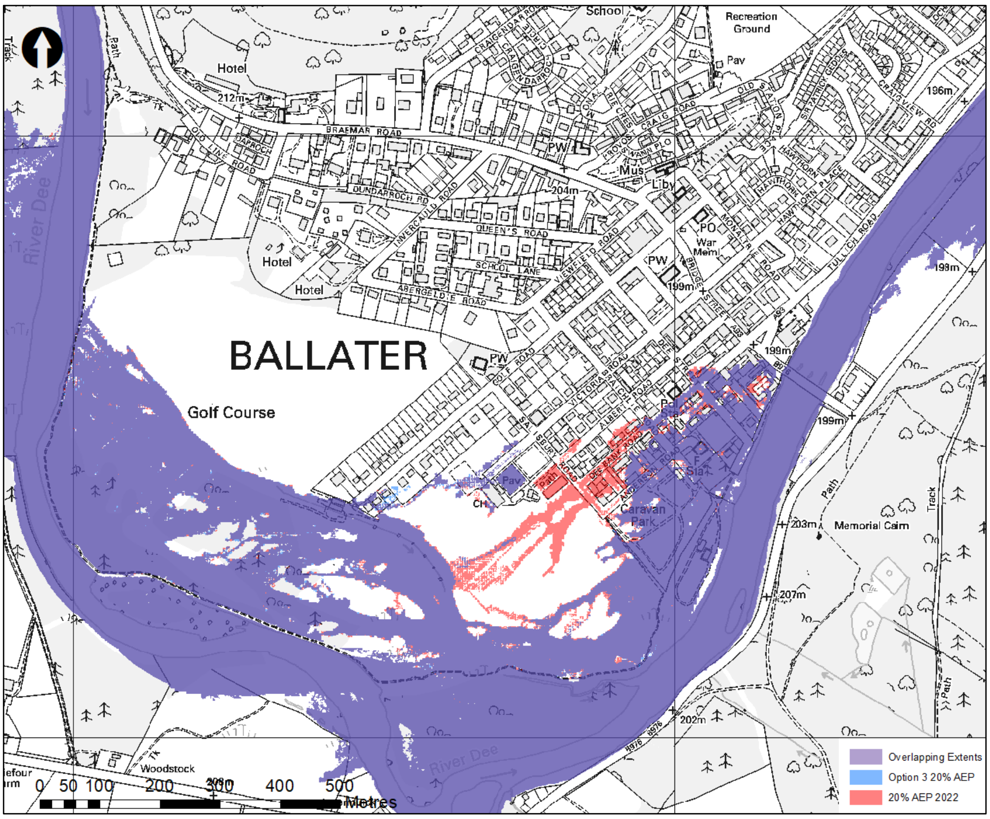


Figure 7.15: Option 3 20% AEP extent

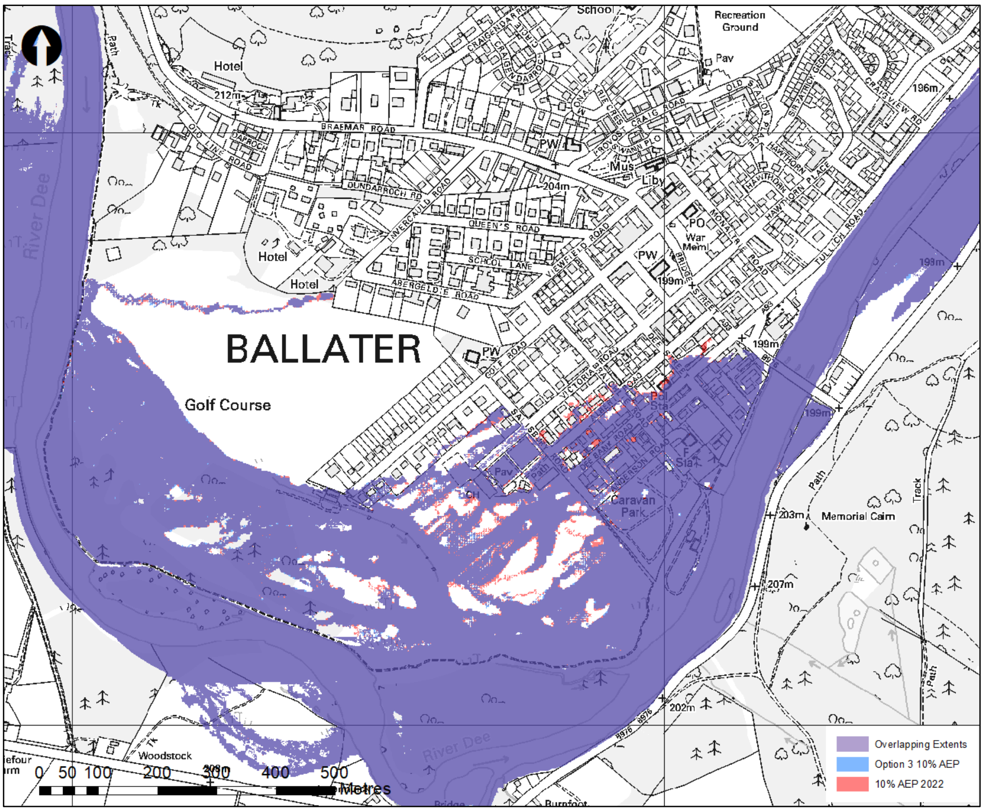


Figure 7.16: Option 3 10% AEP extent

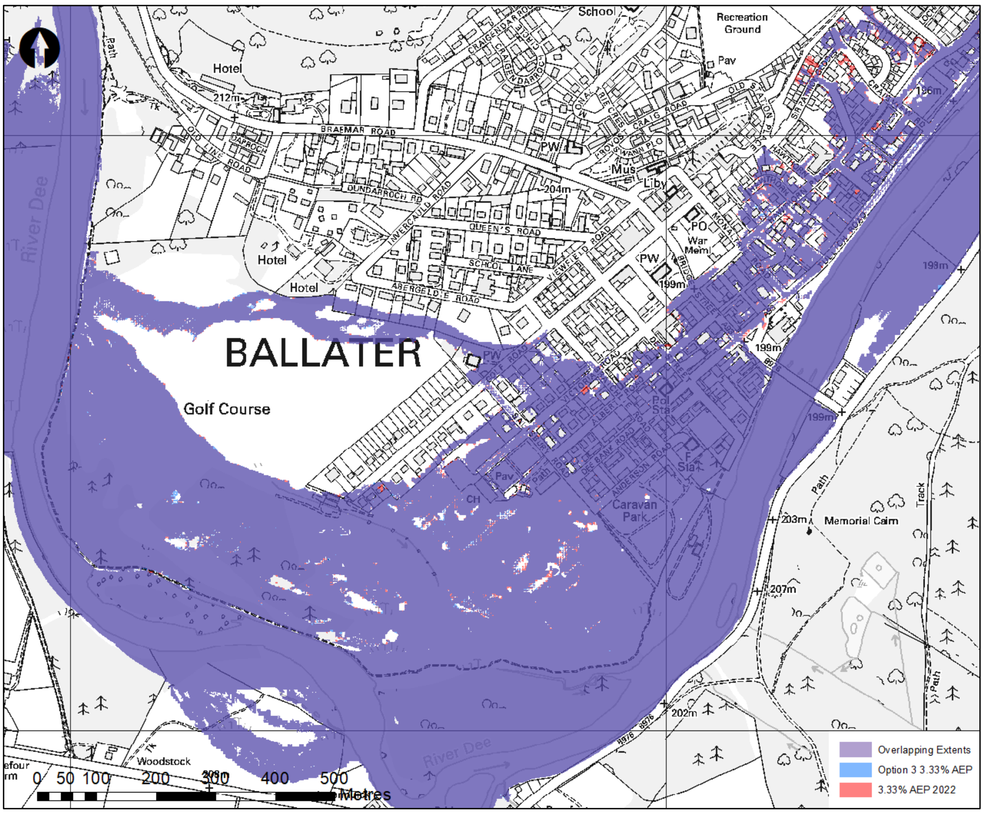


Figure 7.17: Option 3 3.33% AEP extent

7.4 Option 4: New bund at Southern End of Golf Course

Option 4 simulated the addition of a new bund to the left bank of the River Dee, south of Ballater Golf Course. This replaces a bund previously in place at this location which was washed away by the extreme flood event of 2021. Local opinion is that the bund offered a degree of protection to the town before the failure. During site walkover a number of topographic high points were noted either side of the Golf Course drainage channel and it was observed that potential may exist for a longer new bund to link these features. The 2022 hydraulic model was utilised to simulate a new bund linking these topographic high points. Initial simulations utilised a bund approximately 380m long, however it was quickly established that this obstruction intercepted and diverted the main preferential flow path across the Golf Course, exacerbating the flood extents impacting Ballater for all four AEP events (50%, 20% 10% and 3.33%). As such, a shorter 200m bund was tested, effectively extending the footprint of the previously existing bund easterly, terminating at the right bank of the Golf Course outlet channel (Figure 7.18).

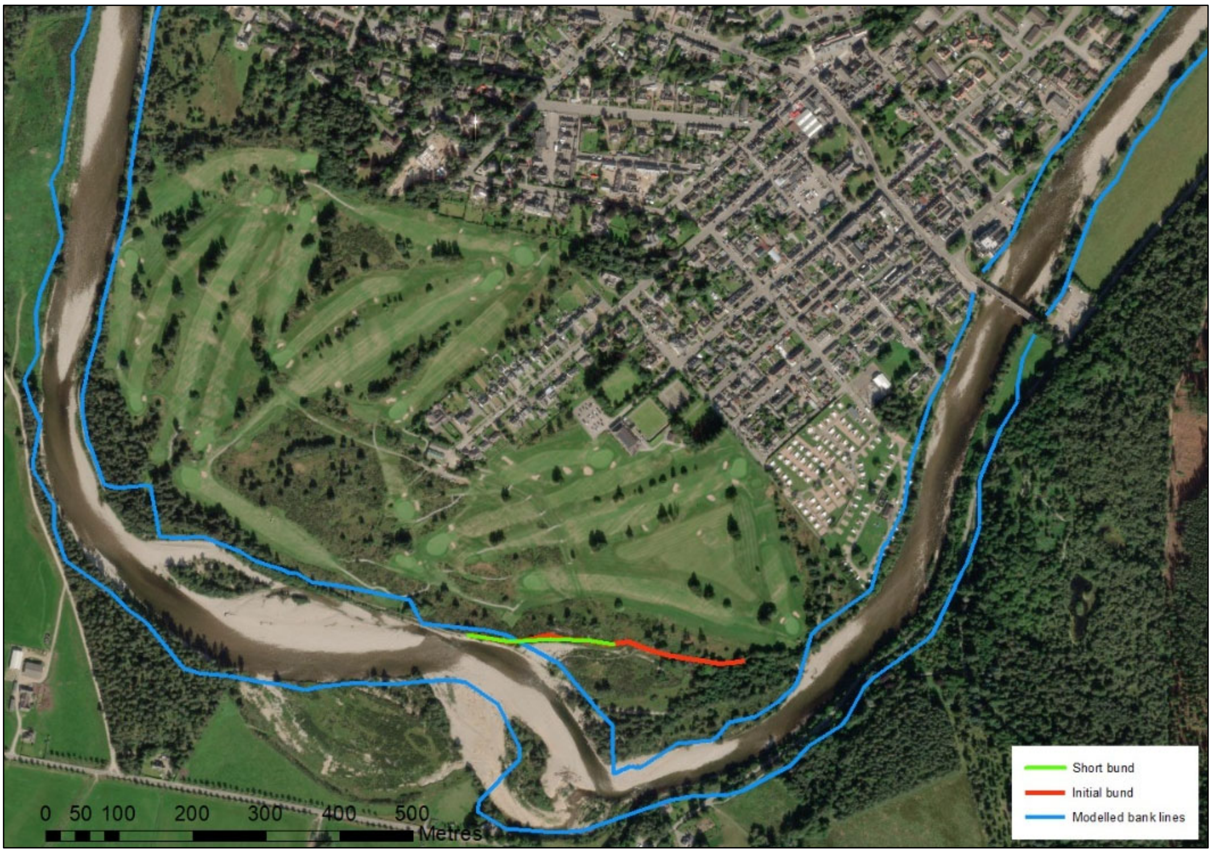


Figure 7.18: Option 4 Development of a new bund at the southern end of Ballater Golf Course

Simulation of a shorter 200m bund for 50%, 20% 10% and 3.33% AEP events still showed little positive change in flood extent and in the instance of the 20% and 10% AEP events, showed minor increase in flooding impacting Ballater between the Caravan Park and Bridge Street (Figure 7.19 to Figure 7.22). Option 4 maintains the number of buildings within the flood extent at 22 as in the 2022 baseline simulation, however for the larger magnitude, less frequent 20, 10 and 3.33% AEP events, Option 4 exacerbates the number of buildings within the subsequent flood extent (Table 7.4).

Table 7.4: Buildings within Option 4 flood extent

Annual Exceedance Probability (%)	2022 Baseline	Option 4	Difference
50	22	22	0
20	97	112	+15
10	143	148	+5
3.33	399	405	+6

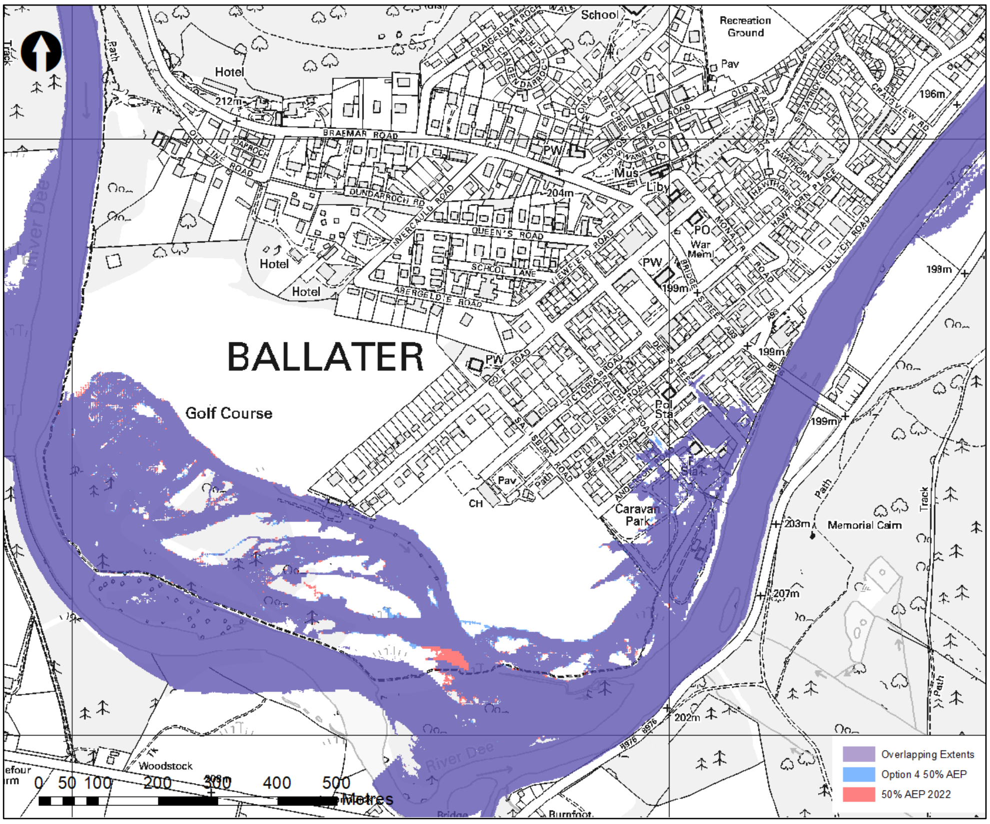


Figure 7.19: Option 4 50% AEP extent

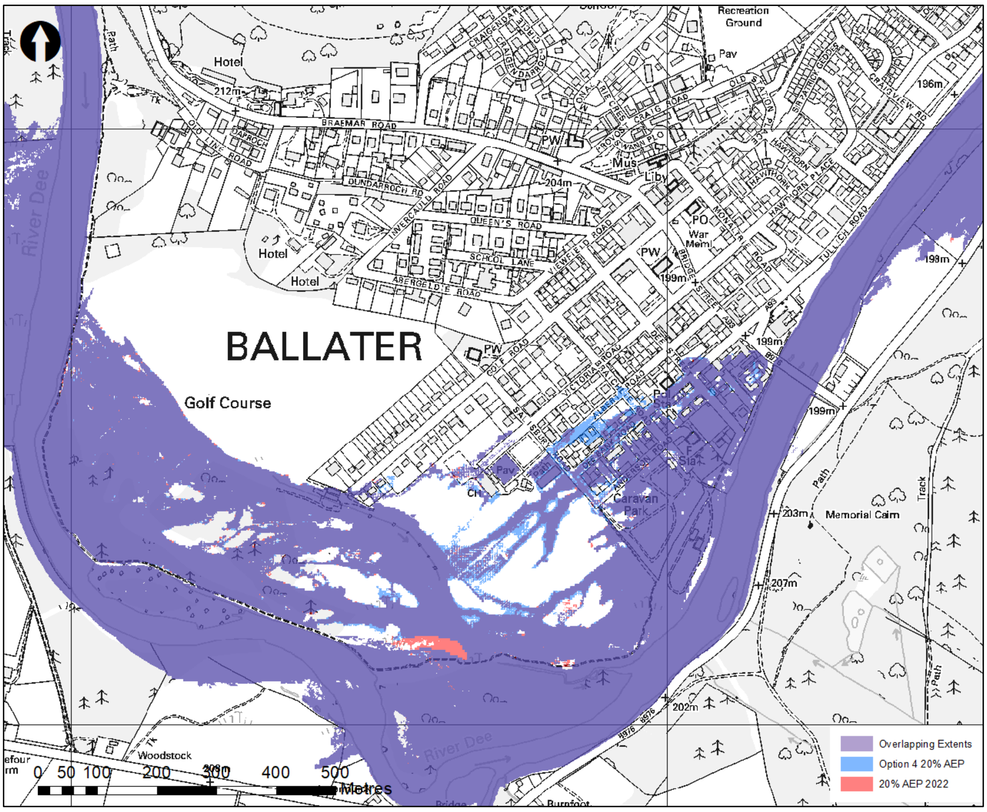


Figure 7.20: Option 4 20% AEP extent

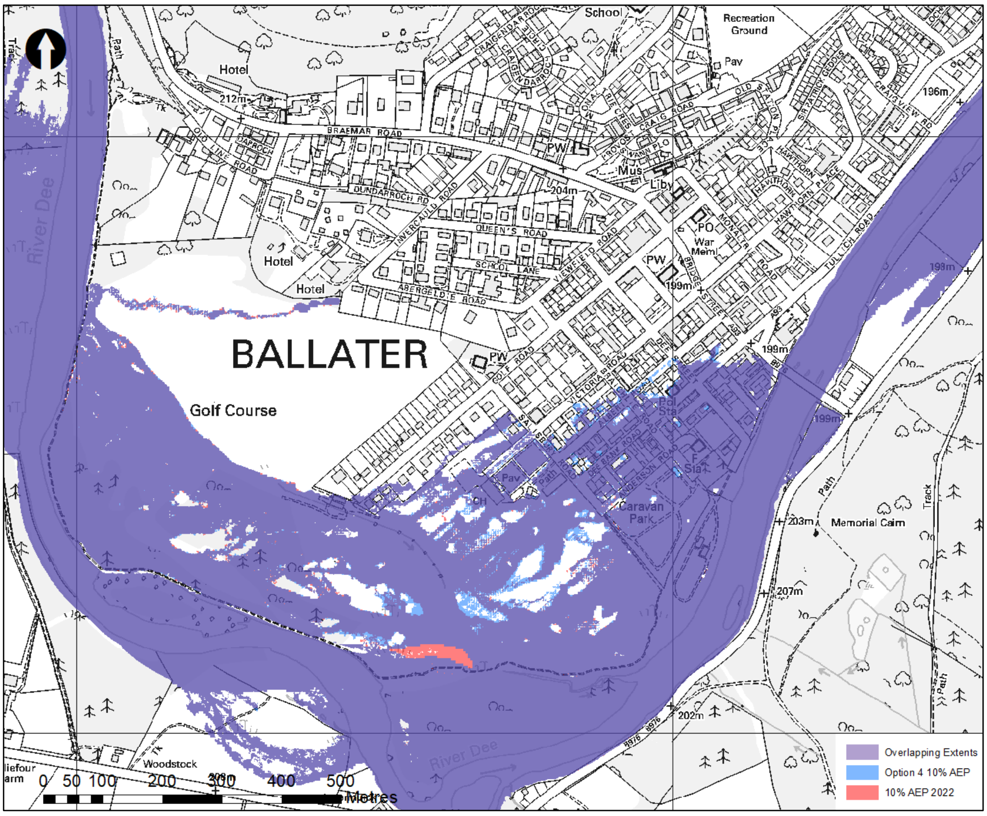


Figure 7.21: Option 4 10% AEP extent

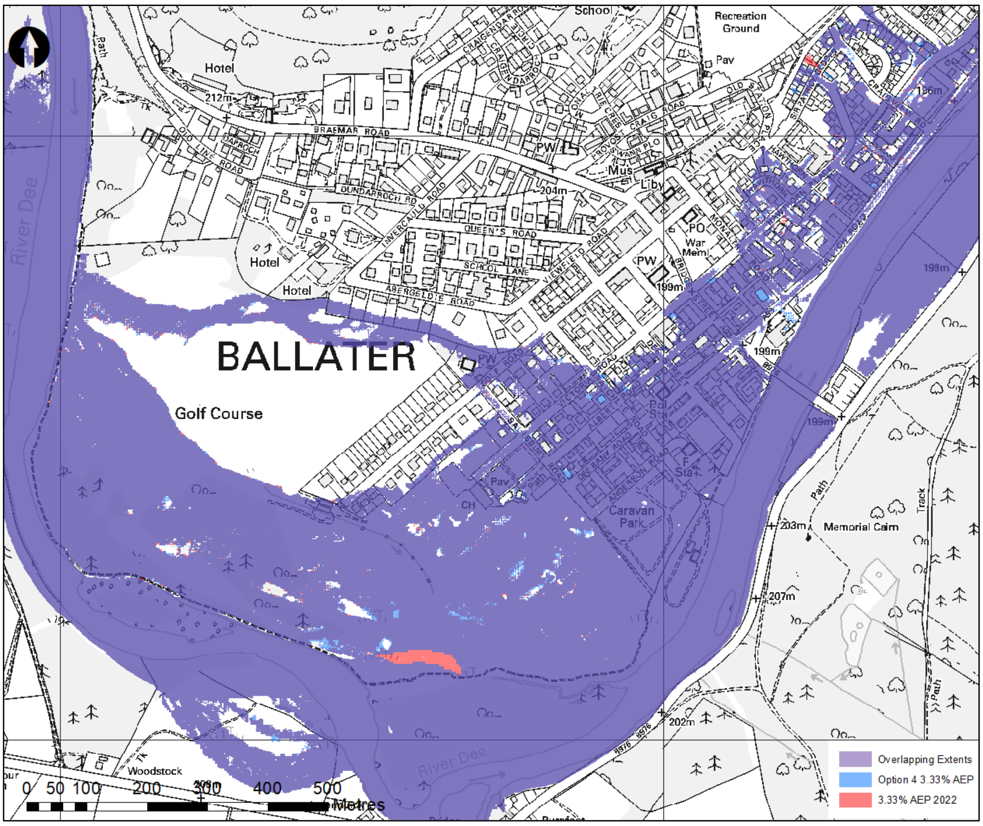


Figure 7.22: Option 4 3.33% AEP extent

7.5 Combined Options 1, 3 and 4 (Option 5)

To ascertain the impact of a combination of minor works on resulting flood extents, an option was simulated which included the removal of dead trees and obstructive vegetation from the area surrounding the Golf Course channel outlet, along with the clearance of the Golf Course channel outlet and the construction a new bund on the left bank of the River Dee, south of the Golf Course (Figure 7.23).

Figure 7.23: Option 5 Combined minor works options

This results show a reduction in flood extent on the Golf Course near the drainage channel outlet for the 50 and 20% AEP events (Figure 7.24 and Figure 7.25), whilst in the 20% AEP event a minor increase is observed north of the Caravan Park, alongside simultaneous decreases on the Golf Course. Similarly, the 10% AEP event shows both minor increases and decreases on the Golf Course to the south-west of the Caravan Park (Figure 7.26). In the 3.33% AEP event, a minor increase is noted north of Bridge Street (Figure 7.27). In the 50% AEP event the same number of buildings exist within the flood extent as in the 2022 baseline simulation, however in the larger magnitude and lower frequency events (20, 10 and 3.33% AEP), the number of buildings within the flood extent is increased (Table 7.5).

Table 7.5: Buildings within Combined minor works option (Option 5) extent

Annual Exceedance Probability (%)	2022 Baseline	Option 5	Difference
50	22	22	0
20	97	112	+15
10	143	149	+6
3.33	399	415	+16

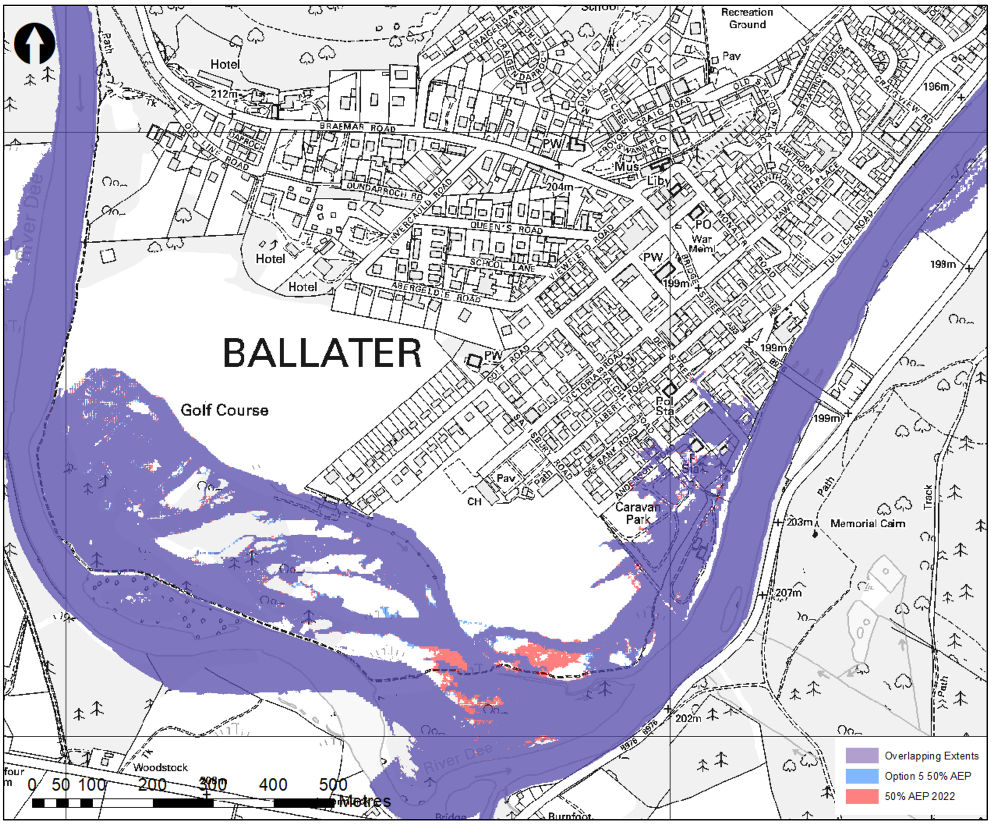


Figure 7.24: Combined minor works option (Option 5) 50% AEP extent

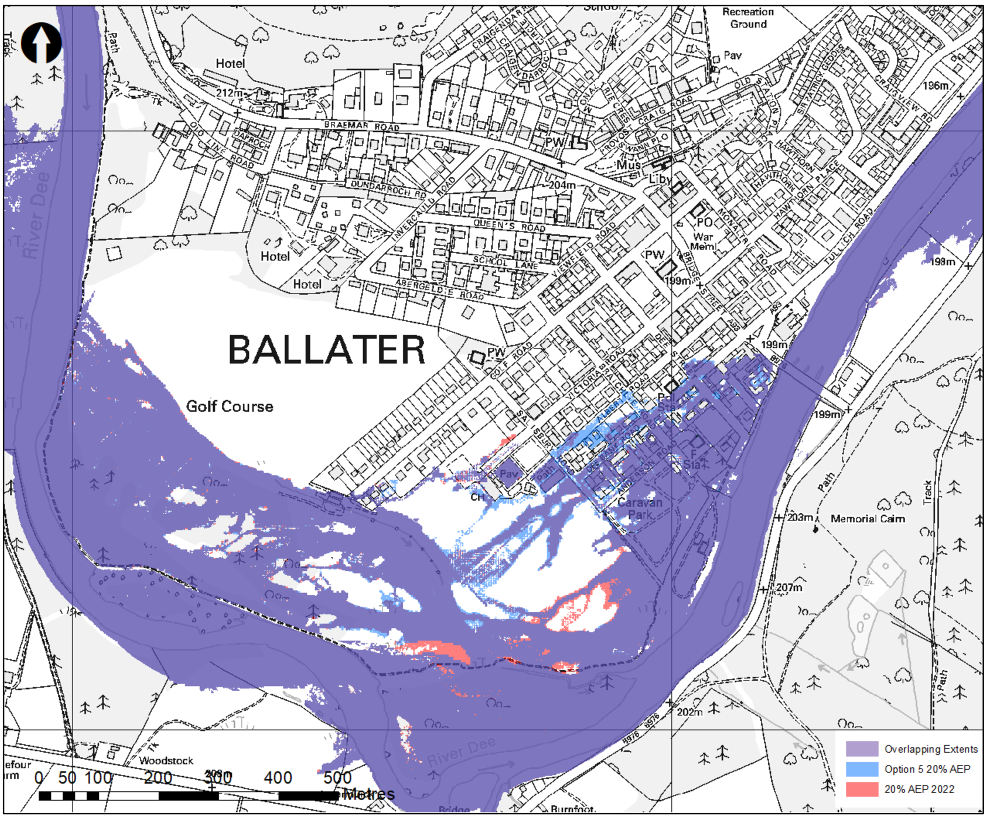


Figure 7.25: Combined minor works option (Option 5) 20% AEP extent

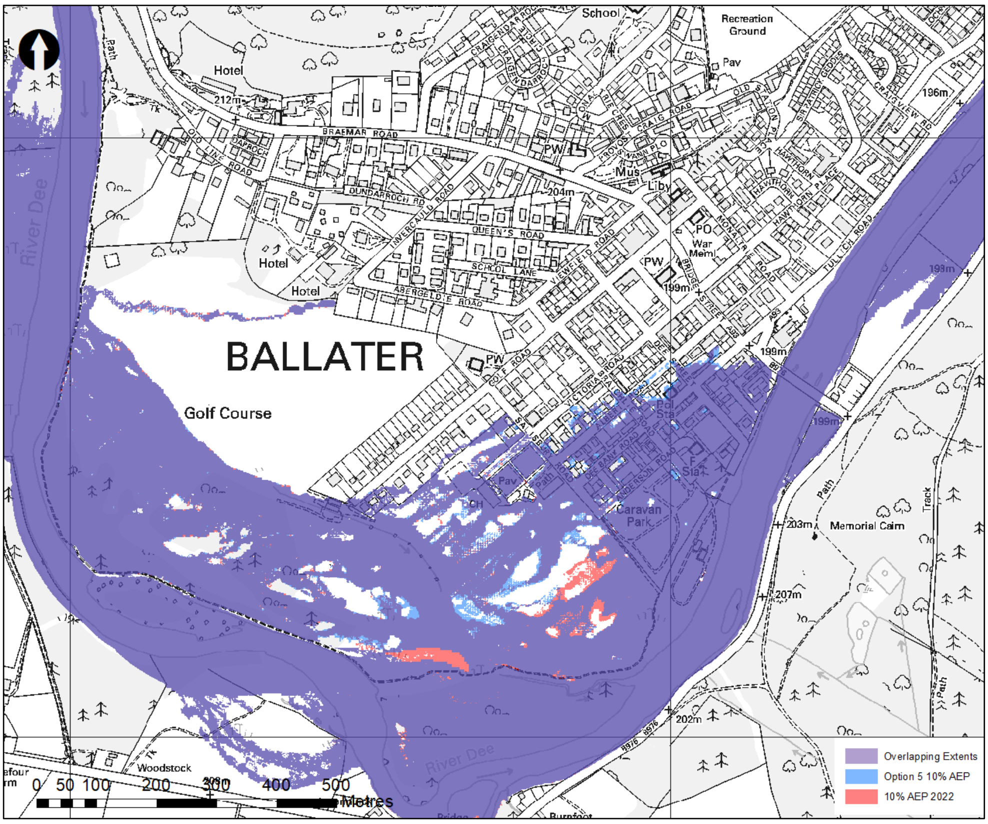


Figure 7.26: Combined minor works option (Option 5) 10% AEP extent

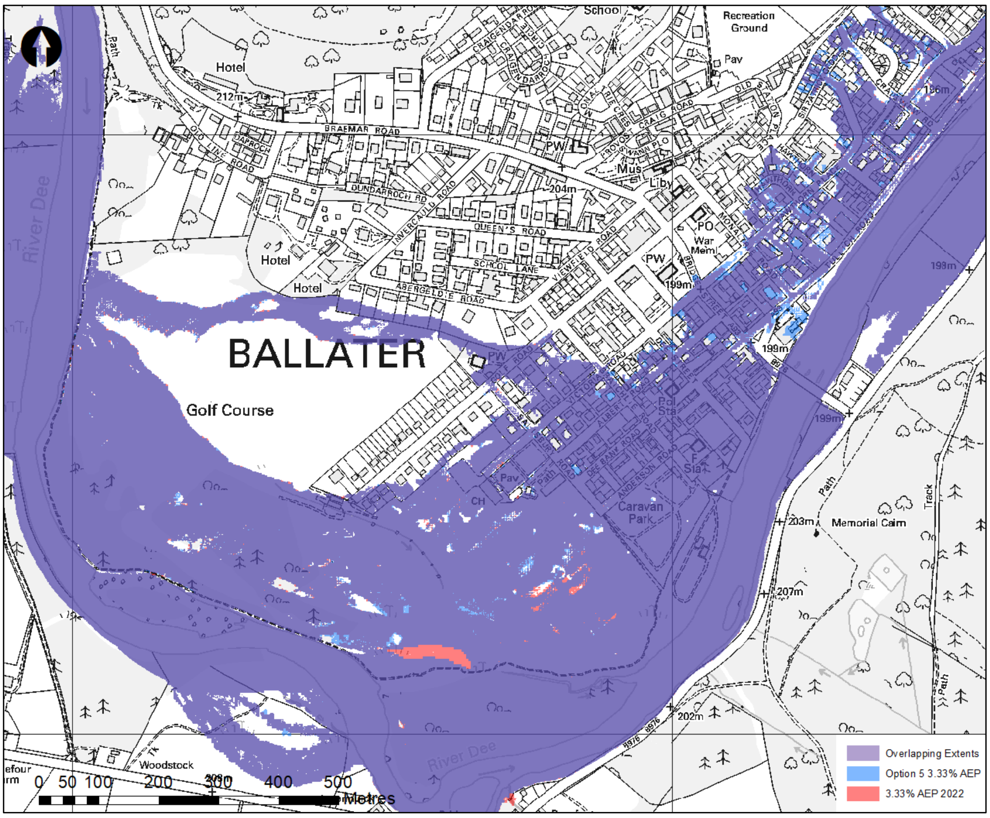


Figure 7.27: Combined minor works option (Option 5) 3.33% AEP extent

7.6 Summary of Options Modelling

The minor works options were assessed for high-frequency flooding in the 50, 20, 10 and 3.33% AEP events. A summary of the potential impact of each option is described below.

Option 1 Removal of dead trees/ debris

Model simulations show Option 1 to have a limited effect in reducing the extent of flooding in the vicinity of the Caravan Park in the 50% AEP event, however some minor increase is noted immediately north of the Caravan Park. Both the 20% and 10% AEP events show limited reductions in flood extents on the Golf Course to the south of the Caravan Park, whilst significant increase in extent is noted elsewhere on the Golf Course in the case of the 20% AEP event, leading to earlier development of the Abergeldie Road preferential flow path in the 10% AEP event. In the 3.33% AEP event, both minor local increases and decreases are noted in flood extents. This option showed increases in the number of buildings within the flood extent in the 50, 20 and 3.33% AEP events.

Instead of the desired effect of reducing floodplain resistance to flow and expediting flood flows crossing Ballater Golf Course, it is probable that increased efficiency of the floodplain may instead facilitate the flow of floodwater from the River Dee into the Golf Course drainage channel, serving to exacerbate flooding.

Some benefit may be found in the removal of large items such as fallen trees and other debris, which have the potential to be carried into the openings of structures such as the nearby downstream Royal Bridge, reducing flow conveyance capacity and in turn increasing potential flood risk. However, larger scale modification of vegetation at this location is not seen as a positive option for managing flood risk to Ballater at this time.

Option 2 Clearance of Channel on Glenmuick side

Option 2 simulations show significant change across all four return periods, with localised increase and decrease in each flood extent. In each instance, flooding emanating from the left bank of the River Dee west of the Golf Course via the Golf Course drainage channel is significantly reduced, including the elimination of the Abergeldie Road preferential flow path in the 3.33% AEP event. However, significant increase in flood extent results in an increased number of buildings within the flood extent in the Option 2 simulation than in the 2022 baseline simulation for all four tested flood events.

As for the ability to reduce erosion of the left bank, any reduction in erosion upstream because of decreases in extent may come at the cost of increased erosion downstream as a result of increased flooding.

RPS have estimated that approximately 20,000– 30,000 m^3 of material would require to be moved, equivalent to between 1,000 and 1,500 lorry loads. Cbec noted that robust detailed design would be required to ensure self-sustainability of any such proposal. There would be considerable maintenance works associated with maintaining the cleared channel which would make this measure unsustainable.

There are numerous negative impacts associated with clearance of the river channel which include the environmental impact to the River Dee designated Special Area of Conservation (SAC) and the major morphological instability it would cause to the river channel.

As a minor works option, the lack of self-sustainability alongside a lack of benefit suggest this is not a positive option for managing flood risk to Ballater at this time. It is possible that further exploration of this option through extensive optioneering and detailed design may identify an optimum channel layout which may produce positive ability to manage the flood risk facing Ballater.

Option 3 Clearance of outlet channel at Golf Course

Similar to Option 1, Option 3 aims to reduce resistance to flow and improve conveyance capacity of the Golf Course drainage channel. Unlike Option 1 which simulated a more efficient flow condition through the area of the drainage channel outlet, Option 3 utilises a targeted approach to improve the conveyance capacity of just the channel through the same area.

Simulation of Option 3 shows a reduction in flood extent for the 50, 20, 10 and 3.33% AEP events. The largest reductions in flood extent are for the 50 and 20% AEP events, with greatest effect shown to properties immediately north-east of the Caravan site in the 50% AEP event, and north of the caravan site in the 20% AEP event. Of the four minor works options, Option 3 is the only option that reduces the number of buildings within the flood extent produced for all four modelled events (50, 20, 10 and 3.33% AEP).

However, the positive potential to modify flood extent is subject to the applied channel schematic. Cbec add a cautionary note on the sustainability of this option, stating likely limitations to long-term effectiveness from the ability of relatively small events to retain the potential to deposit substantial volumes of fine material in these side channels. Therefore, the depositional character of this area can significantly limit the long-term effectiveness of this option. This option will require constant maintenance to ensure that the clearance of the channel is maintained.

Option 4 New bund at southern end of Golf Course

Initial simulations utilised a bund approximately 380m long, however it was quickly established that this obstruction intercepted and diverted the main preferential flow path across the Golf Course, exacerbating the flood extents impacting Ballater for all four modelled events (50%, 20% 10% and 3.33% AEP). As such, a shorter 200m bund was tested, effectively extending the footprint of the previously existing bund easterly, terminating at the right bank of the Golf Course outlet channel.

Simulation of the shorter 200m bund was found to be ineffective against the 50% AEP event (no significant change in flood extent or number of buildings within the flood extent). In the 20, 10 and 3.33% AEP events, simulation of a bund exacerbated both flood extents and the number of buildings within each extent. It is clear that construction of a bund at the proposed location fails to successfully intercept any of the primary flood mechanisms and it is suggested that planform adjustment and geomorphological changes to the River Dee have mitigated any flood risk management potential in constructing a bund in the location modelled.

Option 5 Combination of minor works Options 1, 3 & 4

Simulation of a combination of minor works Options 1, 3 and 4 show a reduction in flood extent on the Golf Course near the drainage channel outlet for the 50 and 20% AEP event, whilst in the 20% AEP event a minor increase is observed north of the Caravan Park, alongside simultaneous decreases on the Golf Course. Similarly, the 10% AEP event shows both minor increases and decreases on the Golf Course to the south-west of the Caravan Park. In the 3.33% AEP event, a minor increase is noted north of Bridge Street. In the 50% AEP event the same number of buildings are within the flood extent as in the 2022 baseline simulation, however in the larger magnitude and lower frequency events (20, 10 and 3.33% AEP), the number of buildings within the flood extent is increased.

It is therefore considered that a combination of these three works options fails to provide a positive option for managing flood risk to Ballater at this time.

7.7 Property Level Protection

Aberdeenshire Council asked RPS to consider how many properties at risk of flooding in a 3.33% AEP event could benefit from the use of Property level protection (PLP), which is the installation and deployment of a range of flood resistance and flood resilience measures. PLP can provide communities in flood risk areas with flood measures that are cost-effective and easy to operate, however it does rely on timely installation of the products and requires long-term storage and maintenance of the products. The use of PLP depends on flood warning, which is provided by SEPA and the Met Office through the Scottish Flood Forecasting Service.

PLP would typically provide protection against flooding for depths of up to 0.6m. As shown in Table 6.4, there are 354 properties identified as being at risk in a 3.33% AEP event that would benefit from PLP. That leaves 45 properties that PLP would not be applicable for. Identified properties should consider the benefits of purchasing PLP where appropriate. Note that a survey of properties has not been completed to identify whether or not PLP would be suitable.

Aberdeenshire Council retains a stock of a small selection of these products and is willing to sell them to the public at cost price. Further details can be found on the Aberdeenshire Council website:

https://www.aberdeenshire.gov.uk/environment/flooding/flood-protection-products/

8 ADDITIONAL MODELLING OF OPTIONS

Workshops were held on 14th December 2022 in Ballater to present the initial findings of the modelling as described in Section 7. The workshops were attended by representatives of the Caravan Park, the Golf Course, Ballater Community Council and invited local residents.

As a result of the workshops, RPS were asked to consider two further options for bunds- one to the north of the Golf Course (Option 6), and one to the south to be combined with Option 3 Clearance of outlet channel at Golf Course (Option 7). The locations of these additional options are shown in Figure 8.1.

Figure 8.1: Locations of additional options to be modelled

The updated hydraulic model has been used to simulate the impact of the two proposed bund locations on flood extents generated by events with AEP of 50%, 20%, 10% and 3.33%. As for the minor works options modelled in Section 7, the flood extents from the updated model as described in Section 6 form the baseline for the assessment of the impact of the two proposed bund locations. Note that in the comparison maps the baseline flood extents from the 2022 study are shown in red, the extents from the minor works option are shown in blue, and any areas where the flood extents overlap are shown in purple. The estimated number of properties at risk in each extent has been included as in Section 7.

8.1 Additional Minor Works- Proposed Northern Bund (Option 6)

Initially a 610m long, 1.5m high bund was modelled in the position agreed following the consultation on 12th December 2022. The modelling showed that this bund failed to successfully intercept the primary flood mechanism at this location, with a large portion of the bund to the north not interacting with any observable flood extent. Subsequently the bund was shortened to 210m, reduced in height to 1m and moved further south along the left bank of the Dee. The location this bund is shown in Figure 8.2.

Figure 8.2: Option 6 Northern bund

Modelling of this scenario showed reductions in flood extent for each of the four return periods considered (see Figure 8.3 to Figure 8.6). The reduction was most notable in the 10% AEP event (Figure 8.5), but also in the 3.33% AEP event (Figure 8.6), where the bund successfully blocks identified flood mechanism 5 (see Figure 6.23). Due to these reductions in flood extents, the number of buildings affected by each extent is also significantly reduced (see Table 8.1), mostly notably in the 10% AEP event.

Table 8.1: Buildings within Option 6 extent

Annual Exceedance Probability (%)	2022 Baseline	Option 6	Difference
50	22	20	-2
20	97	73	-24
10	143	106	-37
3.33	399	377	-22

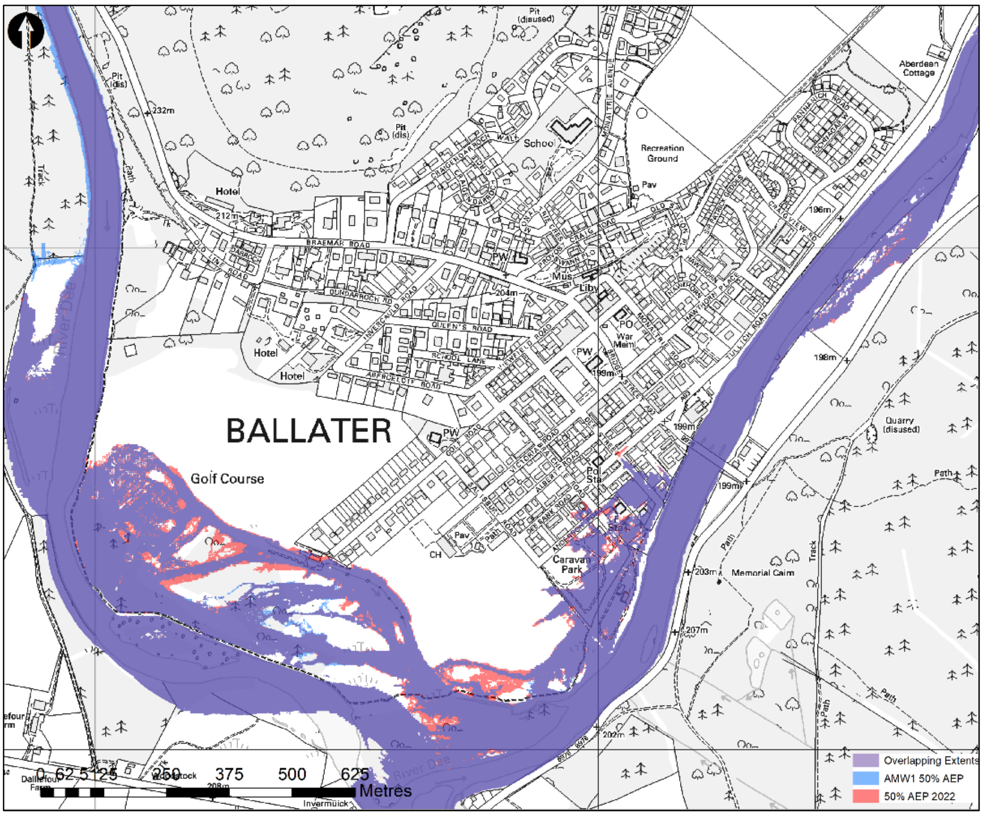


Figure 8.3: Option 6 50% AEP extent

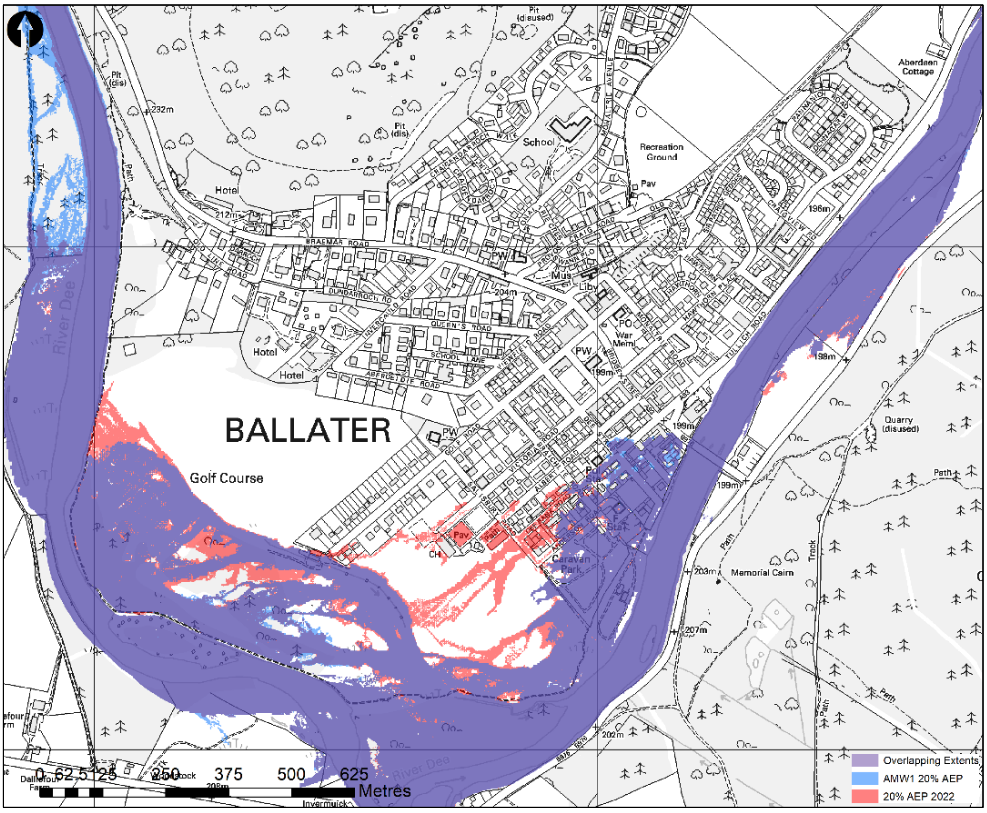


Figure 8.4: Option 6 20% AEP extent

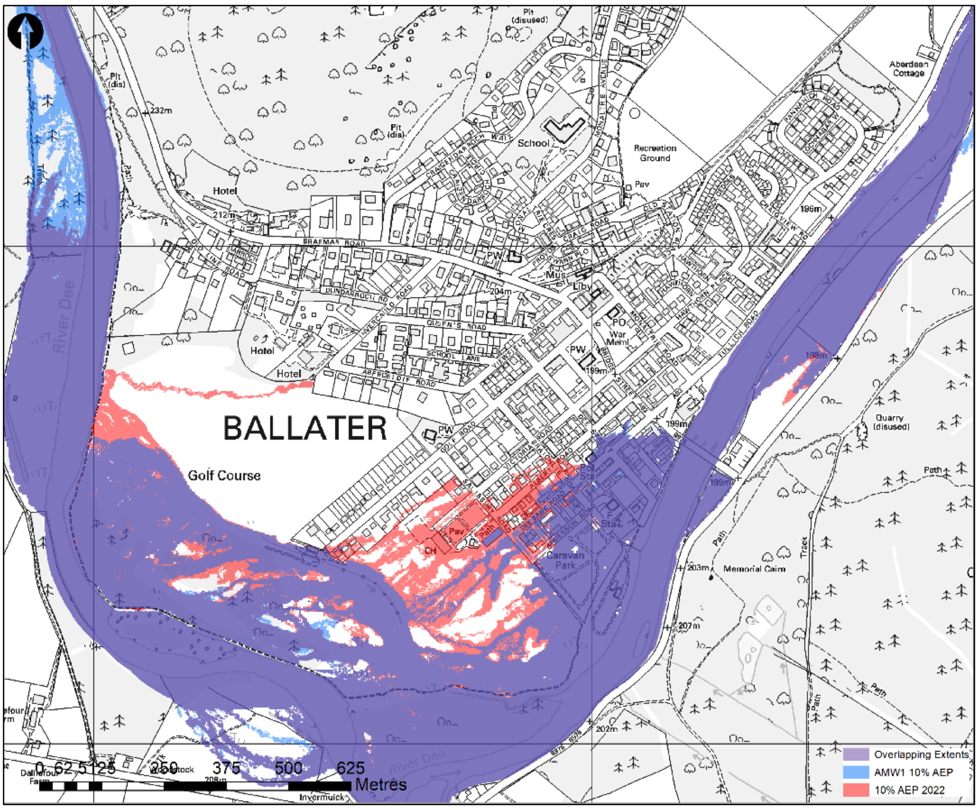


Figure 8.5: Option 6 10% AEP extent

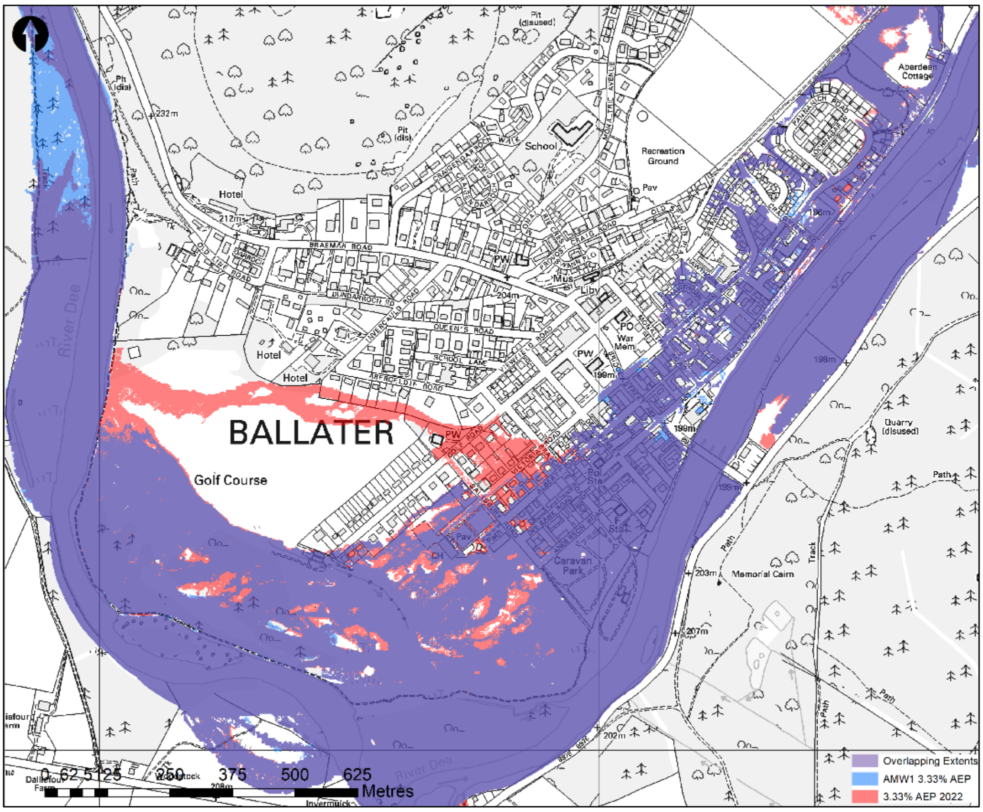


Figure 8.6: Option 6 3.33% AEP extent

At the request of Ballater Community Council, this option was also considered to determine what amendments would need to be made to the bund in order to provide the Standard of Protection necessary for an event with an Annual Exceedance Probability (AEP) of 0.5%. It was subsequently determined that a minimum of 235m of the left bank would need to be increased by as much as 1m, with a further 112m increased by as much as 2.4m. This option is not considered viable on the grounds that implementation of changes on this scale would require extensive construction works at considerable cost and as such is considered far beyond the scope of ‘Minor Works’. Additionally, it is predicted that implementation of this option as described would only provide protection to approximately 78 of the properties currently predicted to be at risk in the 0.5% AEP event (approximately 13%).

8.2 Additional Minor Works- Proposed Southern Bund & Clearance of Outlet Channel (Option 7)

Deepening of a 330m reach of the Golf Course outlet channel by 0.5m was simulated in conjunction with a 440m long, 1.5m high bund on the left bank (see Figure 8.7). This was simulated for the 50%, 20%, 10% and 3.33% AEP events (Figure 8.8 to Figure 8.11). In each instance the results showed a significant reduction in flood extent on the left flood plain of the River Dee in the vicinity of Ballater. Up to the 10% AEP event reductions in left bank extents are most evident south of Bridge Street (Figure 8.10), whilst in the 3.33% AEP event a significant reduction in extent impacting property north of Bridge Street is shown (Figure 8.11). As flood extents impacting Ballater on the left floodplain of the River Dee decrease, an increase in flood extent is observable on the right bank of the River Dee, largely impacting farmland to the north of the Red Braes. Along with reduced flood extents, the number of buildings impacted by each flood extent also decreases (Table 8.2), with the largest decrease observed in the 3.33% AEP event.

Figure 8.7: Option 7 South bund & clearance of outlet channel

Table 8.2: Buildings within Option 7 extent

Annual Exceedance Probability (%)	2022 Baseline	Option 7	Difference
50	22	13	-9
20	97	17	-80
10	143	113	-30
3.33	399	249	-150

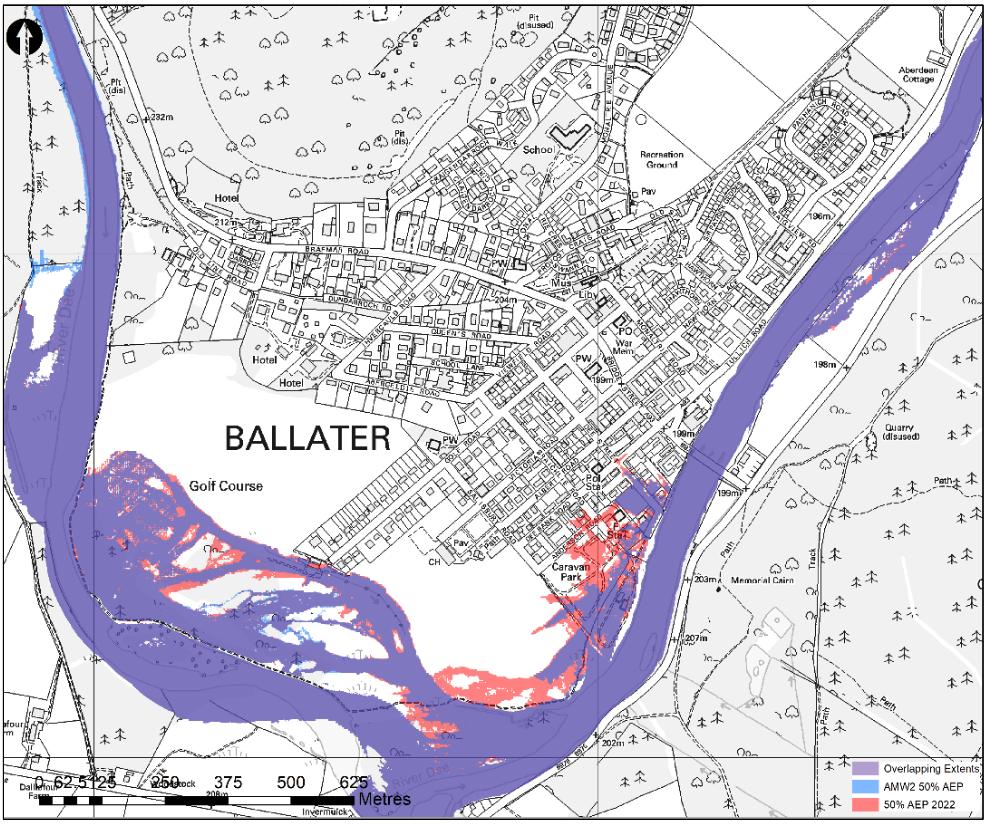


Figure 8.8: Option 7 50% AEP extent

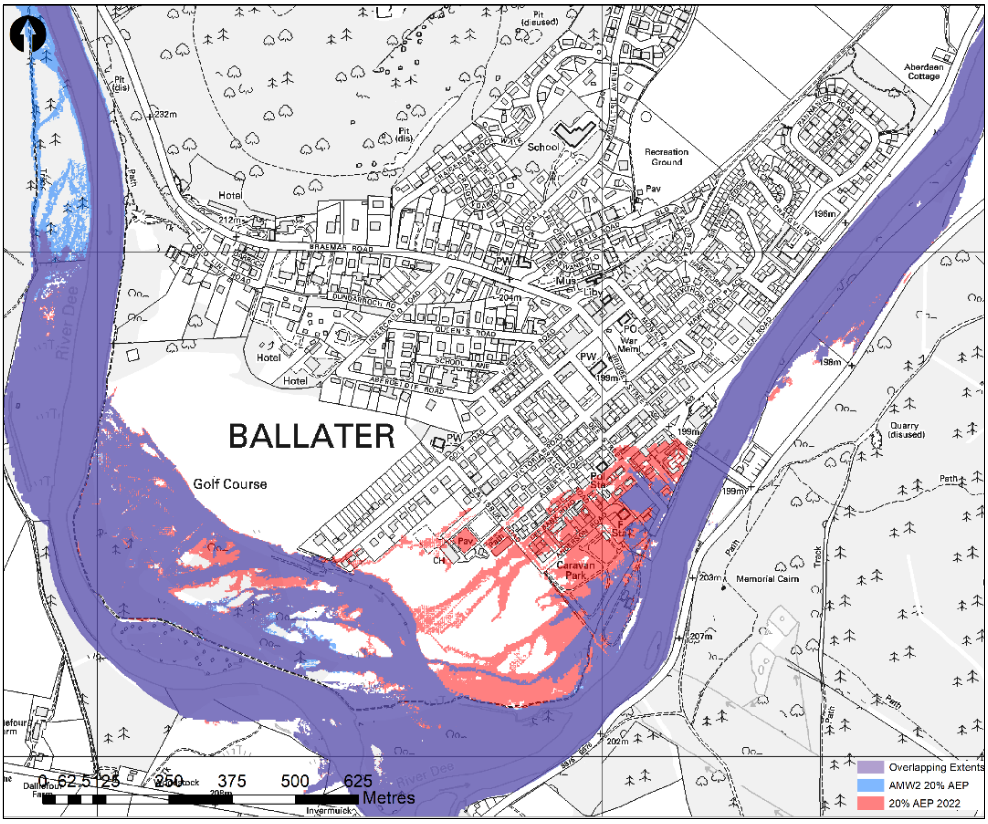


Figure 8.9: Option 7 20% AEP extent

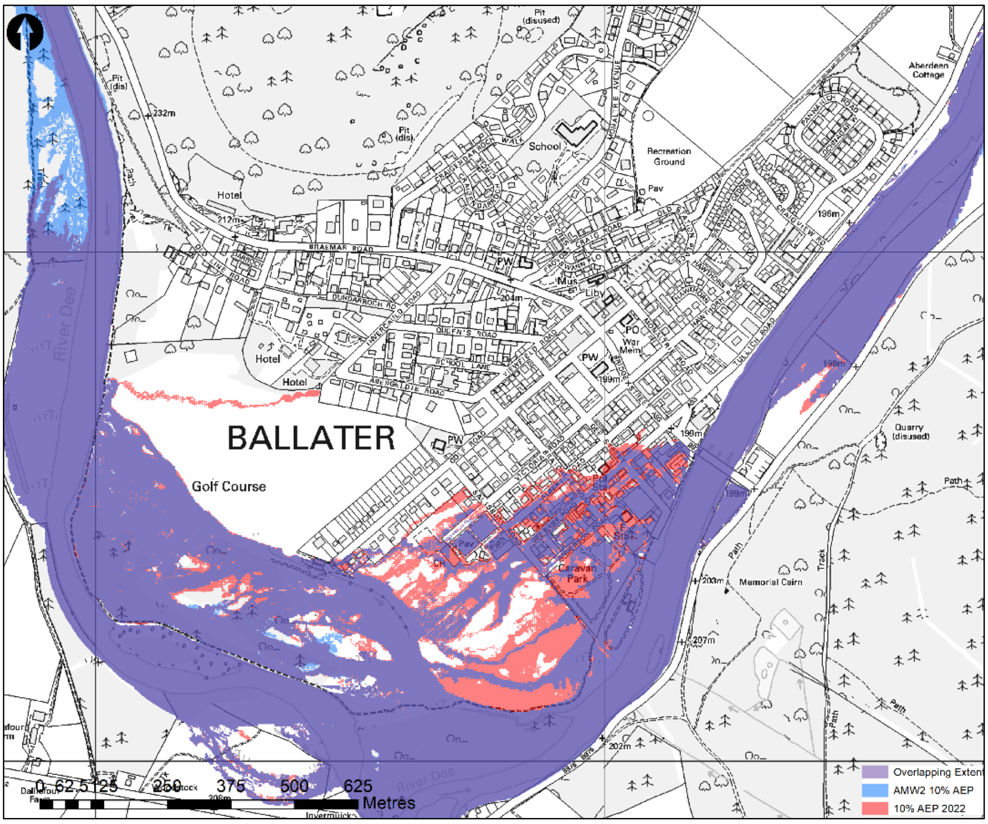


Figure 8.10: Option 7 10% AEP extent

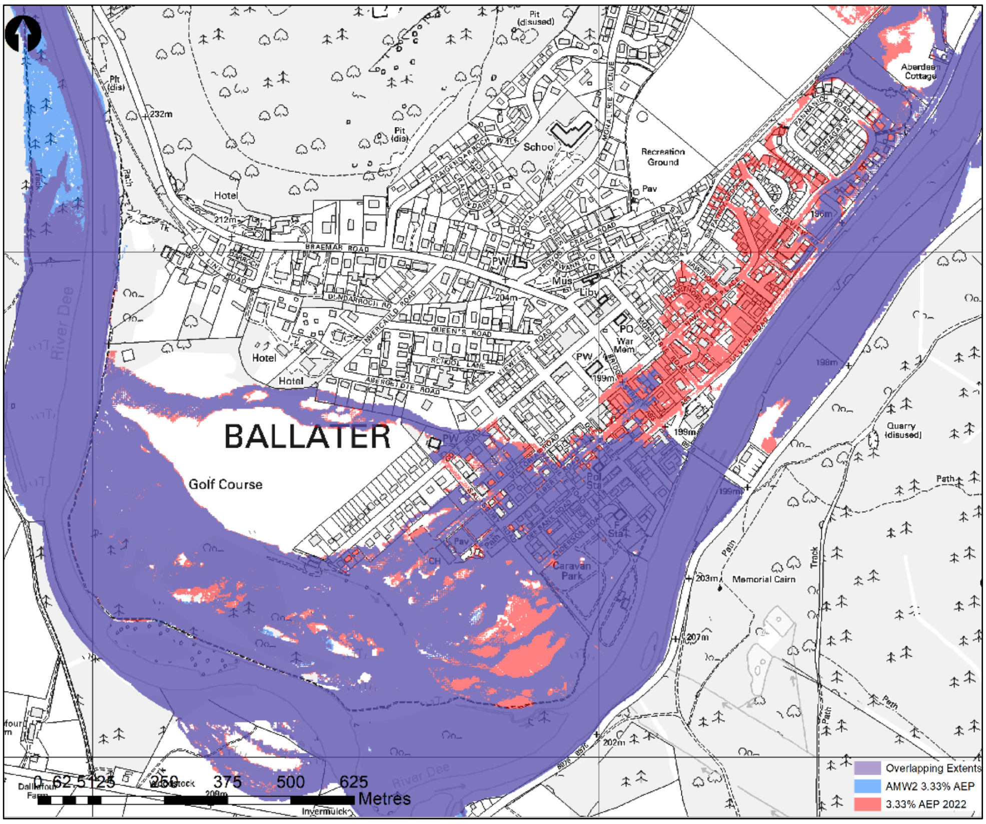


Figure 8.11: Option 7 3.33% AEP extent

9 PREFERRED OPTION

Option 7 is the preferred option to meet the objective of the Ballater Additional Flood Study, which was to assess the potential for minor works to manage the flood risk to Ballater until such time that a decision is made to implement the proposed main scheme.

The combination of a bund to the south of the Golf Course, along with clearance of the Golf Course drainage channel at its outlet showed the most significant reduction in flood extents impacting receptors in Ballater of all of the modelled options. In a 3.33% AEP event, this option can reduce the number of flooded properties from 399 to 249. For the 3.33% AEP event, the depths of flooding at the properties affected have been determined and summarised in Table 9.1.

Table 9.1: Depths of flooding with Option 7 (3.33% AEP)

Depth of flooding (m)	Number of properties
< 0.3	153
0.3 to 0.6	51
0.6 +	45

RPS have reviewed the results of the model to determine if there is any increase in flood risk as a result of the preferred option. In Figure 8.8 to 8.11, any areas that are shown as blue will flood if the preferred option is constructed. There are no properties affected but there are areas of forest on the right bank upstream of Ballater that will be affected.

With implementation of Option 7, residual flood risk is predicted to remain across all four of the modelled return periods considered within the scope of this study (50%, 20%, 10% and 3.33% AEP events). Most notably, this risk impacts properties north of the Caravan Park between Bridge Street and Golf Road. Mechanisms contributing to this residual risk include widespread shallow depth sheet flow across the left bank of the Golf Course drainage channel beyond the western end of the proposed bund, along with shallow depth sheet flow across the left bank of the River Dee beyond the eastern end of the proposed bund.

The iterative approach undertaken to modelling of the preferred option identified any westward extension of the bund as having the potential to increase residual risk to the same area of Bridge Street, as flood plain attenuation has been removed from the Golf Course west of the bund thus elevating levels downstream of the bund. Similarly, to further mitigate against the residual mechanisms beyond the eastern end of the bund, the proposed structure would require an extension of approximately 300m downstream of the current end position. In this instance, the impact in larger magnitude/ lower frequency events is to act to retain flood waters on the flood plain, exacerbating flood risk.

In its current configuration Option 7 offers the best opportunity to offer protection to at-risk properties for flood events of the considered magnitude/ return periods whilst also not exacerbating or contributing to the severity of flood risk likely to exist in larger magnitude/ lower frequency events. Option 7 is therefore the preferred option to meet the objective of the Ballater Additional Flood Study, which was to assess the potential for minor works to manage the flood risk to Ballater until such time that a decision is made to implement the proposed main scheme. Note that the proposed main scheme will provide protection to all properties up to a 0.5% AEP event.

Aberdeenshire Council asked RPS to consider how many properties which remain at risk of flooding in a 3.33% AEP event following the construction of Option 7 could benefit from the use of Property level protection (PLP). PLP would typically provide protection against flooding for depths of up to 0.6m. As shown in Table 9.1, there are 204 properties identified as being at risk in a 3.33% AEP event that may benefit from PLP. That leaves 45 properties that PLP would not be suitable for. Note that a survey of properties has not been completed to identify whether or not PLP would be suitable.

10 CONCLUSION

Ballater has experienced significant flooding from the River Dee in the past. In December 2015, heavy rainfall during Storm Frank caused the River Dee to burst its banks, flooding over 300 properties. In 2018 RPS were commissioned to undertake a feasibility study to identify flood risk associated with the Rivers Dee, Gairn and Muick in the Ballater area and assess options for the alleviation of future flooding. As part of this study, extensive hydraulic modelling was undertaken and a preferred option for Ballater was established, comprising direct defences (permanent and glass walls), pumping stations, relocation, property level protection and resilience measures.

Following a further large magnitude flood event in February 2021 it was noted that the course of the River Dee had changed, most notably in the vicinity of Ballater Golf Course. During this event, extensive erosion to rock armour protection occurred and sections of informal flood defence bund along the left bank of the River Dee in the vicinity of the Golf Course were washed away. RPS were consequently commissioned to undertake an Additional Flood Study, to identify any changes to flood risk resulting from significant morphological changes to the River Dee, and to assess potential for minor works to manage flood risk to Ballater until such time that a decision is made to implement the proposed main scheme.

To facilitate the Additional Flood Study, the 2018 hydraulic model was updated using new 45 channel cross-sections, extending from the northern extent of the Golf Course to the Royal Bridge and supplemented with new high-resolution LiDAR of the Ballater Golf Course area. This new survey was completed in March and April 2022. 13 of the new sections were overlapping with the 2018 survey and these were compared to assess the scale of change – seven sections revealed significant change, and six sections showed no significant change.

The updated model subsequently simulated the range of return periods as in the previous study, with comparative analysis of the 2018 and 2022 studies undertaken. The analysis shows significant increase to flood extent in the 50, 20, 10 and 3.33% AEP events, with minor difference noted between the 2018 and 2022 1% AEP events and greater. Increases in the 50, 20, 10 and 3.33% AEP events are noted on the left bank flood plain in the vicinity of Ballater Golf Course, whilst simultaneous decreases in extent are noted on the right bank, in the vicinity of Royal Bridge, upstream of the Glenmuick confluence and adjacent to the northern extent of Ballater Golf Course. In the 2022 50% AEP event, flood extents encroach upon an additional 22 buildings within the scheme area, an additional 79 buildings in the 20% AEP event, an additional 72 in the 10% AEP event, an additional 195 in the 3.33% AEP event and an additional 40 buildings in the 1% AEP event. It can therefore be assessed that, consequent of significant geomorphological change in the River Dee at Ballater, significant increase in the magnitude of higher-frequency flood events is probable and as such, that increased flood risk exists for Ballater than observed in 2018. It should be noted that the flood extents produced in this Study are representative of the river channel at the time of survey, and that any further alterations to the channel could alter the modelled extents.

Minor works were suggested by members of the local community, and these were further investigated as part of the study:

- Removal of dead trees from river channel and reuse in bank reinforcement (Option 1).

- Clearance of deposited gravel from main river channel on Glenmuick side (Option 2).
- Clearance of outlet channel for watercourse across Golf Course (Option 3).
- Build new bund across rough ground at southern end of Golf Course (Option 4).
- Combined options 1, 3 and 4 (Option 5).

The updated hydraulic model was used to simulate the impact of the proposed minor works options on flood extents generated by events with AEP of 50%, 20%, 10% and 3.33%. Where the hydraulic model does not explicitly allow representation of the existing scenario, RPS endeavoured to achieve accurate representation by modifying model parameters as required. The results of the modelling showed that Option 3 'Clearance of the outlet channel across Golf Course' was the only option that would provide a positive option for managing flood risk to Ballater at this time. The results of this analysis were presented at workshops held on 14th December 2022 in Ballater. The workshops were attended by representatives of the Caravan Park, the Golf Course, Ballater Community Council and invited local residents.

Following the workshops two additional minor works options were simulated- Option 6: reinstatement of a bund on the left bank of the River Dee to the north of the Golf Course (north bund); and Option 7: deepening of the Golf Course outlet channel in conjunction with the construction of a bund on the left bank of the same channel (south bund).

As a result of these simulations, it was determined that Option 7 showed the most significant reduction in flood extents and subsequently the number of impacted receptors. In a 3.33% AEP event, this option can reduce the number of flooded properties from 399 to 249. In its current configuration Option 7 offers the best opportunity to offer protection to at-risk properties for flood events of the considered magnitude/ return periods whilst also not exacerbating or contributing to the severity of flood risk likely to exist in larger magnitude/ lower frequency events. RPS have reviewed the results of the model to determine if there is any increase in flood risk as a result of the preferred option, there are no properties affected but there are areas of forest on the right bank upstream of Ballater that will be affected. Option 7 is therefore the preferred option to meet the objective of the Ballater Additional Flood Study, which was to assess the potential for minor works to manage the flood risk to Ballater until such time that a decision is made to implement the proposed main scheme. Note that the proposed main scheme will provide protection to all properties up to a 0.5% AEP event.