Ballater Flood Protection Study

Feasibility Report

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DOCUMENT CONTROL SHEET

Ballater Flood Protection Study

Feasibility Report

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ABBREVIATIONS

1D	One Dimensional
2D	Two Dimensional
AAD	Annual Average Damage
AEP	Annual Exceedance Probability
AFP	Annual Flood Probability
ArcGIS	Arc Geographic Information System
BCR	Benefit Cost Ratio
BFIHOST	Base Flow Index derived using the HOST soil classification
BH Data	Borehole Data
Cap	Capping Value
CC	Climate Change
Df	Defended
Dp	Depth
DPSBAR	Index of Catchment Steepness
DTM	Digital Terrain Model
ELEV	Elevation
Emerg	Emergency
EvDam	Event Damage
FARL	Flood Attenuation due to Reservoirs and Lakes
FCERM_AG	Flood and Coastal Erosion Management Appraisal Guidance
FFL	Finished Floor Level
FPS	Flood Protection Study
FRM	Flood Risk Management
FRMP	Flood Risk Management Plan
GI	Ground Investigation
GL	Ground Level
GPS	Global Positioning System
HRA	Habitats Regulations Assessment
Int	Intangibles
LiDAR	Light Detection and Ranging
M2Dm	Damage per square metre
MCM	Multi-Coloured Manual
mOD/mAOD	metres above Ordnance Datum
NFM	Natural Flood Management
NPV	Net Present Value

NRFA	National River Flow Archive
OS	Ordnance Survey
PDD	Principal Direct Damage
PDM Model	Probability Distributed Model
PFR	Property Flood Resilience
PLP	Property Level Protection
PROPWET	Proportionate Wet
PV	Present Value
PVA	Potentially Vulnerable Area
PvD	Present Value Damage
QA	Quality Assurance
RBMP	River Basin Management Plan
RP	Return Period
SAAR	Standard Annual Average Rainfall
SAC	Special Area of Conservation
SCFB	Self-Closing Flood Barriers
SEPA	Scottish Environmental Protection Agency
SI	Site Investigation
SoP	Standard of Protection
SPA	Special Protection Area
STREAM	(Sediment Balance Survey)
URBEXT2000	Fractional Urban Extent
Util	Utilities
WEF	Water Environment Fund
WL	Water Level

EXECUTIVE SUMMARY

Aberdeenshire Council commissioned RPS to carry out a feasibility study to identify the flood risk associated with the River Dee, River Gairn and River Muick in the Ballater area and assess options (including economic viability) for the alleviation of future flooding.

This Feasibility Study was carried out following the Scottish Government's Options appraisal for flood risk management: Guidance to support SEPA and the responsible authorities. This guidance uses 3 stages to appraise the flood risk management; Stage 1 – Defining the Purpose; Stage 2 – Develop, Describe and Value; Stage 3 – Compare and Select the most Sustainable Solution.

For Stage 1 RPS reviewed the extent of the flood risk within the Ballater Study Area. Four flood cells were identified and assessed for risk. Flood Cell 1 covered Ballater Town and identified 578 properties at risk along with the A93 road, B976 road and Anderson Road. Other minor roads were also identified as being at risk. Flood Cell 2 covered the River Muick area and identified 7 properties at risk and the B976 Road. Flood Cell 3 covered the River Gairn area and identified 9 properties at risk and the A93 road. Flood Cell 4 covered the Upper Dee area at Polhollick and identified 3 properties at risk with no roads being affected. RPS reviewed the North East Local Flood Risk Management Plan and the brief of this study to establish the study's objectives. The overriding objective is to identify an option or options which would provide a 0.5% Annual Exceedance Probability (AEP) Standard of Protection (SoP), with consideration given to the potential impacts of climate change.

For Stage 2 potential options were developed by identifying a long list of FRM actions. These actions were screened to rule out technically inappropriate actions, technically impractical actions or actions with insurmountable constraints. Where an action was location specific this screening was carried out for each flood cell. It was identified that Direct Defences would form a major part of any viable flood scheme, and so actions were also screened for their potential to reduce the height of the Direct Defences in addition to identifying the SoP that they would provide as a standalone action. Short-listed actions were then combined to develop options. The do minimum option was used as the baseline scenario. All options identified were a combination of structural and non-structural actions. Three options were initially identified which provided protection to all properties within the study area through Direct Defences. The options consisted of Direct Defences (permanent defences only, permanent defences plus Self-Closing Flood Barriers or permanent defences plus Glass Walls), Pumping Stations, and Relocation. Three similar options were also identified where outlying properties were protected through either Property Level Protection or Flood Resilience. An additional seventh option was also identified (Option 1B) which consisted of a combination of Direct Defences, Storage, Property Level Protection and Resilience. Key assumptions made in the option costing are highlighted in Table 3.19 to Table 3.27 and are presented Appendix F. All options were appraised using the Environment Agency (EA) appraisal guidance table. The appraisal considered the flood risk management benefits, the wider positive and adverse impacts, the adaptability to climate change and other future flood risk, whole life cost and uncertainties.

For Stage 3 the options were compared by considering how well they met the objectives, which represented best value for money, which delivered multiple benefits or created adverse impacts and which had uncertainties and risk associated with it. The options were compared with one another. As

Option 3A out-performed the other identified options, it was chosen as the recommended preferred option for Ballater and consists of Direct Defences (permanent and glass walls), Pumping Stations, Relocation, Property Level Protection and Resilience.

The report includes a series of recommendations to be undertaken in order to refine the preferred option identified and then to facilitate scheme development during the outline and detailed design phases of the project. These include additional investigations to reduce uncertainties associated with the hydraulic model outputs, future hydraulic mechanisms due to the dynamic nature of the River Dee and the potential impacts of erosion and scouring as a result of the implementation of a flood alleviation scheme. It is also recommended that actions which were not short-listed and do not contribute to the preferred option in this report remain under consideration in future project stages due to their potential to reduce the height of direct defences or provide other benefits such as reducing channel instability issues.

1 INTRODUCTION

1.1 BACKGROUND

The River Dee is the principle river in Ballater which generally flows in an easterly direction, draining to the North Sea at Aberdeen. The River Gairn and River Muick are tributaries of the River Dee and their confluences are located in Ballater. The watercourses pass through the Cairngorms National Park and Ballater where there is a mix of residential & commercial properties and social amenities such as Ballater Golf Course and Ballater Caravan Park. The study area is defined by the catchment areas of the Dee, Gairn and Muick Rivers. The river model extent and river catchments are shown in Figure 1.1.

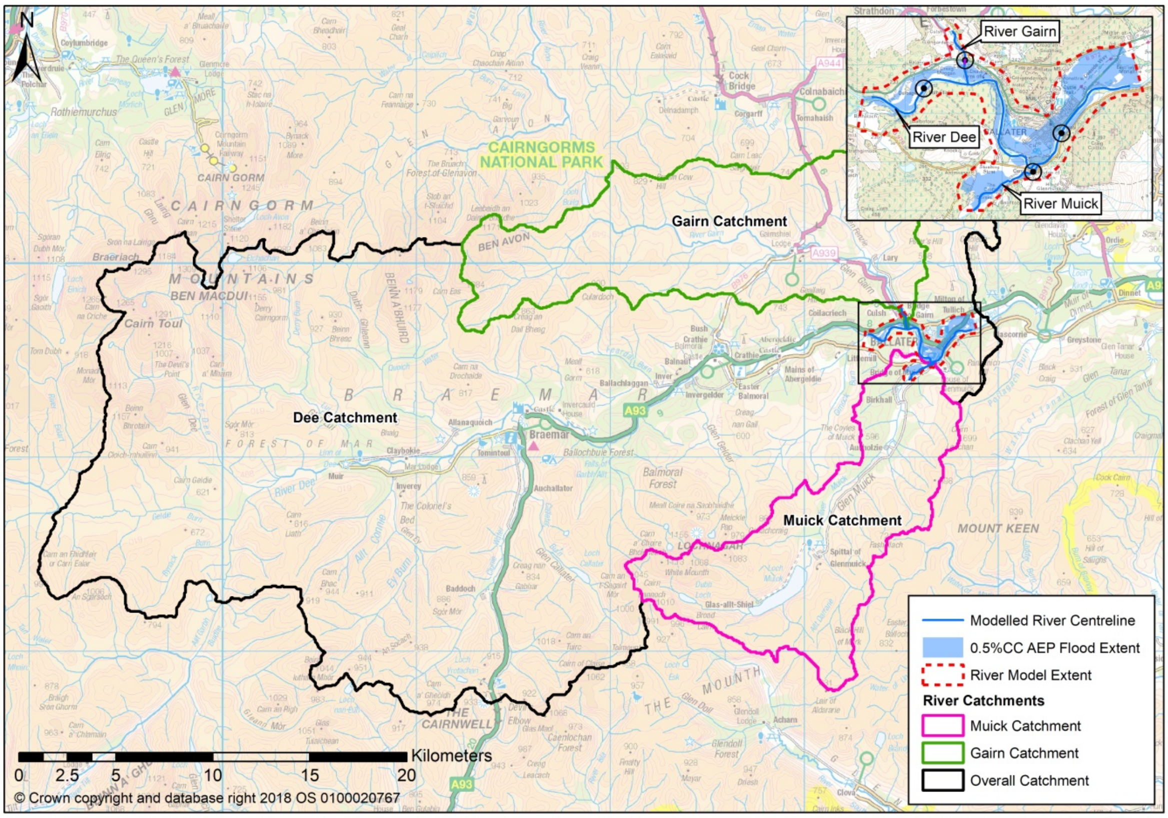

Figure 1.1 Ballater River Model Extent and River Catchments

1.2 AIMS AND SCOPE

The main aims of the flood study are to carry out a hydrological and hydraulic analysis of the River Dee, River Gairn and River Muick catchments and to identify sustainable outline proposals / options for the mitigation of the flooding of properties in Ballater with estimated costs.

The aims of the study are summarised below:

- Undertake a site visit and topographical surveys of the reach of the upper River Dee, including the associated tributaries the River Gairn and River Muick to understand the local flood flow pathways and flood history.
- Hydrological assessment to include and update of the hydrology for the three watercourses and incorporation of the available river gauges and completion of hydrological analysis to determine the design flows at Ballater. Also to derive inflows for 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5%, 0.1%, 3.33% plus climate change and 0.5% plus climate change fluvial annual exceedance probabilities (AEP).
- Construct and deliver a new hydraulic model extending over all River reaches.
- Environmental considerations including completion of an environmental walk-over of the site, scoping of environmental impacts and completion of an environmental survey.
- Calibration of the Ballater model through simulation of at least three events and verify performance through simulation of at least one event. Likely events include: December 2015.
- Sensitivity analysis to be completed for the 0.5% AEP (1 in 200 year return period) event and/or the AEP closest to bank top level.
- Produce flood mapping for a number of design events with and without defences for 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5%, 0.1%, 3.33% plus climate change and 0.5% plus climate change fluvial AEPs.
- Develop options to manage flood risk and provide recommendations for the most sustainable option.

The purpose of this report is to outline sustainable flood mitigation measures identified to protect existing properties and infrastructure in the Ballater Study Area. It is also to determine the technical, economic, social and environmental feasibility of those options and to outline conceptual design. Flood mitigation measures are to be based on a 0.5%AEP flood event plus freeboard (600mm in line with 'Technical Flood Risk Guidance for Stakeholders, SEPA, July 2018'), with consideration given to the potential impacts of climate change. Details of the work undertaken to fulfil the other objectives are located in separate reports.

2 STAGE ONE: DEFINING THE PURPOSE

In defining the purpose of this study a clear description is required of the problems to be addressed, including an understanding of the existing flood risk, how this risk will change over time and if there are any major constraints that may affect the choice of solution.

The Ballater study area covers approximately 8.3km of the River Dee from Balhalach (upstream) to Eastfield of Monaltrie (downstream). Approximately 1.8km and 1.2km of the Rivers Muick and Gairn respectively are also captured. The study area has been broken down into flood cells to simplify the optioneering process and the reporting of it. Careful consideration was taken when choosing flood cells with factors such as flooding mechanisms, receptors at risk and location being taken into account. Four flood cells were identified and are presented in Figure 2.1. The following chapter describes the problems to be addressed for each flood cell.

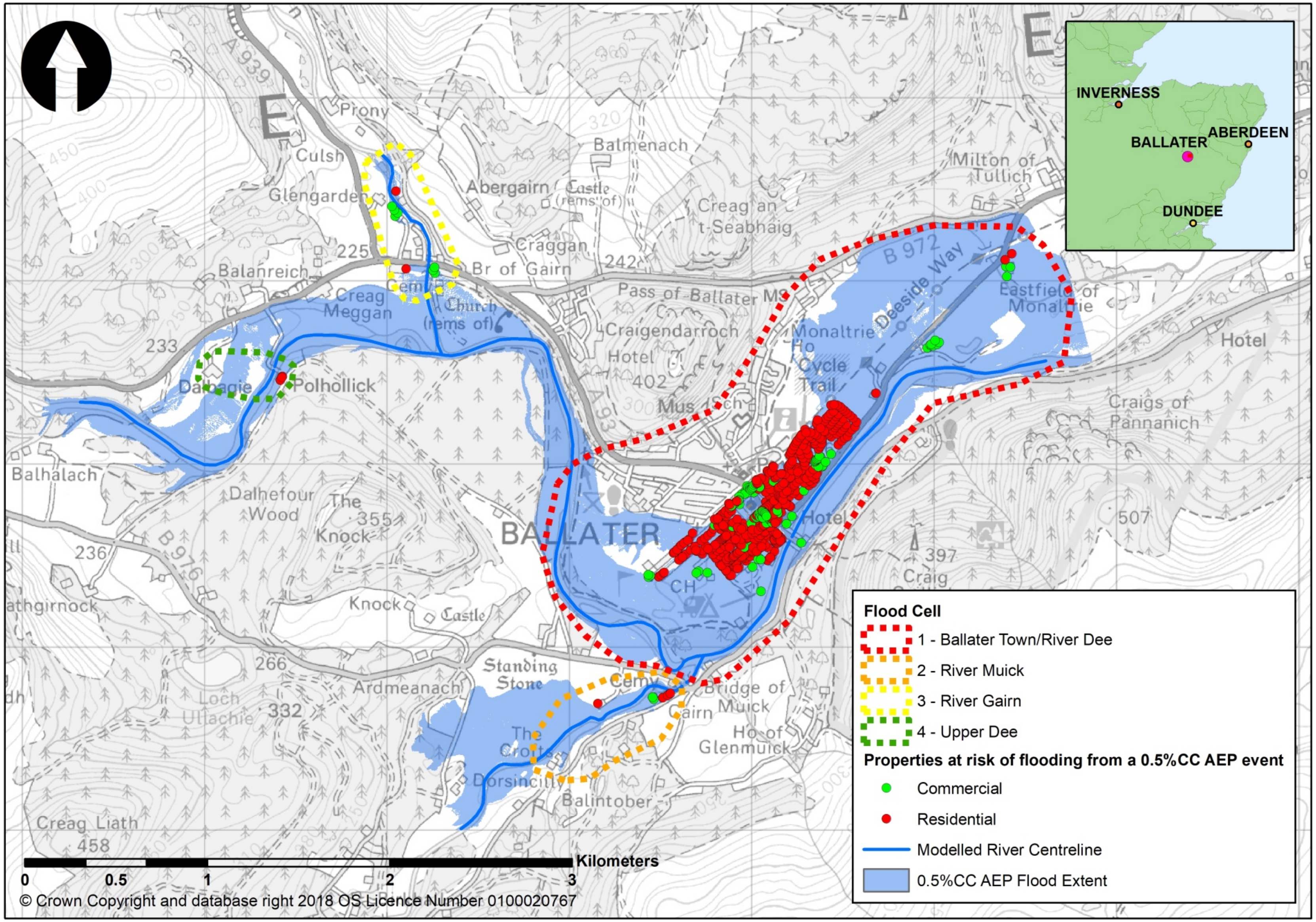

Figure 2.1 - Overview of the Ballater Study Area Flood Cells

2.1 FLOOD CELL 1 – BALLATER TOWN

Most recently Ballater has experienced significant flooding from the River Dee in August 2014 following ex Hurricane Bertha and in December 2015 as a result of Storm Frank. During the August 2014 event the caravan park was closed and 150 people were evacuated from the site. A number of roads were also closed as a result. In December 2015, heavy rainfall during Storm Frank caused the River Dee to burst its banks causing flooding to over 300 residential and commercial properties. More than 100 residents were evacuated from their homes in Anderson Road, Deebank Road and Albert Road. The Cambus O'May Bridge suffered substantial damage and a section of the A93 between Ballater and Balmoral Castle (near Braemar) was washed away. These historical flood events were used in the validation of the hydraulic model and details of this can be found in the Ballater Hydraulics Report.

The hydraulic model simulated the 0.5%CC AEP flood event for the River Dee. The following flooding mechanisms were observed within the Ballater Town Flood Cell:

- Flows greater than channel capacity on the River Dee would cause overtopping of the left bank at several locations: along an informal defence at Ballater Golf Course; slightly upstream of Ballater Caravan Park; at Dee Street; just upstream of the Royal Bridge and; on the A93 Ballater Road slightly upstream of Craigview Street.
- Overland flow would be experienced first through Ballater Golf Course, then in Ballater Caravan Park and Dee Street, before travelling through Anderson Road, Braichlie Road, Deebank Road and Albert Road. As the 0.5%CC AEP flood event progresses the golf course becomes substantially inundated by flood waters.
- Following the inundation of the golf course, flood waters spill onto the adjacent Salisbury Road via overland flow continuing onto Victoria Road.
- Overland flow along the northern extent of the golf course travels to Golf Road.
- The overtopping of the left bank of the River Dee at the A93 Ballater Road results in overland flow causing inundation to all properties in Pannanich Road, Lochnagar Way, Craigview Road and Craigview Place.
- As the 0.5%CC AEP event progresses overland flow inundates hundreds of properties in Ballater.

An assessment of the flood risk was carried out for the Ballater Flood Cell. Table 2.1 and Figure 2.2 present the receptors at risk during a 0.5%CC AEP flood event and also any constraints to potential flood management solutions.

Table 2.1 - Receptors at risk of flooding in the Ballater Flood Cell during a 0.5%CC AEP event

Receptor/Asset affected		**Impact of flooding**	**Constraints to solution**
Residential Properties		471 residential properties at risk with a total potential avoided damage of £25,340,600.	-
Commercial Properties		107 commercial properties at risk with a total potential avoided damage of £7,372,137.	-
A93		Traffic disruption	-
B976		Traffic disruption	-
Anderson Rd Braichlie Rd Dee Bank Rd Salisbury Rd Albert Rd Victoria Rd Golf Rd Dee St Richmond Pl Viewfield Pl Viewfield Rd Abergeldie Rd School Ln Queen's Rd	Church Square Monaltrie Rd Hawthorn Pl Hawthorn Cres Hawthorn Grove Nicol Ct Craigview Rd Pannanich Rd Lochnagar Way Old Station Place Bridge Street Ballater Rd Tullich Rd	Traffic disruption	-
Listed Buildings: Albert Memorial, Station Square 2 & 4 Church Square Glenmuick Parish Church, Church Square Pavilion, Victoria Road Commemorative drinking well, Church Square 1 Church Square, Gordon Cottage 5 and 7 Victoria Road Bank of Scotland, 7, 9 Bridge Street Savings Bank, 1 ,3, Bridge Street 2 Dee Bank Road Inverdene, Bridge Street J Konig, 10 Bridge Street 5 Dee Bank Road 7 Dee Bank Road 9 Dee Bank Road Inchley, Dee Bank Road Dee Bank House, Dee Street Monaltrie Hotel, Bridge Square Ford House, Dee Street		-	Any works to the structures may require Listed Building Consent from Aberdeenshire Council and may be subject to consultation with Historic Environment Scotland.

Receptor/Asset affected	**Impact of flooding**	**Constraints to solution**
St Nathalian's Church, Golf Road Listed Bridges: Ballater, Royal Bridge		
Ballater School Police Scotland Ballater Fire Station Sluiemohr Sheltered Housing	Access roads flooded.	-
Craigendarroch - SSSI	-	Minimise any detrimental impact.
River Dee	-	Salmonid River. Keep in-channel works to a minimum
River Dee - SAC	-	Minimise any detrimental impact.
Ancient Woodland Scotland	-	Minimise any detrimental impact.

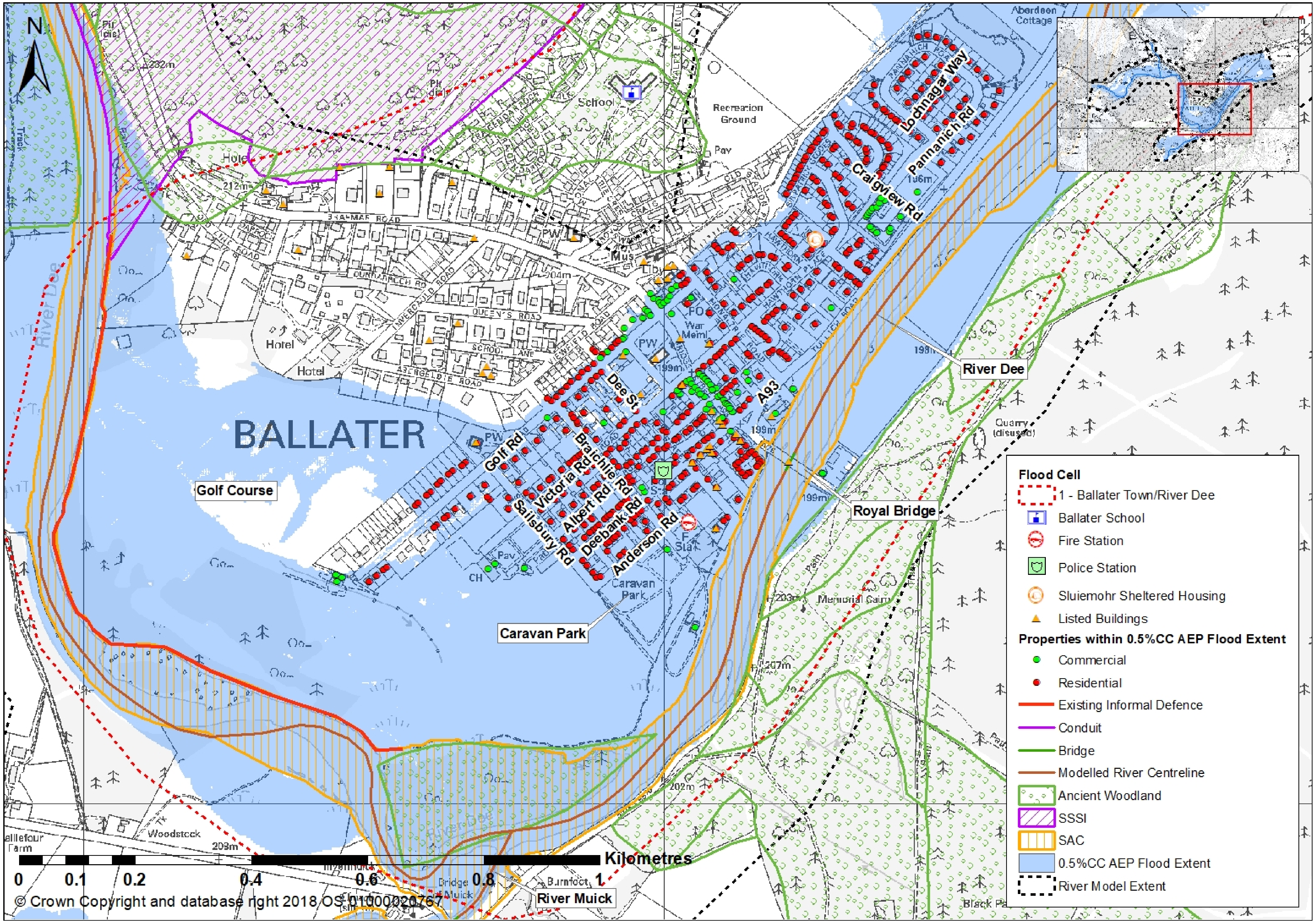

Figure 2.2 – A: Overview of Ballater Town flood cell

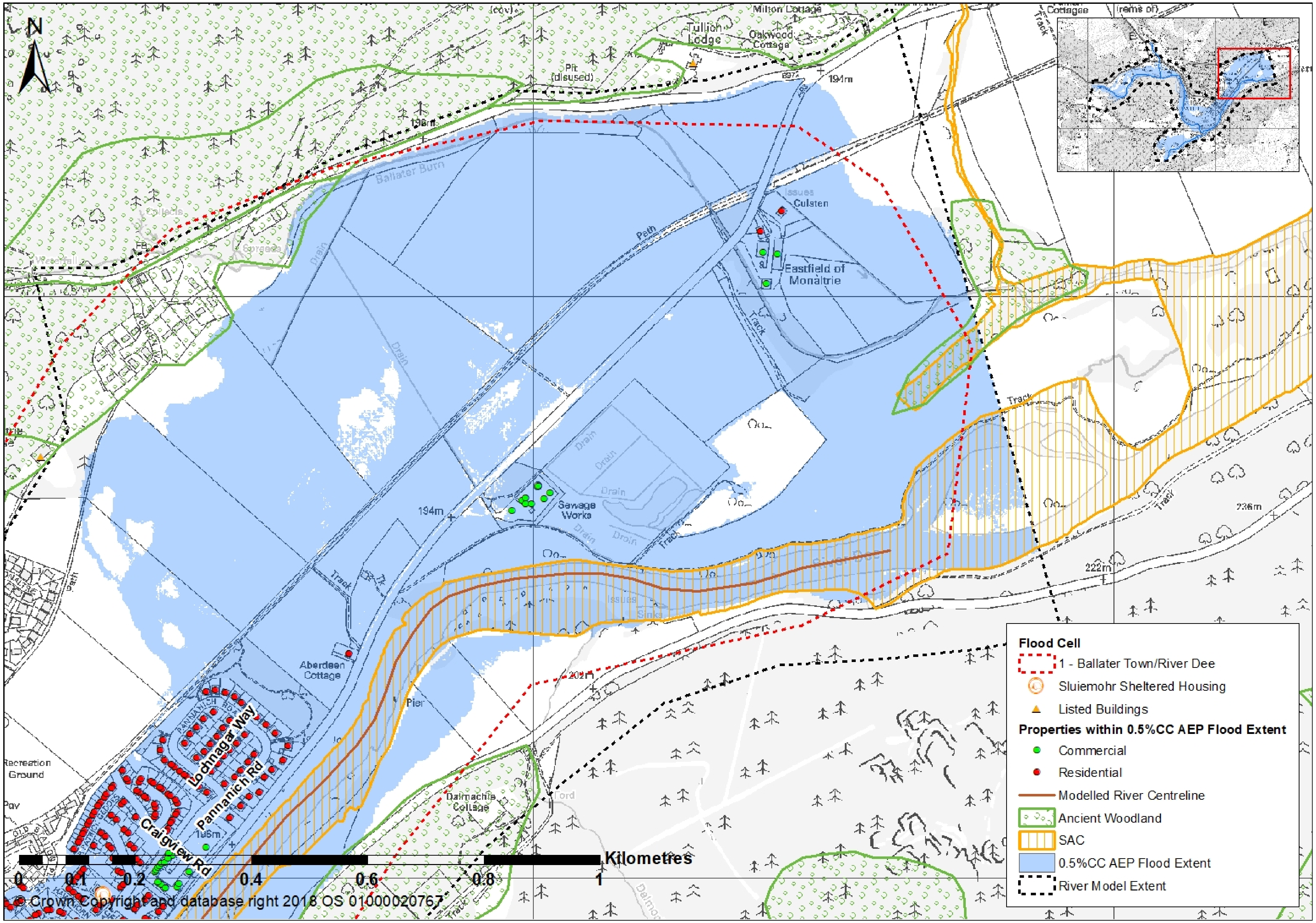

Figure 2.3 - B: Overview of Ballater Town flood cell

2.2 FLOOD CELL 2 – RIVER MUICK

During Storm Frank in December 2015 the River Muick burst its banks after a period of heavy rainfall. It was reported that the flood event left an area of the gardens at Birkhall estate underwater and caused a section of the road near the guarded entrance to crumble away into the river.

The hydraulic model simulated the 0.5%CC AEP flood event and during which the following flood mechanisms were observed within the River Muick flood cell:

- Flows greater than channel capacity on the River Muick would initially lead to overtopping of the right bank towards the Crofts, onto parts of the B976 and inundating the Saw Mill.
- Flow greater than channel capacity would also cause overtopping of the left bank onto agricultural land extending to Milton of Brackley. As the 0.5%CC AEP flood event progresses a large area of agricultural land is inundated with flood waters via overland flow.

An assessment of the flood risk was carried out for the River Muick Flood Cell. Table 2.2 and Figure 2.4 present the receptors at risk during a 0.5%CC AEP flood event and also any constraints to potential flood management solutions.

Table 2.2 - Receptors at risk of flooding in the River Muick Flood Cell during a 0.5%CC AEP event

Receptor/Asset affected	Impact of flooding	Constraints to solution
Residential Properties	5 residential properties at risk with a total potential avoided damage of £61,936.	-
Commercial Properties	2 commercial properties at risk with a total potential avoided damage of £145,656.	-
Main Road B976	Traffic disruption	-
Listed Buildings: Glenmuick Estate, East Lodge with Gate and Gatepiers Listed Bridges: Bridge of Muick	-	Any works to the structures may require Listed Building Consent from Aberdeenshire Council and may be subject to consultation with Historic Environment Scotland.
Areas of Ancient Woodland	-	Minimise any detrimental impact.
River Muick	-	Salmonid River. Keep in-channel works to a minimum
River Muick - SAC	-	Minimise any detrimental impact.

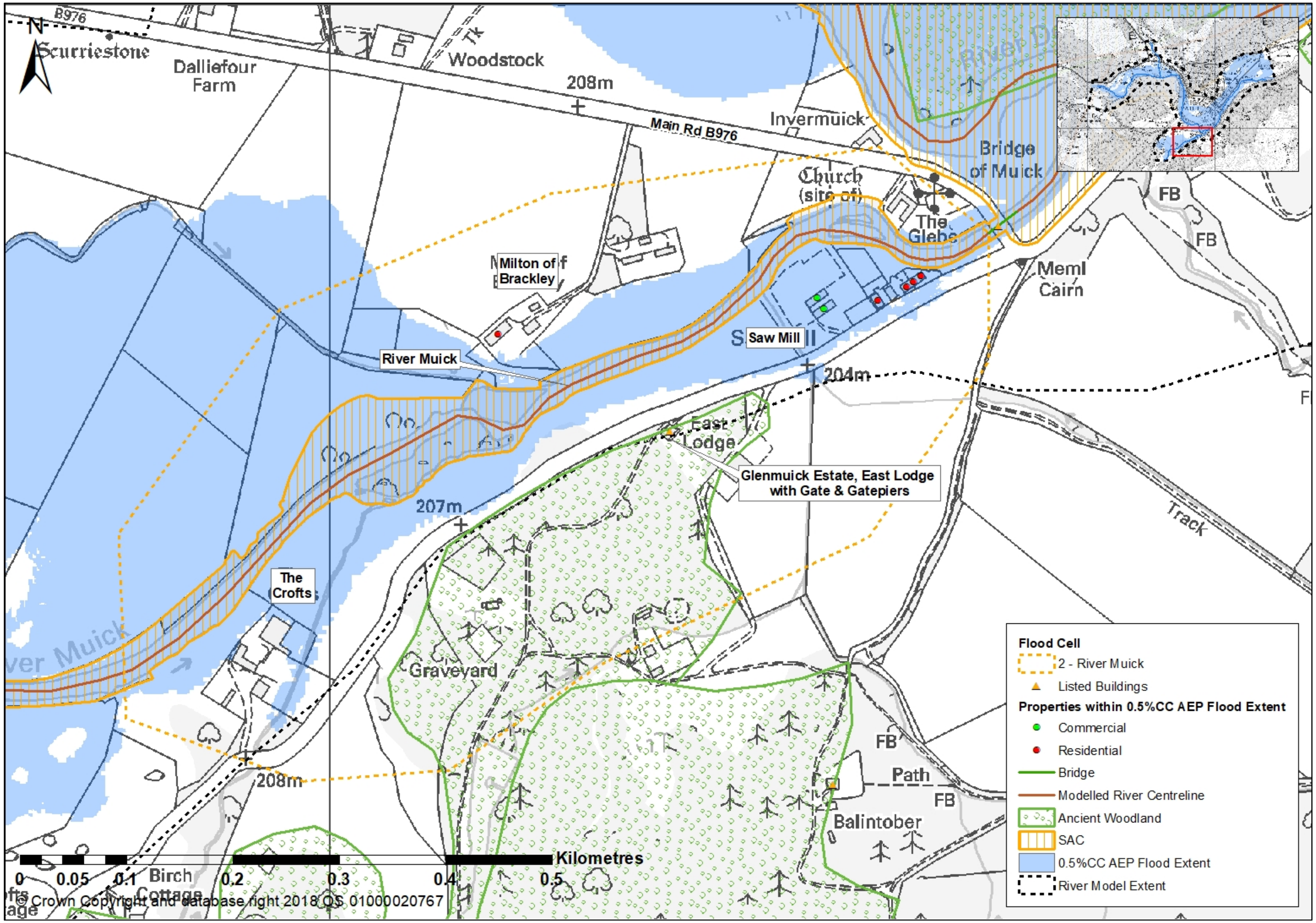

Figure 2.4 – Overview of River Muick flood cell

2.3 FLOOD CELL 3 – RIVER GAIRN

In August 2014, Ballater was affected by the ex-hurricane Bertha. During this event, the River Gairn (a tributary of the River Dee) reached its highest level on record at the Invergairn gauging station.

The hydraulic model simulated the 0.5%CC AEP flood event and during which the following flood mechanisms were observed within the River Gairn flood cell:

- Flows greater than channel capacity would cause the River Gairn to overtop firstly its left bank at Mill of Prony Cottage immediately affecting a residential property at this location.
- Flows greater than the channel capacity would cause overtopping of the right bank at Glengarden putting multiple commercial properties at risk at this location.
- Slightly downstream again flows greater than channel capacity would cause the left and right banks to overtop at the Bridge End of Gairn Farm, with the pipe line and St. Mungo's Well slowly being inundated through overland flow, extending to Balgairn affecting a residential property.

An assessment of the flood risk was carried out for the River Gairn Flood Cell. Table 2.3 and Figure 2.5 present the receptors at risk during a 0.5%CC AEP flood event and also any constraints to potential flood management solutions.

Table 2.3 - Receptors at risk of flooding in the River Gairn Cell during a 0.5%CC AEP event

Receptor/Asset affected	**Impact of flooding**	**Constraints to solution**
Residential Properties	2 residential properties at risk with a total potential avoided damage of £25,507.	-
Commercial Properties	7 commercial properties at risk with a total potential avoided damage of £96,149.	-
A93	Traffic disruption	-
<u>Listed Buildings:</u> Glengarden, Bridge of Gairn	-	Any works to the structures may require Listed Building Consent from Aberdeenshire Council and may be subject to consultation with Historic Environment Scotland.
Areas of Ancient Woodland	-	Minimise any detrimental impact.
River Gairn	-	Salmonid River. Keep in-channel works to a minimum
River Gairn - SAC	-	Minimise any detrimental impact.

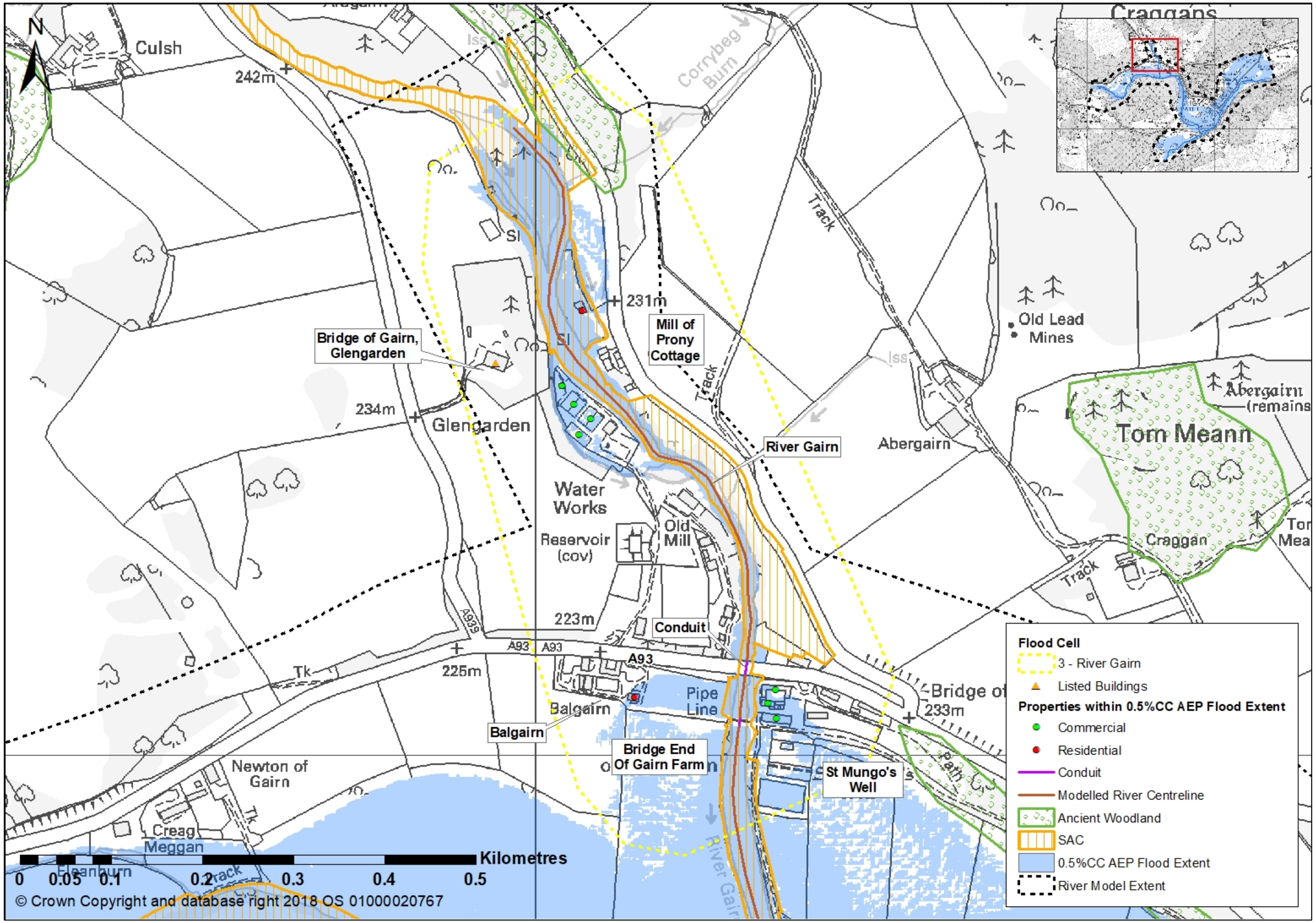

Figure 2.5 - Overview of River Gairn Flood Cell

2.4 FLOOD CELL 4 – UPPER DEE (POLHOLLICK)

The B-listed Polhollick Bridge on the River Dee, Ballater, was damaged when Storm Frank caused havoc across the region during the winter of 2015. Melting snow and incessant rain caused the Dee to burst its banks. Polhollick Footbridge, which dates back to 1892 and forms part of the Seven Bridges Walk, had only recently been reopened to the public in October 2015 following a £420,000 upgrade, when it was badly damaged.

The hydraulic model simulated the 0.5%CC AEP flood event and during which the following flood mechanisms were observed within the Upper Dee (Polhollick) flood cell:

- Flows greater than channel capacity would cause the River Dee to overtop its right bank at Polhollick. As the flood event progresses a large area of floodplain surrounding Polhollick is inundated, including an area designated as ancient woodland.
- Flows greater than channel capacity during the design flood event would also lead to the left bank further upstream overtopping, causing significant overland flow and inundating a large area of agricultural land bound by Dalbagie and Polhollick.
- Water levels in the Dee would reach levels greater than that of the Polhollick Bridge deck, creating a risk for entrapment of debris in the bridge's structure. The bridge however does not cause a significant restriction in flow.

An assessment of the flood risk was carried out for the Upper Dee (Polhollick) Flood Cell. Table 2.4 and Figure 2.6 present the receptors at risk during a 0.5%CC AEP flood event and also any constraints to potential flood management solutions.

Table 2.4 - Receptors at risk of flooding in the Upper Dee (Polhollick) Cell during a 0.5%CC AEP event

Receptor/Asset affected	Impact of flooding	Constraints to solution
Residential Properties	3 residential properties at risk with a total potential avoided damage of £112,669.	-
Commercial Properties	0 commercial properties at risk.	
<u>Listed Bridge:</u> Polhollick Suspension Bridge	-	Any works to the structure may require Listed Building Consent from Aberdeenshire Council and may be subject to consultation with Historic Environment Scotland.
Areas of Ancient Woodland	-	Minimise any detrimental impact.
River Dee	-	Salmonid River. Keep in-channel works to a minimum
River Dee - SAC	-	Minimise any detrimental impact.

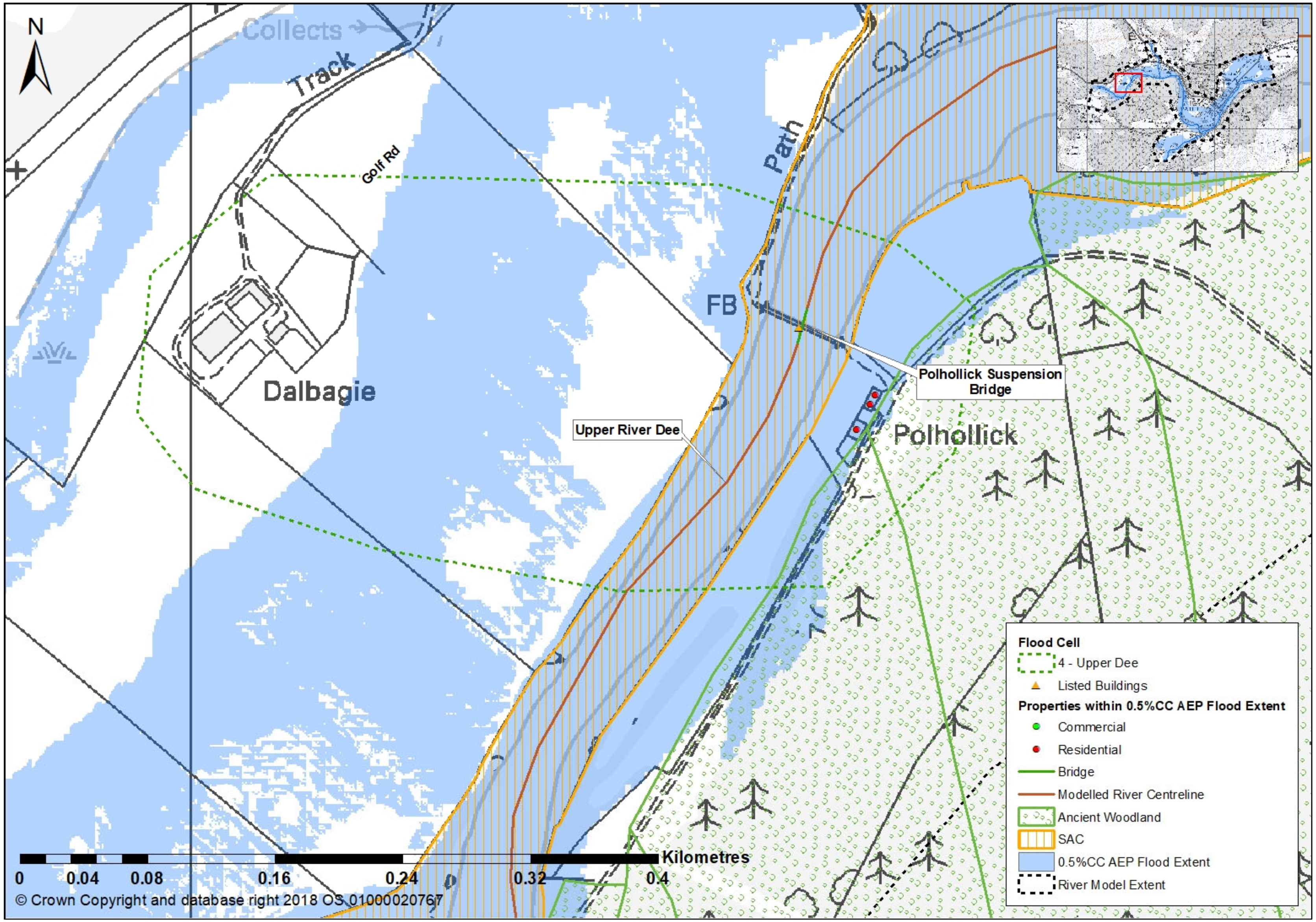

Figure 2.6 - Overview of Upper Dee (Polhollick) Flood Cell

2.5 SET OBJECTIVES

In addition to the aims set out in Section 1.2 of this report, objectives from the Flood Risk Management Plan (FRMP) and specific objectives have been set based on the risks and constraints identified.

2.5.1 Objectives in the North East Local FRMP for Ballater (PVA 06/22)

- To avoid an overall increase in flood risk.
- To reduce overall flood risk.
- Organisations such as utility companies and Historic Environment Scotland to actively maintain and manage their own assets, including the risk of flooding. These actions are not detailed further in the Flood Risk Management Strategies.

2.5.2 Objectives in the River Basin Management Plan (RBMP) for Scotland

- To reduce pressure 'Barrier to fish migration' on the River Dee from Braemar to Ballater and therefore improve 'Access for fish migration' from 'Moderate' to 'Good' by 2027. SEPA state that the fish barrier pressures are mostly complete or affect downstream of Ballater. There are none on the main stem Dee or baseline waterbodies, apart from one on the Leuchar burn which is in a Water Environment Fund (WEF) project to remove.
- To maintain 'Water flows & levels' and 'Freedom from invasive species' at 'High' and maintain 'Physical condition' and 'Water quality' at 'Good' by 2027.

2.5.3 General Objectives

- To identify an option that will produce a 0.5%AEP standard of protection (SoP), with consideration given to the potential impacts of climate change.
- To identify the option with best value for money.
- To reduce the economic damages to residential and commercial properties.
- Identify any opportunities for NFM measures to be implemented.
- Identify a flood mitigation option which will retain some of the amenity value of Ballater.

2.5.4 Other Objectives

- The A93 is to be included in the flood management solution.
- The B976 Main Road is to be considered in the flood management solution.
- Several other roads such as Tullich Road, Dee Bank Road, Dee Street, Anderson Road and Braichlie Road (others listed in Table 2.1) should be considered in the flood management solution.
- Access to several receptors should be maintained during flood events including; Ballater Fire and Rescue (Braichlie Road), Police Scotland (Dee Bank Road), Sluiemohr Sheltered Housing and Ballater School.

3 STAGE 2: DEVELOP, DESCRIBE AND VALUE

3.1 OVERVIEW

In order to develop options to manage flood risk (one of the aims of this study as outlined in Section 2.5), RPS have identified a comprehensive long list of actions (Section 3.2) and options (Section 3.5) which could reduce the flood risk in Ballater; that could be implemented at various scales (catchment level to property level); and that could be combined. This long list of actions was then screened (Section 3.3) in order to remove unfeasible actions. Actions which were deemed technically inappropriate, technically impractical or to have insurmountable constraints were screened out. The remaining actions formed a short-list, from which viable options were developed (Section 3.5) that would meet the objectives set out in Section 2.5.

As stated in Section 1.2, the flood mitigation option should provide a 0.5% AEP Standard of Protection (SoP) with consideration given to the potential impacts of climate change. Initially, a standard of protection of 0.5%+CC AEP was considered however, it was determined that developing this option would not be acceptable as Direct Defences would be required and that the maximum height of these defences would be in excess of 4 metres. Consequently, RPS tested for protecting to both a 0.5% AEP and a 1% AEP event, which resulted in the 0.5% AEP event performing better and was considered as the optimum standard of protection. Therefore, the target standard of protection was revised to 0.5% AEP (with consideration given to the potential impacts of climate change), which would allow an option to be developed to protect Ballater from the equivalent of the December 2015 flood event.

RPS reviewed the potential standard of protection that could be achieved by each action, and concluded that any viable option providing the target standard of protection would have to include Direct Defences. A scheme based on the other actions, or a combination of the other actions, which excluded Direct Defences, would not meet the objective of identifying a cost beneficial flood scheme providing the target standard of protection. A discussion on the development of options, including the potential of measures to contribute to the standard of protection and reduce the height of the direct defences required, is provided in Section 3.5. Each of the identified options were appraised, as discussed in Section 3.6.

3.2 IDENTIFY LONG LIST OF ACTIONS

An assessment was carried out to identify a long list of flood management actions. This list was based on the objectives established in the previous chapter. Actions were considered that; could partially or completely address the flood risk; that could be implemented at various scales (catchment level to property level); and that could be combined. The assessment included actions that could deliver sustainable flood risk management and that could help manage flood risk in the future. Actions that deliver wider benefits such as improved places to live and improved environment and biodiversity were considered along with actions that could improve existing actions such as maintenance regimes.

Using SEPA's standard list of actions (see Appendix C for the full list) the following long list of actions have been identified for Ballater. These are discussed in Section 3.3.1 to Section 3.3.9 of this report.

Table 3.1 – Long list of flood defence actions identified for Ballater

Action	Action Type	Description
Relocation	Avoid	While large scale relocation of properties would be considered an unsustainable approach, there may be specific properties or groups of properties that may be suitable for relocation out of flood risk areas.
Storage	Reduce/Protect (Engineering)	Storage areas may be available within the study river catchments which could reduce the peak flow and therefore the flood risk.
Conveyance	Reduce/Protect (Engineering)	Lack of channel capacity has been identified as a contributing factor to flood risk. Improvement of channel conveyance could reduce this flood risk. However major in-channel works should be avoided given the status of the River Dee and tributaries as salmonid rivers.
Control Structures	Reduce/Protect (Engineering)	Certain control structures have been identified as flooding mechanisms. Modification of these structures could reduce flood risk.
Direct Defences	Reduce/Protect (Engineering)	Flood walls and embankments could be used throughout the study area to reduce flood risk.
Property Level Protection	Reduce/Prepare	While PLP might not be able to provide the design SoP it can reduce the flood risk to suitable properties.
Flood Forecasting & Warning	Reduce/Prepare	Installation of flood forecasting and warning system.
Self Help	Reduce/Prepare	Informing the public or forming community flood action groups who live, work or use a flood risk area on the risks of flooding and how to prepare for flooding. This can minimise the impact of flooding and therefore help to reduce flood risk.
Emergency Plans	Reduce/Prepare	Development of emergency flood response procedures can reduce the impact when flooding occurs.

A long list of NFM measures was also considered and is detailed in section 3.3 as part of the Baseline NFM Assessment.

3.3 SCREENING THE LONG LIST OF ACTIONS

The long list of actions was screened in order to remove unfeasible actions. Actions which were deemed technically inappropriate, technically impractical or have insurmountable constraints were screened out. This included any sustainability or legal issues.

The feasibility of certain actions is dependent on the particular location and river characteristics. These were therefore assessed within each flood cell. Others are considered catchment-wide actions and could be screened at this level. Table 3.2 summarises the results of the screening and the text that follows provides details of the screening assessment. Screening methodology of actions is provided in Appendix G.

Table 3.2 – Summary of results of screening list of actions

Action	Comment	Feasible? Flood Cell 1	Flood Cell 2	Flood Cell 3	Flood Cell 4
Relocation	This action is dependent on the receptors at risk and the appropriateness of relocating them. See Section 3.3.1 for details.	✓	×	×	×
Storage	This action is dependent on the natural topography of the river catchments and the volume of water which would be required to be stored in order to adequately reduce the risk of flooding. See Section 3.3.2 for details.	✓	×	×	✓
Conveyance	This action is dependent on channel capacity along the watercourses within the study area. See Section 3.3.3 for details.	×	×	×	×
Control Structures	This action is dependent on the effectiveness of removing/adding control structures to reduce flood risk. See Section 3.3.4 for details.	×	×	×	×
Direct Defences	This action depends on the locations where out of bank flooding are occurring and if there is enough space available to add direct defences. See Section 3.3.5 for details.	✓	✓	✓	✓
Property Level Protection	This action's feasibility depends on the depth of flooding to the property and is particularly suited to isolated properties. See Section 3.2.9 for details.	✓	✓	✓	✓
Flood Forecasting & Warning	There is an existing flood warning on the River Dee operated by SEPA. See Section 3.3.7 for details.	✓	×	×	✓
Self Help	This action's feasibility is dependent on the knowledge that homeowners and business owners have on how best to protect their properties against flood damage. See Section 3.3.8 for details.	✓	✓	✓	✓
Emergency Plans	This action's feasibility is dependent on the awareness the public has regarding what procedures to follow in a flood emergency. See Section 3.3.9 for details.	✓	✓	✓	✓
Other Works: Resilience	This action's feasibility is dependent on properties having suitable measures in place to ensure their flood resilience.	✓	✓	✓	✓

3.3.1 Relocation

When considering which receptors would be suitable for relocation the social, technical and economic factors were considered. Such factors included:

- Would removing properties have a detrimental impact on the local community;
- Are there other suitable areas zoned to accommodate the relocation;
- Would the cost be disproportionate to the present day damage from flooding;
- Public safety - especially in areas where there may be deep fast flowing water during a flood event, e.g. Ballater Caravan Park;
- Potential to ease restrictions on development of other options e.g. to make space for defences or flood storage / conveyance improvements as part of structural solutions.

When assessing which properties may be suitable for relocation, the market value of the property was considered against the damage which the property may incur through flooding. Properties were considered suitable for relocation if the damage which they may incur through flooding was greater than their market value. Single isolated properties or isolated groups of properties were also only considered suitable.

A review was undertaken as part of the optioneering process, to examine whether any of the other potential actions (assessed in Sections 3.3.1 to 3.3.9) could be improved through the relocation of properties. Storage, conveyance and direct defence actions were assessed to include relocation of properties; these are discussed in Sections 3.3.2, 3.3.3 and 3.3.5. No other flood defence actions could be improved through the relocation of properties.

Figure 3.1 shows the receptors which were identified for relocation.

Ballater Caravan Park was recommended for relocation due to concerns for public safety in times of flood. Figure 3.1 shows the area suggested for its relocation. This area however was zoned for housing in the Cairngorms National Park Local Development Plan 2015 (1^{st} Phase Housing H1) so relocating to this area may be dependent on available space.

Services in Ballater including the fire station, police station and the council depot are at risk of flooding and so these properties are recommended for relocation as part of an overall solution. Consideration should be given to relocating the emergency services on a 'joint-service' basis.

No further properties in Ballater were recommended for relocation as it would be socially unacceptable to relocate large numbers of properties in the town.

If relocation of numerous properties had been assessed to form part of a viable option, then a recommendation would be to implement policies to take advantage of the natural turnover of properties. These policies may include the purchase of properties as they come up for sale and providing assistance for relocation where owners wish to relocate. This would require consultation with Aberdeenshire Council and Historic Environment Scotland (who have confirmed that they would be happy to discuss strategic approaches to the management of listed buildings as part of this study).

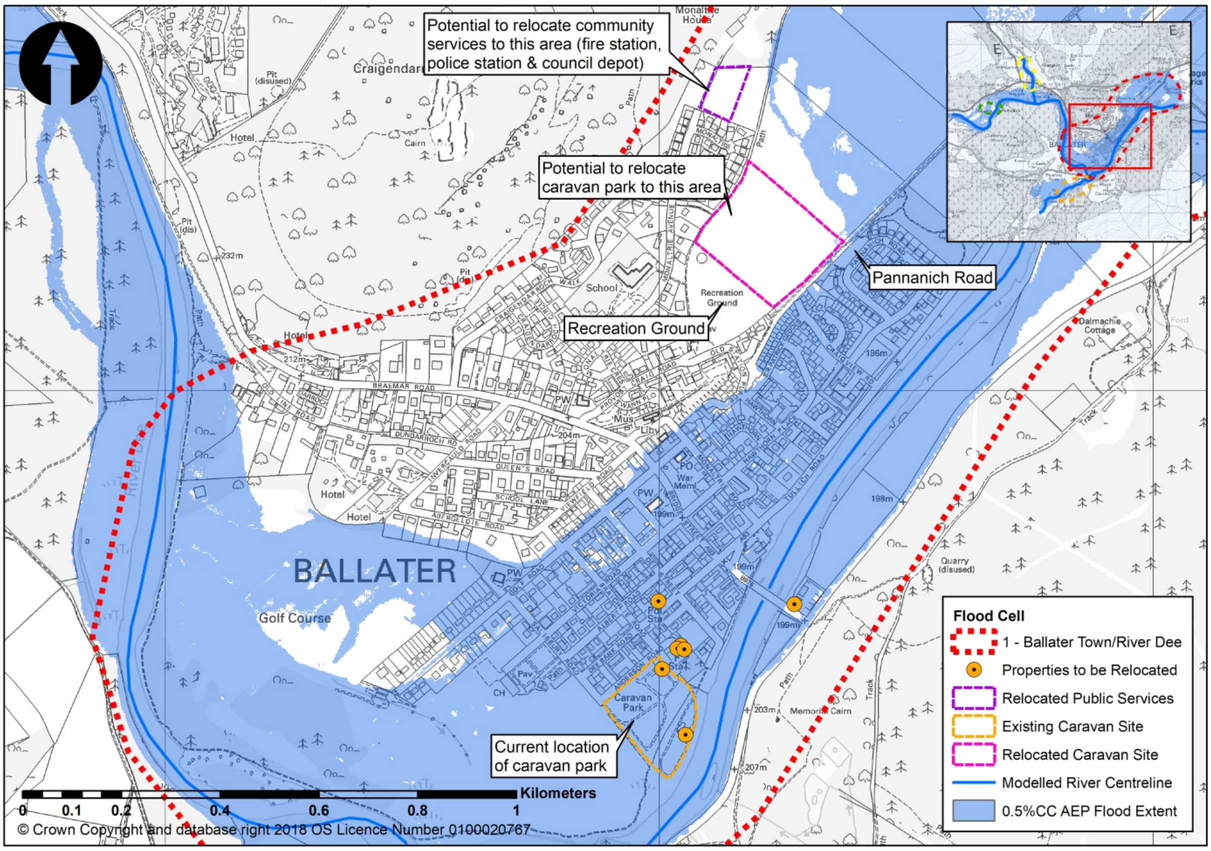

Figure 3.1 - Potential for relocation in the Ballater Study Area

Table 3.3 - Summary of relocation actions

Flood Cell	Action	Feasibility	Progress Action?
1	Relocation of amenity: Ballater Caravan Park	Potential relocation of caravan park to land adjacent to recreation area behind Pannanich Road which is outside of the 0.5%CC AEP flood extent. Potential to be implemented as an interim measure.	✓
1	Relocation of community services: Ballater Fire Station, Police Station & Council Depot	Potential relocation of emergency services on a 'joint-service' basis and relocation of the council depot to an area which is outside of the 0.5%CC AEP flood extent. Potential to be implemented as an interim measure.	✓

3.3.2 Storage

A review was carried out to identify if any areas which may be suitable for storage exist naturally in the topography around the River Dee, River Muick or the River Gairn. The methodology described in Appendix G, supported by a site visit, was used to identify these potential storage areas.

Site walkover

From the site visit, two areas of potential were found, one on the River Muick and one on the River Gairn. These areas are highlighted in Figure 3.2 and Figure 3.3. However, these storage areas alone would be insufficient to provide a significant reduction in flood risk or a significant reduction in the height required for direct defences (as indicated on each Figure).

Review of topography

A review of the topography of the catchment was undertaken to identify further areas of potential for storage. A total of 88 potential storage areas were identified as shown in Figure 3.4. Most areas identified were calculated using a maximum dam height of 10m, whilst some used a maximum dam height of 5m so as to avoid receptors.

The 88 identified storage areas were shortlisted according to those which are most likely to contribute the greatest level of benefit. For example, those which are closest to the area of benefit i.e. Ballater and those which have the greatest storage potential. Efforts were also made to ensure storage areas did not intersect multiple properties or receptors; however approximately 25 properties would need to relocated to accommodate the storage action. Table 3.4 gives a summary of the storage areas identified through a review of the topography. The storage areas were also assessed for their potential to reduced height of direct defences. This is discussed in Section 1.1.1.13.3.11.3 and 3.3.11.4.

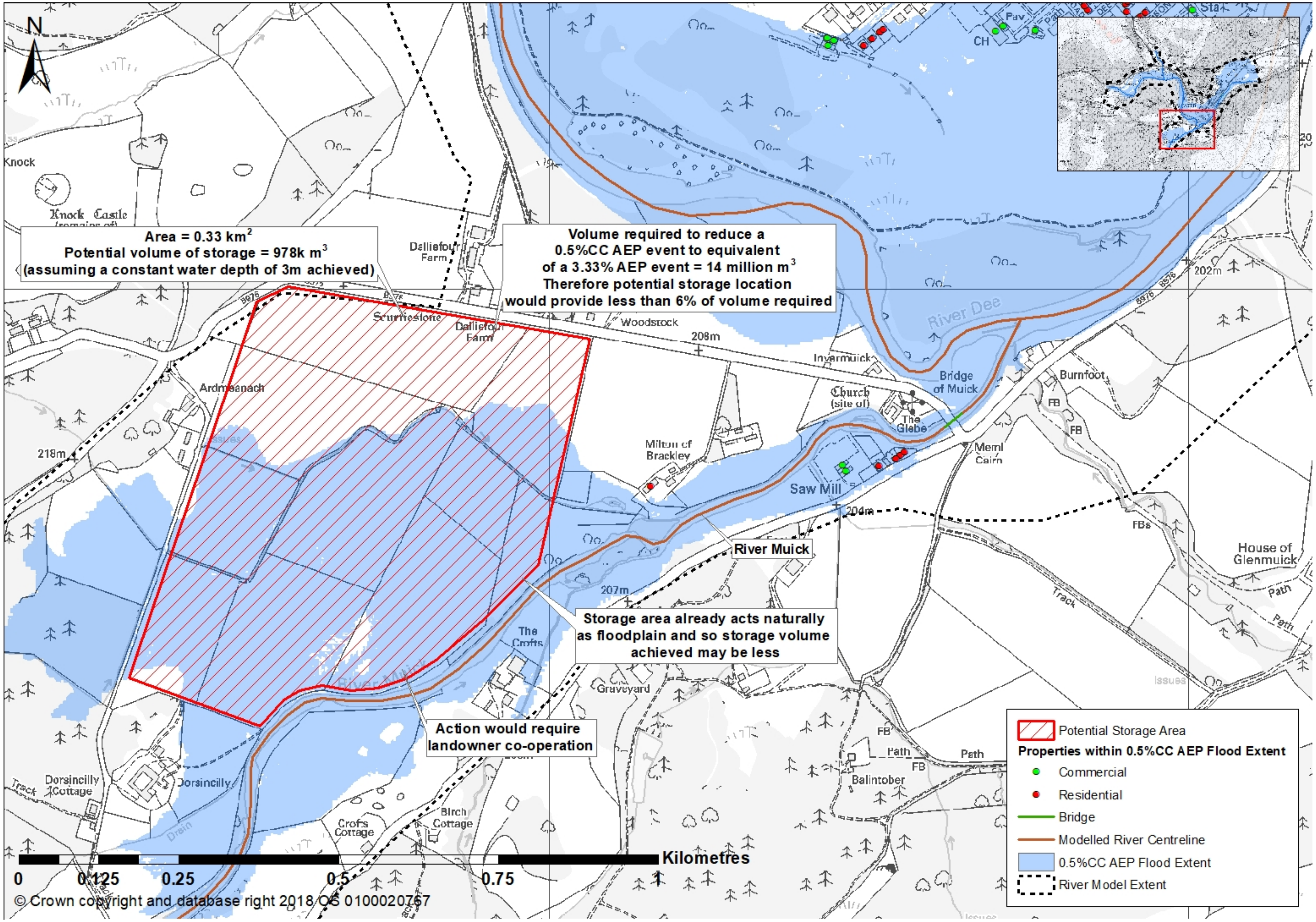

Figure 3.2 - Potential storage area on the River Muick identified through site walkover

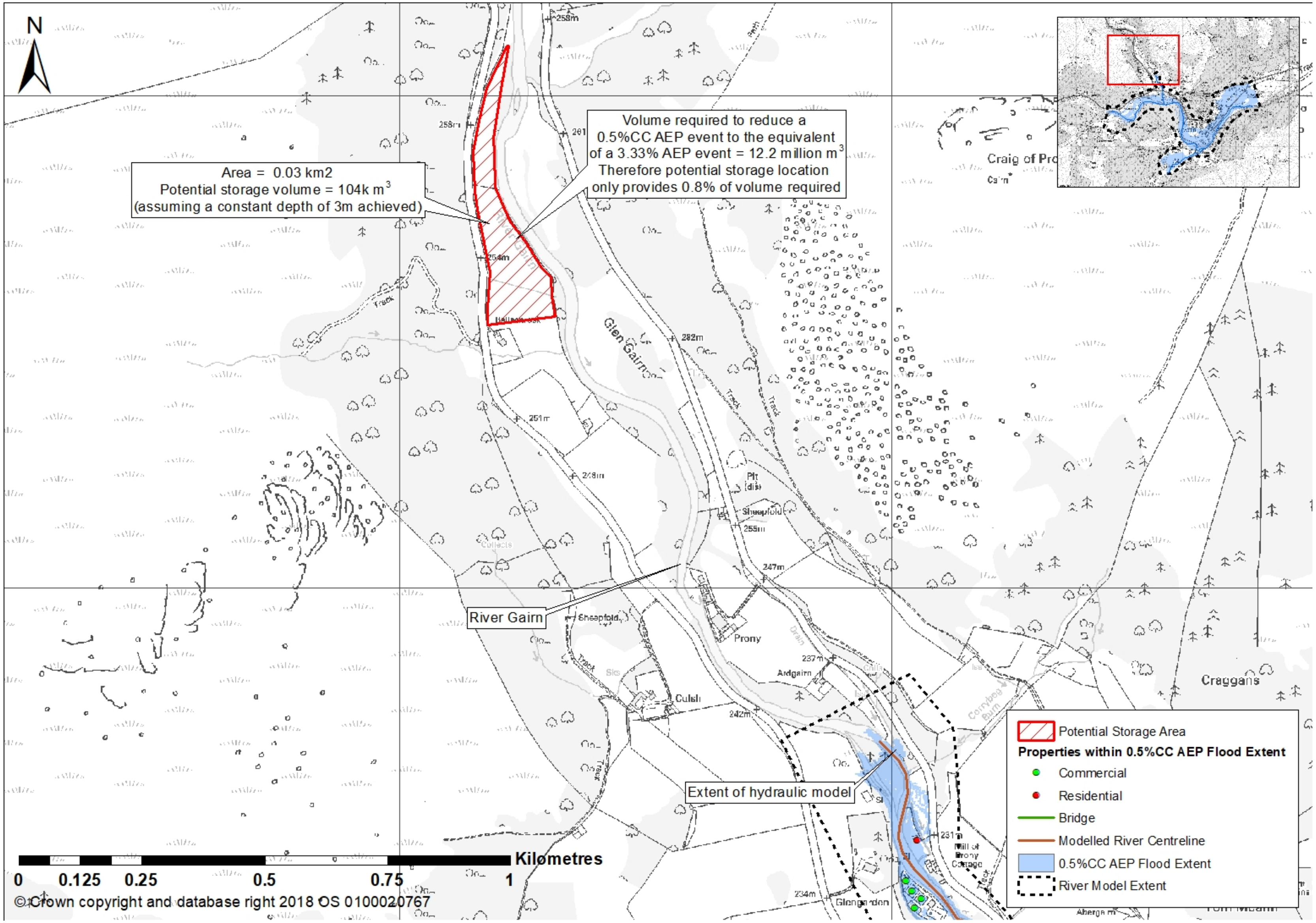

Figure 3.3 - Potential storage area on the River Gairn identified through site walkover

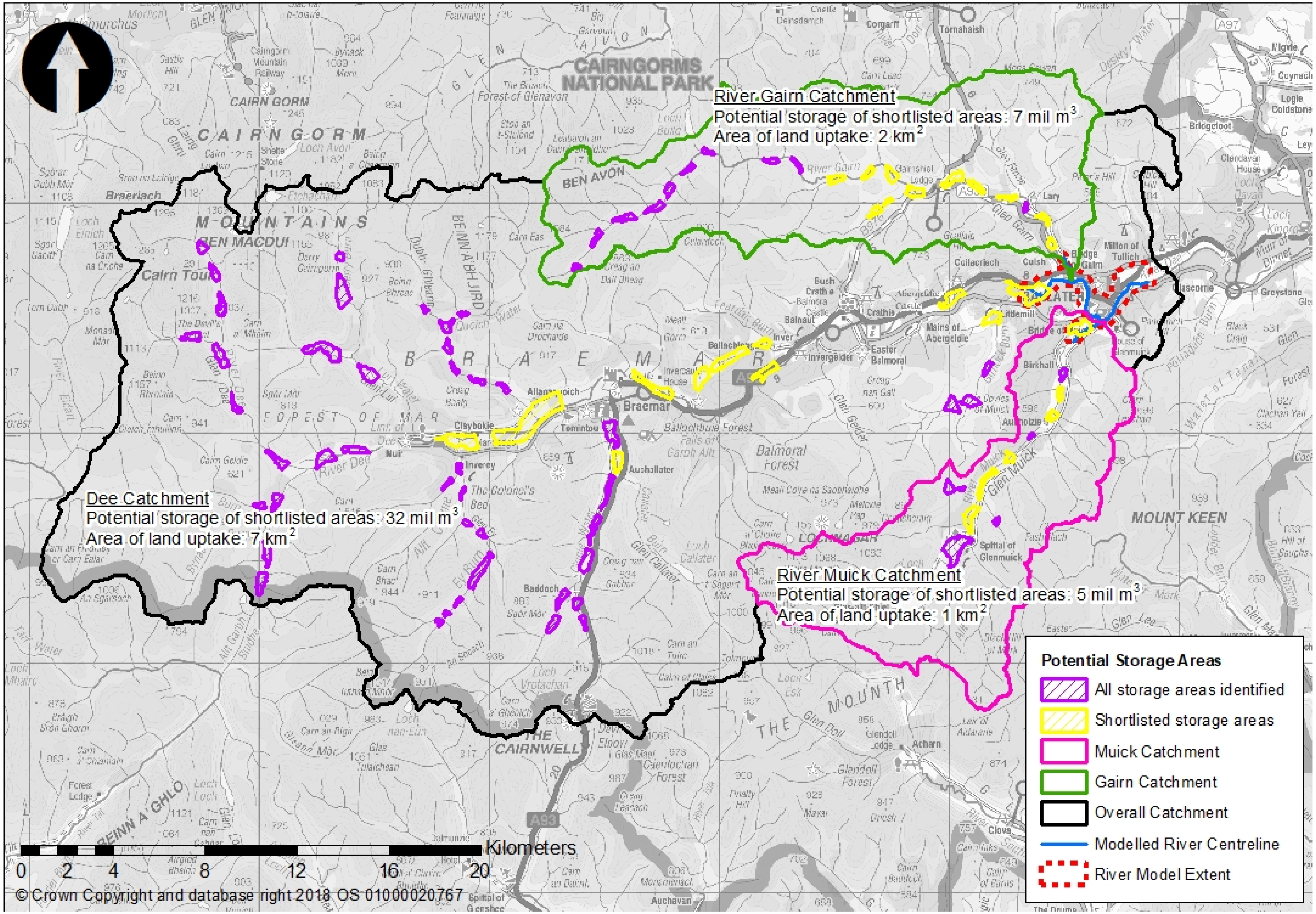

Figure 3.4 - Potential storage areas identified through review of topography

Loch Muick

The potential for increasing the storage on Loch Muick was also reviewed. The hydrology for the Muick catchment was re-calculated assuming that full attenuation of all flow upstream of Loch Muick could be achieved. The results of this indicated that a reduction in flows of approximately 10% would be achieved at the inflow point to the River Muick at the upstream extent of the hydraulic model. These adjustments are illustrated in Figure 3.5 and potential impacts summarised in Table 3.5.

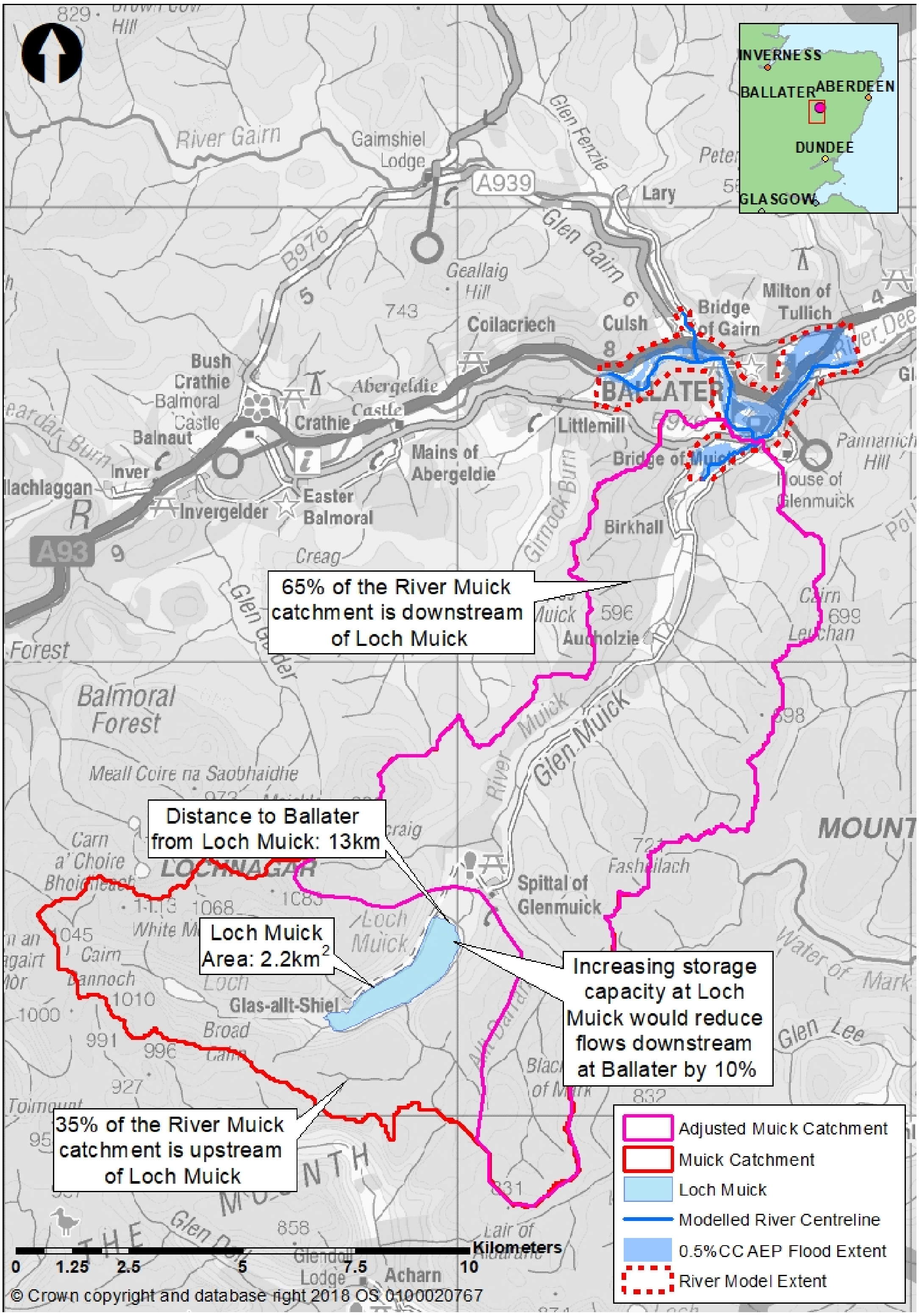

Figure 3.5 – Review of potential increase in storage on Loch Muick

Table 3.4 – Summary of potential storage areas identified through review of topography

Watercourse	Action	Feasibility	Progress Action?
Dee	Storage	If all 52 identified potential storage areas were used (as shown in Figure 3.4), a maximum storage volume of 142million m^3 could be achieved. Upon review, the potential storage areas were refined based on their potential benefit and location. 11 areas were selected and would achieve a maximum storage volume of 32million m^3. This volume of storage would reduce a 0.5% AEP event to the equivalent of approximately a 1.67% AEP event. The action was also assessed for potential to reduce direct Defence height as discussed in Section 3.3.11.3.	✓
Gairn	Storage	If all 21 identified potential storage areas were used (as shown in Figure 3.4), a maximum storage volume of 31 mil m^3 could be achieved. Upon review, the potential storage areas were refined based on their potential benefit and location. 9 areas were selected and would achieve a maximum storage volume of 7 mil m^3. The action was also assessed for potential to reduce direct Defence height as discussed in Section 3.3.11.3.	×
Muick	Storage	If all 12 identified potential storage areas were used (as shown in Figure 3.4), a maximum storage volume of 31 mil m^3 could be achieved. Upon review, the potential storage areas were refined based on their potential benefit and location. 6 areas were selected and would achieve a maximum storage volume of 5 mil m^3. The action was also assessed for potential to reduce direct Defence height as discussed in Section 3.3.11.3.	×

Table 3.5 - Summary of potential storage action on Loch Muick

Watercourse	Action	Feasibility	Progress Action?
Muick	Increase Storage on Loch Muick	Flows reduced by 10% and time for the River Muick to reach its peak flow would also be reduced. In the River Dee, an overall flow reduction of approximately 1.4% is realised. However, to achieve a 20% AEP SoP a flow reduction of 27% is required. Due to the location of Loch Muick at the upstream end of the Muick catchment the benefits of storing all flood waters upstream of the loch would be not be realised downstream at Ballater due to the large number of tributaries which feed into the Muick downstream. This reduction in flows was not considered significant and the action was therefore considered technically unfeasible. The action was also assessed for potential to reduce direct Defence height as discussed in Section 3.3.11.4.	×

3.3.3 Conveyance

The flood mechanisms within each flood cell (as discussed previously in Section 2) were reviewed to identify potential actions to improve channel conveyance through dredging, removal of constrictions and flow diversion channels.

River Dee

Flow Diversion

A flow diversion route was identified on the River Dee as shown in Figure 3.7. The route of the diversion was determined as the most suitable following a site visit and discussions with Aberdeenshire Council. This route partially follows the route of a previous railway line before following the existing road network and a recreation ground before joining the Dee downstream of Ballater. The majority of the flow diversion channel would have to be culverted to allow the existing road network to be maintained.

Alternative routes were also considered, for example, with the intake of the diversion slightly further downstream at the north end of the golf course where a natural flow path exists. This is where the flood mechanism for Golf Road starts. However this was ruled out as this area operates naturally as floodplain and it would be more beneficial to take flow out of the River Dee upstream of the golf course. Further upstream on the Dee was also considered for the intake location however this was considered technically unfeasible due to the topography of the Craigendarroch area. The feasibility of a bypass channel on the right bank of the Dee downstream of Royal Bridge was also reviewed. However as this area is naturally very low lying, it already functions well as floodplain from a 50% AEP event. Also as the topography is very steep beyond the B976 road at Craig Coillich, there is little scope to divert flow in this area. As such a diversion route in this area was considered unfeasible.

A maximum possible size for the diversion channel was determined on the basis of the narrowest point along the diversion route. From this, a box culvert of 12m x 4m in size was modelled. This large size was used with the aim to divert as much flow as possible through the route identified. The flow diversion channel identified is shown in Figure 3.7 and was incorporated within the hydraulic model and a simulation undertaken in order to assess its impact on flood risk, with the outcome described in Table 3.6.

The results of the defended 0.5% AEP with diversion route scenario are discussed in Section 3.3.11.5.

Dredging

There are numerous negative impacts associated with dredging which include the environmental impact to the River Dee designated SAC and the major morphological instability it would cause to the river channel. During dredging, an increase in the level of suspended sediment can result in changes to the water quality potentially effecting flora and fauna and settlement of these sediments can result in smothering or blanketing of habitats, including salmon and freshwater pearl mussels (the qualifying features of the River Dee SAC). The Ballater FPS Geomorphic Process Model and Review of Morphological Impacts report (RPS/cbec, January 2018) describes the dynamic nature of the River Dee, with the reach of the River Dee from the caravan park to downstream of Ballater being dominated by storage processes (Figure 3.6). Consequently, there would be considerable maintenance works associated with maintaining the 1.5m dredged channel depth which would make this measure unsustainable. There would also be a risk that channel instability caused through dredging may quickly undo any benefit gained and could potentially create other issues including the undermining of Royal Bridge and any direct defences located on the river banks.

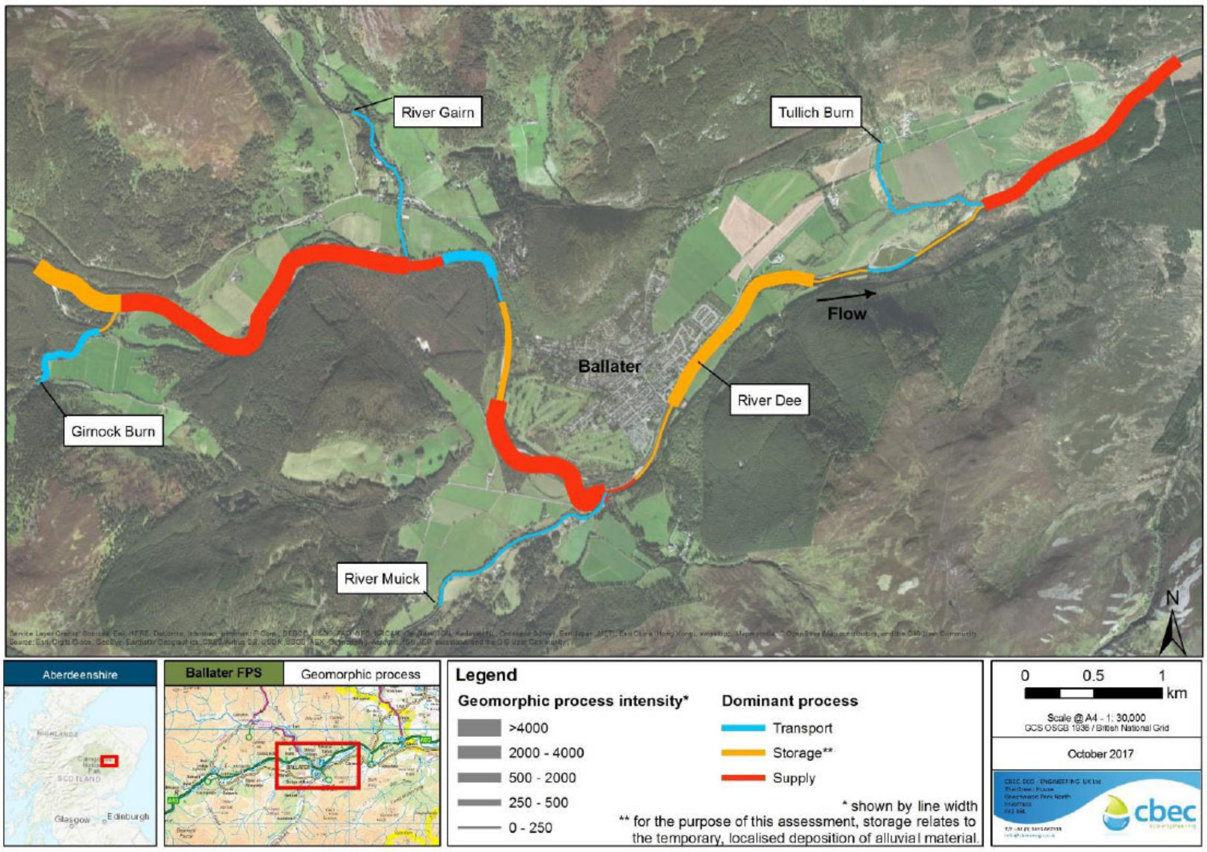

Figure 3.6 - Geomorphic process regime (RPS/cbec, 2018)

Due to aforementioned reasons, it is concluded that dredging should be excluded from any options for Ballater. However, to comprehensively assess the potential of dredging to reduce the flood risk in Ballater, model simulations were undertaken to determine the effect that lowering the Dee's bed level by 1.5m would have during a 20% AEP event (when property flooding occurs) and a 0.5% AEP event (undefended and defended scenarios).

It was shown that this action would reduce the size of the 20% AEP flood extent and as such would provide a 20% AEP SoP for properties in Ballater. Table 7.17 found in Appendix D compares the peak water levels reached between the 20% AEP existing and dredged scenarios.

The results of the 0.5% AEP model simulation also showed a reduction in the size of the flood extent as illustrated in Figure 3.8. Table 7.18 found in Appendix D compares the peak water levels reached between the 0.5% AEP existing and dredged scenarios. A summary of the dredging action is given in Table 3.6.

The results of the defended 0.5% AEP dredged scenario are discussed in Section 3.3.11.6.

River Muick

No opportunities for improvement of conveyance were identified within the River Muick flood cell due to the relative steepness of the watercourse.

River Gairn

No opportunities for improvement of conveyance were identified within the River Gairn flood cell due to the steepness of the watercourse and its largely flashy flood response. A summary of all conveyance actions considered on the Dee is provided in Table 3.6. If conveyance actions had been identified as forming part of a viable option, there would need to be due consideration to the highly dynamic nature of the River Dee (and the potential work required to maintain dredging operations) in addition to the potential environmental impacts within the special area for conservation.

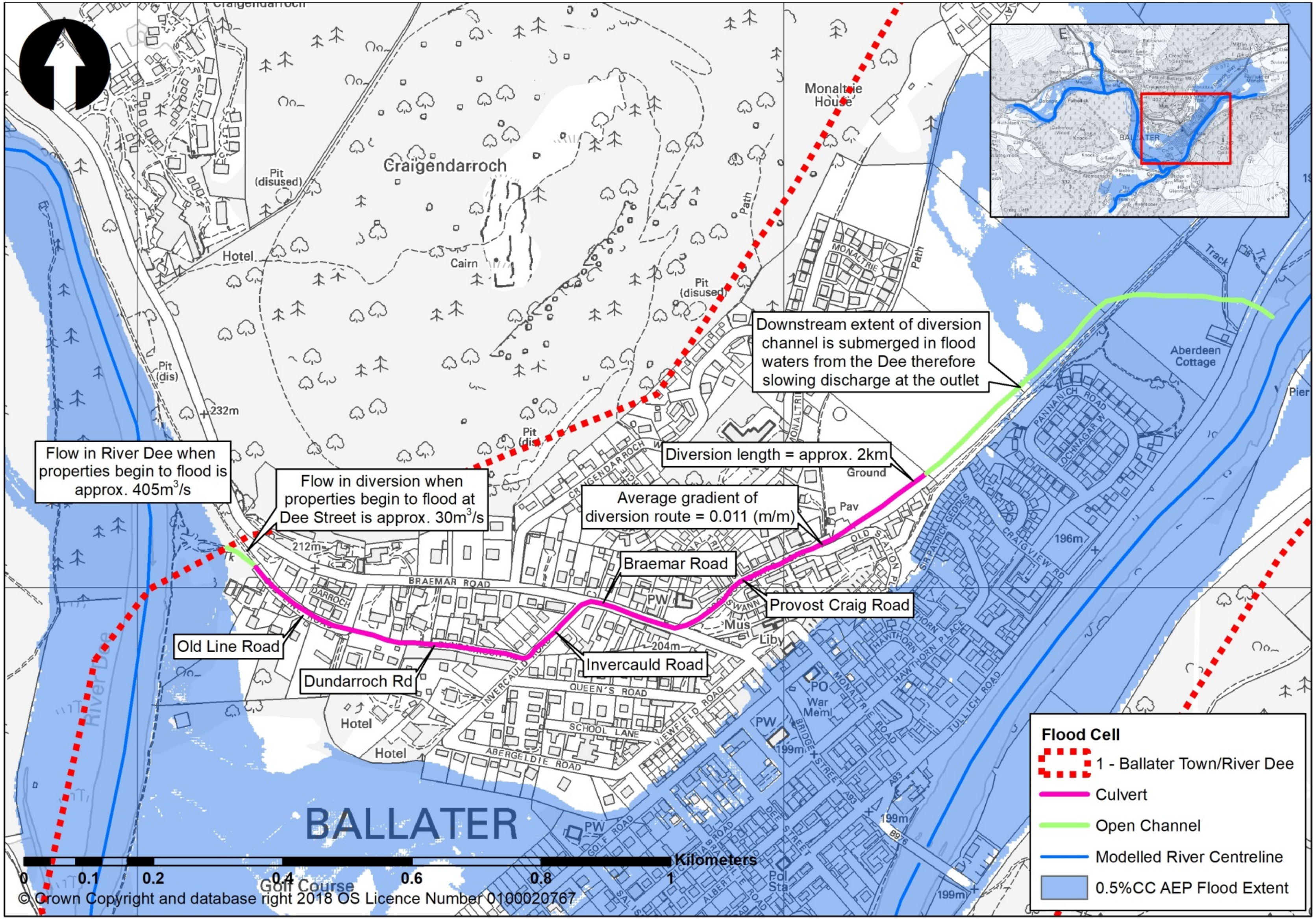

Figure 3.7 - Diversion Route though Ballater from the Dee

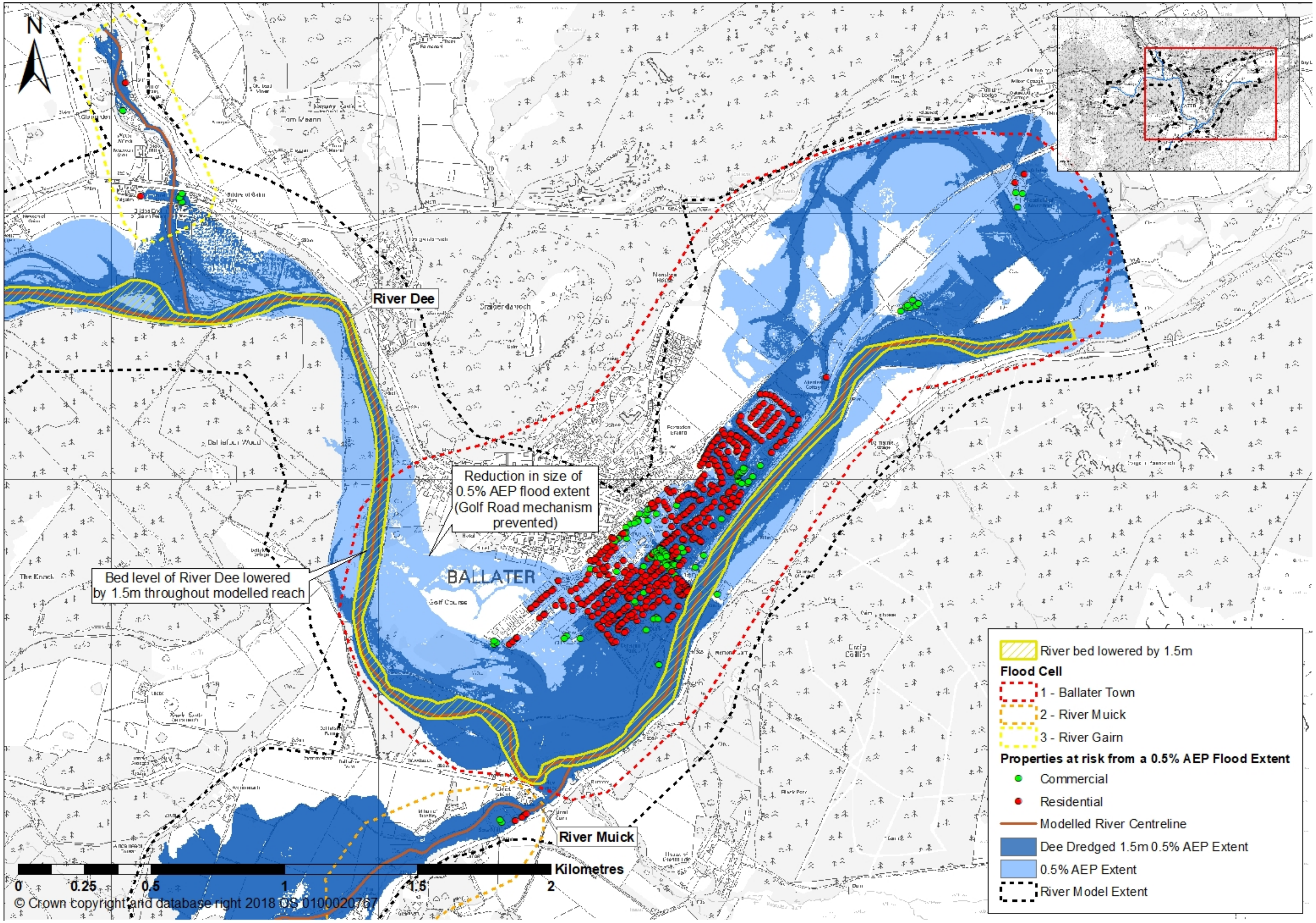

Figure 3.8 – Dee Dredged 1.5m 0.5% AEP extent vs Undredged 0.5% AEP extent

Table 3.6 - Summary of potential conveyance actions

Flood Cell	Action	Feasible?	Progress Action?
1	River Dee – Diversion Route	During a 0.5%CC AEP event, the flow in the Dee at the chosen discharge location when properties in Ballater begin to flood is approximately 400m^3/s. Maximum flow in the Dee is approximately 1360 m^3/s during this return period. Therefore flow required to be carried by diversion is approximately 960m^3/s = equivalent to almost 2.5 extra 'River Dee' sized channels. As such the diversion route was considered technically unfeasible for a 0.5%CC AEP SoP. A lower return period was also considered: during a 3.33% AEP event the flow in the Dee at the chosen discharge location is approximately 400m^3/s. Maximum flow in the Dee for this return period is approximately 815m^3/s. Therefore flow required to be carried by diversion is approximately 415m^3/s, which is roughly equivalent to an additional 'River Dee' sized channel. As such, it was considered technically unfeasible for these flows to be conveyed in the diversion. A 20% AEP event was assessed using the hydraulic model however the addition of the diversion route would not remove the flood risk to properties in Ballater for this return period. As such the action would not provide a SoP as a standalone measure.	×
1	River Dee - Dredging	Comments received from local residents suggested that dredging the River Dee may provide some relief. The feasibility of this action was reviewed however in order for dredging to be effective the River Dee channel would need to be tripled in size to convey the design event flows. It would not be technically feasible to dredge to the required depth to convey design event flows. A model simulation was undertaken to simulate the effect of dredging the Dee by 1.5m for a 20% AEP event. A reduction in flood extents was shown and would provide a SoP to a 20% AEP event. However the major channel instability dredging would cause may quickly undo any potential benefit gained. Dredging may also create a host of other issues including the undermining of Royal Bridge and any direct flood defences on river banks. As such dredging was considered unfeasible and not progressed as a potential flood risk management action.	×

3.3.4 Control Structures

Figure 3.9 highlights the existing bridges within the Ballater Study area. All potential control structures were reviewed in turn within each flood cell and Table 3.7 provides a summary.

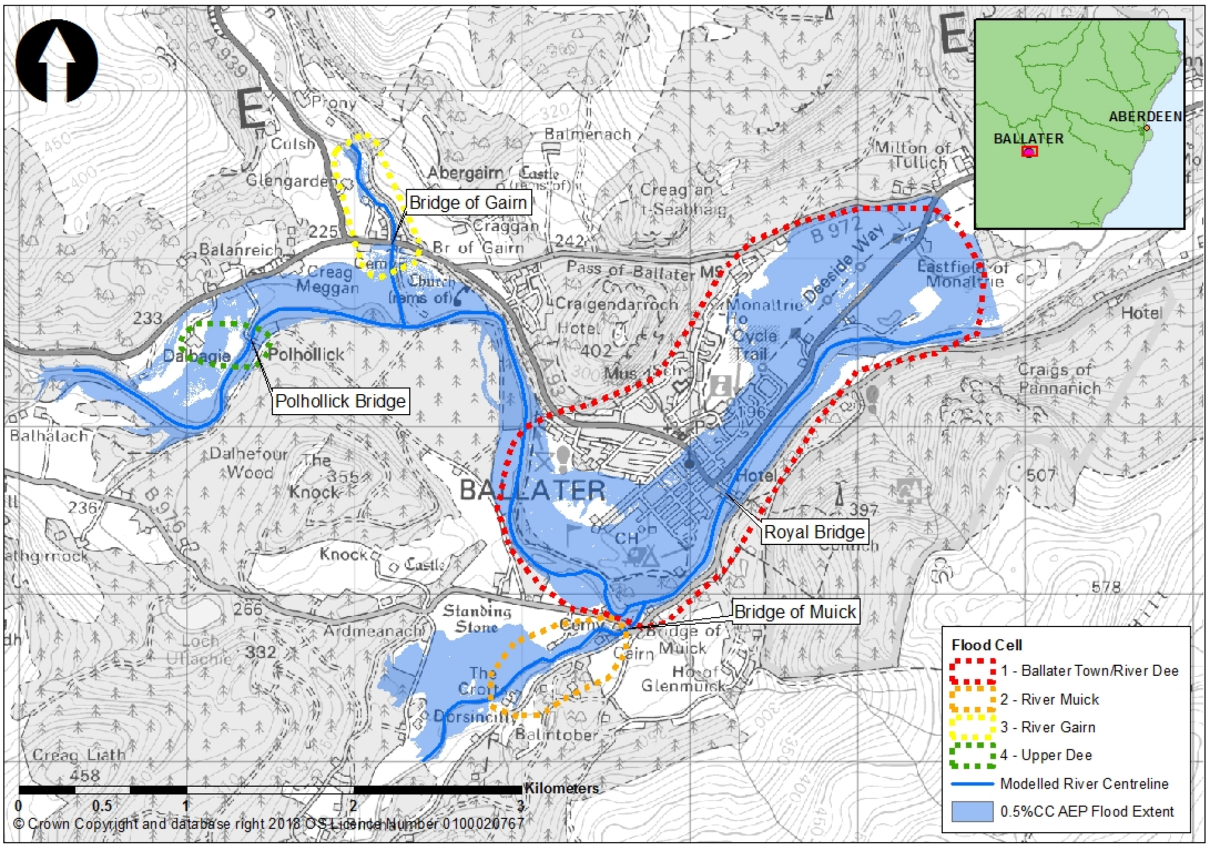

Figure 3.9 - Structures reviewed within the Ballater study area

<u>Flood Cell 1</u>

The Royal Bridge was the only structure identified in Flood Cell 1. Although it was not identified as a control structure during the review of flooding mechanisms in Section 2.1, comments received from local residents suggested that Royal Bridge may cause a restriction in flow and it was suggested that an additional arch on the bridge may provide some flood relief. Investigations were carried out and various hydraulic model simulations were completed to confirm that the bridge does not significantly restrict flow. Discussion on the additional arch model simulation may be found in Section 3.3.11.7 as this was modelled in combination with direct defences.

Model Simulation: Royal Bridge Removal (0.5%+CC AEP)

A hydraulic model simulation was undertaken to simulate the effect of the removal of Royal Bridge. The road embankment on the right hand bank was also removed to ensure there would be no restriction in flow through the reach. Table 7.19, found in Appendix D, displays a comparison between the maximum modelled water levels at key cross-sections for the bridge-in 0.5%+CC AEP scenario and the bridge-out 0.5%+CC AEP scenario. The results of the model simulation showed no significant differences in the River Dee water levels between the bridge-in and bridge-out scenarios. A maximum difference in water level was observed upstream of Royal Bridge (at cross sections RD.092 and RD.093) where water levels were found to be 340mm lower in the bridge-out scenario. However this is not considered significant during a flood event of this magnitude. As the water levels between the two scenarios are very similar this confirms that Royal Bridge does not pose a significant restriction or cause increased water levels upstream.

Although there is still flow bypassing the bridge in this simulation the bypassing flows are relatively low compared to the in-channel flows (as described in Section 3.3.12) and the flooding mechanism here is due to insufficient channel capacity further upstream in the Dee rather than a restriction at Royal Bridge.

Water levels at Royal Bridge: Defended 0.5% AEP event vs Undefended 0.5% AEP event

As determined in Section 1.1.13.3.12, during an undefended 0.5% AEP event, approximately 95% of the total flow at Royal Bridge passes through the bridge in-channel. The water levels at the bridge were assessed.

Figure 3.10 shows a cross-section of Royal Bridge and the peak water level reached during a 0.5% AEP event model simulation. This shows the peak water level and that the bridge still has further capacity, even above this already high return period event.

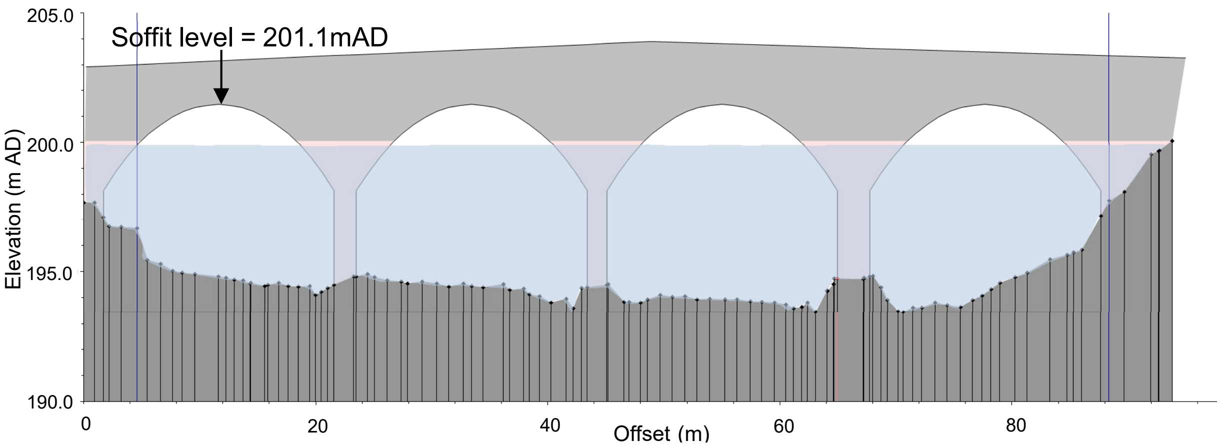

Figure 3.10 - Cross-section showing maximum water level upstream of Royal Bridge Ballater during a 0.5% AEP flood event

Figure 3.11 shows a cross-section of Royal Bridge however this figure illustrates the peak water level reached during the 0.5% AEP Direct Defences model simulation (Section 3.3.5). During this event, the full flows experienced during this flood event would be conveyed through Royal Bridge. The figure shows that the bridge soffit is above the peak water level reached during this simulation and therefore the bridge still has further conveyance capacity.

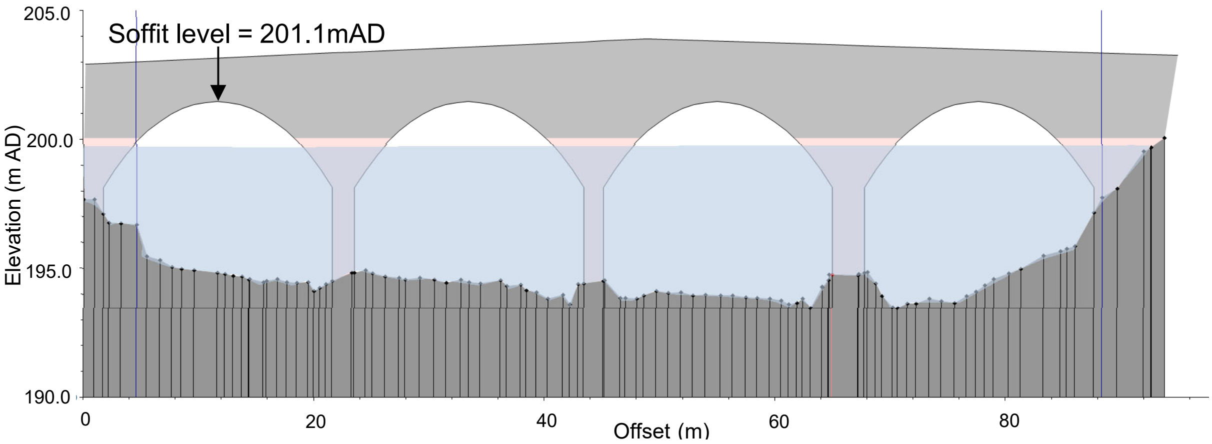

Figure 3.11 - Cross-section showing maximum water level upstream of Royal Bridge Ballater during the 0.5% AEP Direct defences model simulation

For both the Defended 0.5% AEP and 0.5%+CC AEP events a maximum head difference of approximately 66mm was found between the upstream and downstream bridge faces, which is not considered a significant restriction. However, should an option which incorporates direct defences be implemented, it is recommended that additional investigation into the potential for scour is undertaken to ensure that the flood alleviation scheme does not compromise the integrity of the bridge.

Storm Frank Water Levels at Royal Bridge

These modelled river levels are supported by photographs taken during the 2015 flood event (which was estimated to be approximately a 0.6% AEP event or 1 in 167 years). Figure 3.12 shows the river level at the Royal Bridge approximately one hour and twenty minutes before the peak flow was recorded at the Polhollick gauging station (11:45 am) on the 30th December 2015. As there is a significant difference between the bridge soffit and peak water level, this supports the assessment that Royal Bridge has further conveyance capacity and therefore does not provide a significant restriction during flood events.

Figure 3.12 - Photo taken (at 10:25am) on 30/12/15 from the north side of the River Dee, downstream of the Royal Bridge in Ballater

It should be noted that Historic Environment Scotland has stated that the Royal Bridge has been removed from the schedule of nationally important monuments. It remains designated as a Category B listed building (LB21851), however, any works to the structure may require Listed Building Consent with Aberdeenshire Council.

The potential for improvement of channel conveyance at the bridge location was also assessed in combination with the relocation of properties. This action is discussed in Section 3.3.3.

<u>Flood Cell 2</u>

The River Muick Bridge was the only control structure identified in Flood Cell 2. It was assessed and shown to cause no significant restrictions in flow during a 0.5%CC AEP event.

<u>Flood Cell 3</u>

The Bridge of Gairn was the only control structure identified in Flood Cell 3. It was assessed and shown to cause no significant restrictions in flow during a 0.5%CC AEP event.

<u>Flood Cell 4</u>

The Polhollick Suspension Bridge was the only control structure identified in Flood Cell 4. It was assessed and shown to cause no significant restrictions in flow during a 0.5%CC AEP event. This is due to the relatively shallow deck structure being bypassed and overtopped during flood events, resulting in minimal head loss across the structure.

Table 3.7 - Summary of potential control structure actions

Flood Cell	Action	Feasibility	Progress Action?
All	Control Structure	Royal Bridge was found not to significantly restrict flow within the study area therefore the action was considered unfeasible.	×

3.3.5 Direct Defences

3.3.5.1 Proposed Direct Defences

A review was carried out to ascertain where direct defences would be required to protect properties at risk during a 0.5%+CC, 0.5%, 1% and 2%, 3.33% and 10% AEP flood events within the Ballater Study Area. To determine the effectiveness of the direct defences, a hydraulic model was constructed to simulate the method of protection.

For Flood Cell 1 (Ballater Town), the proposed direct defence is considered to follow the optimum route through the golf course and caravan park prior to running along the left bank of the River Dee until it ends downstream of Ballater. This route maximises the floodplain area (on the river side of the defence at the golf course and caravan park) without incorporating sharp bends adjacent to residential areas. Adopting a route which follows the existing property boundaries would result in ponding of flood water during an extreme flood event.

It is acknowledged that the selected route is likely to be amended during future stages of the project due to the numerous other routes which could be adopted (e.g. across the golf course). However, as the proposed option follows the shortest route, it is likely that any route changes will have an associated increase in costs (with a resultant decrease in the benefit cost ratio of the scheme). Consequently, the proposed route was considered to be the most appropriate in determining if there is a viable cost-beneficial flood scheme for Ballater.

It is noted that Flood Cell 1 includes a Scottish Water asset which has been included for protection – this may be amended following stakeholder consultation on the available options (as it may be the responsibility of Scottish Water to consider appropriate protection requirements).

For Flood Cells 2, 3 and 4 (Muick, Gairn and Upper Dee (Polhollick) respectively), it is assumed that the proposed route of the direct defence will be located around the relevant property boundaries.

The locations of the direct defences required to protect all properties within the Ballater Study Area to a 0.5% AEP event are illustrated in Figure 3.13 whilst Figure 3.14 presents an aerial map showing the proposed route of the defence through the golf course.

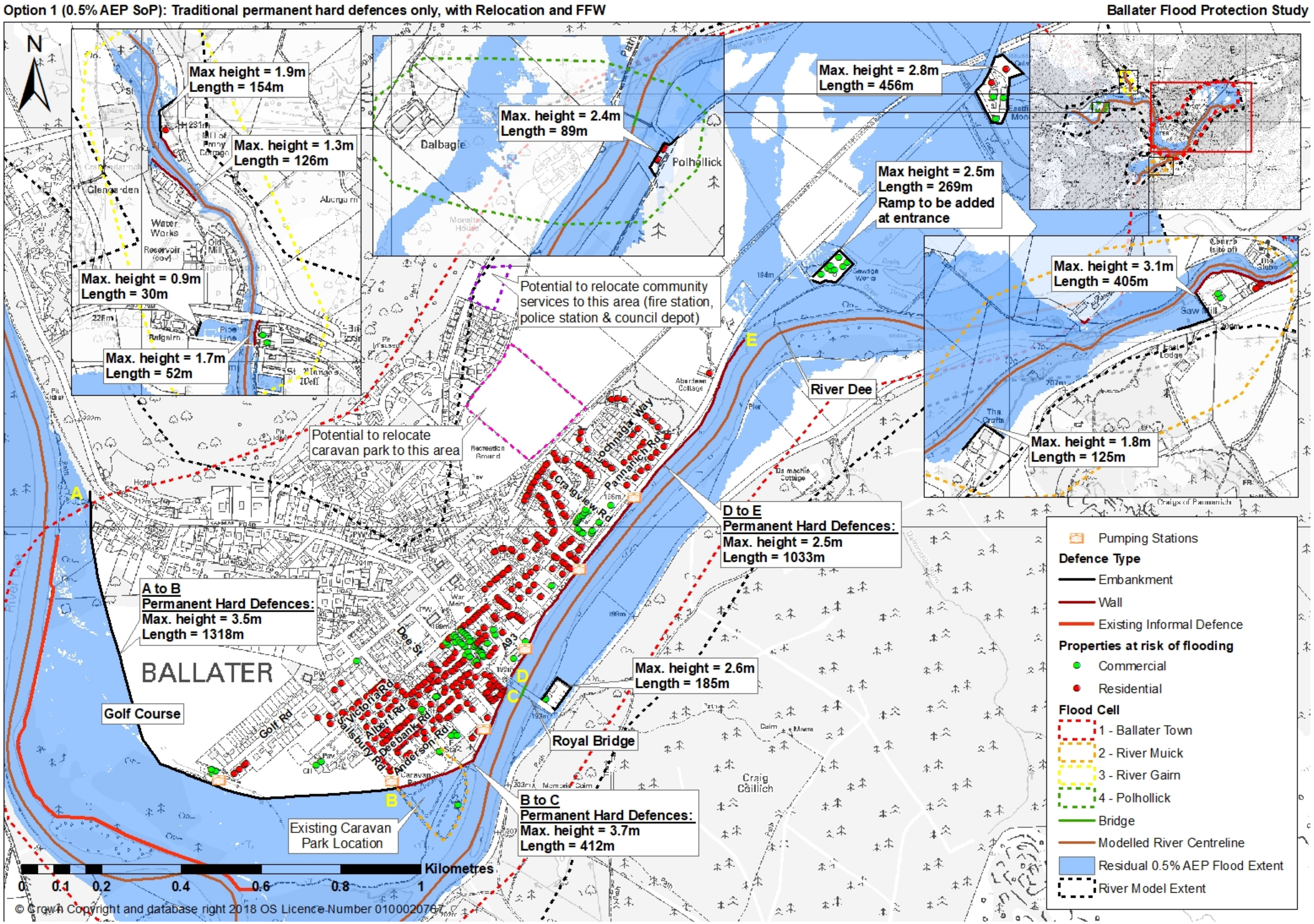

Figure 3.13 – Direct defences required to provide protection to a 0.5% AEP SoP

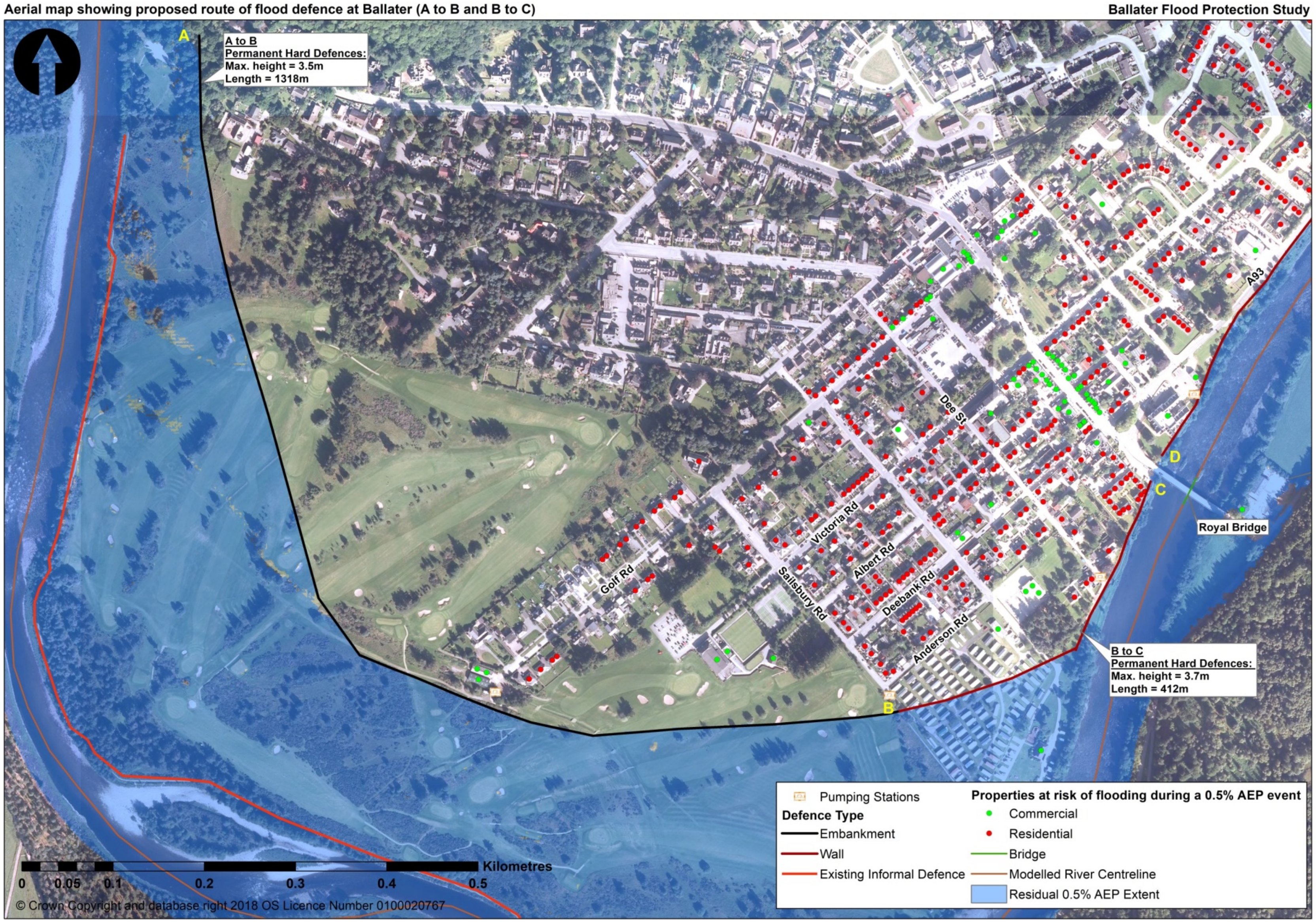

Figure 3.14 - Aerial map showing proposed route of flood defence at Ballater from (A to B and B to C)

Due to the numerous potential routes available, it is recommended that a review of the proposed direct defence route is undertaken during future stages of the project. There are points where the required height of direct defences is higher than may be required if an alternative route was considered, due to natural low areas in the topography. An alternative direct defence route may avoid some of these natural low points; however the relocation of some residential properties would be required (as alternative routes avoiding low areas are only available by moving the direct defences further from the River Dee, towards Ballater - Figure 3.15). If properties in the Dee Street area are to be protected, there are unavoidable low points in this area. Section 3.3.11.2 provides details of an analysis assuming that these properties could be relocated, potentially improving conveyance upstream of Royal Bridge.

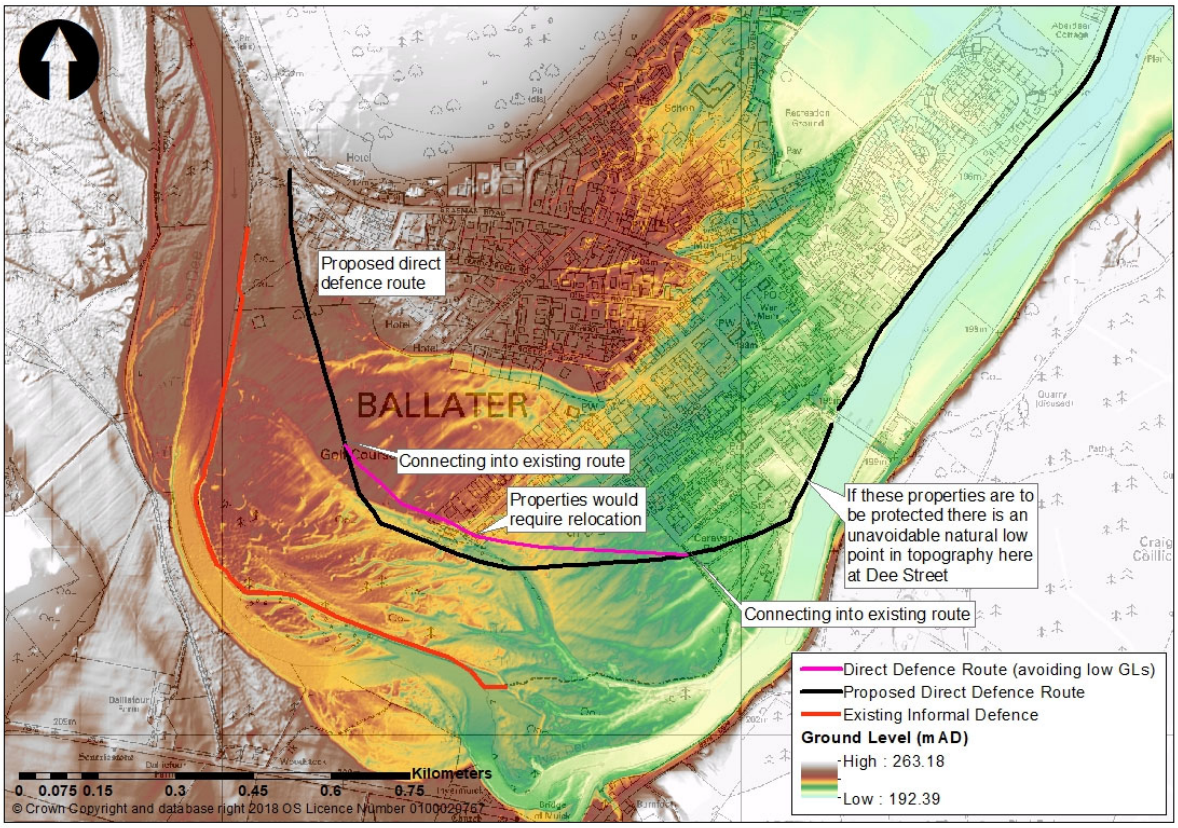

Figure 3.15 – Alternative direct defence route to avoid naturally low ground levels

It is also noted that the flooding mechanisms in Ballater mean that the direct defences required to provide a standard of protection of 3.33% AEP (see Figure 3.16) are similar in length to those required to provide a standard of protection of 0.5% AEP. Approximately 350m less direct defence length would be required to provide a 3.33% AEP SoP. The flooding mechanisms originating from the River Dee via the golf course (to Golf Road and the caravan park) and via the Dee Street area are present during the 3.33% AEP flood event. Consequently, this demonstrates limited potential for direct defences to be considered as part of an interim or short-term flood alleviation measure, or form part of a phased construction process, as the majority of the length of the direct defences which are required to protect to a 0.5% AEP event are also required to provide protection to a 3.33% AEP event. This is illustrated in Figure 3.16 with the dashed black line highlighting the length of defence which would not be required for a 3.33% AEP SoP.

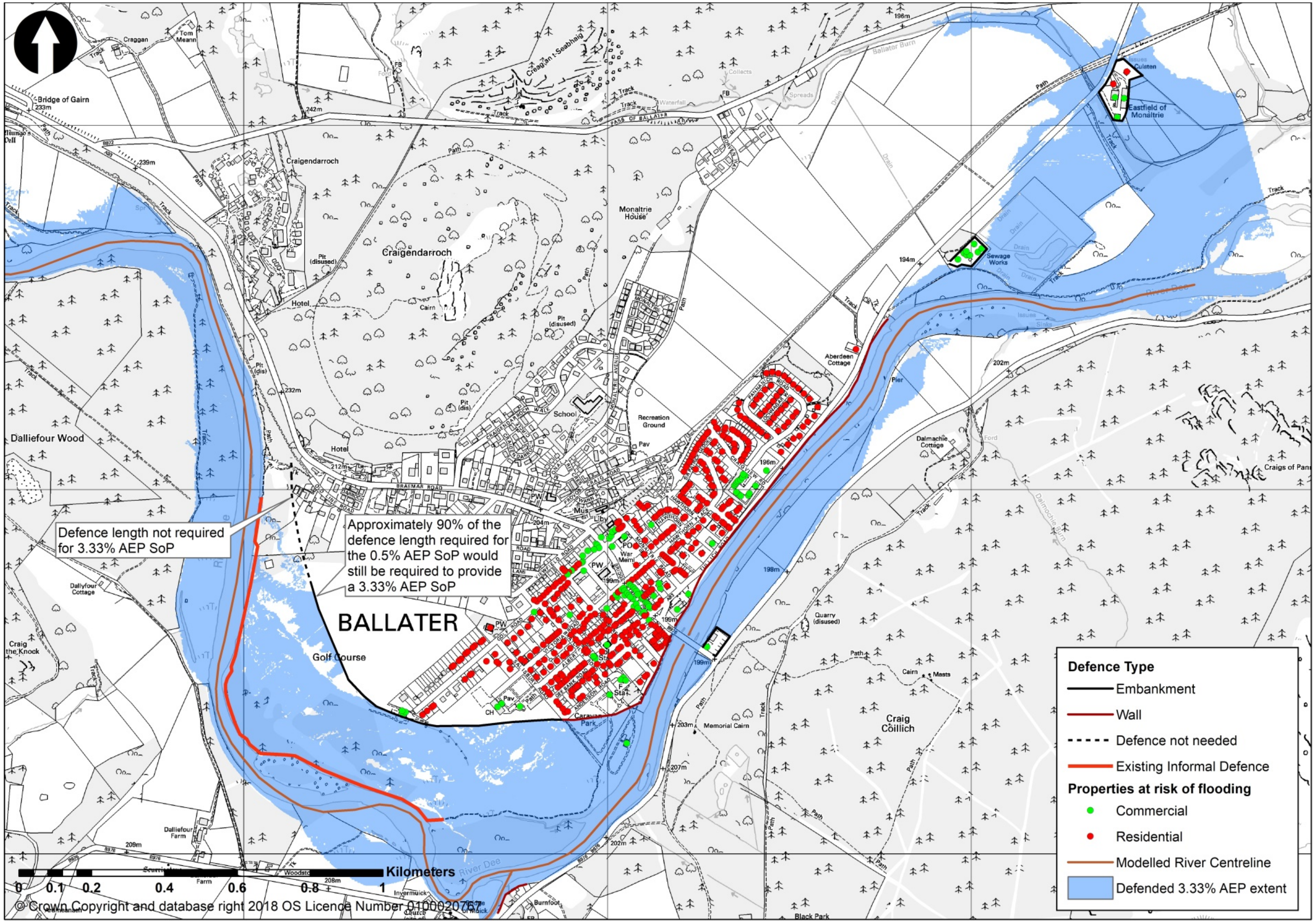

Figure 3.16 – Direct defences required to provide protection to a 3.33% AEP SoP

3.3.5.2 Optimisation of Direct Defences

An iterative process was carried out to find an optimal direct defence solution for Ballater Town which would provide a high standard of protection and also maintain good amenity value in the town. Table 3.8 illustrates the maximum required height of direct defences at each return period assessed. An estimate of the defence height that would be required for a Storm Frank event was also included for comparison purposes.

Table 3.8 - Maximum direct defence height at each return period

Return Period (% AEP)	Return Period (Years)	Maximum direct defence height (m)	Maximum 1D Flow (RD.BR02.U/s – Royal Bridge) (m^3/s)
0.5+CC	1 in 200+CC	4.5	1550
0.5 1+CC	1 in 200 1 in 100+CC	3.7	1300
0.58 (Storm Frank)	1 in 172	3.5	1240
1	1 in 100	3.1	1110
2	1 in 50	2.6	940
3.33	1 in 30	2.0	830
10	1 in 10	1.4	640

Initially the 0.5% AEP+CC SoP was considered however this would require defence heights in excess of 4m and so was considered unacceptable. As such a maximum acceptable height of direct defences considered was 2.5m, however the maximum standard of protection that traditional direct defences of this height would provide is a 2% AEP event which is not considered an acceptable level of protection as it would not protect against a flood event equivalent to Storm Frank in magnitude. Therefore the 0.5% AEP and 1% AEP events were investigated. As the maximum required defence heights for these events are 3.7m and 3.1m respectively other solutions were sought to either reduce the maximum height required or to help maintain some amenity value. Flood Control International were consulted on the possibility of installing either Self-Closing Flood Barriers, or Glass Walls within the direct defence structure. As such, three different combinations of direct defences were considered for both a 0.5% AEP and a 1% AEP SoP with a target of protecting all properties within the study area:

1) Traditional defences only
2) Traditional defences and SCFBs
3) Traditional defences and glass walls

When considering where either SCFBs or Glass Walls should be located, a threshold defence height was initially set at 1.8m (meaning where defences would need to exceed 1.8m in height they would be replaced with either SCFBs or Glass Walls). However, at this threshold more than 1.5km of defences needed to be replaced and costing of this option indicated an estimated whole life cost of approximately £70million and so this threshold was considered economically unviable. As such the threshold for SCFBs/Glass Walls was reviewed and set at 2.5m. This threshold provided options with significantly improved BCRs.

Following further review of the direct defence action, it was considered that for outlying properties (which lie beyond the extent of the main defence at Ballater Town), the flood risk could be reduced through alternative, more sustainable actions without the requirement for direct defences. As such it is considered that the flood risk management to these outlying properties could be addressed through other actions such as Property Level Protection (Section 3.3.6) or Property Flood Resilience (Section 3.3.10). The development of these actions into potential flood risk management options is discussed further in Section 3.5.

It is recommended that viewing platforms/ terracing of direct defences should be considered at detailed design stage to provide improved amenity value where high defences are required to provide a 0.5% AEP SoP. This type of landscaping would also be useful for hiding pumping stations and associated plant within the defence structure.

A summary of the potential direct defence actions is given in Table 3.9.

3.3.5.3 Risks and Uncertainties Associated with Direct Defences

There are inherent risks and uncertainties associated with the Direct Defences action at this stage of the study, examples of which are listed below. These are also reiterated in the appraisal summary tables (Table 3.19 to Table 3.27). Please refer to Section 6 for a full list of recommendations to support option development.

- Utility services locations unknown at this time. Potential conflicts.
- Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course.
- A cut-off of 2m depth was included in costing of direct defences however detailed site/ground investigation works and seepage analysis will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.27 and Figure 3.28.
- Further work should be considered to investigate the potential for pluvial ponding behind direct defences and potential ground water flow mechanisms. Seepage will have to be reviewed with consideration to soil permeability's at various depths following extensive borehole and ground investigation works. Pumping stations would be required at strategic low points in the defences.
- Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events.
- It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.
- It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme in order to improve model calibration for higher frequency return periods i.e. up to and including the 3.33% AEP event.

3.3.5.4 Existing Informal Defences

There are two existing informal flood defences known to exist within the study area. These are discussed below.

Wall Upstream of Royal Bridge

In Flood Cell 1, there is a wall located on the left bank immediately upstream of the Royal Bridge (Figure 3.17). It is considered that the existing wall does not provide a standard of protection as the peak water level remains in-channel at this location during a 20% AEP event, with the properties behind the wall flooding during a 10% AEP event (due to the wall being bypassed by an upstream flooding mechanism). It is assumed that due to the height of the proposed defence that the existing wall could not be incorporated into an action to reduce flood risk (as the wall has not been constructed as a flood defence or to allow such significant adaptation). It is recommended that further investigation is undertaken to confirm this assumption, or otherwise. Although the potential of incorporating the existing wall into an interim flood measure is considered to be low, an assessment was undertaken to determine the length of additional direct defence required in order provide a standard of protection against flooding in Ballater for the purposes of this report. Figure 3.18 shows the length of the existing wall (approximately 75m) and illustrates the additional length of defence which would be required to provide a 10% AEP SoP to properties in Ballater (approximately 360m at the same height as the existing wall).

Figure 3.17 – Wall on left bank upstream of Royal Bridge (view looking downstream)

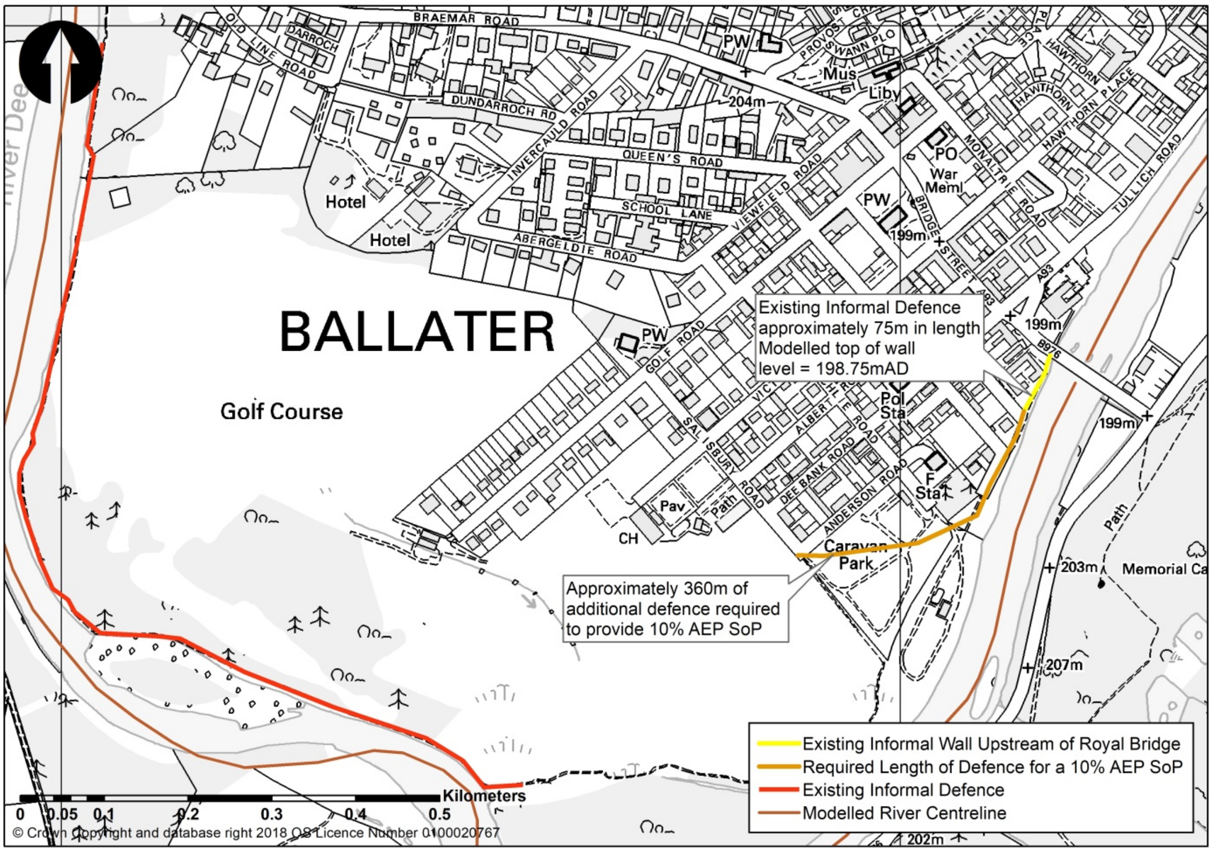

Figure 3.18 – Additional stretch of wall required to provide a 10% AEP SoP

<u>Embankment at Ballater Golf Course</u>

In Flood Cell 1 there is an existing informal defence along the boundary of Ballater Golf Course (Figure 3.19). As discussed in the Ballater FPS Defence Condition Survey Report (RPS, 2018), this embankment (constructed in the 1990's to protect the golf course) was breached during the 2015 flood event. In 2016, sections of the flood bank were reconstructed using material bulldozed from the golf course to create a non-engineered flood defence bank. Aberdeenshire Council also completed the reinstatement of a 40m long section of the flood bank. The defence is predicted to be overtopped from approximately a 10% AEP event (as stated in the Ballater FPS Hydraulics Report). In order to consider the potential impacts of possible future scenarios, the following three options were reviewed:

- **Embankment removal**: The informal embankment was removed from the hydraulic model and was simulated for the 20% AEP to determine the impact of this action. In Figure 3.19 the hatched area highlights where would flood if the embankment was removed, i.e. the areas benefitting from the informal defence during a 20% AEP event, assuming that the integrity of the defence was not compromised. The coloured flood extent shows the areas which would flood during a 20% AEP event with the informal embankment in place.
- **Embankment reinforcement**: This option would involve works to make the embankment a formal flood defence structure which would significantly reduce the risk of the embankment failing during a flood event. Further investigation is recommended in order to determine if it is technically feasible to reinforce the embankment so that it would perform as a flood defence, in addition to determining the future maintenance programme of the structure and the parties

responsible for undertaking maintenance. The benefitting area would remain as shown in Figure 3.19.

- **Increase height of embankment**: Due to the uncertainty in the construction methods used, it would be recommended that site investigation works are undertaken to confirm if this option, and the embankment reinforcement option, is technically feasible.

Based on the available evidence, and subject to site investigation work being undertaken, it is assumed that it would not be technically feasible to incorporate the existing informal embankment into a flood alleviation option for the purposes of this report. It is assumed that in order to have a formal flood defence structure at this location, the existing embankment would have to be removed to allow construction of a new direct defence. It should be noted that any option which considers a direct defence at the location of the existing embankment should consider the highly dynamic nature of the River Dee, and the likely future works required to prevent defences adjacent to the river being compromised due to geomorphic processes within the river.

Table 3.9 - Summary of potential direct defence actions

Option	Action	Feasibility	Progress Action?
1	Traditional defences only	In order to provide the 0.5% AEP SoP defences 3.7m in height would be required close to Ballater Caravan Park. This defence height may be considered socially unacceptable however the action does provide protection to all receptors up to a 0.5% AEP event and so was carried through to option appraisal.	✓
2	Traditional defences & SCFB	This action would provide protection to all properties up to a 0.5% AEP event with permanent defences at a maximum height of 2.5m. SCFBs would replace permanent defences which exceed 2.5m. The action was considered feasible and carried through to option appraisal.	✓
3	Traditional defences & glass walls	This action would provide protection to all properties up to a 0.5% AEP event with permanent defences at a maximum height of 2.5m. Glass walls will replace permanent defences which exceed 2.5m. The action was considered feasible and carried through to option appraisal.	✓

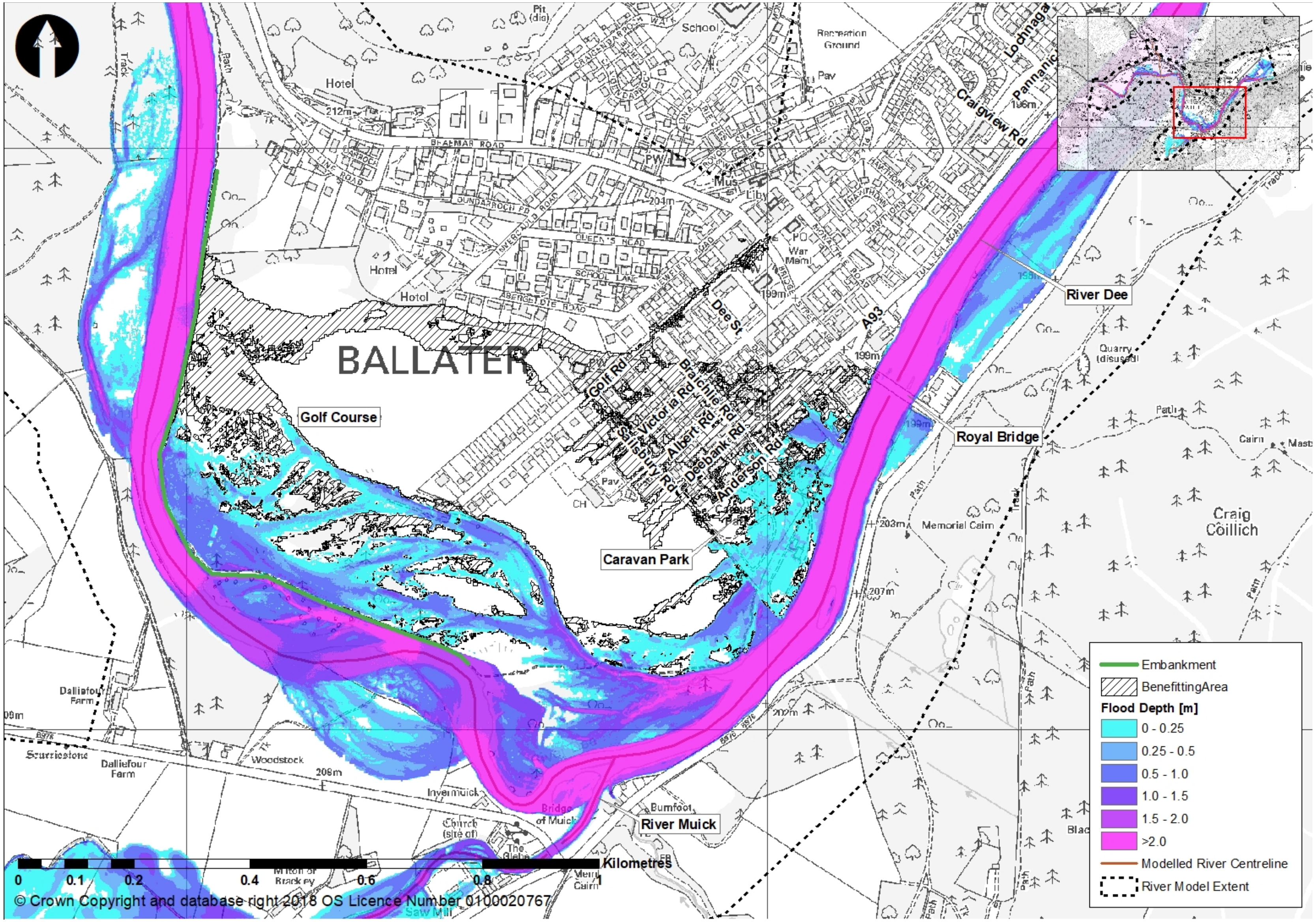

Figure 3.19 – Area benefitting from the informal embankment during a 20% AEP event

3.3.6 Property Level Protection

Property Level Protection (PLP) can be afforded to all at risk properties. This would consist of a way to prevent water entering a property such as flood gates and air vent covers. PLP would provide protection up to a depth of 0.6m, beyond which water would be allowed to spill over the defence and into the house in order to limit the hydraulic pressure exerted on a building's walls and ensure its structural integrity. Some properties would therefore only be protected during lower flood event return periods. Additional uncertainty is inherent with PLP in that it relies on user intervention to erect the defences when required. Additionally, many properties in Ballater are holiday homes and so owners are not in residence all year round and therefore may not be readily available to erect PLP to their properties prior to a flood event. PLP, while not providing the full SoP, would be effective in reducing the flood risk and was therefore considered as feasible.

The prime responsibility for the protection of properties against damage by flooding rests with the owner of the property as stated in the Local Flood Risk Management Plan (LFRMP) and Local Flood Risk Management (Scotland) Act 2009. The LFRMP states that 'Everyone is responsible for protecting themselves and their property from flooding. Property and business owners can take simple steps to reduce damage and disruption to their homes and businesses should flooding happen. This includes preparing a flood plan and flood kit, installing property level protection (PLP), signing up to Floodline and Resilient Communities initiatives, and ensuring that properties and businesses are insured against flood damage'.

Aberdeenshire Council currently provide a small range of flood protection products for individual property protection, which are available for all types of flooding, at cost price with free delivery across Aberdeenshire. Apart from the above flood protection (PLP) products, currently available to property and business owners, it is Aberdeenshire Council intention not to consider or promote deploying temporary flood barriers to protect properties from flood risk in Ballater.

There is some existing borehole data within Ballater (as shown in Figure 3.20 and Figure 3.21). The existing records however reach depths just greater than 2m – borehole records to greater depths would be beneficial to inform option development. As such, it is recommended that further investigation into existing ground conditions and the construction method of properties is undertaken prior to detailed design to confirm that the PLP method adopted would not be compromised by seepage during a flood event.

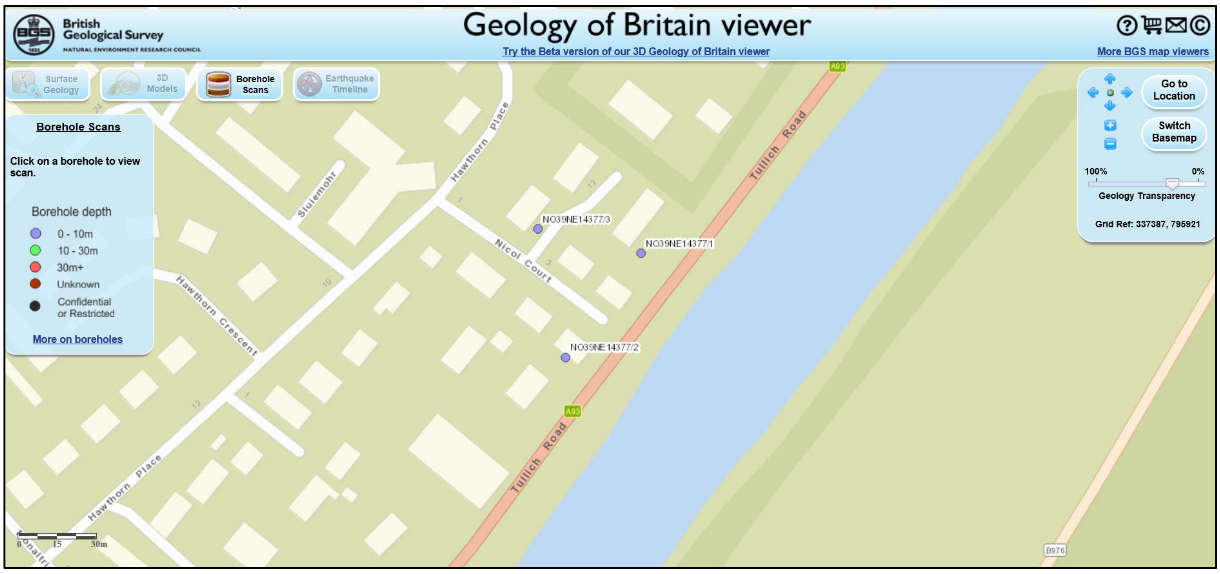

Figure 3.20 – Location of 1986 boreholes, adjacent to Tullich Road (www.bgs.ac.uk)

Carried out for: D. Sampson & Partners

GRAMPIAN SOIL SURVEYS (ABERDEEN) LTD.

Diameter of Boring: 203mm.

Contract No.: 1810/86

Boring No.: B.H. 3

Ground Surface Level: Unknown

BOREHOLE RECORD SHEET

Date: 10/4/86

DESCRIPTION OF STRATA	Legend	Depth below surface From	To	Thickness	SAMPLES TYPE	NO.	Depth of sample	GROUND WATER OBSERVATIONS	Standard Penetration Test No. of Blows N.	REMARKS
Gravelly top soil		G.L.	0.50	0.50						Borehole cased to: 1.90m.
Dense to very dense brown coarse sand and fine to coarse gravel with cobbles		0.50	1.60	1.10	B	3/1	1.00		C.P.T. at 1.00m. 9/8/10/18/25/31; N=84	
Cobbles and boulders with some gravelly coarse sand		1.60	2.20	0.60	B	3/2	2.00	DRY		Chiselling from 1.60m. to 2.20m. – 2½ hrs.
Large boulder		2.20	2.30	0.10 proved						Chiselling from 2.20m. to 2.30m. – 1 hr. Hole stopped because of slow progress
BOREHOLE ABANDONED										

Figure 3.21 – Example of available borehole data (www.bgs.ac.uk)

3.3.7 Flood Forecasting & Warning

The Scottish Flood Forecasting Service (a joint initiative between SEPA and the Met Office) delivers ‘Floodline’, which forecasts and provides information on when and where flooding is likely to occur. SEPA accesses hydrological information and combines this with meteorological information from the Met Office to produce daily, national flood guidance statements which are issued to Category 1 and 2 agencies, such as emergency responders, local authorities and other organisations with flooding management duties. Each daily statement gives an assessment of the risk of flooding for the next five days and provides organisations with valuable time to put preparations in place to reduce the impact of flooding.

The Flood Forecasting system for the River Dee at Ballater consists of two type of models – rainfall run-off (PDM) and River Models (Flood Modeller). The three PDM models are located at Mar Lodge, Invergairn and Invermuick gauging stations. These models use observed and forecast rainfall data to generate a flow estimate that is then used within the river model.

There are two river models – Mar Lodge to Polhollick gauging stations and Polhollick to Woodend gauging stations – this includes the flood warning location of Ballater. The main purpose of dividing the river models is to provide an opportunity for the flow forecast to be error corrected at the Polhollick gauging station and therefore, improving the flow estimate in real-time based on observed data. The river models convey the flow down the river system and convert the flow from the PDM models into a water level in the River Dee at Ballater. The flood warning thresholds for Ballater were set from a Flood Modeller - TUFLOW model that was developed based on topographic survey information collected on behalf of SEPA in 2016.

As the existing flood forecasting service is error corrected at the Polhollick gauging station, it therefore accounts for snow melt (which made a significant contribution to flood flows in Ballater during the 2015 flood event). It is acknowledged that there is more uncertainty in the analysis of snow melt; however, there is ongoing research within SEPA to identify improvements to current forecasting methods at a national scale. It is noted that a flood warning was issued the day before flooding commenced during Storm Frank in 2015.

SEPA intend to continue to provide the flood warning service to Ballater. This service is not dependent on the outcomes of this assessment and, therefore, flood forecasting and warning is excluded from the options identified within this report. It should be noted that the service provided can be modified to suit any flood mitigation solutions which are ultimately delivered on the ground.

3.3.8 Self-Help

Although Ballater has experienced large flood events in the last several years, a public awareness campaign would be useful to ensure residents and business owners are aware of the types and sources of flooding in their area and the options they have to reduce the risk of flooding to their property. This would allow individuals to take informed actions to help prevent their property from flooding. It is important to note that many properties in Ballater are holiday homes and so owners are not in residence all year round and therefore may not be readily available to provide protection to their properties prior to a flood event. Particularly in the winter months outside of the holiday season when the largest flood events on the Dee are most likely to occur.

SEPA and the local authorities have a plan to raise public awareness of flood risk. They engage with; the community through local participation in national initiatives, including partnership working with Neighbourhood Watch Scotland; as well as local authorities and community resilience groups where possible. A community led flood action group is already active in Ballater. Property and business owners can take simple steps to reduce damage and disruption to their homes and businesses should a flood event occur. This includes preparing a flood plan and flood kit, installing property level protection, signing up to Floodline and Resilient Communities initiatives, and ensuring that properties and businesses are insured against flood damage. Aberdeenshire Council provide a small range of flood protection products for individual property protection, which are available, at cost price with free delivery across Aberdeenshire.

3.3.9 Emergency Plans

For Ballater, there is a category 1 and 2 responder's team which is the responsibility of local authorities, the emergency services and SEPA. The emergency response by these organisations is co-ordinated through regional and local resilience partnerships. The preparations of these emergency response plans are beneficial in the event of a severe flood so as to help residents and business owners affected safely evacuate the area. Continued access to key social receptors as identified in Section 2 is desirable. In Ballater, the police station and fire station are at risk of flooding from a 3.33% AEP and a 10% AEP event respectively. As such, the relocation of these emergency services to an area which is not at risk of flooding has been recommended, as described in Section 3.3.1.

Identifying alternative, risk free routes would also minimise traffic disruption and reduce the impact on residents' way of life. It is recommended that during times of flood, traffic should be diverted away from flooded areas to minimise the tidal wave action from cars driving through flood waters which would potentially increase flood damages to properties in flooded areas.

The A93 North Deeside Road and B976 South Deeside Roads begin to flood at a 10% AEP event and a 2% AEP event respectively. However at these return periods the full width of the road is not yet inundated and may still be passable with care. At a 3.33% AEP event both roads would be fully inundated however the A93 should remain passable for emergency services vehicles. Figure 3.22 shows how traffic disruption may be minimised during a flood event and how access may be maintained for the emergency services.

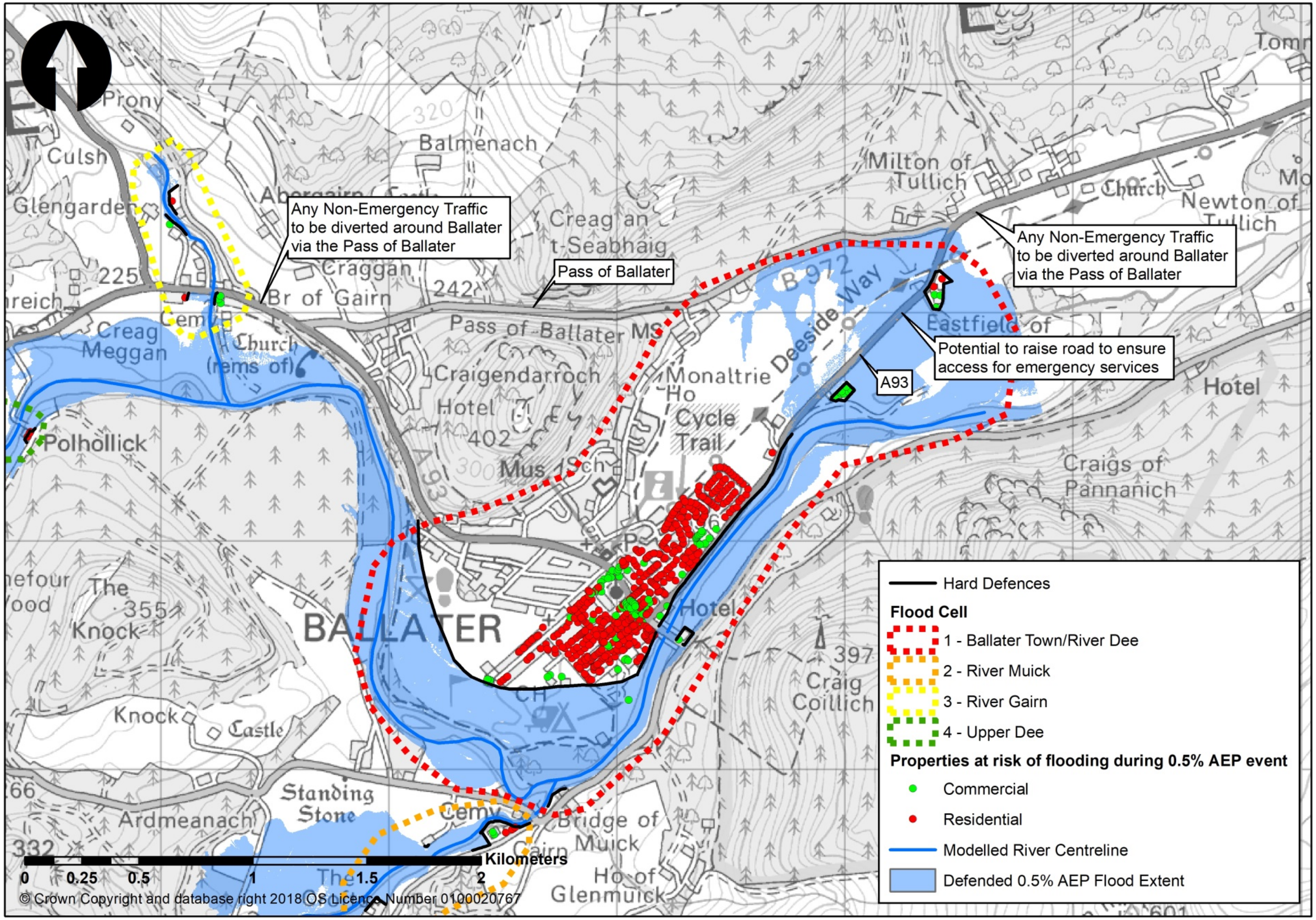

Figure 3.22 - Traffic management during 0.5% AEP flood event with direct defence action

3.3.10 Other Works

Other potential works which may be carried out in the Ballater Study area includes making some properties flood resilient.

Property Flood Resilience (PFR) measures are designed to make people and their property more resilient to the physical and emotional impacts of flooding[1]. Implementation of these resilience measures will minimise the impact should water enter the house speeding up the recovery process.

Examples of works which may be undertaken to improve a property's flood resilience include pointing or waterproofing brickwork, adding airbrick covers, waterproofing floors and substructures, installing non-return valves and moving vulnerable features such as wall plug sockets and wiring above the design standard of protection flood elevation level.

There are several outlying properties on the Gairn and the Muick which may not require significant modifications in order to make the properties resilient. These properties were identified as potentially suitable for flood resilience measures as the depths of flooding expected during a 0.5% AEP event exceed 0.6m in depth. Alternatively these properties would require a significant length of direct defence to be constructed in order to provide protection up to a 0.5% AEP event, which is likely be costly in comparison.

The properties identified with potential for flood resilience are shown in Figure 3.23.

[1]https://www.gov.scot/publications/flood-resilient-properties-framework-for-scotland/

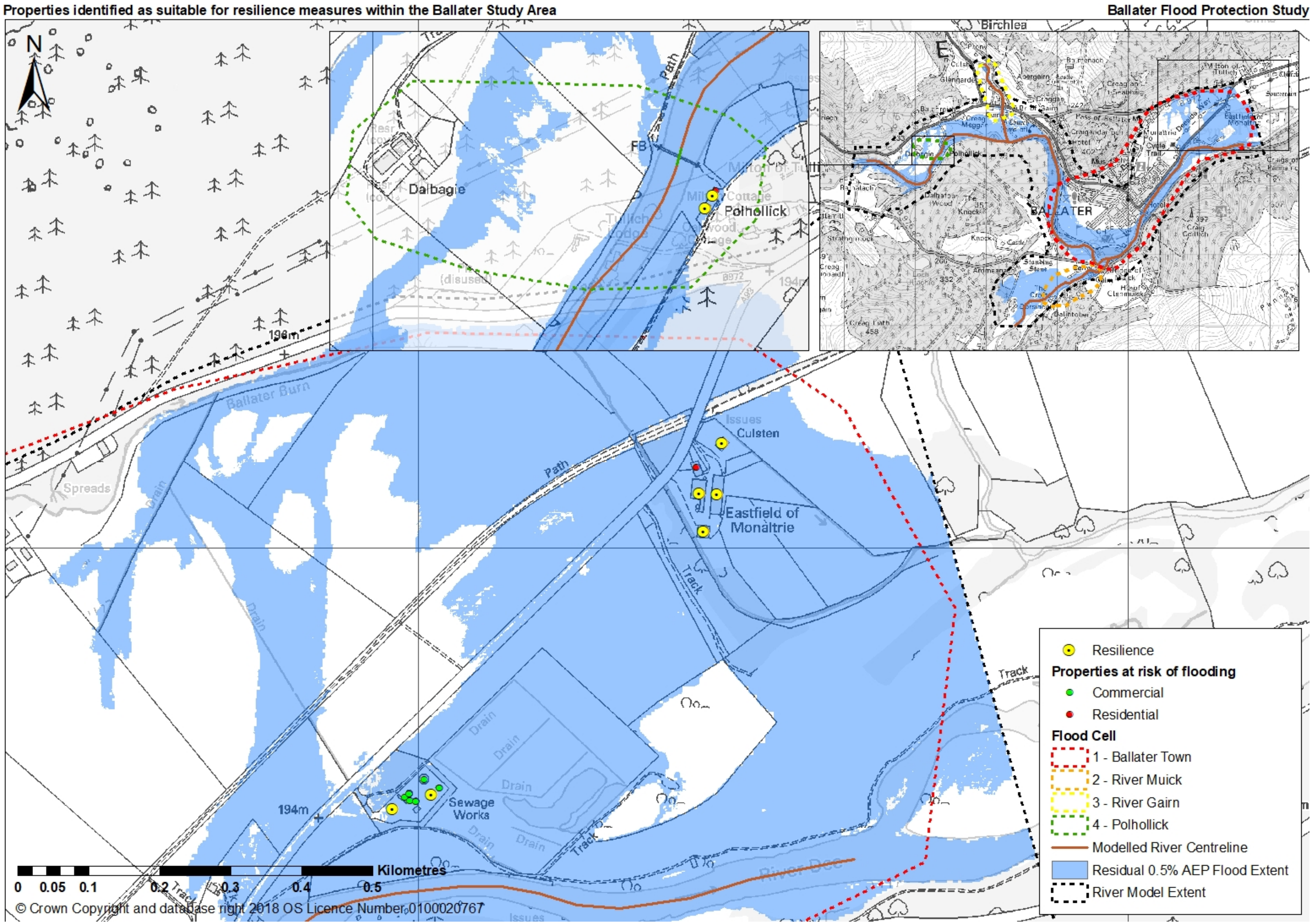

Figure 3.23 - Properties identified as suitable for resilience within the Ballater Study Area

3.3.11 Actions Assessed in Combination

It is recognised that some actions may perform better if they are implemented in combination with other actions. As such several combinations of actions were assessed as part of this study.

It is also recognised that if a flood defence scheme is to afford an acceptable level of protection to Ballater, direct defences must form a major part of that scheme. As such, if an action showed potential to reduce the required direct defence height, the action was assessed through calculations or hydraulic modelling. If the action was found to reduce the required defence height significantly, then the action would progress to form part of an option. For a 0.5% AEP SoP, a significant reduction in direct defence height was considered to be at least 500mm.

3.3.11.1 Relocation (76 properties) with Royal Bridge Removed and Improved Floodplain Utilisation

Improving the conveyance along the reach of the Dee upstream and downstream of Royal Bridge was assessed. A model simulation was undertaken which included relocation of 75 properties on the left bank of the Dee and one property on the right bank. Royal Bridge was also removed in the simulation to ensure no restriction was being caused. The ground level was also lowered along the left bank of the Dee around the golf course up to Royal Bridge and further downstream on the right bank. Figure 3.24 shows how much the ground levels were lowered by in these areas and also shows the new maximum ground level for each of these areas. The results from the model simulation are shown in Figure 3.25 whilst a summary of the results of this combination of actions may be found in Table 3.10.

Table 3.10 - Summary of results of the combination of Relocation, Removal of Royal Bridge and Improved Floodplain Utilisation Model Simulation

Flood Cell	Action	Feasible?	Progress Action?
1	Relocation with Royal Bridge Removal and Improved Floodplain Utilisation	The results of a model simulation incorporating these actions showed that during the 10% AEP event, the point at which properties would first begin to flood due to out of bank flooding from the River Dee moves to downstream of Royal Bridge, causing flooding to properties in the Pannanich Road area, where there was no flood risk previously for a 10% AEP event. Edits to the model to prevent this, again resulted in flooding, this time emanating around 70m upstream of Royal Bridge. The option was therefore considered technically unfeasible, as it did not reduce flood risk and does not provide a SoP.	×

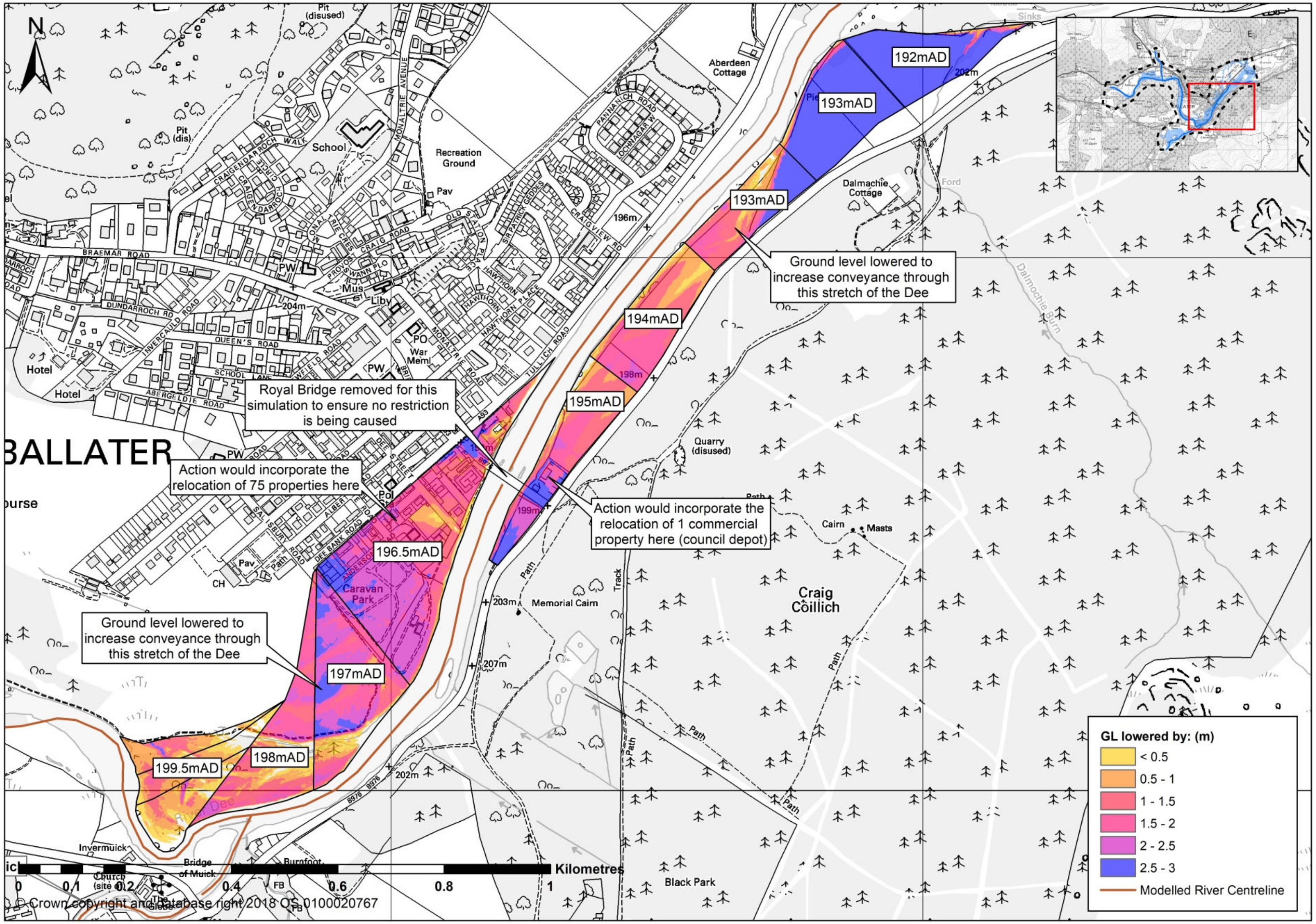

Figure 3.24 - Details of ground levels lowered for model simulation (including removal of Royal Bridge and relocation of 76 properties)

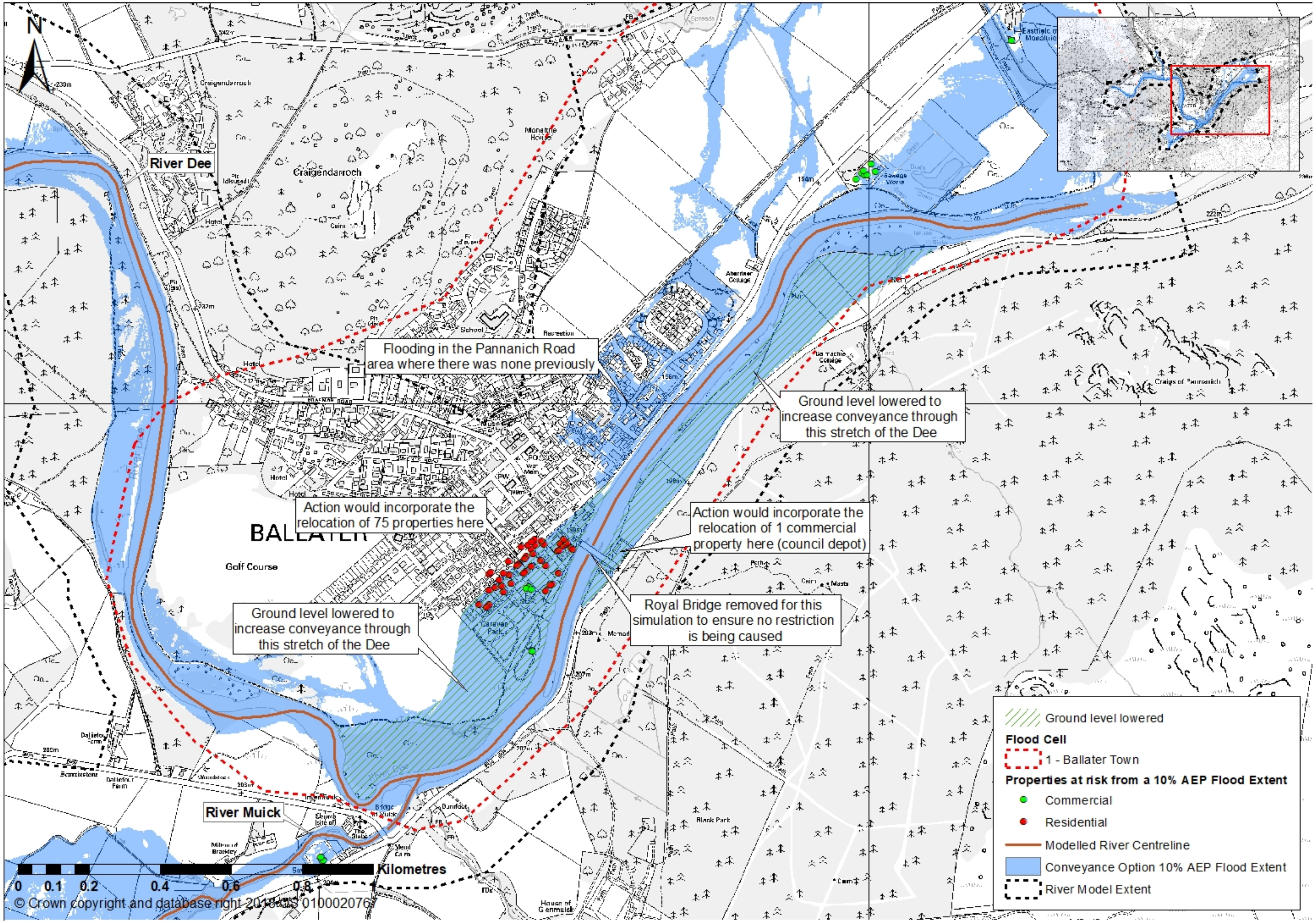

Figure 3.25 – 10% AEP flood event results from combined Relocation with Royal Bridge Removal & Improved Floodplain Utilisation

3.3.11.2 Direct Defences with Relocation (Four Properties)

An alternative direct defences route was considered, which would involve the relocation of four residential properties (in addition to the Caravan Park, Fire Station and Council Depot previously recommended for relocation). The alternative route was considered in an effort to improve conveyance of flood flows through this stretch of the Dee where flooding first occurs to properties. Figure 3.26 shows the alternative defence alignment in this area.

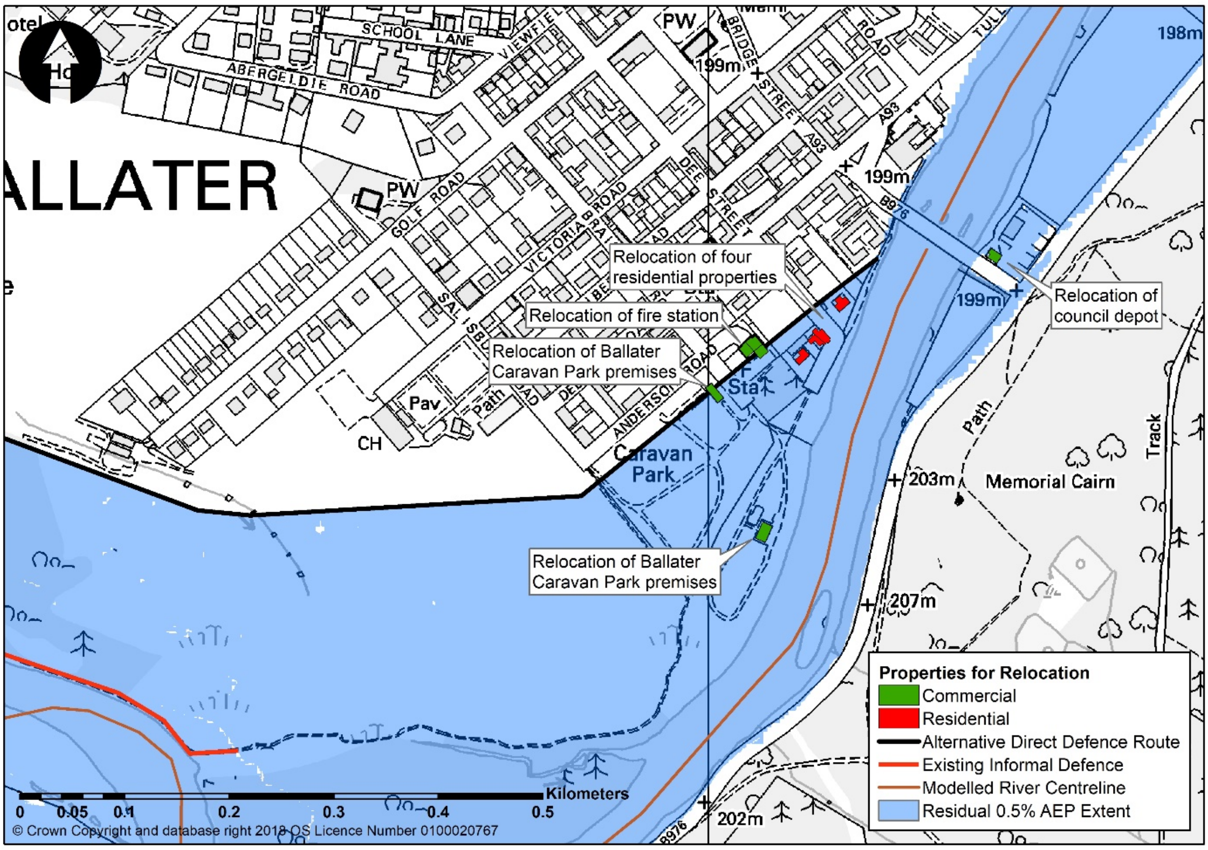

Figure 3.26 – Alternative Direct Defence Alignment incorporating the relocation of four residential properties

A summary of the results of the model simulation are given in Table 3.11. Table 7.21 found in Appendix D also compares the maximum water levels between the defended 0.5% AEP scenario with the defended (alternative route) 0.5% AEP scenario.

Table 3.11 - Summary of results of Direct Defences (Alternative Route) with Relocation of Residential Properties

Flood Cell	Action	Feasible?	Progress Action?
1	Direct Defences (Alternative Route) & Relocation of Residential Properties	The results of the model simulation showed no significant changes in water levels through the modelled reach of the Dee. There were slight variations in the region where the defence was realigned with a maximum reduction in WL at cross-section RD.086 by approximately 260mm. A change in the distribution of flow between 1D and 2D where the defence is realigned was also noted, with greater flows observed in the 2D along this reach. No significant changes were observed upstream or downstream of this reach. No significant changes in velocity were observed. As no significant benefit was gained through reduction in height of direct defences the action was not progressed.	×

3.3.11.3 Direct Defences with Storage Areas Identified through Topography Review

As described previously in Section 3.3.2, the topography in the Dee, Gairn and Muick catchment was reviewed and potential storage areas were identified. The areas were shortlisted to include those which were likely to afford the greatest benefit to Ballater, i.e. those which were closest. A summary of the potential for these shortlisted areas to reduce the height of direct defences is given in Table 3.12.

Table 3.12 - Summary of results of Direct Defences with Storage in Areas Identified through topography review

Watercourse	Action	Feasible?	Progress Action?
Dee	Direct Defences & Storage in Dee Catchment	Eleven potential storage areas were shortlisted (Section 3.3.2) and would achieve a maximum storage volume of 32million m^3. If this storage action was used in combination with direct defences (see Section 3.3.5) this would potentially reduce the required height of direct defences (for a 0.5% AEP SoP) by approximately 1m. This was considered a significant reduction and so the action was progressed.	✓
Gairn	Direct Defences & Storage in Gairn Catchment	Nine potential storage areas were shortlisted (Section 3.3.2) and would achieve a maximum storage volume of 7 million m^3. If this storage action was used in combination with direct defences no significant reduction in the height of direct defences is anticipated (for a 0.5% AEP SoP) and so the action was considered technically unfeasible.	×
Muick	Direct Defences & Storage in Muick Catchment	Six potential storage areas were shortlisted (Section 3.3.2) and would achieve a maximum storage volume of 5 million m^3. If this storage action was used in combination with direct defences a reduction in the height of direct defences of approximately 85mm is anticipated (for a 0.5% AEP SoP). This is not considered significant and so the action was considered technically unfeasible.	×

3.3.11.4 Direct Defences with Storage on Loch Muick

As described previously in Section 3.3.2, storage potential on Loch Muick was reviewed.

To determine the impact this would have on the height of direct defences, these flows were simulated in the hydraulic model. The results indicated that direct defences would be reduced by a maximum of 59mm at Ballater Caravan Park, with limited benefit realised upstream of the Dee/Muick confluence. Limited benefit would also be realised downstream and the action proved it would not help to reduce risk to outlying properties on the lower reach of the River Muick where there may be increased water levels post implementation of the flood defence scheme.

Table 3.13 - Summary of results of Direct Defences with Storage on Loch Muick

Watercourse	Action	Feasible?	Progress Action?
Muick	Direct Defences & Storage on Loch Muick	The results of the model simulation showed a maximum reduction in defence height of approximately 59mm which was not considered significant therefore the action was considered unfeasible.	×

3.3.11.5 Direct Defences with Diversion Route

As described in Section 3.3.3, the feasibility of a flow diversion route through Ballater was assessed. A model simulation was also completed for the defended 0.5% AEP event to determine if the height of direct defences may be reduced with inclusion of the diversion channel (as it would convey a small portion of the flood event flow). It was determined that the height of the defences may be reduced by an average of 250mm. This reduction in direct defence height was not considered significant for a return period of this magnitude and so the action was not progressed.

Table 3.14 - Summary of results of Direct Defences with Diversion Route

Flood Cell	Action	Feasible?	Progress Action?
1	Direct Defences & Diversion Route	The results of the model simulation showed an average reduction in defence height of approximately 250mm which was not considered significant therefore the action was not progressed further.	×

3.3.11.6 Direct Defences with River Dee Dredging

As discussed in Section 3.3.3, a model simulation was completed for a defended 0.5% AEP dredged event, where the modelled length of the River Dee was dredged by 1.5m. The results of the simulation showed a potential reduction of approximately 1.1m in the required height and 1.6km in the main required length of direct defences could be achieved.

Although the action has the potential to significantly reduce the height and length of the direct defences required for the scheme, the negative environmental impacts would be severe and would outweigh the potential benefits. Significant maintenance would be required to maintain the 1.5m depth and dredging the Dee would cause substantial geomorphic instability in the channel. These issues were considered insurmountable and so the action was considered unfeasible.

Table 3.15 - Summary of results of Direct Defences and River Dee Dredging

Flood Cell	Action	Feasible?	Progress Action?
1	Direct Defences & River Dee Dredging	The results of the model simulation showed a potential reduction of 1.1m in defence height and a reduction of 1.6km in defence length. However the severe negative impacts associated with dredging including channel instability, onerous maintenance and negative environmental impacts are considered to outweigh any potential benefits. As such the action as considered unfeasible.	×

3.3.11.7 Direct Defences with Additional Arch at Royal Bridge

Section 3.3.4 provides details on the analysis undertaken to demonstrate that Royal Bridge is not a significant restriction to flow during high return period flood events. It was noted in this section of the report that local residents believe an additional arch on the right bank at Royal Bridge may help to improve conveyance. As such a model simulation was completed to determine if an additional arch would provide a significant benefit, either through reduced height of direct defences or to reduce the impact of scouring around the piers of Royal Bridge.

Table 7.21, found in Appendix D, shows the maximum modelled water levels for the 0.5% AEP defended plus additional arch scenario compared against the 0.5% AEP defended scenario. The model results show that the water levels are largely similar between the two scenarios. The greatest difference in water level is observed at cross-section RD.093, immediately upstream of Royal Bridge, where there is a local reduction of 320mm with the additional arch. This local reduction however is not considered significant for a flood event of this magnitude.

When interrogating flows in the hydraulic model, it was found that in the additional arch scenario the in-channel flows at Royal Bridge are reduced by approximately 5% which brings them in-line with the flows observed in the undefended 0.5% AEP scenario. Therefore although the additional arch would not provide a significant reduction in the height of the direct defences it would convey the additional flow which bypasses the bridge in the undefended 0.5% AEP event. As such implementation of this measure may avoid an increase in pressure on Royal Bridge and reduce the potential for scour. Consequently, as this action would not provide a significant reduction in the height of direct defences, it is not progressed to form part of an option. However, it is recommended that this is considered during future phases of the project due to its potential to reduce scour and erosional processes in the vicinity of Royal Bridge.

Table 3.16 - Summary of results of Direct Defences with Additional Arch at Royal Bridge

Flood Cell	Action	Feasible?	Progress Action?
1	Direct Defences & Additional Arch at Royal Bridge	The results of the model simulation showed no significant reduction in the height of the direct defences. However the additional arch would convey the small percentage increase in flow at Royal Bridge as a result of the direct defences.	×

3.3.12 Assessment of Conveyance at Royal Bridge with Direct Defences

This section of the report describes the flooding mechanisms occurring in the vicinity of Royal Bridge. The hydraulic model was interrogated for a 0.5% AEP design scenario to gain a full understanding of how flood flows are conveyed in this stretch of the River Dee. Conveyance along the reach is also interrogated for the 0.5% AEP defended scenario. This allows comparisons to be made between the undefended and defended simulations and determine the effects implementation of direct defences may have on the river channel or on Royal Bridge. Full details of the direct defences used in the defended scenario may be found in Section 3.3.5.

<u>Conveyance around Royal Bridge during a 0.5% AEP event</u>

As described previously in Section 2.1, during a 0.5% AEP flood event, a significant area of Ballater town is inundated by flood waters due to insufficient channel capacity in the Dee upstream of and adjacent to Ballater Golf Course. Flood waters emanating from these areas travel via overland flow affecting properties in Ballater which are located upstream of Royal Bridge. A large proportion of this 'out of bank' flow in the 2D area discharges back into the River Dee at Dee Street, upstream of Royal Bridge, with only approximately 65m^3/s of flow bypassing Royal Bridge through Ballater town on the left-hand bank. This bypassing flow is equivalent to approximately 5% of the total flow which passes Royal Bridge during this flood event. Therefore during a 0.5% AEP event (undefended), approximately 95% of the flow passing Royal Bridge remains in channel (within the 1D model domain). Figure 3.27 shows a screenshot taken from the hydraulic model with vector arrows showing the direction of flow. In this image, vector arrows are only displayed for flows greater than 0.5m^3/s. Larger red arrows along the left bank upstream of Royal Bridge indicate the predominant flow paths from the 2D model domain into the 1D model domain (river channel).

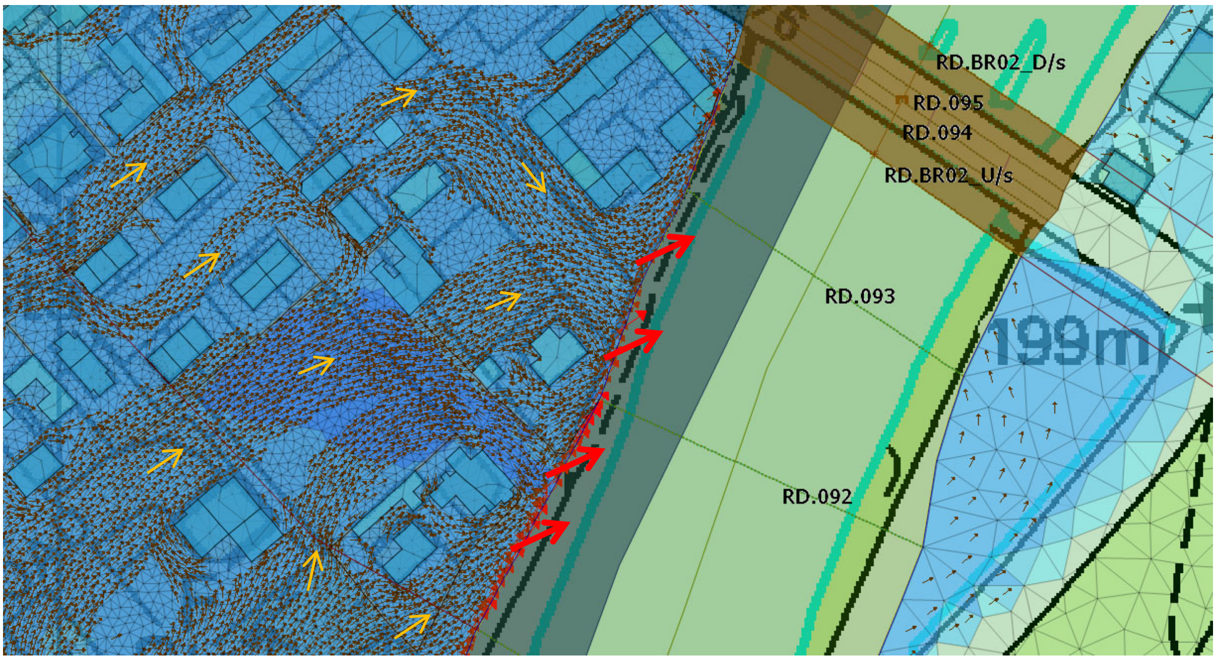

Figure 3.27 - Vector arrows show direction of flow in hydraulic model during the 0.5% AEP event

Figure 3.28 shows a screenshot of an overview of the hydraulic model with vector flow arrows. This illustrates the large transfer of flow from the 2D floodplain into the 1D channel along a long section of the left bank upstream of Royal Bridge (red arrows). It also identifies where flood water leaves the river channel and flows onto the floodplain (green arrows).

It is also useful to note that in the 0.5% AEP event, downstream of Royal Bridge in the floodplain on the right bank of the Dee, flows reach approximately 300m^3/s (modelled cross-section RD.101). Whereas flows in the floodplain on the left bank (Pannanich Road area) flows are much lower, reaching a maximum of approximately 38m^3/s. Although the floodplain on the left bank appears large in size, the flow at this point is equivalent to less than 3% of the total flow at this cross-section. Therefore more than 97% of the flow at this point in the undefended scenario is already conveyed within the Dee channel or through the floodplain on the right bank.

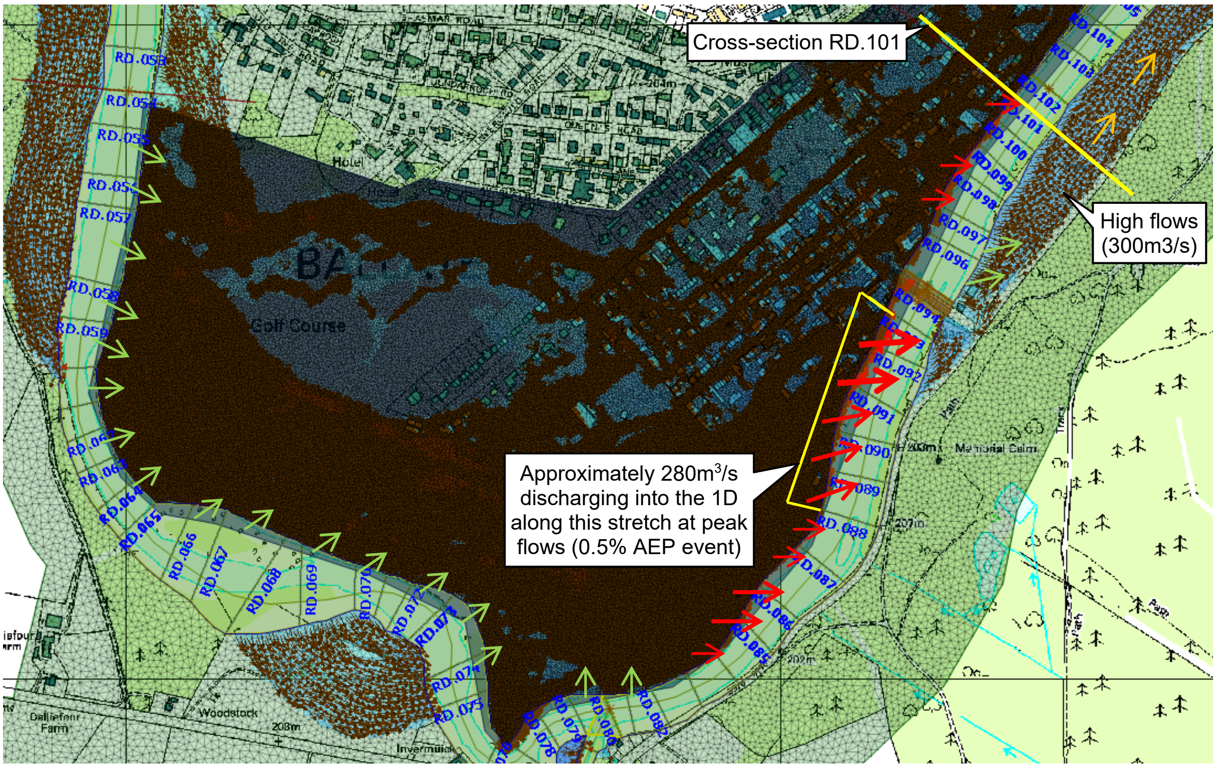

Figure 3.28 – Screenshot showing overview of hydraulic model with vector flow arrows

<u>Conveyance at Royal Bridge with Direct defences</u>

Implementation of a flood alleviation scheme would remove the flooding mechanisms through the town (for the specified standard of protection), resulting in an increase in the flow conveyed via the channel through Royal Bridge. A review was undertaken to determine how water levels and flows would be impacted in the vicinity of Royal Bridge through the incorporation of the defended scenario into the hydraulic model.

In the defended scenario at Royal Bridge, in channel flows are increased by approximately 5% and velocities are also increased by approximately 2%. A small increase in water levels at the bridge is also observed (approximately 90mm or 0.05%) however this increase is not considered significant. Table

7.21 found in Appendix D, shows the maximum modelled water levels from cross-section RD.055 to cross-section RD.130. The table shows the difference and percentage difference in water level at each cross-section between the undefended and defended scenarios. The table shows that overall there is generally a small increase in water levels from the undefended to the defended scenario.

Figure 3.29 shows a comparison of the discharge hydrographs at Royal Bridge (modelled cross-section RD.BR02.U/s) for the undefended and defended scenarios. For the undefended scenario, the hydrographs are presented for both 1D (blue line) and 2D (purple line) flow at this location. The 1D and 2D flows for this undefended scenario have also been summed (green line) and shown on the figure to clearly illustrate any changes in flows from the undefended to the defended scenario. The 1D flow at this cross-section for the defended scenario was also plotted (yellow line). As there is no 2D flow on the left bank floodplain in the defended scenario, the undefended 1D-2D flow is compared with the defended 1D flow. In Figure 3.29, the hydrograph for the defended scenario (yellow line) sits below the hydrograph for the summed 1D-2D undefended scenario (green line) and as the difference in flows is negligible between the two scenarios, the yellow line is almost entirely overlain by the green line. Small differences in flows are noted around the peak of the hydrographs however this may be due to minor instabilities in the hydraulic model around the time of the peak flows in the undefended simulation.

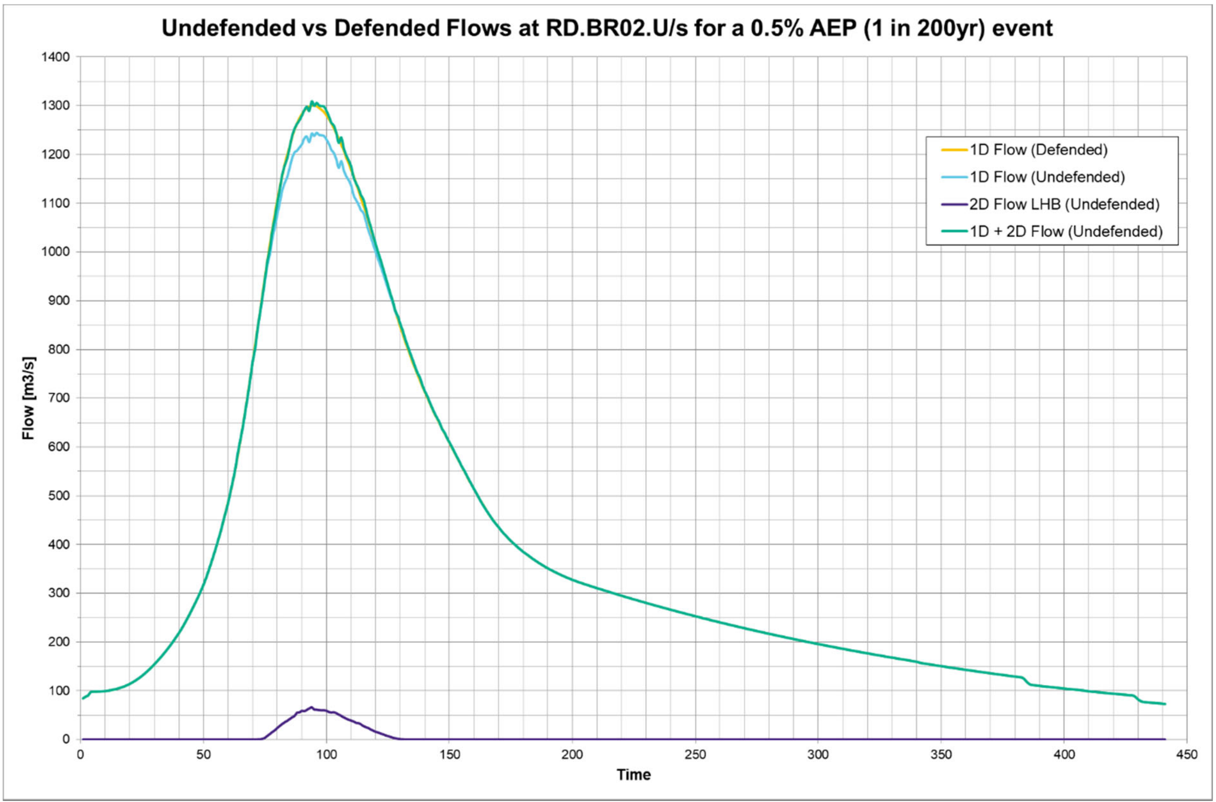

Figure 3.29 - Undefended vs Defended flow at Royal Bridge

Consultation with Innovyze

RPS have liaised with Innovyze (hydraulic model software providers) regarding the representation of Royal Bridge within the hydraulic model who have confirmed that the bridge is being represented correctly. Innovyze confirmed that as the channel at the bridge is very wide and the bridge openings are wide with only minimal obstruction to flow, headloss at the bridge is not expected to be significant until the openings are fully submerged. From review of the modelled 0.1% AEP event, it was found that the peak water level at the bridge would not reach the soffit level of the bridge and therefore the openings would not be fully submerged even during a 0.1% AEP flood event.

Summary of Conveyance at Royal Bridge

Overall, as approximately 95% of the flow at Royal Bridge is already conveyed through the bridge during the undefended 0.5% AEP event, the conveyance of any additional flow through Royal Bridge due to implementation of direct defences is not expected to cause any significant additional increase in discharge or water levels (as a consequence of increased velocities at the bridge). It is however recommended that investigations into potential for scour and erosion should be carried out at outline design stage. This recommendation and others are included in Section 6 of this report.

3.4 BASELINE NFM ASSESSMENT

A baseline NFM assessment has been undertaken to identify where opportunities to restore or enhance natural processes may benefit flood risk. In accordance with current guidance, the elements included in the assessment are:

- Catchment Characterisation
- Long listing of measures

3.4.1 Catchment Characterisation

The purpose of characterising the catchment area is to develop an understanding of how the catchment currently operates under flood conditions and the areas of the catchment that contribute most to flooding. The available information to assist with this process within the study area is as follows:

- Ballater Flood Protection Scheme – Hydrology Report (RPS)
- Natural Flood Management maps (SEPA)
- Land Cover Map 2007 (Centre for Ecology & Hydrology)

Ballater Flood Protection Scheme – Hydrology Report (RPS)

The main Study catchments are shown in Figure 3.30 including the major tributary catchments; the River Muick and the River Gairn.

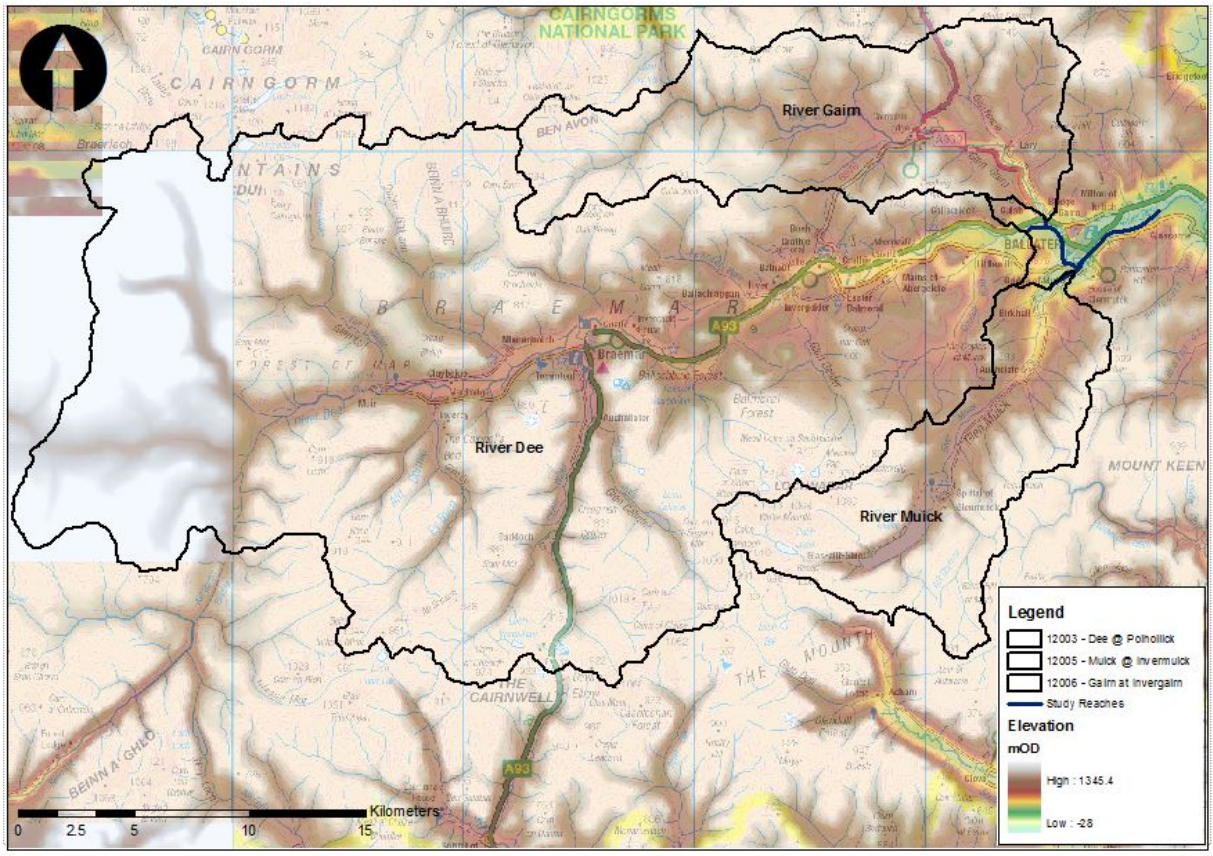

Figure 3.30 – Main Study Catchments

The **Dee catchment** (Figure 3.31) rises in the mountainous region of the Cairngorms national park and has very steep upper reaches. The Dee meanders through hilly terrain draining tributary catchments to the north and south before reaching Ballater. The National River Flow Archive describes the catchment at Dee as being upland with mountainous headwaters, which are snowy in winter. The bedrock of the catchment is composed of Dalradian and Moinian metamorphics with basic intrusions. The bedrock is predominantly classified as low permeability (95%) with mixed superficial deposits. The land use is predominantly mountain / heath / bog (85%) with some woodland (8%) and grassland (7%). The NRFA website states that there have been no known significant catchment changes.

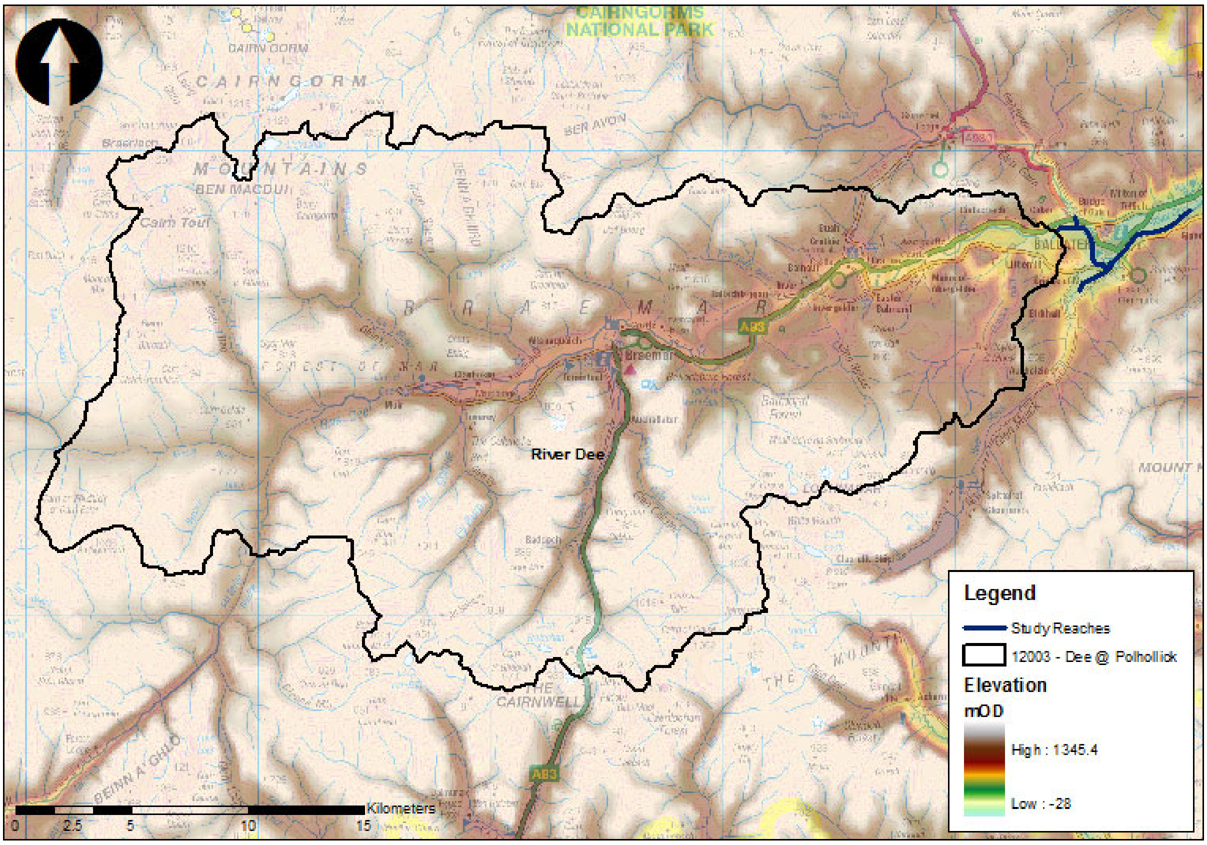

Figure 3.31 – The River Dee Catchment

The **River Muick catchment** (Figure 3.32) drains the area of Glen Muick located in the mountainous area of the Cairngorms to the south west of Ballater. Similar to the Dee catchment, the National River Flow Archives describes the catchment to the Muick gauging station near the confluence with the Dee as being upland with mountainous headwaters, which is often snowy in winter. The bedrock is described as Dalradian intrusive basics with more than half overlain by superficial deposits. The bedrock is classified entirely as low permeability. The land use is predominantly mountain / heath / bog (82%) with some woodland (9%) and grassland (8%). The only known changes to the catchment would be developed forestry operations. At the head of Glen Muick is a large natural loch called Loch Muick. The surface area of the loch is large (>2km^2) and although the loch is located in the upper catchment, meaning much of the catchment does not drain through it, it is expected that it would have some attenuating effect on flood flows.

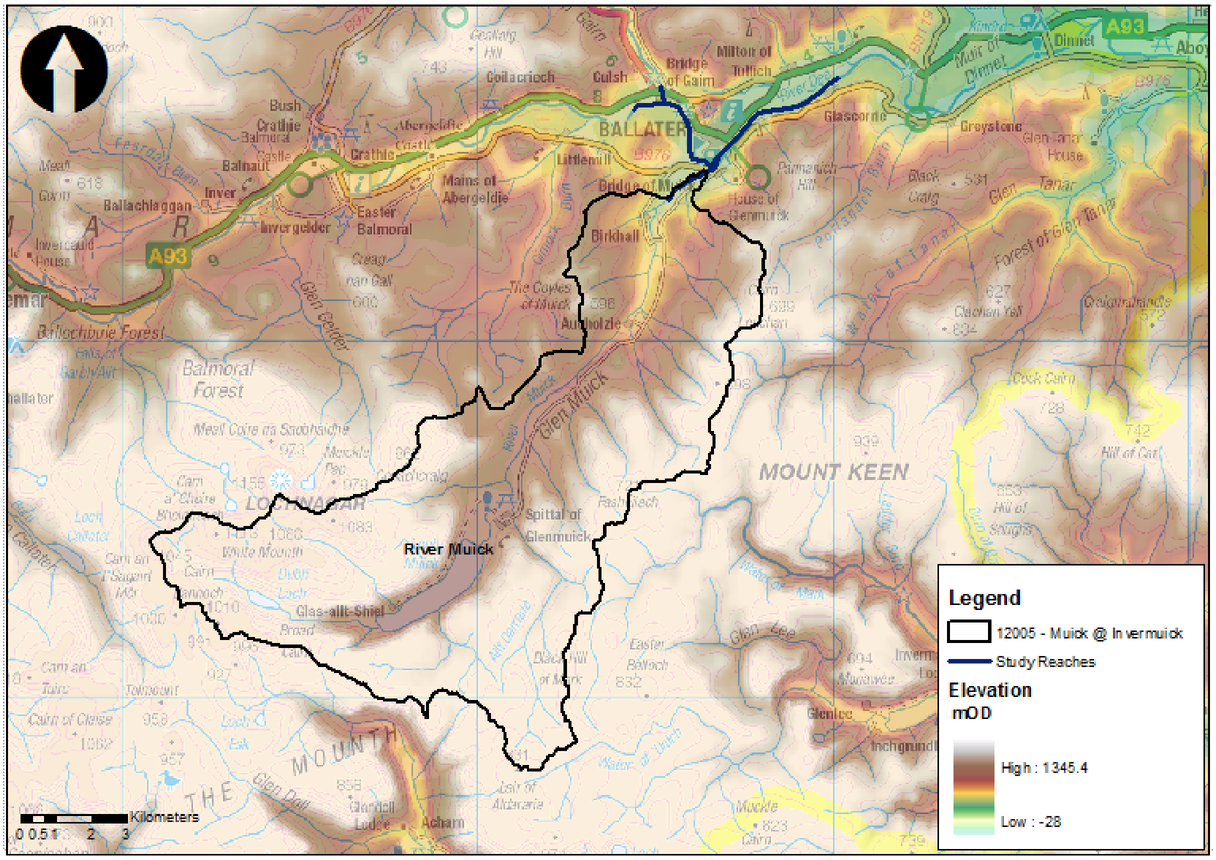

Figure 3.32 – The River Muick Catchment

The **River Gairn catchment** (Figure 3.33) drains the area of Glen Gairn located in the mountainous area of the Cairngorms to the north west of Ballater. As with the previous two gauges, the National River Flow Archives describes the Gairn catchment as being upland with mountainous headwaters often snowy in winter. The bedrock is described as having some Dalradian metamorphics but it is mainly granite intrusive. Half of catchment is also overlain by superficial deposits. The bedrock is classified entirely as low permeability. The land use is predominantly mountain / heath / bog (86%) with some grassland (12%) and a small degree of woodland (2%). The NRFA website states that there have been no known significant catchment changes.

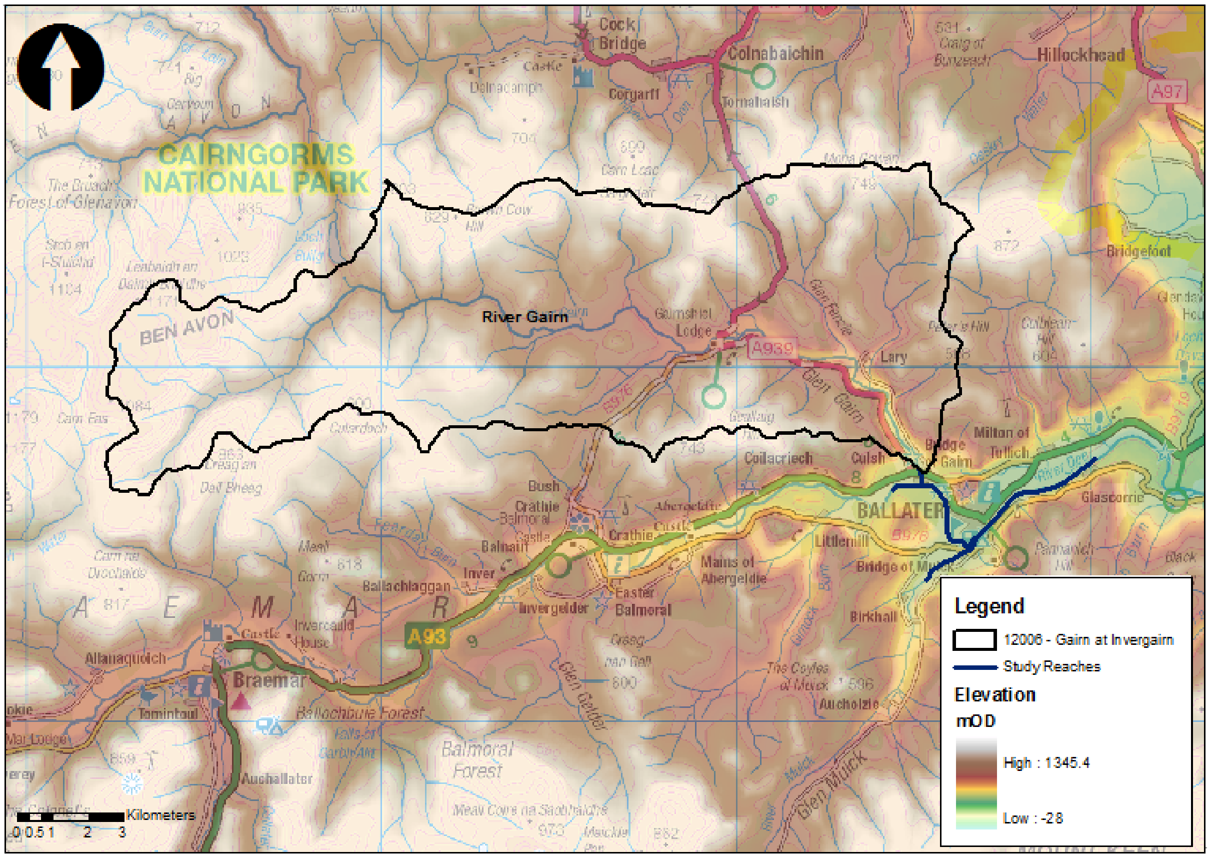

Figure 3.33 – The River Gairn Catchment

The main catchment descriptors for the three rivers upstream of Ballater are presented in Table 3.17. The catchment descriptor URBEXT2000 describing the urbanisation within the catchment has not been presented here despite the effect it may have on flood flows. This is because the URBEXT2000 values are all very low (<0.0007) meaning the catchments may all be treated as entirely rural.

Table 3.17 – Summary of Main Catchment Descriptors

Catchment	Area (km^2)	SAAR (mm)	PROPWET	DPSBAR (m/km)	BFIHOST	FARL
Dee	690	1231	0.68	219.5	0.459	0.986
Muick	107	1244	0.68	188.6	0.512	0.896
Gairn	146	1048	0.64	180	0.452	0.997

As can be seen from the table the catchments have all largely got similar catchment descriptors. The Gairn is a slightly drier catchment based on the latest full meteorological period for SAAR (1961-90) however it is noted on the NRFA website that the rainfall values may be underestimated. All three catchments can be described as steep with moderate to moderate/low baseflow index values suggesting that the catchments would be expected to be flashy. The Muick catchment has a FARL value significantly lower than 1 reflecting the significant attenuation feature (Loch Muick) within the catchment.

SEPA Natural Flood Management Maps

The natural flood management (NFM) maps (http://map.sepa.org.uk/floodmap/map.htm) identify areas where the alteration or restoration of natural features could be most effective in storing or slowing the flow of water, or in managing in stream sediment. A total of five maps are available that identify opportunity areas for a set of different NFM techniques. Each map provides a high level assessment of areas within catchments where the implementation of NFM could be most effective and merit further investigation. The runoff reduction map is discussed below, the floodplain storage and sediment management maps are discussed in Section 3.4.2.4 and Section 3.4.2.8 of this report respectively. The other two maps (Estuarine surge attenuation and wave energy dissipation) are not applicable to Ballater.

The Runoff reduction map indicates the areas shown in Figure 3.34, identified as having predominantly medium potential. Due to the high level nature of the assessment used to generate the SEPA Maps, site specific datasets (such as those reviewed below) can be considered to be of more benefit in identifying potential areas for NFM.

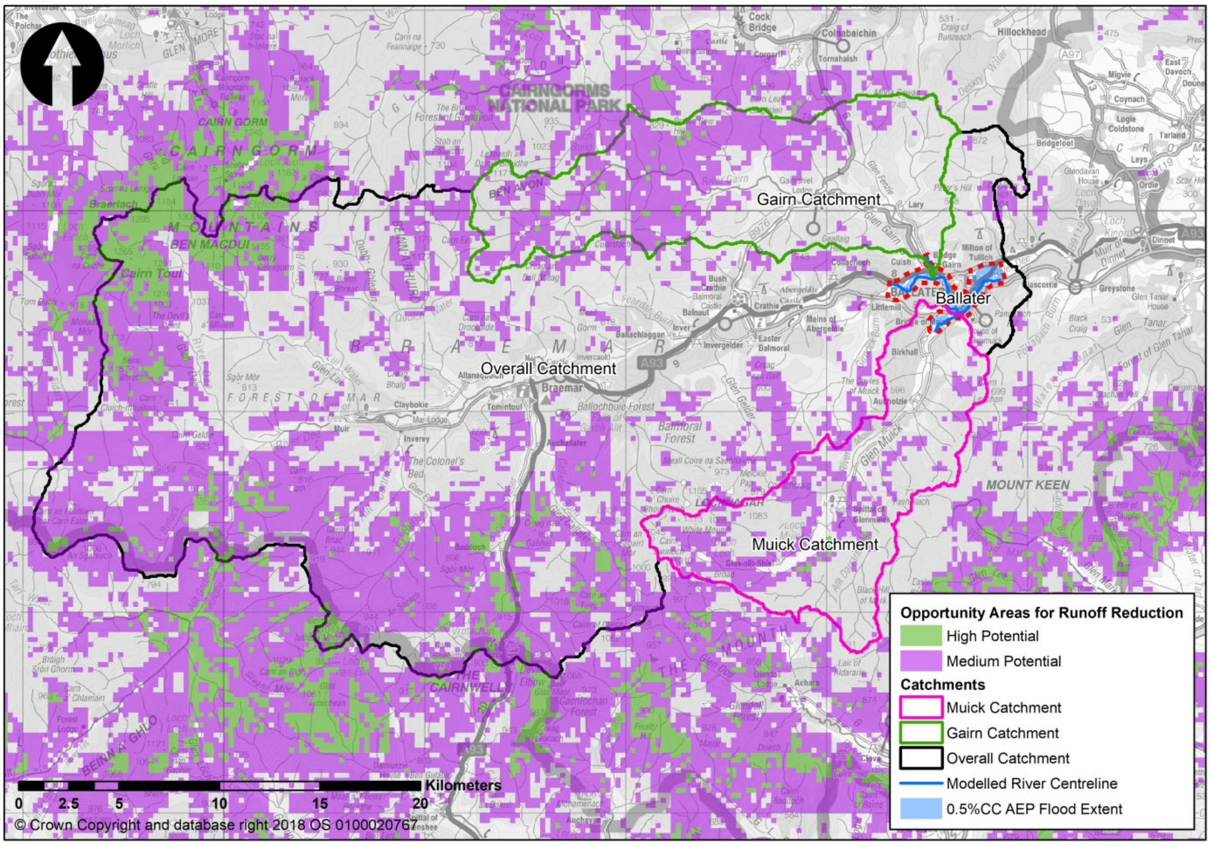

Figure 3.34 – Opportunity Areas for Runoff Reduction

<u>Land Cover / Land Use</u>

Figure 3.35 shows the land cover / land use mapping for the Ballater catchments. This shows that the majority of the River Dee catchment is Montane Habitats and heather, with some bog areas on the upper reaches of the catchment. Along the river corridor, especially in the middle to lower reaches of the Dee catchment is predominantly coniferous woodland. The Gairn catchment is predominantly heather, bog and montane habitats, with some acid grassland. The Muick catchment comprises predominantly of heather grassland and montane habitats.

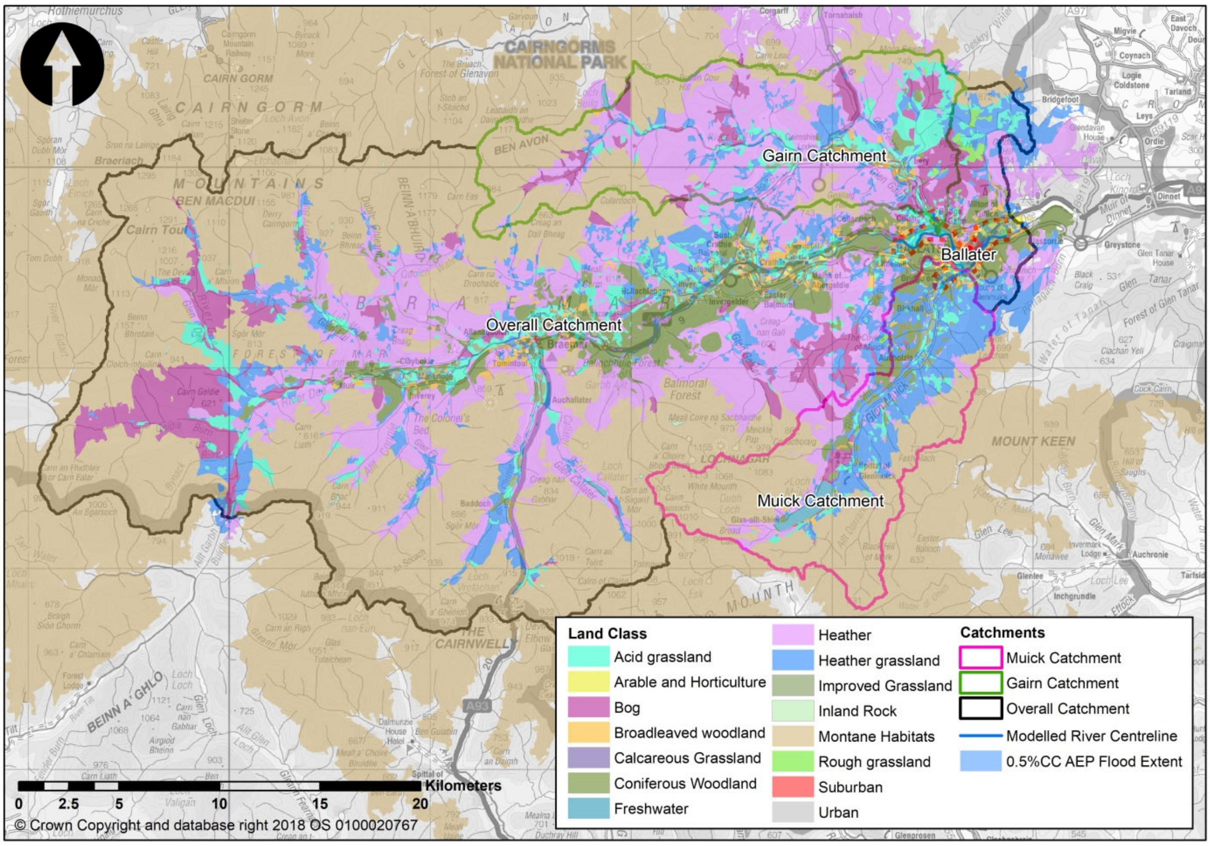

Figure 3.35 – Land Cover / Land Use Map

3.4.2 Long Listing of Measures

In addition to the information discussed in Section 3.3, a review of the following projects, studies and datasets was carried out:

- Historical Mapping
- Dee Catchment Partnership Assessment (2018)
- Cairngorms National Park Woodland Expansion Target Area (Forestry Commission)
- Interrogation of the study's hydraulic model
- "SEPA's Natural Flood Management: Opportunity Areas for Floodplain Storage" dataset;
- "Physical Restoration Options to address morphology and flood pressures on the River Dee – A Pilot Study report" (cbec / SEPA, 2013)
- "Ballater Flood Protection Scheme – Geomorphic Process Model and Review of Morphological Impacts" (RPS / cbec, 2017).

3.4.2.1 Historical Mapping

A review of historical mapping 'OS One Inch, 1885-1900' was undertaken in order to identify any changes in watercourse route in the catchment upstream of Ballater, however no significant changes were found. This is supported by the NRFA website which states that there have been no known significant catchment changes.

3.4.2.2 Dee Catchment Partnership Assessment (2018):

Figure 3.36 was provided to Aberdeenshire Council summarising work undertaken by the Dee Catchment Partnership in 2018. This indicates areas where there is potential for delivery of green engineering, leaky barriers, floodplain reconnection, tree planting and woody debris. The site identified for floodplain reconnection is assessed within Section 3.4.2.4 of this report, as is floodplain storage (which is excluded from the Dee Catchment Partnership Assessment). Information on the areas identified for green engineering, leaky barriers, tree planting and woody debris will be beneficial in the future when detailed analysis is undertaken to identify specific sites for NFM.

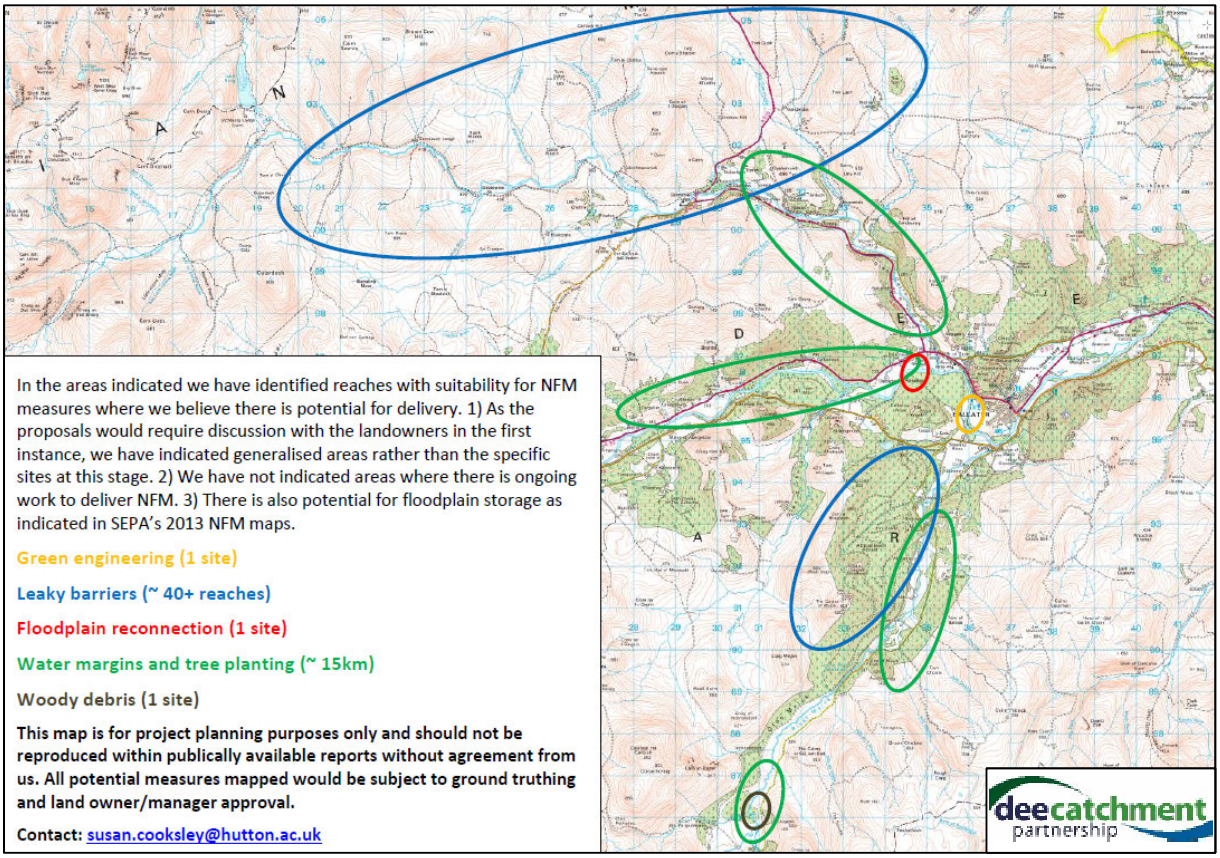

Figure 3.36 – Dee Catchment Partnership identification of areas suitable for NFM

3.4.2.3 Cairngorms National Park Woodland Expansion Target Area

This dataset identifies the areas shown in Figure 3.37 as being part of the Woodland Expansion Target area. A review of the information discussed in Section 3.4.1 was undertaken in order to identify the areas most likely to benefit from NFM. The River Muick and Upper River Dee catchments were selected for implementation of NFM measures as they contribute the majority of flows and have a less flashy flood response than the River Gairn. If flows were slowed in these catchments it may be possible to desynchronise the overall catchment flood response.

The dataset shows that there is a potential to plant 60% of the Upper Dee catchment and 58% of the Muick catchment.

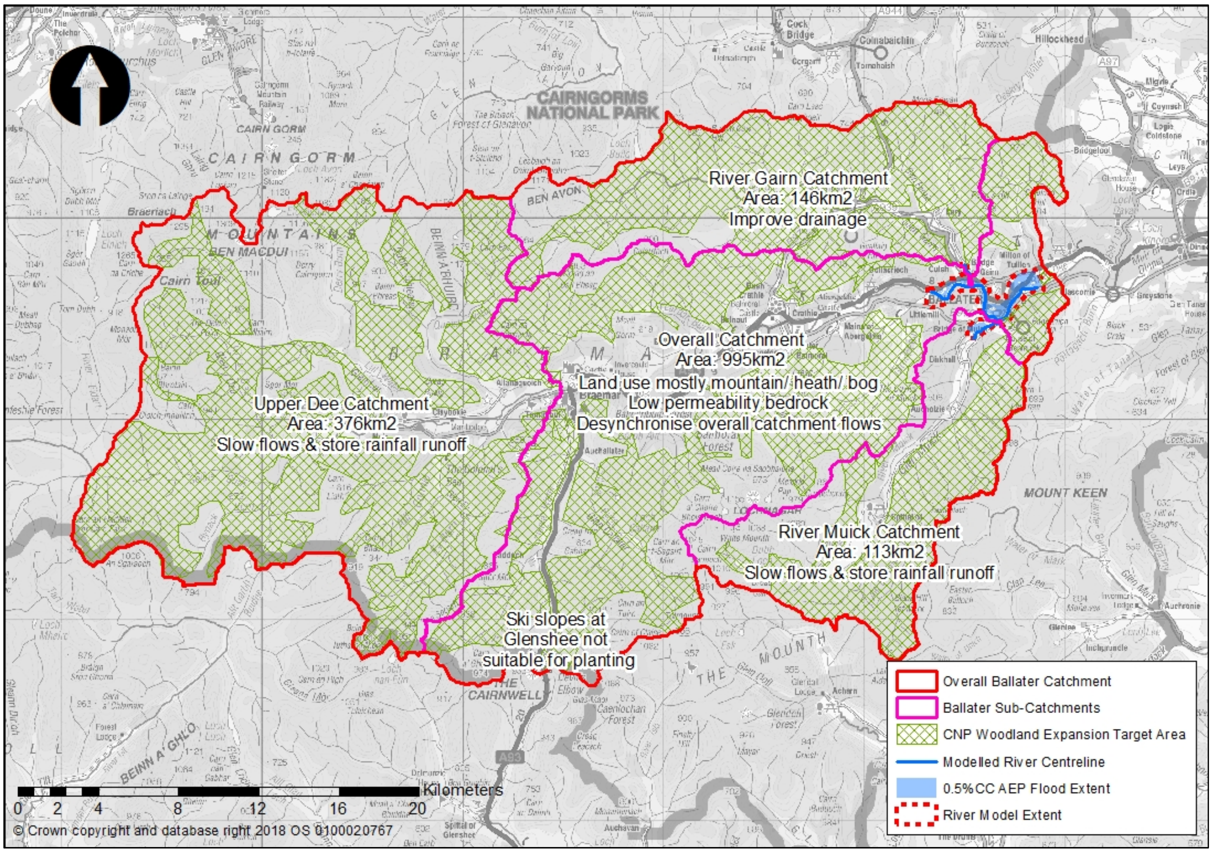

Figure 3.37 – CNP Woodland Expansion Area

3.4.2.4 Hydraulic model & SEPA online flood maps

From review of the hydraulic model and SEPA's online flood maps, areas of potential for planting of floodplain woodland were identified. These are illustrated in the NFM Assessment Map in Appendix H Potential areas for floodplain reconnection were also identified through review of the hydraulic model and aerial photography. This is discussed in conjunction with the review of "Ballater Flood Protection Scheme – Geomorphic Process Model and Review of Morphological Impacts" (RPS / cbec, 2017).

3.4.2.5 Physical Restoration Options to address morphology and flood pressures on the River Dee – A Pilot Study report (cbec / SEPA, 2013)

This report assesses NFM potential for two broad categories of measures: floodplain reconnection measures and out-of-floodplain land use and drainage re-naturalisation measures.

The key findings of this report were:

- There is a very low degree of confidence in the absolute values of flow attenuation. The results are of limited value for determining the actual benefit to vulnerable areas or for assessing the benefits of the measures relative to other flood management measures. It recommends more detailed hydraulic modelling at sites where favourable measures have been identified in order to provide greater understanding of the absolute NFM benefit. All of the floodplain reconnection measures identified in this report are located downstream of Ballater.

- Table 3.6 in the 2013 report identifies predicted decreases in flow resulting from water body re-naturalisation. For the waterbodies nearest to Ballater, the River Gairn (upper catchment) was predicted to reduce by 0.3% and the River Muick by -0.1%. The greatest predicted percentage reduction of flow at Culter (near to the tidal limit of the Dee, downstream of Ballater) resulting from land use re-naturalisation in any single water body was 0.59 %, indicating that even when undertaken at the scale of a water body, land use changes are unlikely to result in a significant reduction in flood peaks at the catchment scale. Re-naturalising land cover in all headwater water bodies resulted in a 1.74% flow reduction at Culter, which is also unlikely to be of significant benefit to flood risk. Figure 3.38 shows the results of the modelled influence of land cover and drainage re-naturalisation.

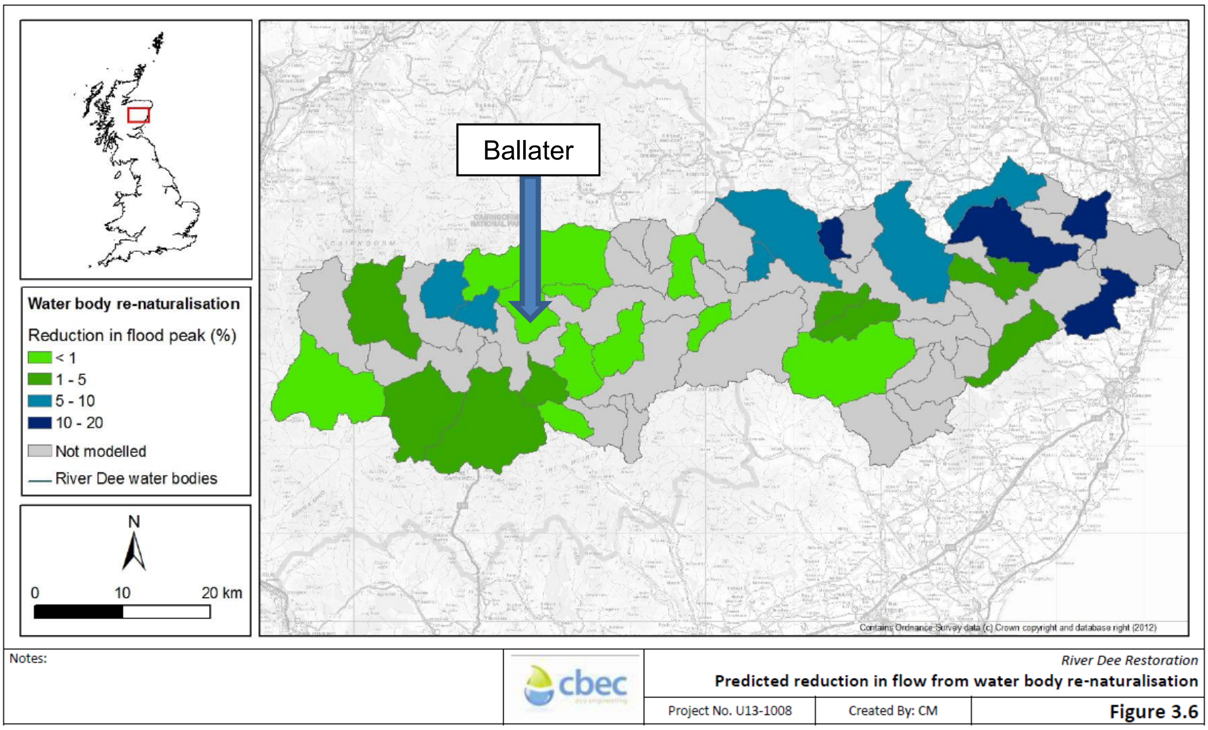

Figure 3.38 –Predicted reduction in flow from water body re-naturalisation (cbec, 2013)

3.4.2.6 Ballater Flood Protection Scheme – Geomorphic Process Model and Review of Morphological Impacts (RPS / cbec, 2017)

A key finding of this report, regarding floodplain storage, is that the left bank floodplain immediately upstream of the River Gairn confluence, offers a potential opportunity for the installation of set-back embankments, to retain water within this area during flood events, as a form of Natural Flood Management. It recommends that the River Dee is allowed to utilise old channels in the left bank floodplain (adjacent to the Golf Course) and adjacent right bank floodplain area during periods of high flow, it will likely reduce strain on the left bank immediately upstream of this area.

The key findings of this report, regarding sediment management, were:

- The section of River Dee bordering Ballater Golf Course scored the highest of all sections of river surveyed, in terms of potential for future change.
- The channel in the vicinity of the Red Brae and surrounding area, is dominated by erosional processes.
- Significant embankments along the left bank of the River Dee around Ballater Golf Course, disconnect the river from its natural floodplain. During flood events, the confined flow puts significant strain on the river banks (and the associated embankments) in this area. These structures can eventually breach, resulting in significant flooding to the Golf Course and, in very large flood events, Ballater itself (as occurred during Storm Frank).
- The left bank floodplain immediately upstream of the River Gairn confluence, offers a potential opportunity for the installation of set-back embankments, to retain water within this area during flood events, as a form of Natural Flood Management.

The report also made the following recommendations:

- Sediment transport (i.e. morphodynamic) modelling should be undertaken along the section of the River Dee upstream of the Red Brae, extending downstream towards the meander bend by the sewage works.
- Consideration should be given to allowing the river to utilise old channels in the left bank floodplain (adjacent to the Golf Course) and adjacent right bank floodplain area during periods of high flow. This has also been highlighted in the overall NFM catchment map located in Appendix H.

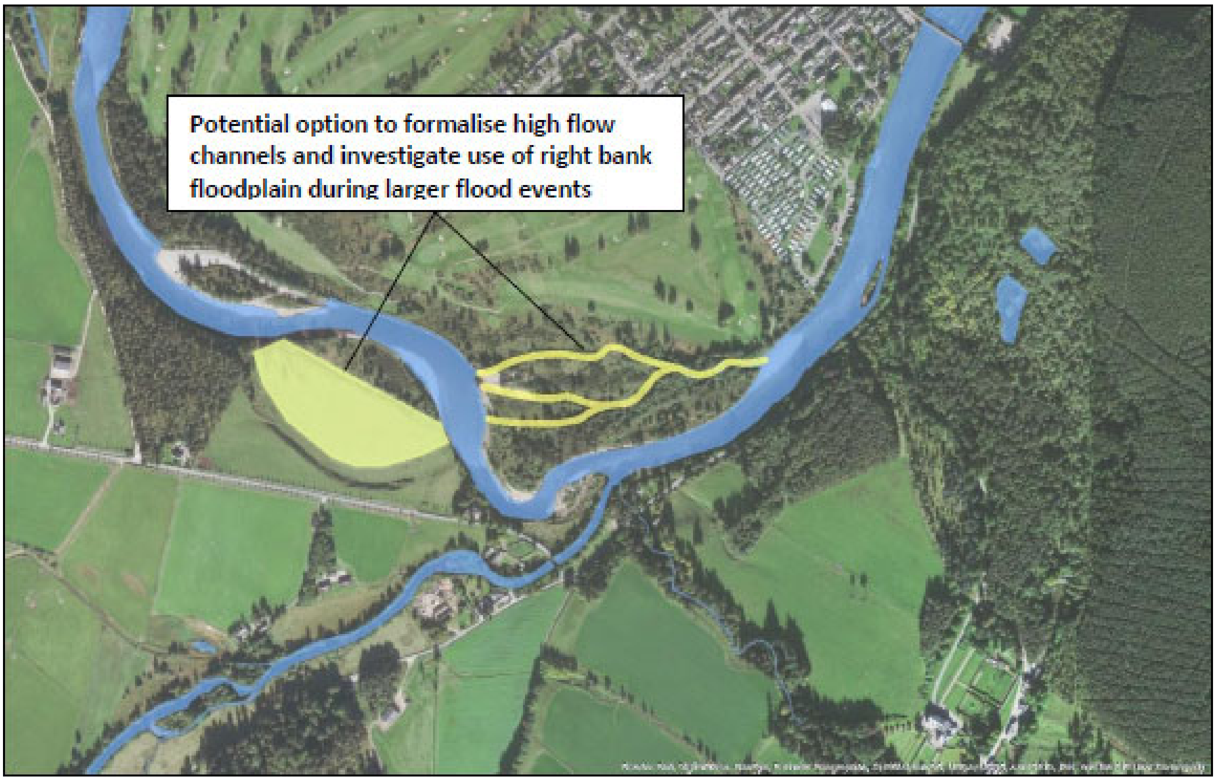

Figure 3.39 - Potential to utilise old channels in the left bank floodplain of the River Dee (cbec, 2017)

- Investigation into the potential use of the left bank floodplain (upstream of the River Gairn) during flood events should be undertaken, to assess the feasibility and benefit of this option. This area is highlighted Figure 4.2 in the cbec report, and is repeated here as Figure 3.40 for reference.

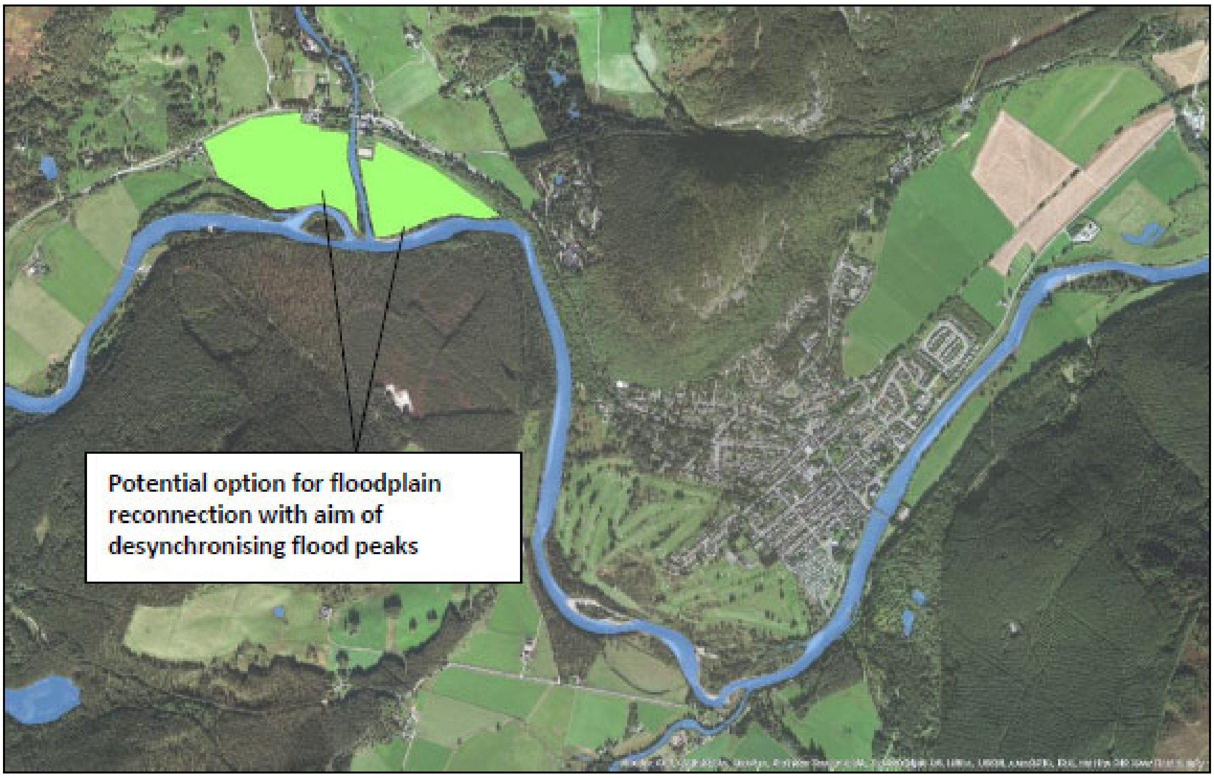

Figure 3.40 – Potential for reconnection of left bank floodplain on Dee at confluence with the River Gairn (cbec, 2017)

3.4.2.7 NFUS Sediment and Flood Risk Report (2017)

The amount of sediment coming into the River Dee at Ballater from upstream is likely to be relatively low for a river of this size. This is principally due to variations in the slope of the river upstream which means that a lot of the sediment coming from the upper catchment does not reach Ballater. The river is however still subject to very high flows at Ballater, which generate the energy to erode and transport sediment. The combination of high flows and relatively low sediment input in this part of the river means that overall there is erosion. This has probably been exacerbated by the occurrence of several very high flows in recent years. It is notable in this case that despite there being overall erosion there has clearly also been localised deposition. The deposition has occurred in large sections of the river and as such has no bearing on flood risk. Removal of this sediment would make no appreciable difference to flood risk.

3.4.2.8 SEPA Flood Maps (2015)

These include the first national natural flood management maps in Scotland showing the areas where natural techniques to help reduce flood risk could be most effective. The mapping which identifies opportunity areas for sediment management were produced by a high level assessment (nationwide sediment transport assessment (STREAM)) to identify areas where the alteration or restoration of natural features could be most effective in managing in stream sediment and merit further investigation.

Figure 3.41 identifies the opportunity areas for sediment management in Ballater, based on the SEPA sediment management flood maps.

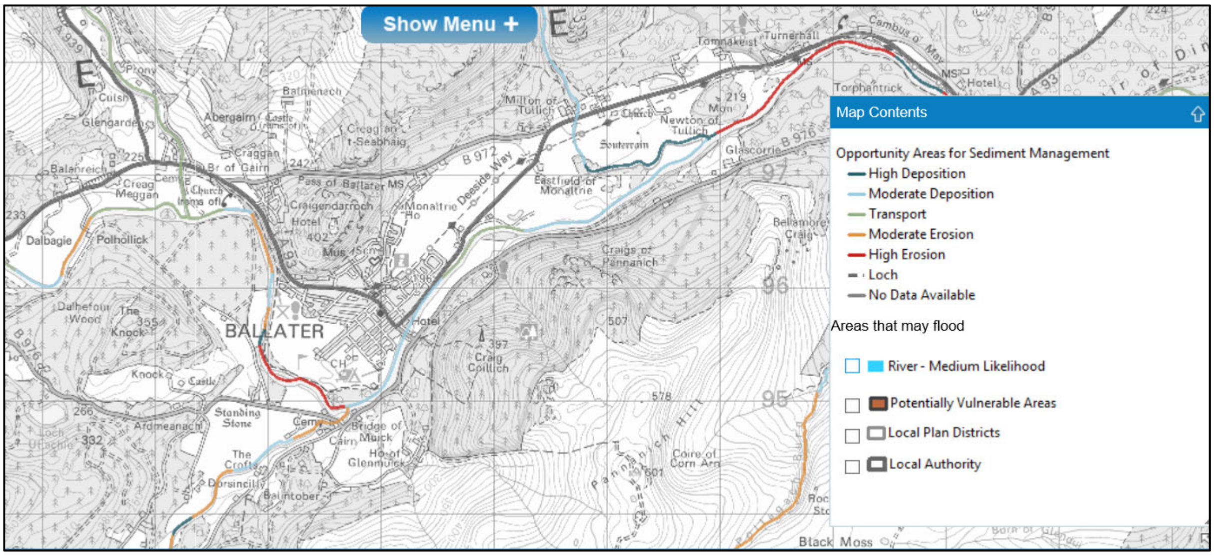

Figure 3.41 – Opportunity Areas for Sediment Management in Ballater (SEPA Flood Maps)

Due to the high level nature of the assessment used to generate the SEPA Flood Maps, site specific studies (such as the SEPA 2017 report and cbec 2018 report) can be considered to better reflect the sediment transportation mechanisms within the study area. In the SEPA 2017 report, it was concluded that sediment input to the River Dee at Ballater is naturally low and that sediment was not related to flooding in this reach. Therefore there is not an evidence base to support sediment management measures being taken forward as part of a flood alleviation scheme. The cbec 2018 report states that given the observed and predicted future geomorphic instability in the vicinity of Ballater, developing hydraulic models to assess flood risk based solely on the current channel configuration is deemed to possess limited value and recommends additional morphodynamic modelling to:

- Allow for a sufficiently detailed assessment of the impacts of erosion and deposition in the Red Brae to River Muick area;
- Reduce uncertainty regarding the dominant processes in the section of channel immediately downstream of Ballater Bridge;
- Predict how the river will react during future flood events (and inform design of future flood alleviation works).

3.4.2.9 Identification of potential NFM measures

Based on the characteristics of the catchment as described in the previous section a long list of potential NFM measures were identified. Actions that would reduce runoff, attenuate flow and manage sediment were considered. Building on the data from previous studies and analysing datasets including, OS mapping, Aerial Photography, DTM, Land Cover Mapping, Wetland's Inventory, NFM Opportunity Mapping and Potential for Woodland Creation the Ballater Catchment was assessed for identification of NFM opportunities. The NFM measures which were identified as potentially being suitable for the catchments influencing Ballater are:

- Non-Floodplain Wetland Enhancement
- Drainage Modification
- Land Use Management Techniques
- Catchment Woodlands
- Instream Structures
- Floodplain Woodlands

The main output of this section is a map with potential NFM opportunities identified within the catchment included on it. This can be found in Appendix H of this report. The following describes how NFM opportunities were identified.

Non-Floodplain Wetland Enhancement: While the Wetland Inventory data identifies a large proportion of the upper catchment as wetland area not all of it would be suitable for restoration or enhancement. A review of the wetland areas was carried out using the datasets above. Areas which naturally store water in ponds and relatively flat areas were identified as having potential for enhancement measures. Creation of scrapes or small earth bunds and disconnecting the outgoing drainage paths could increase the attenuation capacity of these areas and contribute to runoff reduction. Figure 3.42 which refers to Image 1 in the NFM opportunities map in Appendix H, shows an example of a wetland area in the Ballater Catchment which may be suitable for Non-Floodplain Wetland measures. Enhancing these wetland areas could also contribute to other benefits such as reducing the amount of sediment that reaches the watercourses and providing a productive ecosystem.

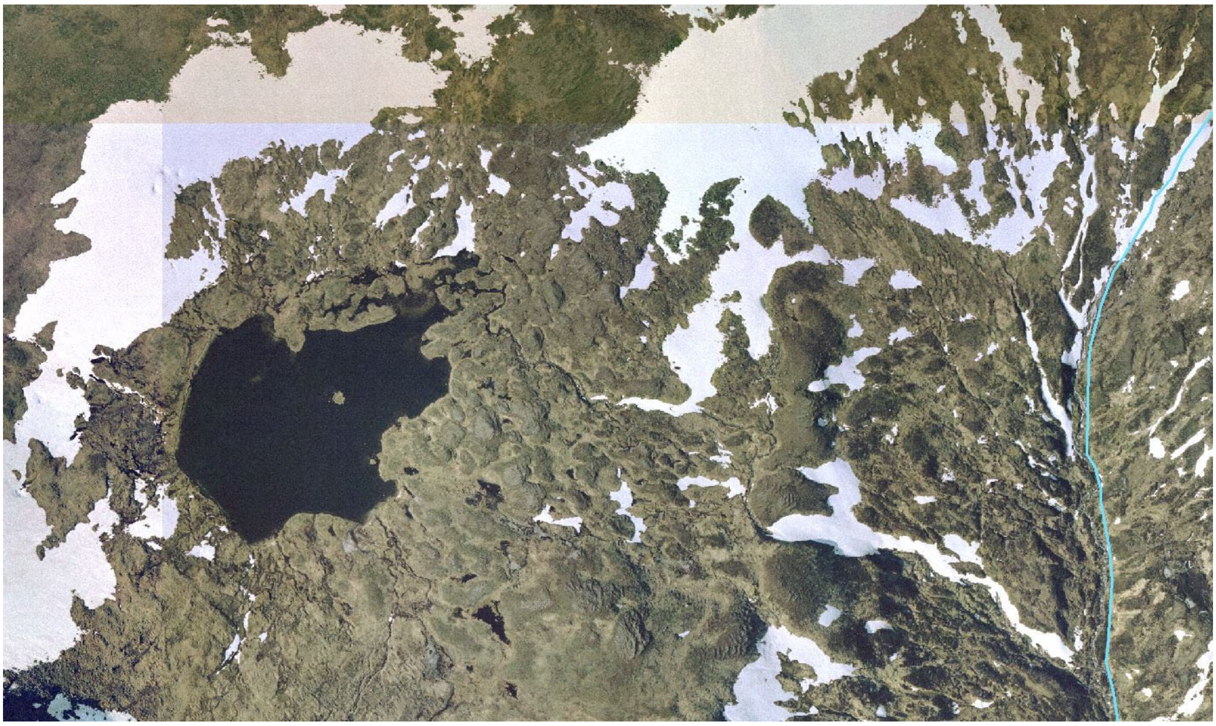

Figure 3.42 - Wetland area example (Aberdeenshire Council 2008)

Drainage Modification: The majority of the Ballater Catchment remains in its natural state, i.e. it has not been modified through improved drainage in order to farm the land. There are however many areas within the mountainous landscape where drainage paths have developed over time (see Figure 3.43

which refers to Image 2 in the NFM opportunities map in Appendix H) and have the effect of increasing the runoff within the catchment. Drainage modification measures could therefore be implemented in these areas to slow the overland flow before reaching the watercourses. Measures such as barriers made of wood, stone or earth could be placed periodically along identified flow paths in order to achieve this. This measure would also contribute to improving water quality and sediment control as the barriers would encourage sediment to settle at the barriers.

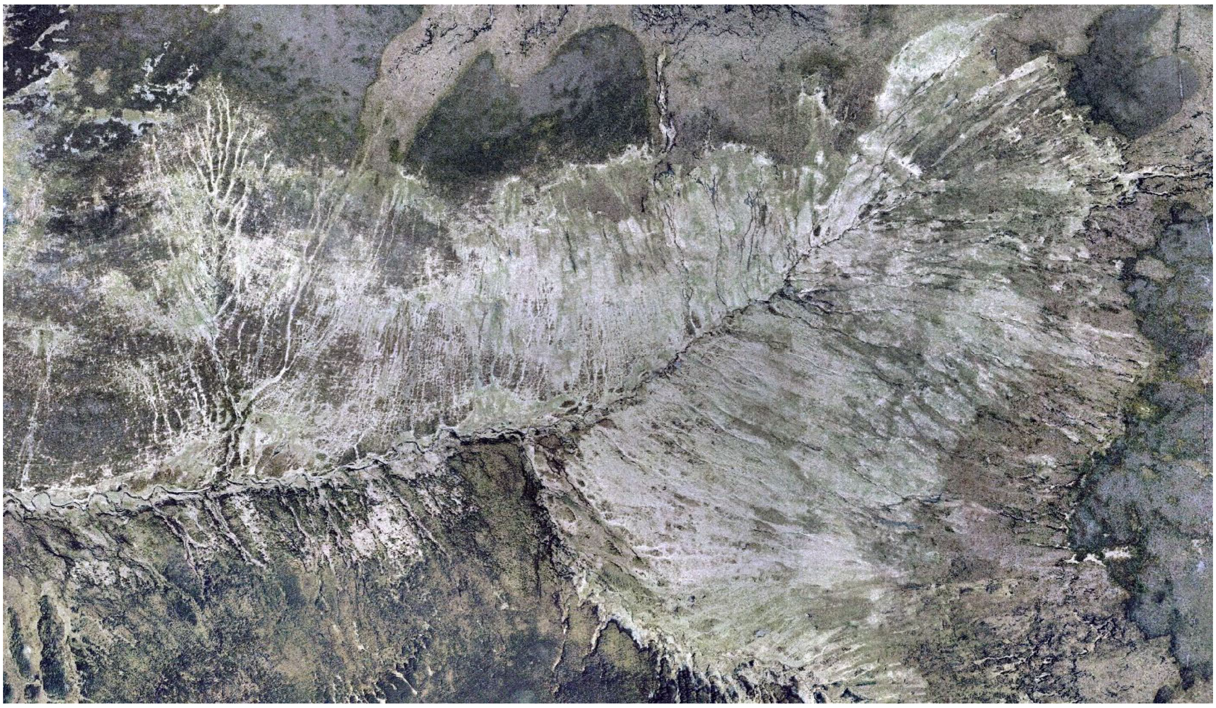

Figure 3.43: High density drain network (Aberdeenshire Council 2008)

Land use management techniques: A significant proportion of the Ballater Catchment consists of heather or heather grasslands. This is a managed area with controlled burning of heather (see Figure 3.44, which refers to Image 3 in the NFM opportunities map in Appendix H). While the practice of burning heather is deemed necessary for the rejuvenation of the vegetation and in providing a food source for the various animals living within the catchment it also has the potential to increase flood risk as the vegetation loss would increase surface runoff. As a land use management technique flood risk should be considered. Current legislation in Scotland restricts heather burning between the 1st October and the 15th April. This timeframe however is when the largest floods have taken place in Ballater and are likely to occur in the future. The hydrological analysis carried out as part of this study has identified that the months of December and January are particularly susceptible to the largest flood events. The burning of heather in or before these months could therefore contribute to larger flood flows and therefore flood risk. The scale of burning and timing of burning could therefore be considered with the land management plan with a view to focusing this activity to after January.

Figure 3.44: Heather Burning (Aberdeenshire Council 2008)

Catchment Woodlands: Catchment woodland creation was considered as a measure that could reduce runoff. Studies have shown that woodlands can be effective in reducing runoff as they intercept precipitation via their tree canopy and intercept runoff by providing a barrier to the flow and increasing infiltration into the ground through their root system. The need to increase the amount of woodland areas within Scotland has been recognised and SEPA and the Forestry Commission produced a dataset identifying potential areas for woodland creation. This dataset was reviewed within the Ballater Catchment and refined by the following criteria:

- It is not recommended that trees be planted above the natural tree line. A review of the existing tree line in Ballater found that this line is at approximately 550mOD.
- Existing woodland areas were excluded from the woodland potential dataset. A review of this woodland was carried out and areas where deforestation has taken place (see Figure 3.45 which refers to Image 4 in the NFM opportunities map in Appendix H) or where woodlands are sparsely populated were added to this potential measure.
- Areas unsuitable for tree planting, such as crags and very steep areas were also discounted as potential areas.

Figure 3.45 shows an example area which has experienced deforestation within the Ballater catchments. The total area identified with potential for planting of catchment woodland is approximately 260km^2.

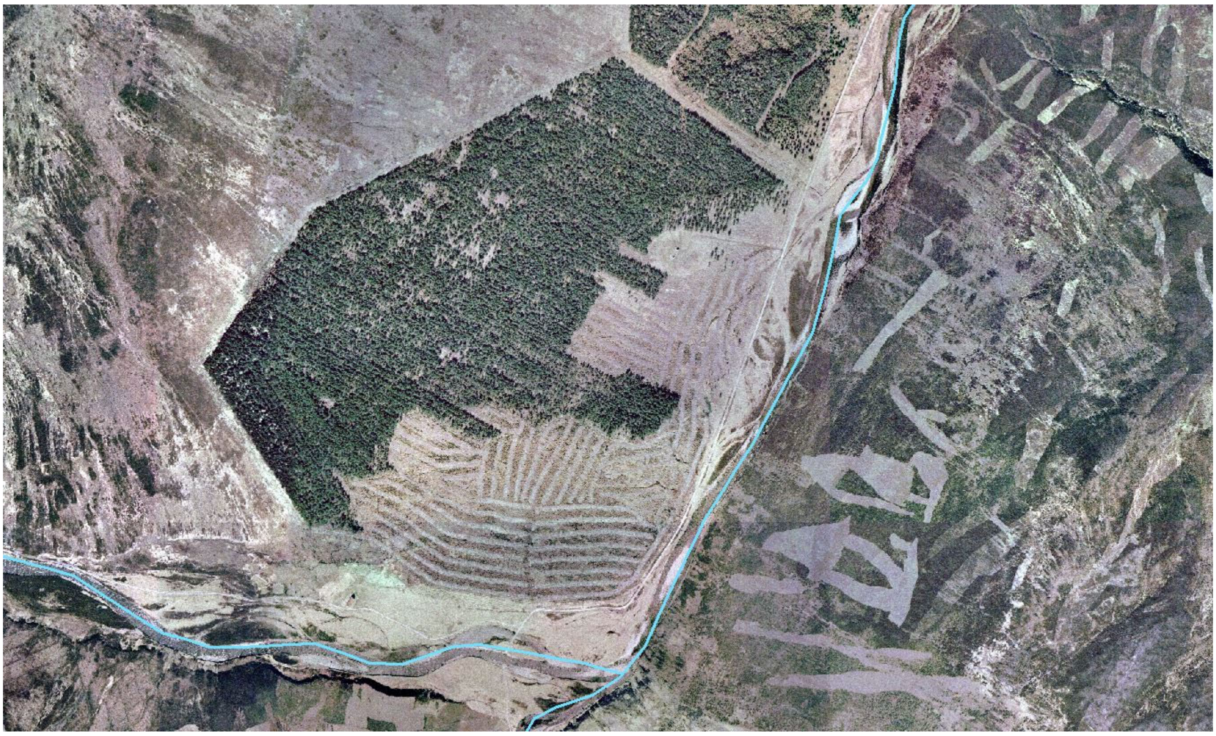

Figure 3.45: Example of Deforestation (Aberdeenshire Council 2008)

Instream Structures: Instream Structures have the potential to reduce flood flows by slowing the water down and forcing it out into the floodplain where it would be stored or slowed further. Barriers can consist of woody debris dams, or rock/boulder weirs. A review was carried out of the watercourses in the Ballater catchment. All reaches that were considered suitable were highlighted in the NFM opportunity map presented in Appendix H. Reaches discounted included reaches where the river becomes too large and an engineered weir solution would be required to achieve the same impact. In addition, reaches that are too steep and have no floodplain into which flood water could be forced, would have limited potential to reduce flood flow and were therefore also discounted. Existing structures such as bridges, properties and settlements were also considered. Reaches of watercourses in close proximity of these areas were also discounted as increased floodplain flow could increase flood risk to these receptors. Many of the reaches identified are located within a natural valley with a well-defined floodplain. There are therefore good opportunities to implement this measure.

Floodplain Woodland: A complimentary measure to the Instream Structures is the addition of Floodplain Woodlands. These woodlands are located within the floodplain of the river and act as a barrier to the water flowing through the floodplain. A review was carried out to identify areas where Floodplain Woodlands would be suitable. Areas where a defined floodplain was identified and where the land was not considered valuable agricultural land or developed were considered suitable. Similar to the Catchment Woodland restrictions no land above 550mOD (the natural tree line) was considered.

3.5 SHORTLIST OF ACTIONS: DEVELOPING OPTIONS

The screening of actions identified all feasible actions from the long-list. From this short-list, viable options were developed that would meet the objectives set out in Section 2.5.

The Do Minimum option was included to provide a consistent baseline against which other solutions could be compared.

RPS reviewed the potential standard of protection that could be achieved by each action, and concluded that any viable option with an acceptable standard of protection would have to include Direct Defences. A scheme based on the other actions, or a combination of the other actions, which excluded Direct Defences, would not meet the objective of identifying a cost beneficial flood scheme providing a target standard of protection. Consequently, each option identified (with the exception of Do Minimum) incorporates Direct Defences.

Three potential combinations of Direct Defences were identified in Section 3.3.5.2: 1) Traditional defences only; 2) Traditional defences with Self-Closing Flood Barriers (SCFBs), and; 3) Traditional defences with glass walls.

Relocation of Ballater Caravan Park to accommodate the direct defence route is to be included as part of each option. Relocation of the emergency services and the council depot has also been recommended and will be incorporated into each option. The relocation of these receptors is also an action which should be considered for interim works that may be undertaken prior to the implementation of a flood alleviation scheme. The continued maintenance of the existing flood warning system is recommended however as this is part of the existing regime it will not be presented as part of each option.

It was recognised during the screening of the long list of actions, that providing flood protection to outlying properties may not offer the most economically desirable flood management solution. As such further options may be considered which protect outlying properties through other actions such as Property Level Protection (PLP) or Property Flood Resilience (PFR). Those properties with a flood depth of less than 0.6m were considered suitable for PLP, whilst properties with a flood depth of greater than 0.6m were considered suitable for flood resilience.

The screening process also identified eleven potential storage areas within the Dee catchment. This action would still require direct defences in order to provide the target standard of protection however should be appraised and compared as a flood management option against the other solutions to identify the most sustainable option.

As such all options identified are a combination of both structural and non-structural actions. Option 1 in Table 3.18 proposes traditional Direct Defences, with Options 2 and 3 providing alternative Direct Defences (SCFB or Glass Walls) in order to reduce the impact of the required height of the direct defences. Options 1A, 2A and 3A are similar to Options 1, 2 and 3 but incorporate PLP and resilience for outlying properties. All of the other actions were subsequently reviewed to identify which could be implemented along with Direct Defences to potentially significantly reduce the required height of the Direct Defences with only Storage being identified as being viable (Option 1B). Table 3.18 summarises the options identified.

It is recommended that actions which were not short-listed and do not contribute to the preferred option in this report remain under consideration in future project stages due to their potential to reduce the height of direct defences or provide other benefits such as reducing channel instability issues e.g. incorporating an additional arch within Royal Bridge may help to reduce the risk of increased scour (although it does not provide a significant reduction in flood levels).

Table 3.18 - Summary of viable options

Option	Descriptions of action
Do Minimum	Baseline Assessment (Maintain Existing Regime)
Option 1	Direct Defences (traditional only), Relocation
Option 2	Direct Defences (traditional & SCFB), Relocation
Option 3	Direct Defences (traditional & glass walls), Relocation
Option 1A	Direct Defences (traditional only), Relocation, PLP, Resilience
Option 2A	Direct Defences (traditional & SCFB), Relocation, PLP, Resilience
Option 3A	Direct Defences (traditional & glass walls), Relocation, PLP, Resilience
Option 1B	Direct Defences (traditional only), Storage, Relocation, PLP, Resilience

3.5.1 Do Minimum

The baseline option will be to maintain the existing regime within the study area. There is one known length of informal embankment along the boundary of Ballater Golf Club with the River Dee. As discussed in Section 3.3.5.4, sections of the embankment (which is located on private land) are considered to be non-engineered. It is assumed that maintaining the existing regime would incorporate completion of ad-hoc repairs following identification of damage to the embankment. There is an existing flood forecasting and warning system in operation for Ballater. Maintaining the existing regime should include continuation of this flood warning.

3.5.2 Option 1

This option would consist of 2.1km of flood wall and 2.6km of flood embankment. The maximum height of defence would be 3.7m and would provide flood protection up to a 0.5% AEP event. The option meets the objective to reduce flood risk and provide a benefit to the study area. Defences on the River Dee, River Muick and on the River Gairn would in general wrap around at risk areas/properties tying into high ground. Where space permits embankments are the preferred defence type, and in all other areas would be reinforced concrete retaining walls with a reinforced concrete cut-off to a depth of 2m. Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Due to the risk of surface water flooding within Ballater Town pumping stations should be added into the defence structure at key locations to ensure the risk from surface water flooding is managed. Six small pumping stations were added into the calculated cost for the option. Some outlying properties would require defences along their entire boundary and therefore would require demountable defences at entrance locations to allow access during times of no flood. The option would also incorporate the relocation of Ballater Caravan Park, Police Station, Fire Station and Council Depot.

3.5.3 Option 2

This option is similar to Option 1, however, where defences exceeded 2.5m in height; they have been replaced with Self-Closing Flood Barriers (SCFBs). The SCFBs would be 1.5m in height therefore defences which exceeded 2.5m would now be reduced in height by 1.5m. In the event of a flood the SCFBs would raise automatically, and so no manual intervention is required. Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Overall the option would consist of 1.8km of permanent flood wall, 2.4km of permanent flood embankment and 0.5km of Self-Closing Flood Barrier.

3.5.4 Option 3

This option is similar to Option 1, however where defences exceeded 2.5m in height, they have been replaced by glass walls which are 1.5m in height. As such defences which previously exceeded 2.5m in height would now be effectively reduced in height by 1.5m from a visual perspective, with the top 1.5m of defence replaced with glass walls allowing some amenity value to be retained. Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Overall the option would consist of 1.8km of permanent flood wall, 2.4km of permanent flood embankment and 0.5km of Glass Wall.

3.5.5 Option 1A

This option is similar to Option 1, however outlying properties in Flood Cells 2, 3 and 4 which had been protected by direct defences, are now provided protection through Property Level Protection (where flood depths are less than 0.6m) or through flood resilience (where flood depths exceed 0.6m). As such, some of the outlying properties would have a SoP less than a 0.5% AEP event, however all properties would benefit from an overall reduced level of risk. Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Overall the option would consist of 1.3km of flood wall, 1.5km of flood embankment, 17 properties provided PLP and 11 properties made flood resilient.

3.5.6 Option 2A

This option is similar to Option 2, however outlying properties in Flood Cells 2, 3 and 4 which had been protected by direct defences, are now provided protection through Property Level Protection (where flood depths are less than 0.6m) or through flood resilience (where flood depths exceed 0.6m). As such, some of the outlying properties would have a SoP less than a 0.5% AEP event, however all properties would benefit from an overall reduced level of risk. Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Overall the option would consist of 1km of flood wall, 1.3km of flood embankment, 0.5km of SCFB, 17 properties provided PLP and 11 properties made flood resilient.

3.5.7 Option 3A

This option is similar to Option 3, however outlying properties in Flood Cells 2, 3 and 4 which had been protected by direct defences, are now provided protection through Property Level Protection (where flood depths are less than 0.6m) or through flood resilience (where flood depths exceed 0.6m). As such, some of the outlying properties would have a SoP less than a 0.5% AEP event, however all properties would benefit from an overall reduced level of risk Figures which show the location of the proposed defences may be found in Appendix E whilst long-sections of the main direct defences may be found in Appendix I. Overall the option would consist of 1km of flood wall, 1.3km of flood embankment, 0.5km of glass wall, 17 properties provided PLP and 11 properties made flood resilient.

3.5.8 Option 1B

This option is similar to Option 1A however the height required for direct defences is reduced as storage areas are provided in the Dee catchment. The option would consist of 11 areas of storage, 1.3 km of flood wall, 1.5 km of flood embankment, 17 properties provided PLP and 11 properties made flood resilient. Around 25 properties would also require to be relocated in order to accommodate the storage areas identified.

3.5.9 NFM

A long list of NFM opportunities was identified as detailed in Section 3.3.11. This long list was not shortlisted as part of this study which would further assess the effect on flood risk and the additional benefits (and dis-benefits) provided. As such it is not possible to appraise and compare NFM with the other potential options, either as a standalone option or incorporated into a structural option. NFM has therefore been considered further in Section 6 where recommendations to support option development are detailed.

3.6 OPTION APPRAISAL: DESCRIPTION AND VALUE

The options described in Section 3.3.11 were appraised. The following components were assessed:

- Estimates of flood risk management benefits
- Wider positive and adverse impacts
- Adaptability to climate change and other future flood risk
- Whole life cost
- Uncertainty in costs and benefits

Table 3.19 to Table 3.27 presents the appraisal of the options.

Table 3.19 - Appraisal Summary Table 1

Option	Baseline			Option 1			Option 2		
Overview/Description	Do-minimum to maximise residual life of existing defences and maintenance of watercourse channels and infrastructure. Maintain existing Flood Forecasting/Warning.			Direct defences, consisting of 2km of flood walls and 2.7km of flood embankment. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.			Direct defences, consisting of 1.7km of flood walls, 2.2km of flood embankment and 0.8km of SCFB. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.		
Technical issues	None			None			None		
Assumptions and uncertainties	None			Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.			Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.		
Approaches to adaptation	None			Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to revise Self Help and Emergency Plans.			Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to revise Self Help and Emergency Plans.		
Cost	£ 187,044			£29 million			£52.7 million		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Economic Impacts									
Properties	611 properties at risk of flooding	PV damages: £34.5 million	-	582 properties afforded protection up to the 0.5% AEP event.	PV damages: £4.57 million	-	582 properties afforded protection up to the 0.5% AEP event.	PV damages: £4.57 million	-
Transport	Major roads at flood risk: A93 and B976 Other roads at flood risk, see Table 2.1,	Disruption to Ballater town and surrounding area	-	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of	Impacts not valued	-	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of	Impacts not valued	-

	Table 2.2, Table 2.3 and Table 2.4.			Monaltrie and B976 will remain at risk.			Monaltrie and B976 will remain at risk		
Infrastructure	Sewage Works (Ballater Road) at risk from flooding, see Table 2.1.	Loss of service, potential sewer flooding	Impacts not valued	Sewage works afforded protection up to the 0.5%AEP event.	Impacts not valued	-	Sewage works afforded protection up to the 0.5%AEP event.	Impacts not valued	-

Table 3.20 - Appraisal Summary Table 1

Option	Baseline			Option 1			Option 2		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Environmental Impacts									
Flora Fauna	No significant impacts expected	-	-	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-
Soil	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Water	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Use of natural resources	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Climatic factors	No significant impacts expected	-	-	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-
Landscape	No significant impacts expected	-	-	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-

Table 3.21 - Appraisal Summary Table 1

Option	Baseline			Option 1			Option 2		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Social Impacts									
Way of life	During and post flooding there would be loss of transport routes and recreational sites for the community. Flooding of residential homes and business would impact on owner's health and wellbeing.	Impacts not valued	-	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-
Culture	Damage to listed buildings.	Impacts not valued	-	Protection provided to listed buildings	Impacts not valued	-	Protection provided to listed buildings	Impacts not valued	-
Community	Ballater Fire and Police Station at risk of flooding along with Golf Course. Sluiemohr Sheltered Housing at risk.	Impacts not valued	-	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-

Table 3.22 - Appraisal Summary Table 2

Option	Option 3	Option 1A	Option 2A
Overview/Description	Direct defences, consisting of 1.7km of flood walls, 2.2km of flood embankment and 0.8km of glass wall. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.	Direct defences, consisting of 1.8km of flood walls, 1.6km of flood embankment. 13 properties provided PLP. 9 properties made flood resilient. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.	Direct defences, consisting of 1.5km of flood walls, 1.1km of flood embankment and 0.8km of SCFB. 13 properties provided PLP. 9 properties made flood resilient. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.
Technical issues	None	None	None
Assumptions and uncertainties	Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.	Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.	Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.
Approaches to adaptation	Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to revise Self Help and Emergency Plans.	Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to add PLP and revise Self Help and Emergency Plans.	Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to add PLP and revise Self Help and Emergency Plans.
Cost	£33.4 million	£27million	£50.3 million

Category	Description and quantification of impacts	Value of impacts	Assumptions and uncertainties	Description and quantification of impacts	Value of impacts	Assumptions and uncertainties	Description and quantification of impacts	Value of impacts	Assumptions and uncertainties
Economic Impacts									
Properties	582 properties afforded protection up to the 0.5% AEP event.	PV damages: £4.57 million	-	554 properties afforded full protection up to the 0.5% AEP event and 28 properties afforded partial protection up to the 0.5% AEP event.	PV damages: £4.6 million	-	554 properties afforded full protection up to the 0.5% AEP event and 28 properties afforded partial protection up to the 0.5% AEP event.	PV damages: £4.6 million	-
Transport	Majority of roads afforded protection up to the 0.5%AEP event. A93 at	Impacts not valued	-	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of	Impacts not valued	-	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of	Impacts not valued	-

	Eastfield of Monaltrie and B976 will remain at risk.			Monaltrie and B976 will remain at risk.			Monaltrie and B976 will remain at risk.		
Infrastructure	Sewage works afforded protection up to the 0.5%AEP event.	Impacts not valued	-	Sewage works afforded partial protection up to the 0.5% AEP event.	Impacts not valued	-	Sewage works afforded partial protection up to the 0.5%AEP event.	Impacts not valued	-

Table 3.23 - Appraisal Summary Table 2

Option	Option 3			Option 1A			Option 2A		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Environmental Impacts									
Flora Fauna	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-
Soil	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Water	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Use of natural resources	No significant impacts expected	-	-	No significant impacts expected	-	-	No significant impacts expected	-	-
Climatic factors	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-
Landscape	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-

Table 3.24 - Appraisal Summary Table 2

Option	Option 3			Option 1A			Option 2A		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Social Impacts									
Way of life	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-
Culture	Protection provided to listed buildings	Impacts not valued	-	Protection provided to listed buildings	Impacts not valued	-	Protection provided to listed buildings	Impacts not valued	-
Community	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-

Table 3.25 - Appraisal Summary Table 3

Option	**Option 3A**			**Option 1B**		
Overview/Description	Direct defences, consisting of 1.5km of flood walls, 1.1km of flood embankment and 0.8km of glass walls. 13 properties provided PLP. 9 properties made flood resilient. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Emergency Plan & Traffic Management Plan.			Direct defences, consisting of 1.8km of flood walls, 1.6km of flood embankment. 11 storage areas. 13 properties provided PLP. 9 properties made flood resilient. Relocation of Ballater Caravan Park, Police Station, Fire Station & Council Depot. Relocation of approximately 25 properties to accommodate identified storage areas. Emergency Plan & Traffic Management Plan.		
Technical issues	None			None		
Assumptions and uncertainties	Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.			Utility services locations unknown at this time. Potential conflicts. Land Owner negotiations required for relocation of caravan park, police station, fire station, council depot and defences through golf course. A cut-off of 2m depth was included in costing of direct defences however ground investigation works will be required to confirm design of flood defences. Previously a cut-off of 5m depth was included in costings however this proved very costly and so a lower cut-off depth was considered. Details of existing available borehole data are shown in Figure 3.20 and Figure 3.21. Due to the predicted future geomorphic instability in the vicinity of Ballater it is recommended that additional morphodynamic modelling is undertaken to reduce uncertainty in the dominant processes in the Dee channel and to predict how the river will react during future flood events. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme with more detailed information on the roughness coefficients, to provide increased confidence in the model outputs.		
Approaches to adaptation	Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to add PLP and revise Self Help and Emergency Plans.			Limited adaption available with flood walls. Base can be overdesigned in order to add height later. See Section 4.4 for further details. Potential to review option at detailed design to provide protection for future climate change. Periodic review of risk required over the lifetime of this option in order to add PLP and revise Self Help and Emergency Plans.		
Cost	£31 million			£126.7 million		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Economic Impacts						
Properties	554 properties afforded full protection up to the 0.5% AEP event and 28 properties afforded partial protection up to the 0.5% AEP event.	PV damages: £4.6 million	-	554 properties afforded full protection up to the 0.5% AEP event and 28 properties afforded partial protection up to the 0.5% AEP event.	PV damages: £4.6 million	-
Transport	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of Monaltrie and B976 will remain at risk.	Impacts not valued	-	Majority of roads afforded protection up to the 0.5%AEP event. A93 at Eastfield of Monaltrie and B976 will remain at risk.	Impacts not valued	-
Infrastructure	Sewage works afforded partial protection up to the 0.5%AEP event.	Impacts not valued	-	Sewage works afforded partial protection up to the 0.5%AEP event.	Impacts not valued	-

Table 3.26 - Appraisal Summary Table 3

Option	Option 3A			Option 1B		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Environmental Impacts						
Flora Fauna	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-	Vegetation along line of defence will be removed in year 1 and replaced to regenerate over lifespan of option River Dee SAC will be impacted in year 1 and regenerate over the lifespan of option.	Impacts not valued	-
Soil	No significant impacts expected	-	-	No significant impacts expected	-	-
Water	No significant impacts expected	-	-	No significant impacts expected	-	-
Use of natural resources	No significant impacts expected	-	-	Use of agricultural land may be reduced while storage water impounded	-	-
Climatic factors	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-	Carbon emissions significant in year 1 due to construction.	Impacts not valued	-
Landscape	Significant landscape changes expected along river corridor and line of defence.	Impacts not valued	-	Significant landscape changes expected along river corridor, line of defence and at storage areas.	Impacts not valued	-

Table 3.27 - Appraisal Summary Table 3

Option	Option 3A			Option 1B		
Category	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**	**Description and quantification of impacts**	**Value of impacts**	**Assumptions and uncertainties**
Social Impacts						
Way of life	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-	Way of life significantly improved through protection of properties, and transport routes	Impacts not valued	-
Culture	Protection provided to listed buildings	Impacts not valued	-	Protection provided to listed buildings	Impacts not valued	-
Community	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-	Protection afforded to Ballater Caravan Park, Fire Station, Police Station, Council Depot and Sluiemohr Sheltered Housing and partial protection afforded to Golf Course.	Impacts not valued	-

4 STAGE 3: COMPARE AND SELECT THE MOST SUSTAINABLE OPTIONS

In order to select the most sustainable option a decision was made based on the appraisal detailed in Section 3.4 which considered the economic, social and environmental impacts, whole life cost, and consideration of the risk and uncertainty. The following questions were considered in this comparison and selection:

- Does the option meet the objectives?
- Does the option represent best value for money?
- Does the option deliver multiple benefits? What are the adverse impacts?
- What are the uncertainties in the appraisal? What are the risks of implementation?

4.1 DOES THE OPTION MEET THE OBJECTIVES?

Table 4.1 summarises the objectives identified in Section 2.5 and whether they would be met by implementing each option. The objective to identify the option with best value for money has been omitted from this section and will be discussed in the Section 4.2.

The table shows that the baseline option, Do Minimum, would not achieve any of the objectives set in this study.

The target standard of protection is the 0.5% AEP. All other options would provide protection to a 0.5% AEP event and as such may be considered acceptable. These options would meet the objective to reduce overall flood risk, maintain access to key receptors and to incorporate surface water management measures.

All options fail to provide protection to the A93 and B976 roads to a 0.5% AEP SoP.

Options 2, 2A, 3 and 3A meet the objective to retain some amenity value through use of either SCFBs or Glass Walls.

The options were reviewed to ensure no increase in flood risk elsewhere in the study area. Overall there is no significant increase in flood extents, flows or water levels when compared to a design 0.5% AEP present day event and no additional receptors were identified as at risk. Figure 4.1 below shows a comparison for Option 3A on the River Dee whilst Figure 4.2 shows a comparison on the River Muick. Downstream of Ballater at the Wastewater Treatment Works, a small increase in water levels (approximately less than 10mm) is predicted. As part of Option 3A, PLP/resilience has been recommended for these receptors however it is acknowledged that Scottish Water may wish to provide their own measures to reduce the risk of flooding to this asset, and so the action to reduce the risk at the Wastewater Treatment Works will be reviewed following stakeholder consultation. On the Muick, any increase in risk to receptors has been mitigated through the provision of direct defences. On the River Gairn, no change in the flood extents or water levels was evident.

When considering the objectives Options 2, 3, 2A and 3A would provide the most sustainable solutions.

Table 4.1 - Summary of options against objectives

Objective	Option							
	Baseline	**Option 1**	**Option 2**	**Option 3**	**Option 1A**	**Option 2A**	**Option 3A**	**Option 1B**
	Maintain existing regime	Traditional HDs only	Traditional HDs + SCFB	Traditional HDs + Glass Walls	Traditional HDs and PLP/resilience for outlying properties	Traditional HDs + SCFB and PLP/resilience for outlying properties	Traditional HDs + Glass Walls and PLP/resilience for outlying properties	Storage, traditional HDs and PLP/resilience for outlying properties
Provide 0.5% AEP SoP to majority of at risk properties	×	✓	✓	✓	✓	✓	✓	✓
Reduce flood risk	×	✓	✓	✓	✓	✓	✓	✓
Avoid increase in flood risk	×	✓	✓	✓	✓	✓	✓	✓
Retain amenity value of Ballater	×	×	✓	✓	×	✓	✓	✓
Protect A93 & B976 to 0.5% AEP SoP	×	×	×	×	×	×	×	×
Access to key receptors maintained	×	✓	✓	✓	✓	✓	✓	✓
Reduce RBMP pressures	×	×	×	×	×	×	×	×
Incorporate surface water runoff management measures	×	✓	✓	✓	✓	✓	✓	✓

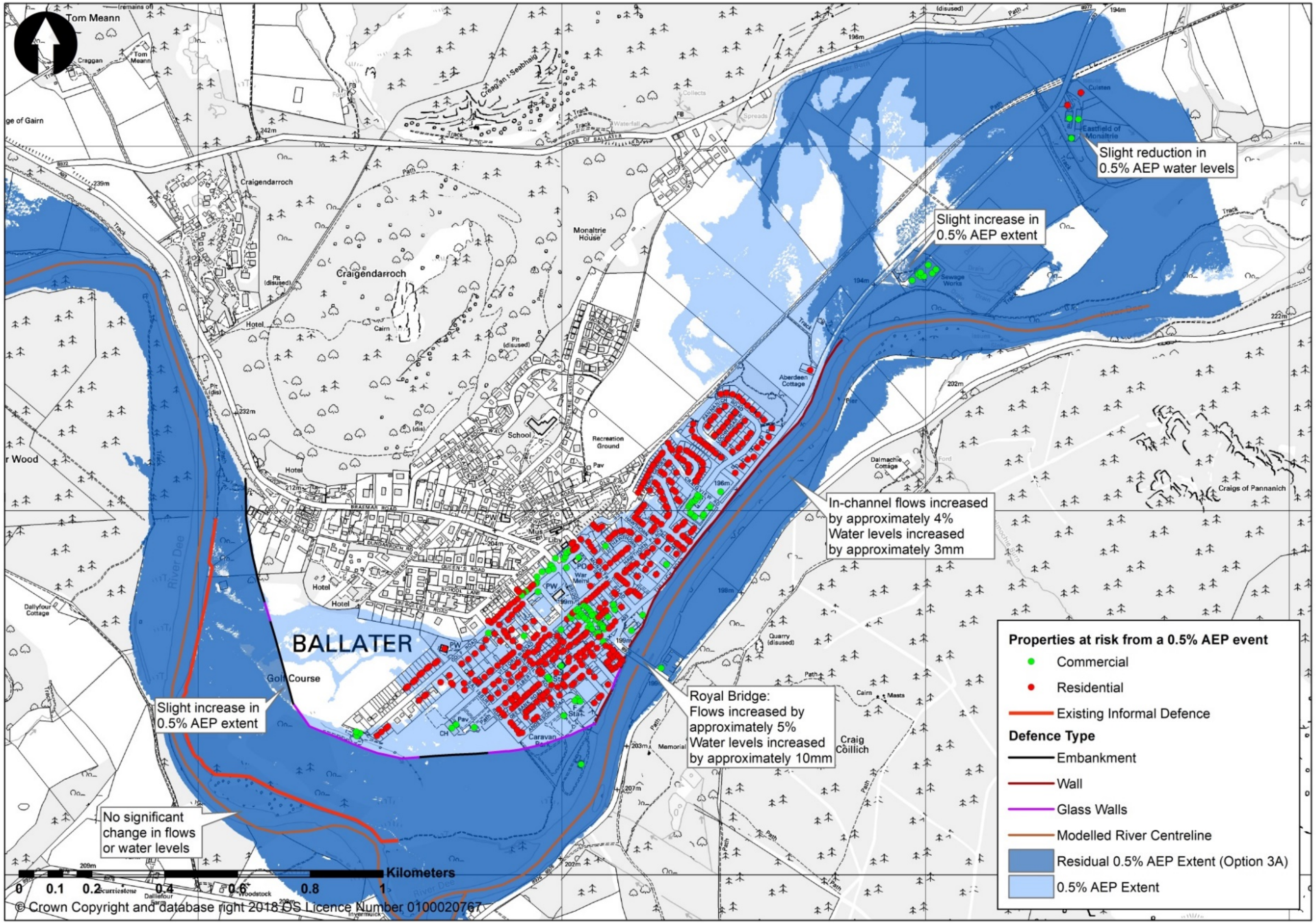

Figure 4.1 – Comparison of flood extents, flows and water levels between 0.5% AEP present day event and Option 3A 0.5% AEP event

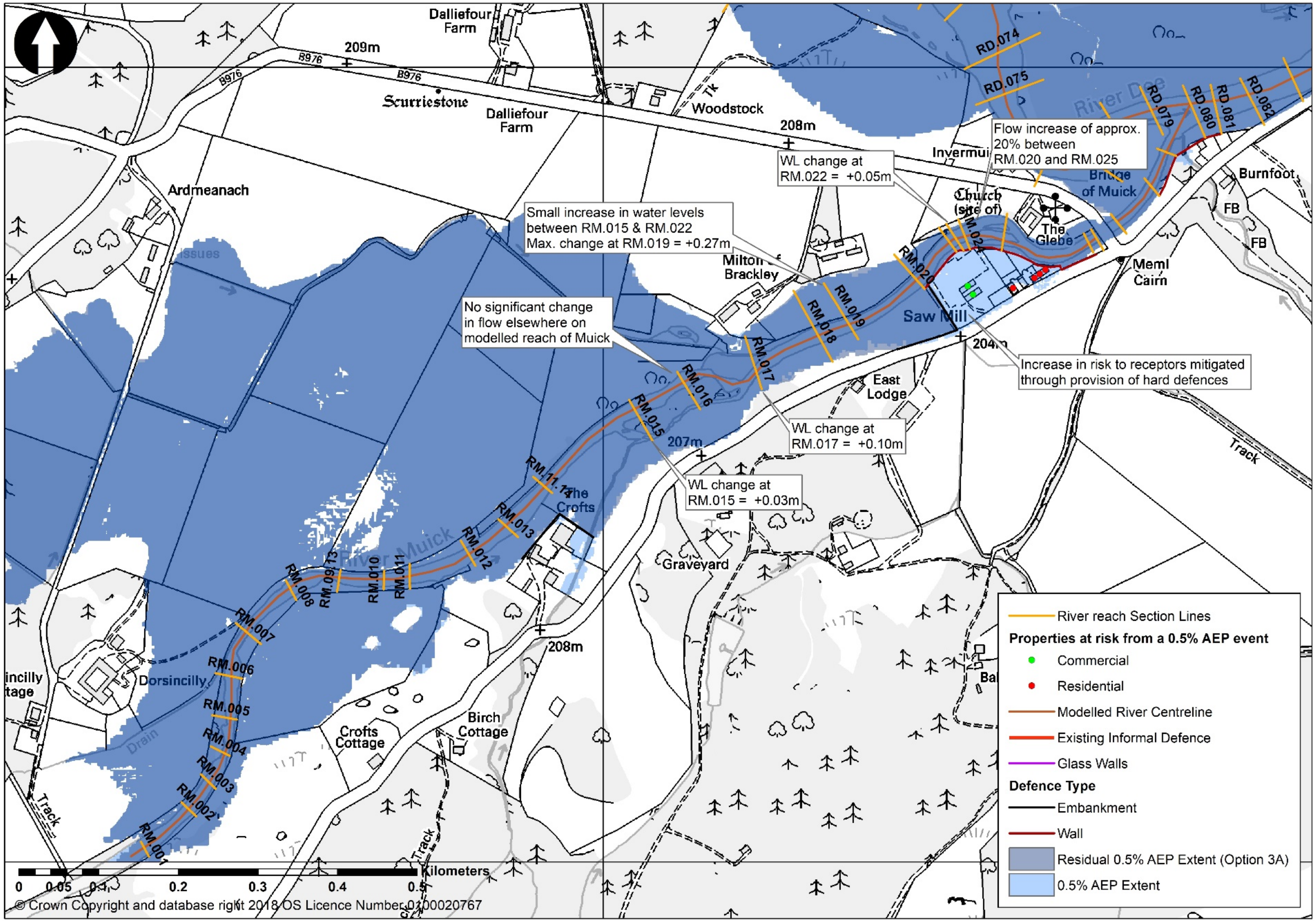

Figure 4.2 - Comparison of flood extents, flows and water levels on the Muick between 0.5% AEP present day event and Option 3A 0.5% AEP event

4.2 DOES THE OPTION REPRESENT BEST VALUE FOR MONEY?

RPS undertook a benefit-cost analysis to demonstrate the economic case for the identified options. This involved an assessment of the benefits (i.e. reducing flood impact) and the costs of the options over a 100 year design life span. This approach ensures that Aberdeenshire Council has a robust economic argument which shows that the preferred option provides best value for money.

Full details of the Economic Appraisal including option costing and damage assessment assumptions are presented in Appendix A, B and F. Table 4.2 summarises the results of the Economic Appraisal.

The results from the economic appraisal indicate that Options 1, 3, 1A, and 3A are economically viable whilst all other options are economically unviable.

Table 4.2 - Summary of Economic Appraisal

	Baseline	Option 1	Option 2	Option 3	Option 1A	Option 2A	Option 3A	Option 1B
	Costs (£)							
Capital costs	-	17,845,000	32,579,000	20,537,000	16,551,000	31,104,000	19,038,000	78,244,000
Optimism Bias Adjustment	-	10,892,000	19,753,000	12,527,000	10,116,000	18,867,000	11,628,000	47,507,000
Maintenance Costs (NPV over 100 years)	187,044	309,000	342,000	342,000	309,000	342,000	342,000	935,000
Total Present Value Costs	187,044	29,046,000	52,674,000	33,406,000	26,976,000	50,313,000	31,008,000	126,686,000
	Benefits (£)							
Present Value Damage	34,486,000	4,574,000	4,574,000	4,574,000	4,601,000	4,601,000	4,601,000	4,601,000
Present Value Damage Avoided	0	29,912,000	29,912,000	29,912,000	29,885,000	29,885,000	29,885,000	29,885,000
Intangible Benefit	0	3,243,000	3,243,000	3,243,000	3,233,000	3,233,000	3,233,000	3,233,000
Total Present Value Benefit	0	33,155,000	33,155,000	33,155,000	32,993,000	32,993,000	32,993,000	32,993,000
	Benefit Cost Ratio							
Average benefit/cost ratio	-	1.14	0.63	0.99	1.22	0.66	1.06	0.26

4.3 DOES THE OPTION DELIVER MULTIPLE BENEFITS? WHAT ARE THE ADVERSE IMPACTS?

Section 3.4 describes the positive and negative impacts resulting from each option were it to be implemented. It was identified that implementing the Do Minimum option would have significant adverse economic and social impacts, while there is no anticipated environmental impact.

All options have landowner uncertainties with regards to the golf club and the relocation of the caravan park, police station, fire station and council depot. These uncertainties are dependent on the co-operation of landowners. The options may have an adverse impact to the Way of Life by creating a barrier between the river and the town, although this has been reduced in Options 2, 2A, 3 and 3A through implementation of either SCFBs or glass walls. Options 1, 1A, 3 and 3A have a maximum permanent defence height of 3.6m which may be considered socially unacceptable however Options 2 and 2A have a maximum permanent defence height of 2.6m through the use of SCFBs which only rise to provide the 0.5% AEP SoP in the event of a flood.

4.4 WHAT ARE THE UNCERTAINTIES AND ROBUSTNESS IN THE APPRAISAL? WHAT ARE THE RISKS OF IMPLEMENTATION?

Section 3.4 identified the associated uncertainties with each option. Options 1A, 2A, 3A and 1B have uncertainties regarding the effectiveness and therefore potential benefit of the Property Level Protection as it may be dependent on manual erection before flooding occurs. As many of the properties in Ballater are second homes, residents may not be available to erect their PLP. There are uncertainties associated with the technical difficulty and cost of all options due to the environment that the flood defences would be constructed in and there are further landowner uncertainties associated with the relocation of receptors and route of direct defences. At this stage of the process the impact of utility services, other structures, traffic restrictions and ground conditions are unknown.

There are uncertainties associated with the hydraulic modelling of the preferred option's direct defences. As shown in the long section drawings found in Appendix I, there is a step down in the defence height of approximately 1.3m in defence section B-C where the defence changes from being defined by the peak water level in the 2D domain to being defined by the peak water level in the 1D domain in the hydraulic model. The hydraulic model was reviewed in order to gain an understanding of the flood mechanisms occurring in this area. It was found that there is a greater drop in bed level and water level in the 1D domain (river channel) from cross-section RD.082 to RD.090 than the drop in water level in the 2D domain at the direct defences, as shown in Figure 4.3. RPS liaised with Innovyze (hydraulic model software providers) regarding this mechanism, who stated that the water level in the river cross-section and 2D mesh elements, although in close proximity, are calculated in different ways within the model explaining why there is a difference in levels. RPS consider that this, in conjunction with the aforementioned differences in gradient along the river reach and the floodplain, result in elevated flood depths in the 2D domain in comparison to the 1D domain at RD.090.

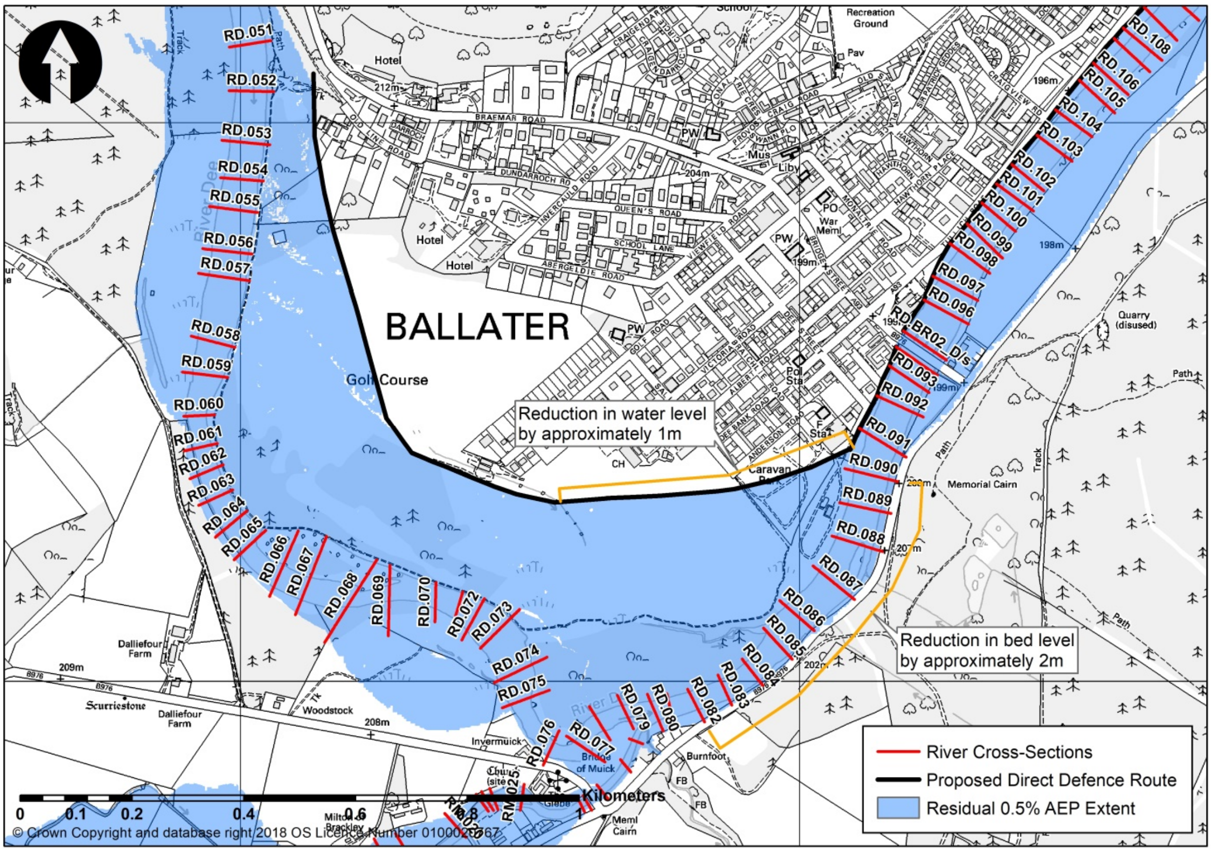

Figure 4.3 – Explanation of drop in water between 2D and 1D model domains

There are significant uncertainties associated with sensitivity to channel and floodplain roughness coefficients within the hydraulic model. It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme to account for the current hydraulic regime at that time with more detailed information on the roughness coefficients. If more detailed information on the land use within the modelled area was obtained this would improve the resolution of the roughness coefficients used in the hydraulic model. This in turn would provide increased confidence in the model outputs and reduce the uncertainties associated with the recommended preferred option.

There are also uncertainties associated with the dynamic nature of the River Dee following Storm Frank in 2015. Any flood alleviation option is likely have a significant impact on the bed of the river as conveying all of the discharge via the channel (and not allowing overland flow) will significantly increase river bed sheer stresses. This may destabilise the channel and could impact the behaviour of the river channel for some distance up and downstream of the location. The potential consequences of this could be the undermining of the Royal Bridge, undermining of some of the flood defences constructed as part of future works (e.g. where they are close to the bank of the Dee from the caravan park to Pannanich Road), and undermining of sections of road on the south side of the Dee close to the channel. It is recommended that further investigation should be carried out during future project stages to ensure that the preferred flood alleviation option is as robust as possible against the predicted future evolution of the channel.

There are also uncertainties associated with the synchronisation of flood flows between the River Dee and its tributaries, and in the verification of more frequent design flood events up to the 3.33% AEP event. It is recommended that further work is undertaken to verify the hydraulic modelling performance.

It is also important to note that a Habitats Regulations Assessment (HRA) is likely to be required to ensure any proposed flood mitigation plans for Ballater do not have a negative impact on the favourable conservation status of any protected areas (SAC's/SPA's). It is recommended that prior to carrying out any construction work targeted surveys are undertaken for all protected species identified to be potentially present within the survey area.

There are also uncertainties with the potential impacts of climate change. As outlined in the Ballater Hydrology Report (IBE1358Rp01, Section 1.7), RPS have considered the impact as a 20% increase of present day flow rates by the 2080s in line with SEPA guidance note 'Flood Modelling Guidance for Responsible Authorities (Version 1.1). For the 2080 time horizon the North Eastern region flood peaks are expected to increase by between 2% and 33%. The central, 50th percentile estimate for a medium emissions scenario is 14%. The 67th percentile estimate for a high emissions scenario as used in SEPA's fluvial hazard maps is 24%. In this context it is considered that 20% increase is appropriate for the 2080s for the North Eastern region within which the Dee is located. It is not as high as the 67^{th} percentile high emissions uplifts used by SEPA but it is above the median estimate (14%).

A model simulation of the preferred option was undertaken for the 0.5% AEP flood event plus 20% uplift in flows to allow for climate change. It was found that the peak water level increase along the majority of the direct defences would be less than 0.6m, however there is a short section (approximately 40m in length) where water levels would be increased by slightly more than 0.6m (approximately 0.62m). This is illustrated in Figure 4.4. Therefore if constructed (assuming no loss in height of the defences through settlement over time) the defences may be a risk of overtopping if a 0.5% AEP+CC event occurred. The direct defences were not bypassed by flood flows at their upstream and downstream extents during this scenario.

It is recommended that the preferred option is reviewed at detailed design stage to provide protection for future climate change e.g. base of flood wall can be overdesigned in order to allow an increase in height of the wall in the future. This review should be based on the latest climate change projections available at that time. It is acknowledged that SEPA are currently undertaking work to understand the implications of the UKCP18 projections on future flood risk, released in November 2018. This information will then be used to inform updated guidance for climate change and land use planning; Coastal, river and surface water flood hazard maps and Future National Flood Risk Assessments and Flood Risk Management Strategies.

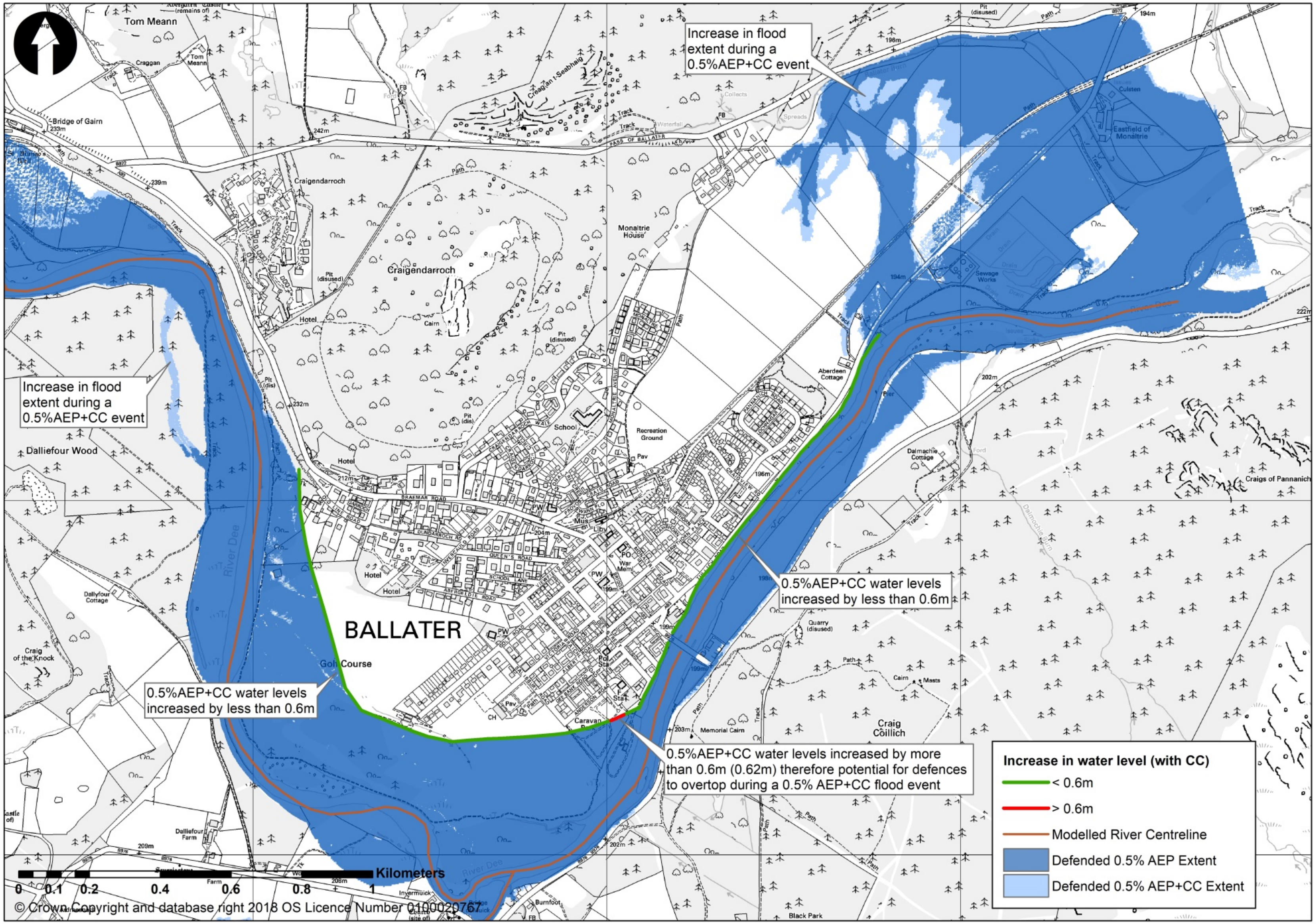

Figure 4.4 - Water level increase at defences during a 0.5%AEP+CC event

5 PREFERRED OPTION

Table 5.1 shows that when every criterion is given equal weighting Options 1A, 2A and 3A offer the most sustainable solutions.

The target standard of protection is the 0.5% AEP. All options would deliver a 0.5% AEP SoP to the majority of receptors and as such may be considered acceptable.

Options 1, 1A, 3 and 3A would provide better value for money than Options 2, 2A and 1B. However, Options 2 and 2A retain a greater amenity value for Ballater due to a reduction in the height of permanent direct defences from a visual perspective through use of SCFBs. Similarly, Options 3 and 3A retain a greater amenity value for Ballater through the use of glass walls at high points in the defences.

From the appraisal of all options, Option 3A is the recommended preferred option as it protects properties in Ballater to a 0.5% AEP SoP and delivers other benefits other than reduced flood risk to receptors such as retained amenity value.

Table 5.1 - Summary of most sustainable option in Study Area

	Performance						
	Option						
	1	2	3	1A	2A	3A	1B
Meets objectives							
Value for money							
Impacts							
Uncertainty & risk							
Total	**8**	**7**	**8**	**9**	**9**	**10**	**5**

Key		
Rating	Score	Total Score
Good	3	10 -12
Average	2	7 - 9
Poor	1	4 - 6

6 RECOMMENDATIONS TO SUPPORT OPTION DEVELOPMENT

During the analysis undertaken in developing this report, a number of recommendations have been made for further work. For clarity, these recommendations are summarised below. The list of recommendations is not exhaustive and it is acknowledged that further investigations and analysis in addition to those specified below will be required in order to implement a flood alleviation scheme in Ballater.

Refinement of Preferred Option

- It is recommended that further detailed analysis of the flooding mechanisms throughout the duration of a flood event is undertaken (including those identified in Section 4.4) to facilitate the justification (or otherwise) of including measures other than direct defences as part of the preferred option;
- It is recommended that actions which were not short-listed and do not contribute to the preferred option in this report remain under consideration in future project stages due to their potential to reduce the height of direct defences or provide other benefits such as reducing channel instability issues;
- It is recommended that a review of the proposed route of the direct defences, especially through the golf course and caravan park area, is undertaken in the next stage of the project;
- It is recommended that further investigation is undertaken to determine the consequences of raising the A93 road prior to detailed design stage, and determining the benefits of this measure during a flood event (considering potential flooding on roads outside of the study area in this report);
- Although NFM has not been progressed as it is not technically feasible, it is recommended that NFM is further considered during future stages of the Ballater Flood Protection project in order to potentially realise some of the other benefits that NFM offers e.g. improvements in biodiversity, water quality and carbon storage and its potential to reduce flood risk;
- It is recommended that relocation of properties is considered in future project stages, potentially as part of the staged construction of a flood alleviation scheme (subject to stakeholder consultation);
- It is recommended that further investigation is undertaken into options to reduce any residual risk remaining after implementation of the preferred option. This should include analysis of flood warning lead times and options to improve emergency response times;
- It is recommended that, if a viable flood alleviation scheme cannot be implemented, further investigation is undertaken to determine if it is technically feasible to reinforce the existing informal embankment (along the golf course) so that it would perform as a flood defence in the future, in addition to determining the future maintenance programme of the structure and the parties responsible for undertaking maintenance;
- It is assumed that due to the height of the proposed defences that the existing informal wall upstream of Royal Bridge could not be incorporated into an action to reduce flood risk (as the wall has not been constructed as a flood defence or to allow such significant adaptation). It is recommended that further investigation is undertaken to confirm this assumption, or otherwise.

Outline Design

- It is recommended that the hydraulic model is reviewed and updated prior to the detailed design of the flood alleviation scheme to account for the current hydraulic regime at that time with more detailed information on the roughness coefficients, to provide increased confidence in the model and verification of the model outputs for the full range of design scenarios. This should consider the assumptions made as outlined in the Ballater FPS Hydraulics Report and the uncertainties associated with the model as outlined in Section 4.4 of this report. The scope of works could include making use of available flood data recorded following completion of this report to improve model calibration, acquisition of data to improve roughness coefficients within the channel and floodplain, recording survey information to capture any geomorphological changes, review of model schematisation and liaison with software developers to determine the most representative method to simulate floodplain flow returning to the river channel in the defended scenario;
- Sediment transport (i.e. morphodynamic) modelling should be undertaken along the section of the River Dee upstream of the Red Brae, extending downstream towards the meander bend by the sewage works. This will reduce uncertainty regarding the dominant processes in the section of channel immediately downstream of Ballater Bridge and predict how the river will react during future flood events (and inform design of future flood alleviation works);
- Investigation into the potential for scour at the Royal Bridge should be undertaken to ensure that a flood alleviation scheme does not compromise the integrity of the bridge;
- Acquisition of an Envirocheck report which presents relevant site desk study information e.g. geological maps; historic topographical maps; hydrogeological, waste, hazardous substances and industrial land use data; and mining and ground stability data, and would be required to inform any future GI design;
- It is recommended that a seepage analysis (SEEPW) should be undertaken to facilitate the design of flood defences;
- It is recommended that prior to carrying out any construction work targeted surveys are undertaken for all protected species identified to be potentially present within the survey area;
- A comprehensive investigation into the potential for the flood alleviation scheme to increase river bed sheer stresses resulting in undermining of structures (e.g. roads, bridges, flood defences) and channel destabilisation should be undertaken prior to implementation of the scheme. This investigation should be undertaken in consultation with SEPA;
- It is recommended that public utility services such as water and electricity are reviewed to identify possible diversionary work (with associated costs and uncertainties) and facilitate detailed design.

Detailed Design

- Site investigation works required to determine ground conditions which will facilitate the design of flood defences;
- It is recommended that viewing platforms/ terracing of direct defences should be considered at detailed design stage to provide improved amenity value where high defences are required to

provide a 0.5% AEP SoP. This type of landscaping would also be useful for hiding pumping stations and associated plant within the defence structure;

- Site investigation works required to confirm if reinforcing the existing informal embankment adjacent to the golf course, or increasing its height, is technically feasible;
- Site investigation works and investigation into construction methods required to confirm if properties recommended for property level protection are suitable for this measure;
- This report assumes a freeboard allowance of 600mm is required for each flood defence, as stated in the Technical Flood Risk Guidance for Stakeholders, SEPA, Version 10, July 2018. This is a minimum requirement unless a more detailed assessment of freeboard is made and is in line with CIRIA Guidance (CIRIA C624 Development and Flood Risk – Guidance for the Construction Industry 2004). The freeboard is to account for uncertainties involved in flood estimation, and other physical factors and it is therefore recommended that a more detailed assessment is made during detailed design of the flood alleviation scheme to reduce the uncertainties. The detailed assessment should be based on current best practice e.g. Accounting for residual uncertainty: updating the freeboard guide (Report – SC120014), Environment Agency, February 2017.
- It is recommended that the preferred option is reviewed at detailed design stage to allow for the potential impacts of climate change and to ensure that future resilience to climate change is secured e.g. base of flood wall can be overdesigned in order to allow an increase in height of the wall in the future. This review should be based on the latest climate change projections available at that time.

7 REFERENCES

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