Ballater Outline Design

Hydrology and Hydraulic Modelling Report

Ballater (RD) Ltd. & Ballater and Crathie Community Council

cbec eco-engineering UK Ltd

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Ùghdarras Pàirc Nàiseanta a' Mhonaidh Ruaidh

cbec eco-engineering UK Ltd

Suite MF04

Marr House

Beechwood Business Park,

Inverness, IV2 3BW

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Project Manager: Alison Wilson

Author: D. Piggott

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1. INTRODUCTION

1.1 PROJECT BACKGROUND

cbec eco-engineering (cbec) was commissioned by Ballater Community Trust [Ballater (RD) Ltd] and Ballater & Crathie Community Council to carry out a hydrological assessment of the River Dee and River Muick at Ballater, Aberdeenshire. This was to feed into hydraulic modelling of the rivers at this location. The purpose of the modelling was to assess flood risk and flow routes at Ballater under existing conditions, to inform flood risk management options for Ballater.

This project was enabled and supported by Grants from the Cairngorms National Park Authority & Aberdeenshire Council Marr Area Committee for which Ballater Community Trust and Ballater & Crathie Community Council are very grateful and without which this project could not have proceeded.

1.2 SITE LOCATION

The project site is Ballater, Aberdeenshire (see Figure 1.1). This is located at approximately grid reference NO 36289 95375.

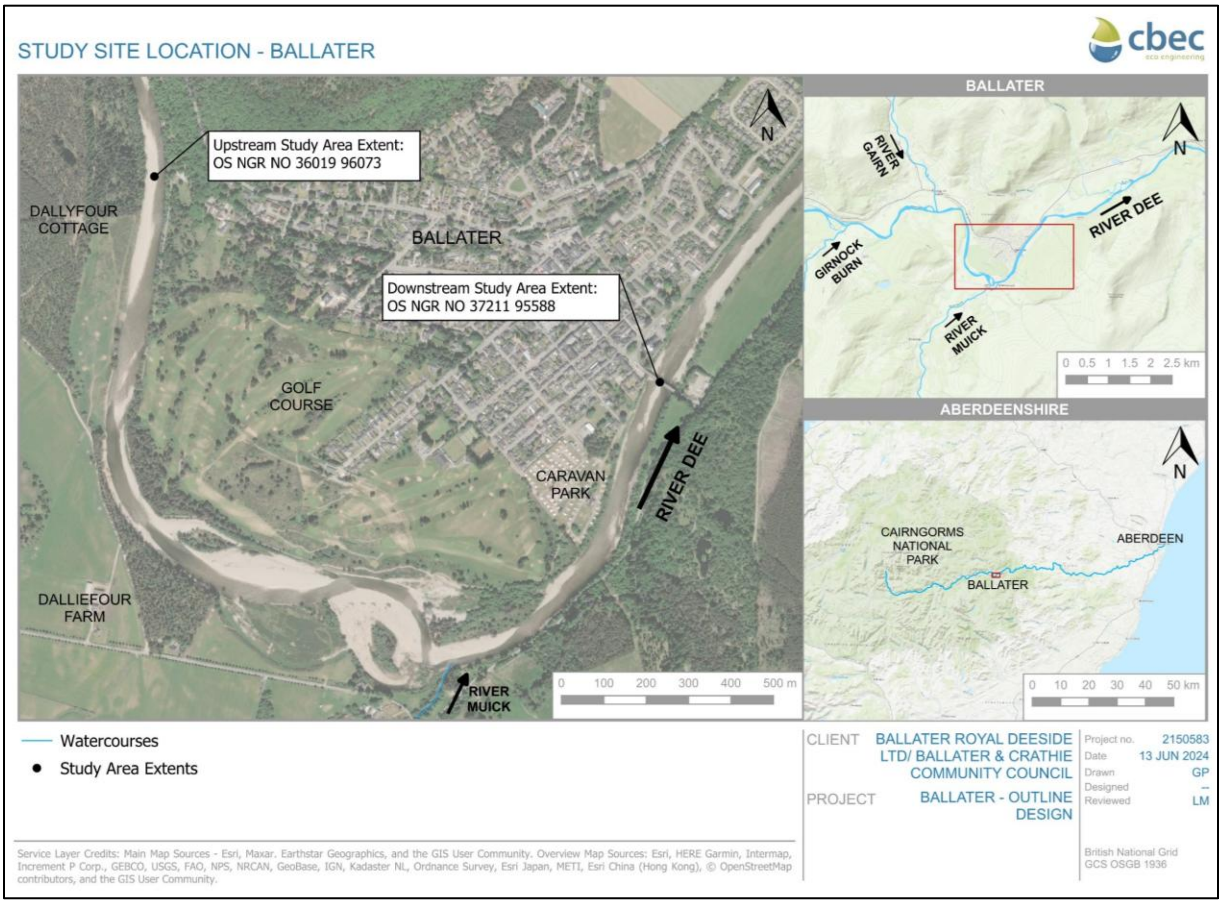

Figure 1.1. Project site.

2. HYDROLOGY

2.1 INTRODUCTION

Flow inputs were required for the hydraulic model. These needed to be storm hydrographs, to show the river's response to flood events and how these affect Ballater. The following sections describe the assessment method used for deriving the required flows.

2.2 CATCHMENT AREA AND DESCRIPTORS

There are two catchments included in the assessment: the River Dee and the River Muick. These are shown in Figure 2.1 and Figure 2.2. The key catchment descriptors are shown in Table 2.1. The Dee catchment includes the River Gairn, and the gauge data for the Gairn was included within the assessment, as part of the Dee catchment hydrology.

The River Dee catchment is an upland catchment with mountainous headwaters, which are known to generally be snow-covered in winter. The land use is highly rural (as also indicated by the URBEXT2000[1] value of 0.0002), comprising mountain, moorland, pasture and forestry. The National River Flow Archive (NRFA) indicates no known significant catchment changes.

The River Muick catchment is similar, though with the addition of Loch Muick. This is reflected in the Flood attenuation of Reservoirs and Lakes (FARL)[2] value of 0.897, which indicates the Loch is likely to have an effect on the catchment response. The NRFA does note that forestry operations are developed in the catchment.

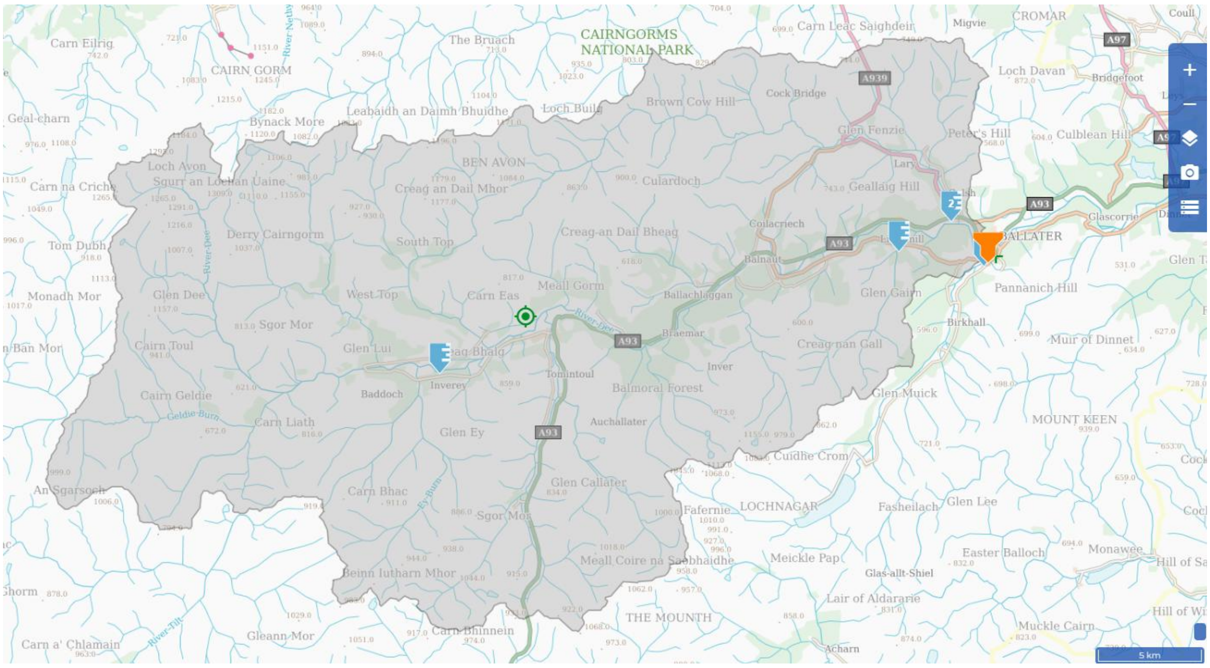

Figure 2.1. River Dee catchment.

[1] This parameter measures the urban extent of a catchment.

[2] This parameter provides a measurement for the flood attenuation by reservoirs and lakes.

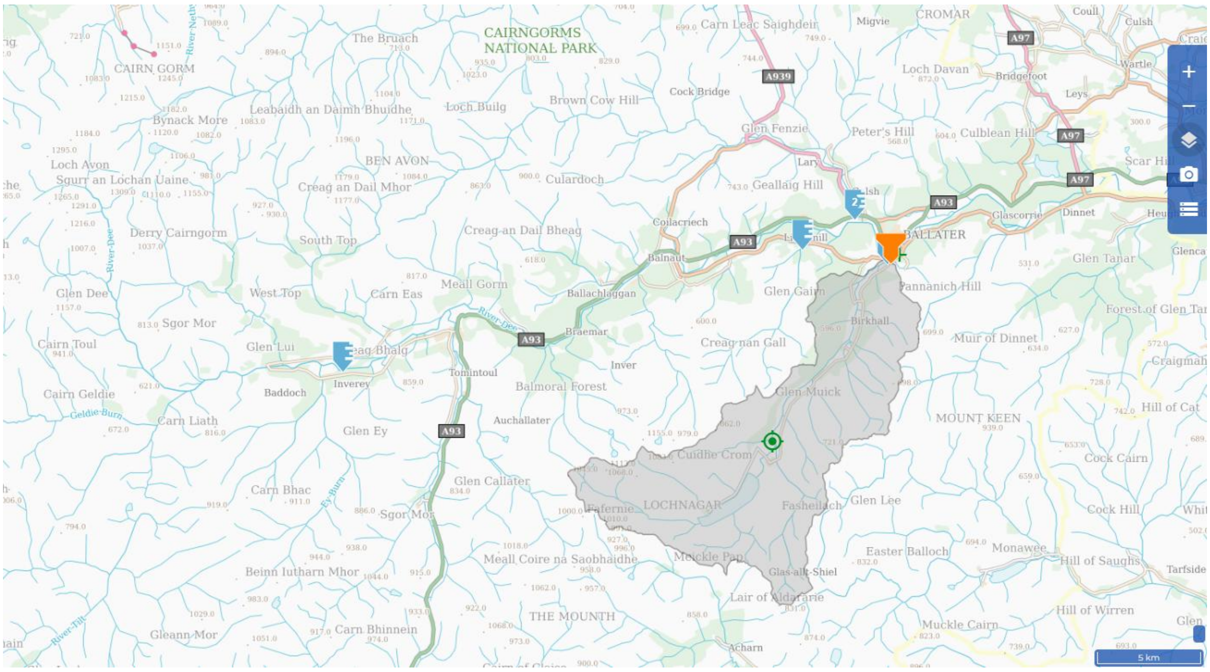

Figure 2.2. River Muick catchment.

Table 2.1. Key catchment descriptors.

Site	River Dee	River Muick
Site location	NO 36650 94950	NO 36600 94800
Centroid Easting	313992	330776 mm
Centroid Northing	792078	785879 mm
Catchment area	850.49 km²	110.45 km²
SAAR	1197 mm	1240 mm
BFIHOST19	0.405	0.467
FPEXT	0.0378	0.0295
FARL	0.988	0.897
URBEXT2000	0.0002	0.0001

2.3 GAUGES

There are several NRFA gauges in the catchment that are relevant to the study. On the River Dee there are:

- Mar Lodge
- Polhollick
- Woodend
- Park
- There is also the Invergairn gauge on the River Gairn which, for this assessment, falls within the River Dee catchment hydrology.

There is one gauge on the River Muick:

- Invermuick

These gauges were all included in the WINFAP (Wallingford Hydrosolutions software) statistical pooling groups, to provide flow records from the local catchments. They were also used to derive the WINFAP QMED (the median annual maximum flood) estimates.

2.4 METHODS USED

The study used the Flood Estimation Handbook (FEH) and Revitalised Flood Hydrograph (ReFH) rainfall-runoff assessments, as well as WINFAP statistical methods. SEPA's "Technical Flood Risk Guidance for Stakeholders"[3] notes that there are potential issues with available catchment data for small catchments, meaning the FEH rainfall-runoff approach is often preferred. However, in large catchments, such as the River Dee, the WINFAP statistical approach is expected to provide a good assessment of catchment flows. Particularly with the incorporation of the available gauge data on both the Dee and the Muick. The guidance does highlight that ReFH rainfall-runoff may not be as accurate in catchments with a FARL lower than 0.9, which is the case for the River Muick.

2.5 CLIMATE CHANGE ALLOWANCE

Based on SEPA's "Climate change allowances for flood risk assessment in land use planning"[4] and the accompanying web map[5], the site is in the North East Scotland region. As the catchment area is greater than 50 km^2 and outwith Orkney and Shetland, the peak river flow uplift should be applied. For this region, the appropriate climate change allowance is therefore 34%.

2.6 ASSESSMENT OF FLOWS

2.6.1. FEH Rainfall-Runoff

The FEH rainfall-runoff approach was applied using Flood Modeller software. The catchment descriptors were exported from the FEH web service and used in the FEH boundary function in the software.

For the River Dee catchment, a 0.25 hour data interval was used, with a design storm duration of 14.25 hours (with a given critical storm duration of 14.25 hours).

For the River Muick, a 0.25 hour data interval was used, with a design storm duration of 9.25 hours (with a given critical storm duration of 9.06 hours).

The resulting peak flow estimates are summarised in Table 2.2.

Table 2.2. FEH rainfall-runoff peak flow estimates.

Return period (yrs)	River Dee Urbanised peak flow (m^3/s)	River Muick Urbanised peak flow (m^3/s)	Combined peak flow (m^3/s)
2	322.75	60.44	383.19
5	446.35	85.03	531.38
10	531.86	102.91	634.77
30	677.93	133.61	811.54
50	755.38	150.04	905.42

[3] ss-nfr-p-002-technical-flood-risk-guidance-for-stakeholders.pdf
[4] climate-change-allowances-guidance.docx
[5] Climate Change Allowances for Flood Risk Assessment in Land Use Planning

75	810.00	161.68	971.68
100	854.37	171.18	1025.55
200	971.25	196.33	1167.58
200 CC	1301.48	263.08	1564.56
1000	1339.21	276.67	1615.88

2.6.2. ReFH

The ReFH rainfall-runoff was applied using the ReFH 2.3 software. Catchment descriptors from the FEH web service were imported and used to carry out the assessment.

For the River Dee catchment, the recommended storm duration of 5.5 hours was used, with a 0.5 hour time step. For the River Muick catchment, a recommended storm duration of 4.5 hours was used, with a 0.5 hour time step.

The resulting flows are summarised in Table 2.3.

Table 2.3. ReFH rainfall-runoff peak flow estimates.

Return period (yrs)	River Dee Urbanised peak flow (m^3/s)	River Muick Urbanised peak flow (m^3/s)	Combined peak flow (m^3/s)
1	320.94	47.51	368.45
2	352.38	52.38	404.76
5	461.10	68.65	529.75
10	542.96	80.85	623.81
30	694.11	103.88	797.99
50	777.65	117.02	894.67
75	850.57	128.89	979.46
100	905.71	138.10	1043.81
200	1049.29	162.59	1211.88
200 CC	1406.05	217.87	1623.92
1000	1422.94	227.13	1650.07

2.6.3. WINFAP Statistical

The WINFAP assessment was carried out using WINFAP software (version 5.2.9014) and Peak Flow Dataset 13.0.3, which was the most current at the time. A pooling group analysis was carried out for both the River Dee and the River Muick catchments.

To derive the QMED estimates, the donor approach was used. The default donor group was edited to include the NRFA gauges on both the Rivers Dee and Muick.

For the pooling groups for both catchments, the default group was reviewed and adjusted to improve homogeneity. Catchments were assessed for similarity in BFIHOST and SAAR values, as well as checked for factors such as FARL and Lskew. The NRFA gauges for the Dee and Muick were also added to the group.

The resulting peak flow estimates are summarised in Table 2.4.

Table 2.4. WINFAP statistical peak flow estimates.

Return period (yrs)	River Dee Urbanised peak flow (m^3/s)	River Muick Urbanised peak flow (m^3/s) (GL)	Combined peak flow (m^3/s)
2	360.26	67.68	427.94
5	461.45	90.22	551.67
10	534.95	105.98	640.93
30	664.26	132.75	797.01
50	732.76	146.52	879.28
75	791.84	158.21	950.05
100	836.57	166.94	1003.51
200	955.04	189.68	1144.72
200 CC	1279.75	254.17	1533.92
1000	1300.83	253.33	1554.16

2.7 PEAK FLOW COMPARISON

The peak flow estimates for all approaches are summarised in Table 2.5. A plot comparison is shown in Figure 2.3. The results show generally a good correlation between all three methods. As noted previously, the large size of the catchments, combined with the available NRFA gauge data, from multiple gauges, suggests the WINFAP statistical approach should be the most accurate. SEPA guidance also indicates the potential issue with using ReFH for the River Muick site.

Given the area is flood sensitive, however, and based on discussions with SEPA at similar sites, it was decided to use the ReFH results, as these are the highest on the River Dee. The Dee is the dominant watercourse and the main source of flood risk to Ballater. The ReFH results are the lowest of the three methods on the Muick, potentially due to the impact of the Loch FARL value. The Muick contribution is much lower, however, so was given less weighting in the decision process.

Table 2.5. Summary of peak flow estimates for all approaches.

	FEH		ReFH		WINFAP	
Return period (yrs)	River Dee (m^3/s)	River Muick (m^3/s)	River Dee (m^3/s)	River Muick (m^3/s)	River Dee (m^3/s)	River Muick (m^3/s)
2	322.75	60.44	352.38	52.38	360.26	67.68
5	446.35	85.03	461.10	68.65	461.45	90.22
10	531.86	102.91	542.96	80.85	534.95	105.98
30	677.93	133.61	694.11	103.88	664.26	132.75
50	755.38	150.04	777.65	117.02	732.76	146.52
75	810.00	161.68	850.57	128.89	791.84	158.21
100	854.37	171.18	905.71	138.10	836.57	166.94
200	971.25	196.33	1049.29	162.59	955.04	189.68
200 CC	1301.48	263.08	1406.05	217.87	1279.75	254.17
1000	1339.21	276.67	1422.94	227.13	1300.83	253.33

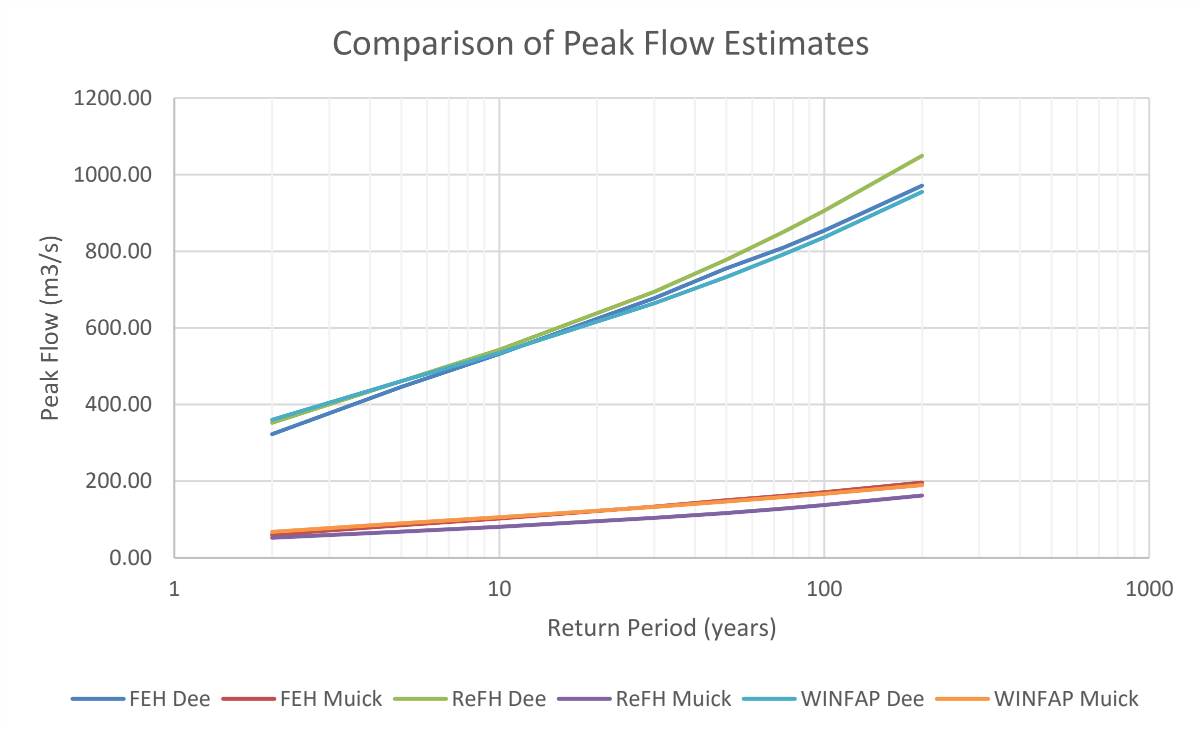

Figure 2.3. Plot of peak flow estimates.

cbec is aware that the ReFH results are less likely, of the three approaches, to be the most representative of the flows experienced on site, however, given the nature of the flood risk to Ballater and the surrounding area, it was determined that a conservative approach is likely to be most appropriate for application on this project.

2.8 FINAL DESIGN FLOWS

The selected ReFH design flows for the model are shown in Table 2.6.

Table 2.6. Final design flows (ReFH) for use in the model.

Return period (yrs)	River Dee Urbanised peak flow (m^3/s)	River Muick Urbanised peak flow (m^3/s)	Combined peak flow (m^3/s)
1	320.94	47.51	368.45
2	352.38	52.38	404.76
5	461.10	68.65	529.75
10	542.96	80.85	623.81
30	694.11	103.88	797.99
50	777.65	117.02	894.67
75	850.57	128.89	979.46
100	905.71	138.10	1043.81
200	1049.29	162.59	1211.88
200 CC	1406.05	217.87	1623.92
1000	1422.94	227.13	1650.07

2.9 HYDROGRAPHS

Hydrographs for the hydraulic model were obtained from the ReFH software, which includes them as one of the outputs. These are shown in Figure 2.4 and Figure 2.5.

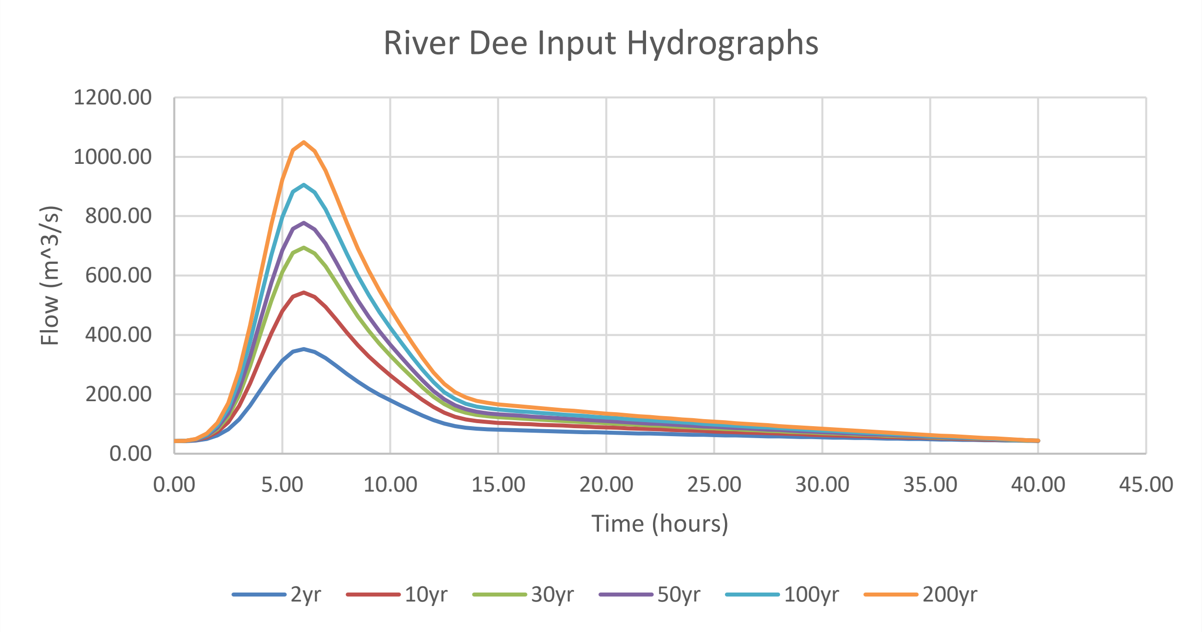

Figure 2.4. River Dee hydrographs.

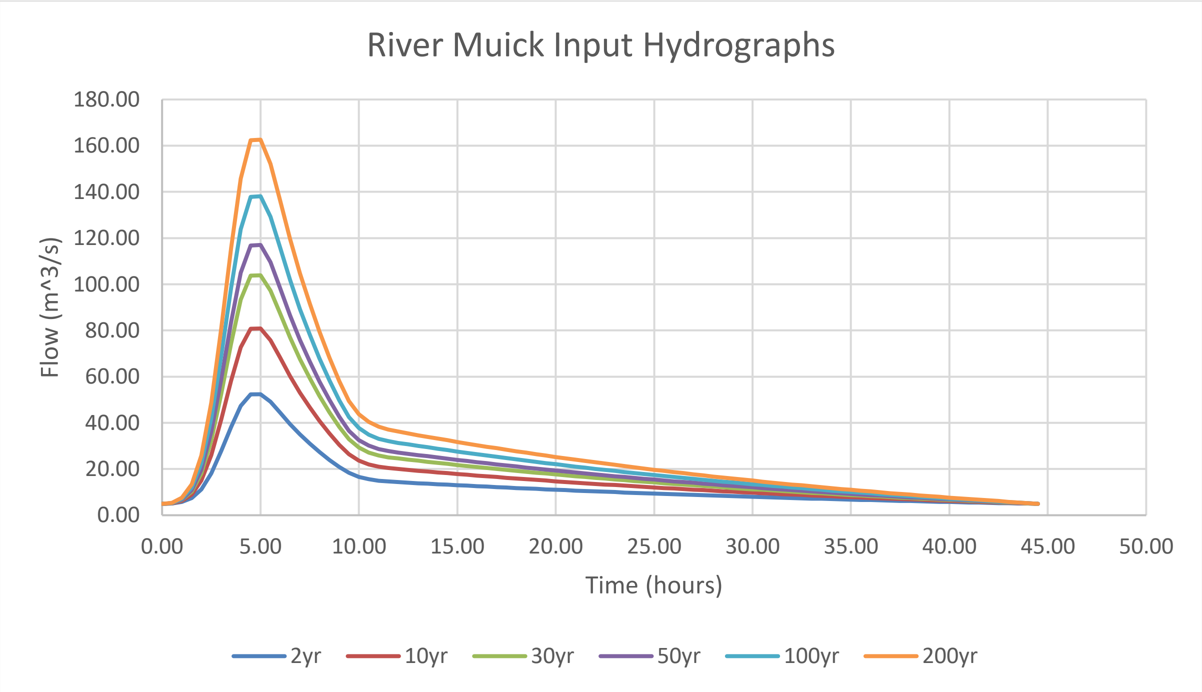

Figure 2.5. River Muick hydrographs.

3. HYDRAULIC MODELLING

3.1 MODELLING RATIONALE

At the request of the client, a linked 1D-2D model approach was taken, using Flood Modeller and TUFLOW. The intention was to use existing SEPA modelling (which was also carried out using Flood Modeller and TUFLOW) as a comparison. However, following liaison with SEPA, it was confirmed that neither the model itself nor the resulting outputs could be provided for use for this project.

The linked 1D-2D approach means the channel capacity is modelled using 1D cross sections. Once the water level in the channel breaches the riverbanks, it connects into the 2D model of the floodplain. This allows for the overland flow to be better represented (over 1D sections). The 1D representation of the channel will provide arguably a better representation of channel conveyance than a fixed 2D grid.

3.2 SOFTWARE USED

The model was developed using the following software:

- Flood Modeller v7.0
- TUFLOW Classic, build 2023-03-AC-iSP-w64

3.3 DATA USED

The following data was used to develop the 1D cross sections and 2D terrain surface:

- Topographic survey data, carried out by cbec in June and December 2024, and January 2025.
- Topographic survey data, carried out by Aspect Surveys for RPS, and provided to cbec by the client. Two surveys were carried out; one in 2017 and one in 2022.
- LiDAR data, publicly available online.

3.4 MODELLING METHODOLOGY

3.4.1. Model Extents

The model extents are shown in Figure 3.1. The upstream and downstream extents were selected as to be far enough away from the main area of interest (the River Dee as it flows around Ballater) as to not affect the results in that area.

The model also includes a 670 m stretch of the River Muick as it converges with the Dee. The confluence is situated within the project site extent, so it was necessary to include it within the model, as the flow input will be significant.

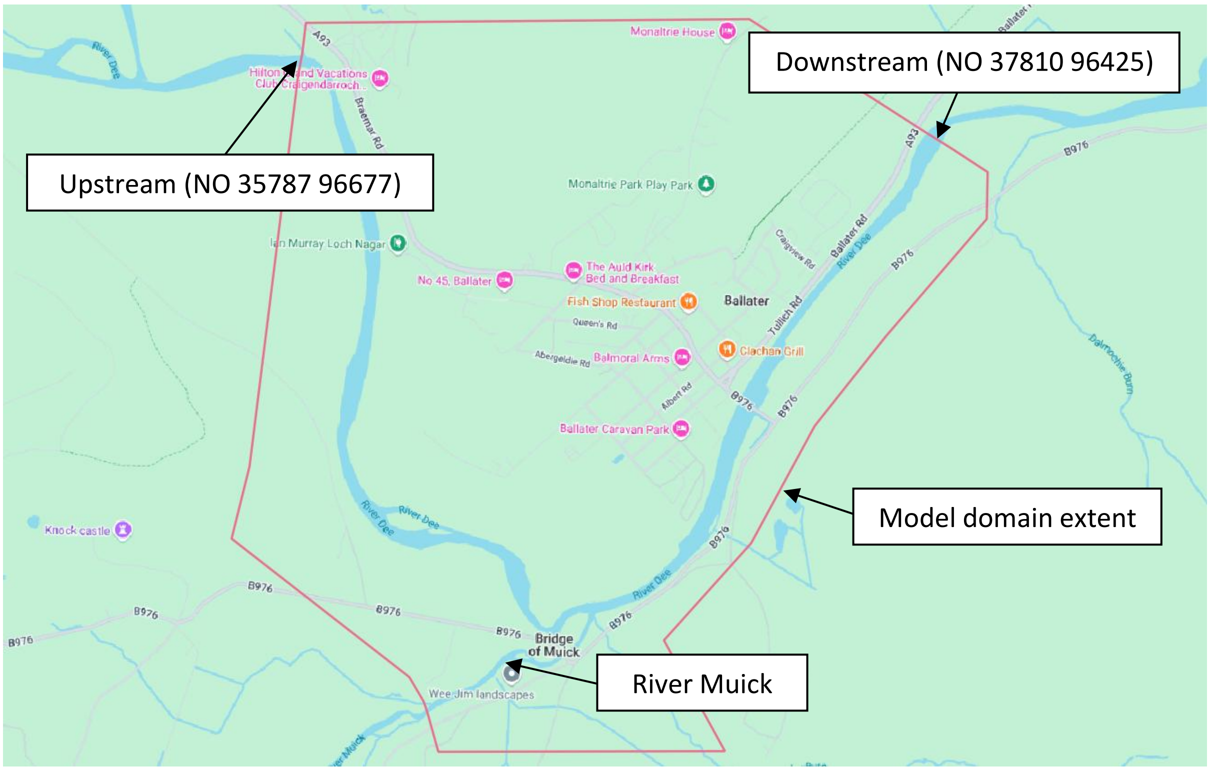

Figure 3.1. Model extents.

3.4.2. Model Domain

The model domain incorporates the 1D Flood Modeller model of the channel, and the 2D TUFLOW model of the floodplain. The 1D section spacing varies, however, they're generally between 50 to 100 m apart, depending on channel features.

The 2D model uses TUFLOW Classic, with a fixed grid of 2 m cells. This provides a high degree of model resolution, which is beneficial in representing the complex overland flow paths across the floodplain.

3.4.3. Model Boundaries

There are three model boundaries: an inflow at the upstream extent of the Dee, an inflow at the upstream extent of the Muick and an outflow at the downstream extent of the Dee.

The inflows are applied in the 1D model, with flow-time boundaries. The data for these was derived from the ReFH outputs.

The model outflow comprises boundaries both in the 1D model and the 2D domain. In the 1D model, the boundary is a normal depth, using the default option of calculating the slope from the channel bed. In the 2D domain, two boundary lines were digitised either side of the channel. These were assigned as stage/flow boundaries, with the TUFLOW function to automatically generate a curve based on a given slope. The slope values were measured from the terrain.

3.4.4. Model Roughness

Within the 1D model, the channel was assigned a Manning's n value of 0.035. In the 2D domain, spatially varying roughness values were applied using Manning's n regions, assigned with values appropriate to the land type, e.g. general floodplain, trees, buildings, and so on. The land type regions were delineated using satellite imagery and photographs taken in the field. The Manning's n values assigned to each region are summarised in Table 3.1.

Table 3.1. Manning's n values used in 2D domain.

Land type	Manning's n value
General floodplain	0.05
Heavy vegetation	0.06
Trees	0.08
Buildings	0.3

3.4.5. Structures

There are two bridges in the model domain (see Figure 3.2). These are Ballater Bridge on the River Dee, and the B976 Bridge on the River Muick.

Figure 3.2. Bridges within the model domain.

The Ballater Bridge is included in the 1D model, using the arch bridge unit in Flood Modeller. The dimensions of the bridge were taken from the Aspect survey data. The cross-section is presented in Figure 3.3.

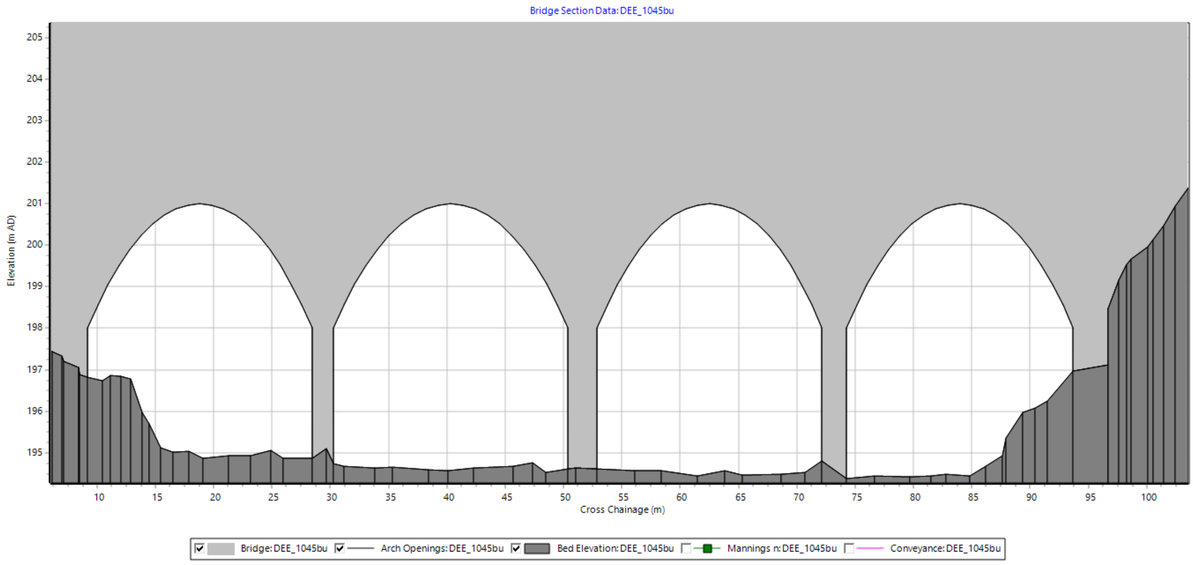

Figure 3.3. Ballater Bridge model unit cross section.

The second bridge within the model boundary is situated on the River Muick. This is the B976 road. Section details were unavailable; cbec's topographic survey did not cover the River Muick and the data provided in the Aspect survey did not include this bridge. However, field photos indicate that the bridge deck is substantially higher than the channel, meaning it's unlikely to be affected by, or have any impact on, fluvial flow from the River Muick. Flooding on the Muick is also not significant to the project site, so any potential afflux occurring as a result of the bridge will be negligible in terms of affecting the overall model results. For these reasons it was determined feasible to omit the bridge from the model.

Maximum stage results through the Ballater Bridge are shown in Section 4.2.

3.4.6. Design Scenario

At this stage, there is no design scenario to be modelled. The project brief required modelling of the existing case only, to inform future design.

3.5 ASSUMPTIONS AND LIMITATIONS

There are limitations inherent in the 1D/2D approach, regarding the representation of the dynamic braided/mobile reach of channel in the River Dee through the southern section of the study site, where there are prominent sand/gravel bars as evident in Figure 3.4 and Figure 3.5.

This stretch of the River Dee is characterised by a braided channel under low/daily flow conditions and is highly mobile. Historic imagery shows significant lateral movement of the main channel, within the constraints of the wider sand/gravel channel bars.

In a 1D channel model, the river is represented by fixed cross-sections. These interpolate detail between each section. Within the section they also use an average velocity and a consistent water level across the entire section. The approach can't represent velocity and water distribution across the channel that would be seen, particularly in channels of this nature.

Figure 3.4. Satellite imagery of the River Dee bend, with prominent sand/gravel bars and mobile channel.

Figure 3.5. cbec drone imagery of the River Dee bend around Ballater.

Within the 1D model, cross-sections cover the width of the general channel. These can be seen in Figure 3.6. These sections will represent the approximate conveyance of the channel, but won't accurately represent the braided channel and variance in velocities and flows across the full channel width.

As the channel is also known to be highly mobile in places, and so the model is only representative of the channel at a fixed point in time. Any change to the channel layout will require a rebuild of the 1D model in this area. It is not expected that the general conveyance capacity will change though, so this is less likely to be an issue with flood flows, particularly the more extreme events.

Figure 3.6. 1D model cross section locations.

3.6 MODEL VERIFICATION

3.6.1. Validation

Model outputs were checked against the existing SEPA flood hazard maps[6] of the area. The online maps provide relatively low-resolution assessment of the potential flood likelihood of occurrence for three specific flood return intervals:

- High frequency, lower level flooding = SEPA Map 1:10yr
- Low frequency, higher level flooding = SEPA Map 1:200 yr
- Very Low frequency, very high level flooding = SEPA Map 1:1000 yr

[6] SEPA flood zone maps showing fluvial, surface water and coastal estimates. Available online from: https://map.sepa.org.uk/floodmap/map.htm (Last accessed March 2025)

This was a visual assessment only, however, a good correlation was found between the SEPA maps vs cbec's model outputs, with cbec's model producing similar flood routes and affected areas. It was noted that cbec's model showed more extensive flooding under the same events (likely a reflection of the use of conservative hydrological estimates feeding into the hydraulic model).

cbec also approached SEPA for data from previous flood modelling, however, SEPA were unable to provide any data for this study.

3.6.2. Calibration

Tit was intended that the current model would be calibrated using data/outputs from SEPA's existing flood model. However, following consultation with SEPA, it was advised that it would not be possible to obtain such model data, and so this calibration could not be undertaken.

However, on-the-ground observations were considered during the project and used where possible to validate the model results.

4. MODELLING RESULTS

4.1 MAP OUTPUTS

The model results are shown in Figure 4.1 to Figure 4.8. These clearly show the floodplain covering the area within the River Dee bend, as it flows from west to east around the southern side of Ballater. The outputs match with the floodplain area identified in SEPA's flood mapping, and align the expected outcome based on discussion with the client.

The results highlight the high risk of fluvial flooding to areas of Ballater, and importantly, show the predicted flow routes under each of the flood scenarios modelled (with the exception of the 1:2year and 1:5 year model, as there are so many localised variations in flow under these smaller flood events, some of which won't be represented accurately given the capabilities/resolution of the 1D/2D modelling approach).

Critically, this information will enable more informed decisions on potential flood management options, based on how channel – floodplain flows interact at this fixed point in time.

A number of key locations, listed in Table 4.1, are indicated in the maps to facilitate analysis.

Table 4.1. Key locations

Map ID	Location	OS National Grid Reference
1	Dee Street Bollards	NO 37130 95481
2	Green Keeper's shed	NO 36454 95376
3	Golf Clubhouse	NO 36694 95384
4	Hesco boxes beside Shaun's bridge	NO 36708 95138
5	Sluievannachie (back garden last house)	NO 36132 95962
6	15th Tee box ((Gents or Ladies?)	NO 36271 95734
7	16th White Tee box	NO 36607 95662
8	Fire station	NO 37032 95495
9	Police station	NO 37011 95563
10	13th green	NO 36010 95665
11	Salisbury road / Victoria Road	NO 36774 95505
12	Salisbury road / Anderson road	NO 36884 95370
13	Fisherman's Cottage (opposite Red Brae)	NO 35982 95363

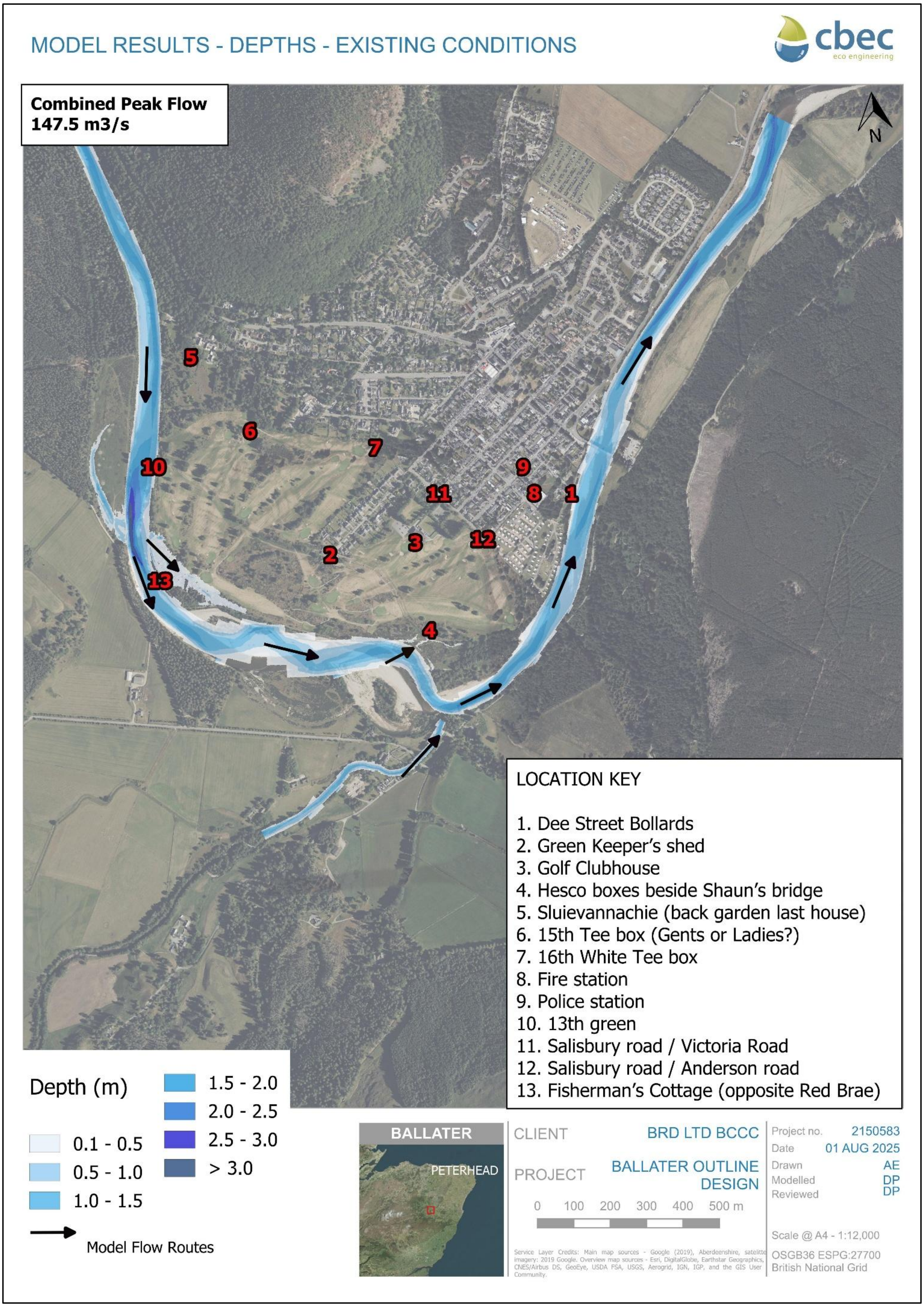

Figure 4.1. Incipient out of bank flow (the point at which flood flow first breaks out of bank)

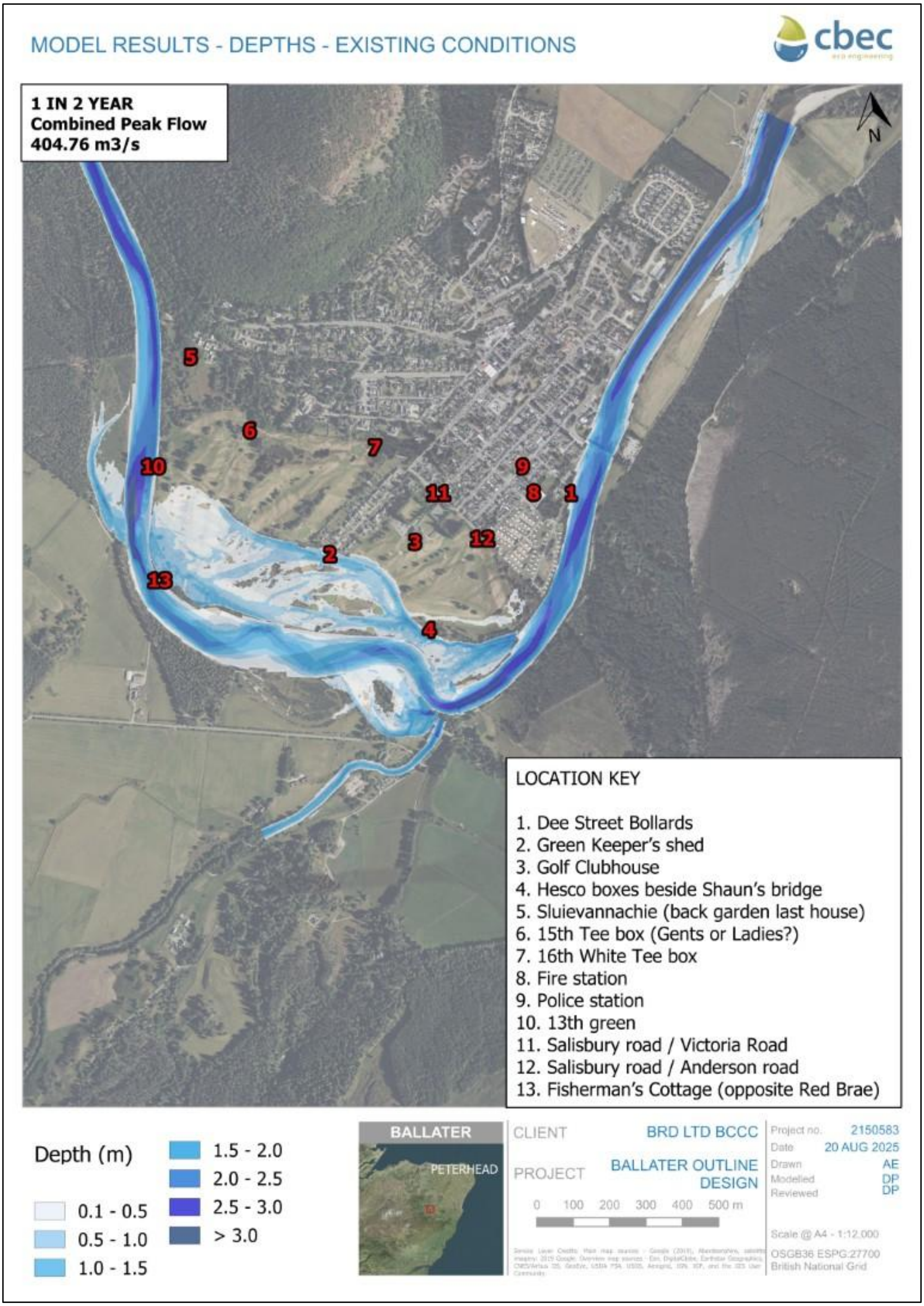

Figure 4.2. Model results for the 1 in 2 year event.

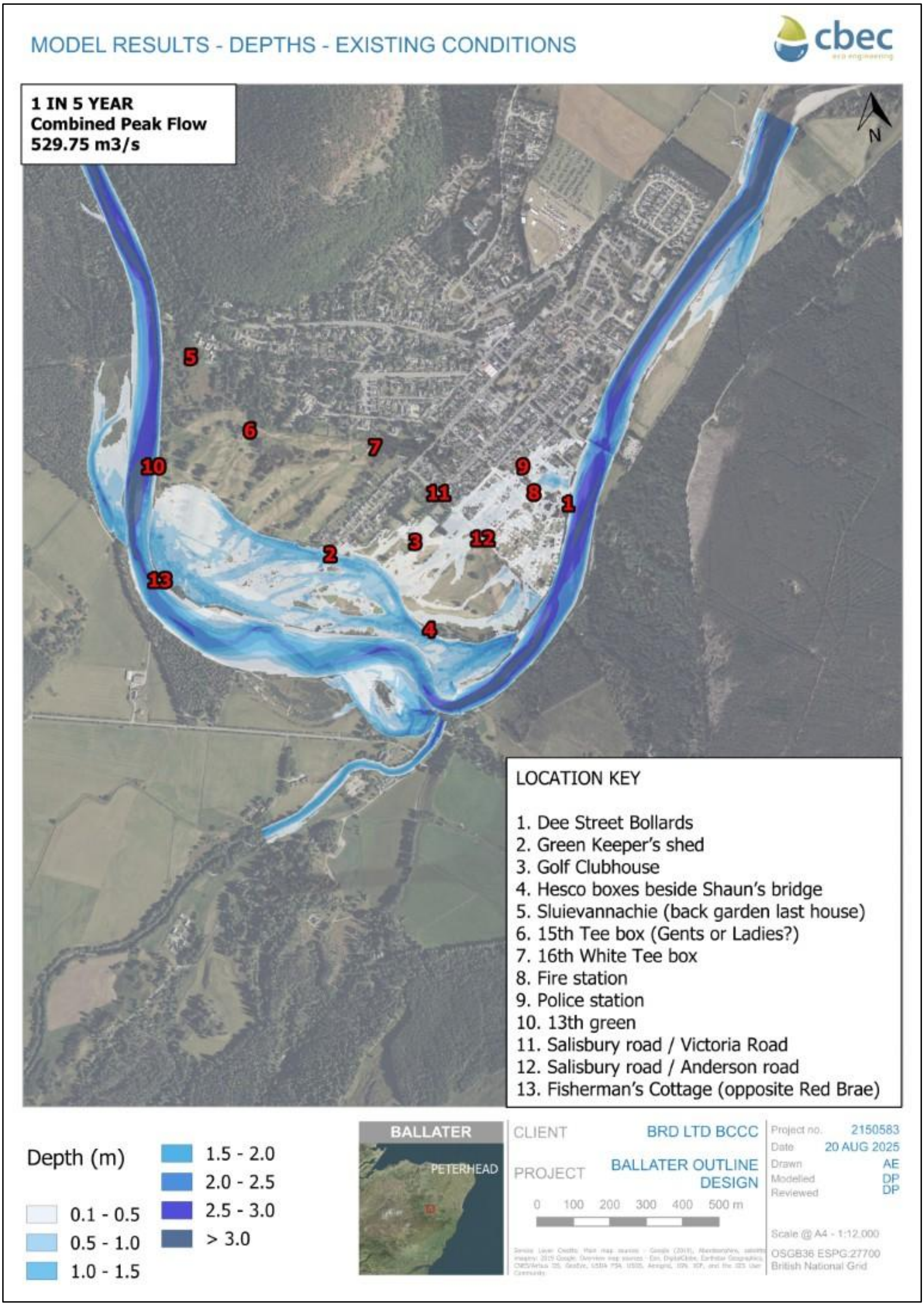

Figure 4.3. Model results for the 1 in 5 year event.

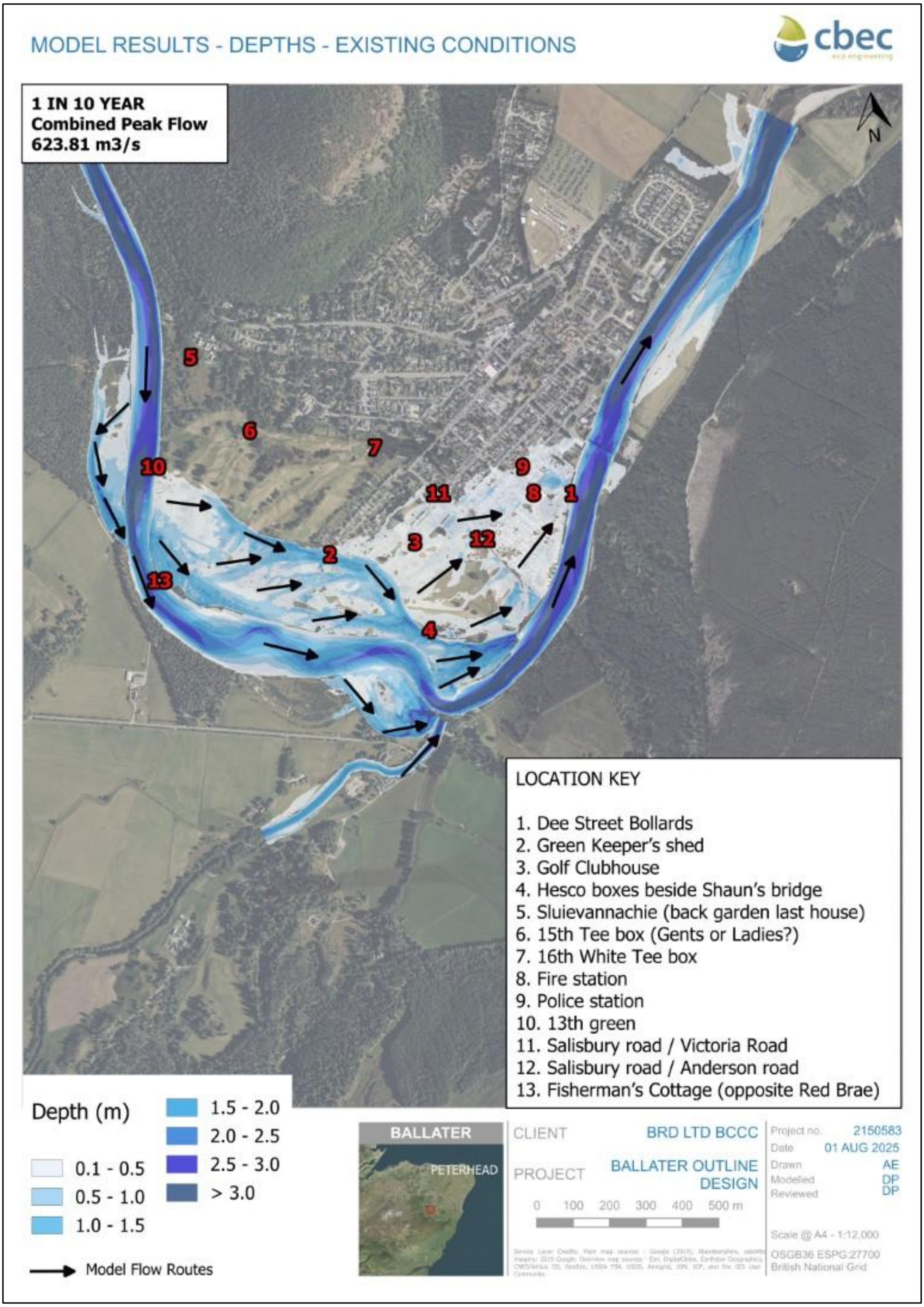

Figure 4.4. Model results for the 1 in 10 year event.

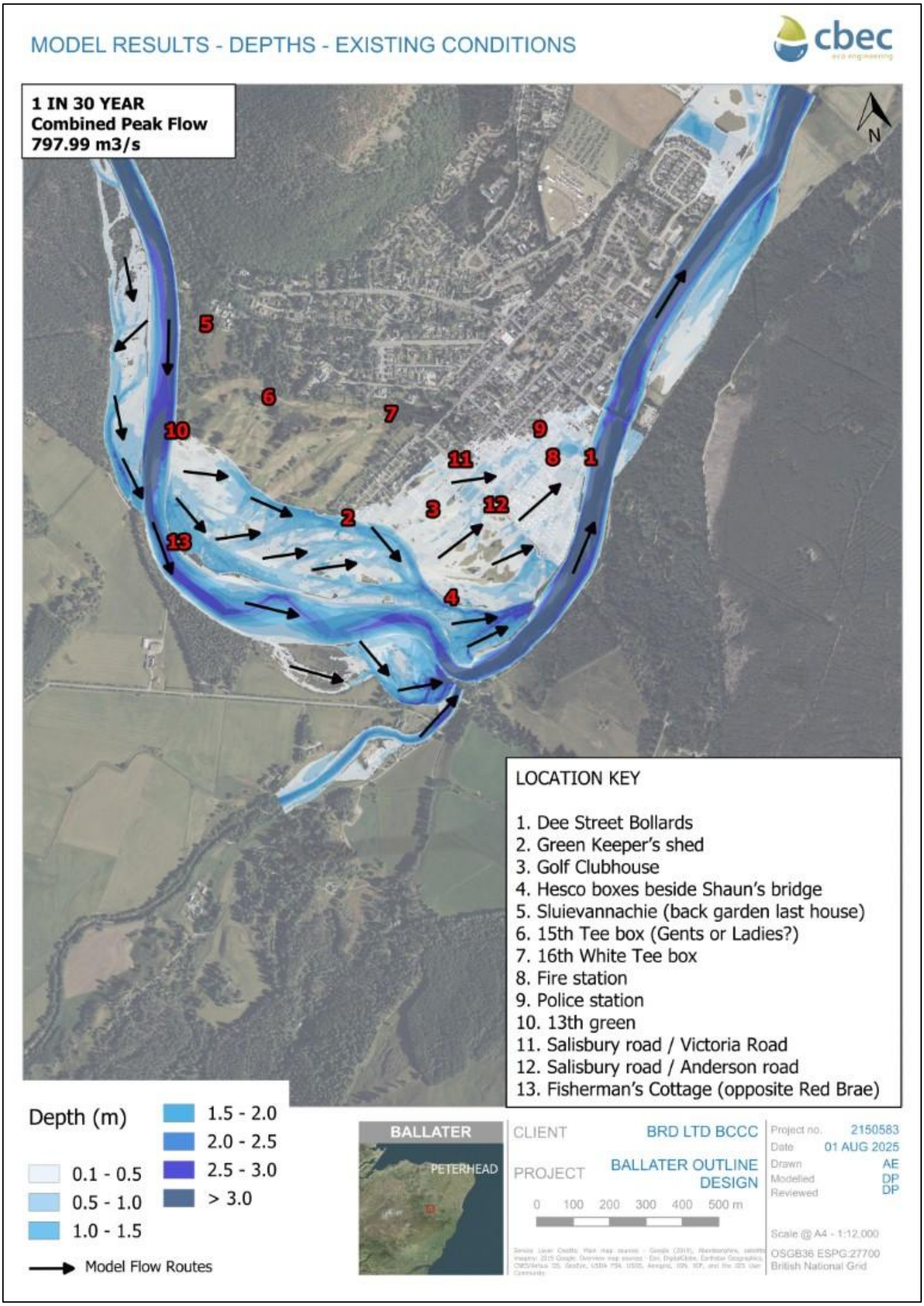

Figure 4.5. Model results for the 1 in 30 year event.

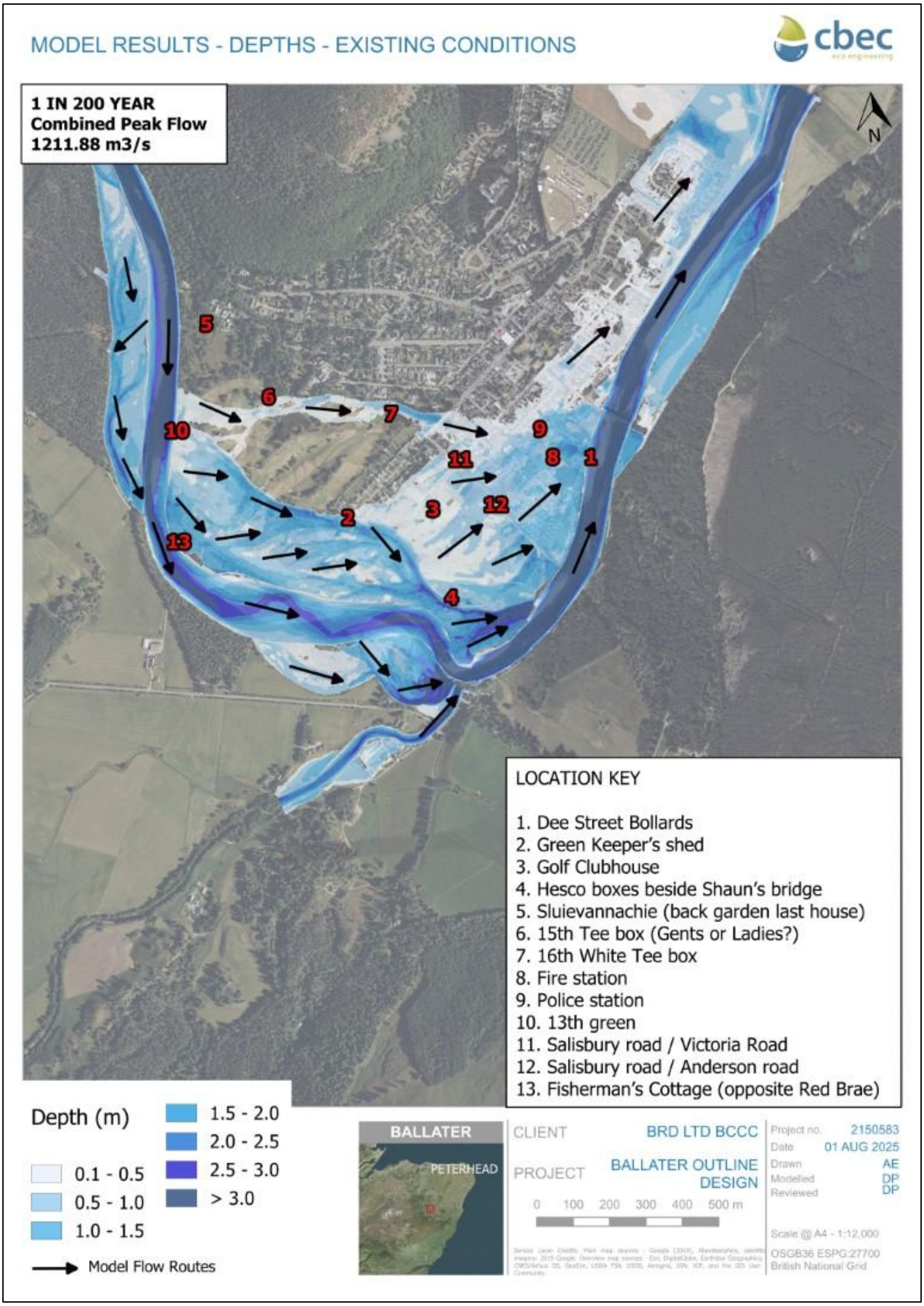

Figure 4.6. Model results for the 1 in 200 year event.

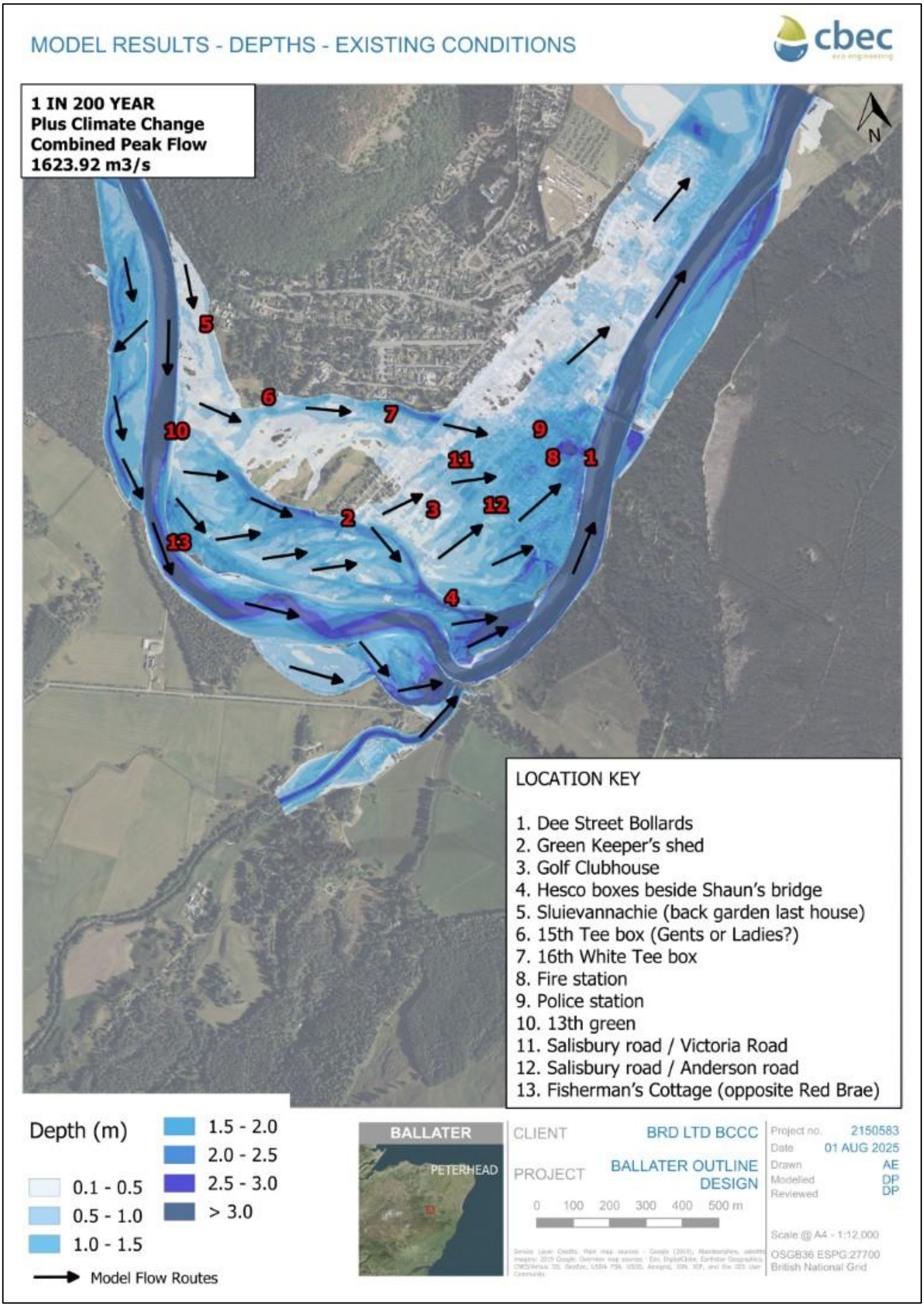

Figure 4.7. Model results for the 1 in 200 year plus climate change event.

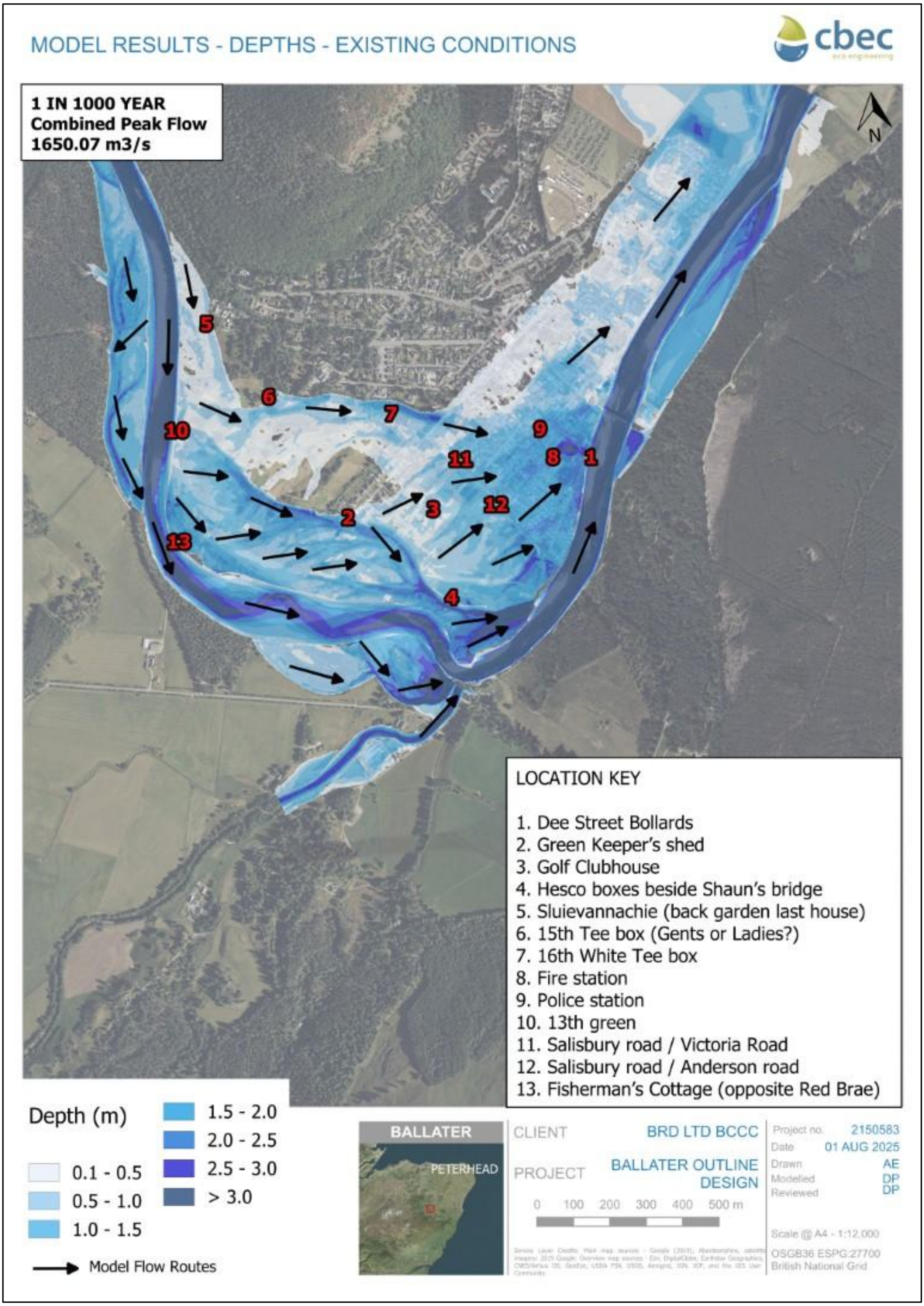

Figure 4.8. Model results for the 1 in 1,000 year event.

4.2 MAX STAGE PROFILES THROUGH BALLATER BRIDGE

The maximum stage profiles through Ballater Bridge are shown in Figure 4.9. This plot indicates the impact of the bridge on peak water levels. There's a demonstrable drop in peak water level due to the energy losses through the bridge openings.

The maximum water levels (stage) at the bridge cross-section are shown in Figure 4.10.

4.3 CHANNEL CAPACITY AT DEE STREET

During discussion with the project team, it was noted that the channel capacity near to Dee Street was of interest. Examination of the model results show that Dee St bank full channel capacity is in the region 560 m^3/s.

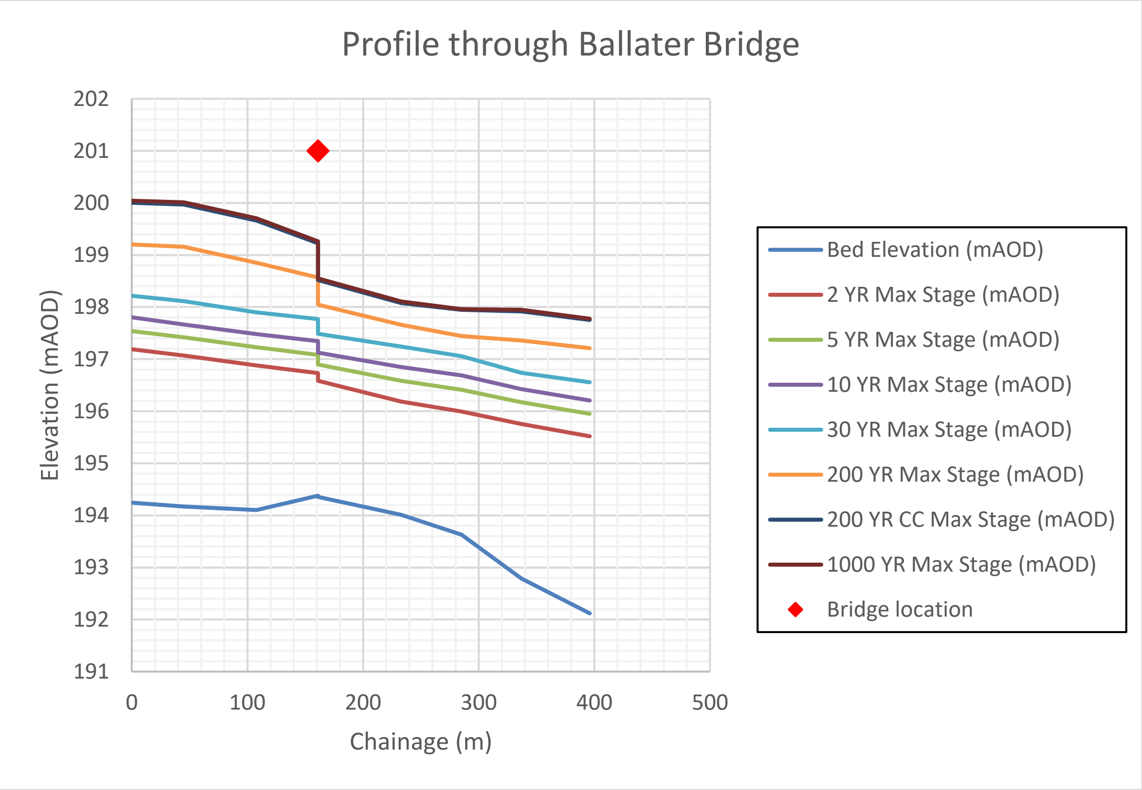

Figure 4.9. Max stage profiles through Ballater Bridge.

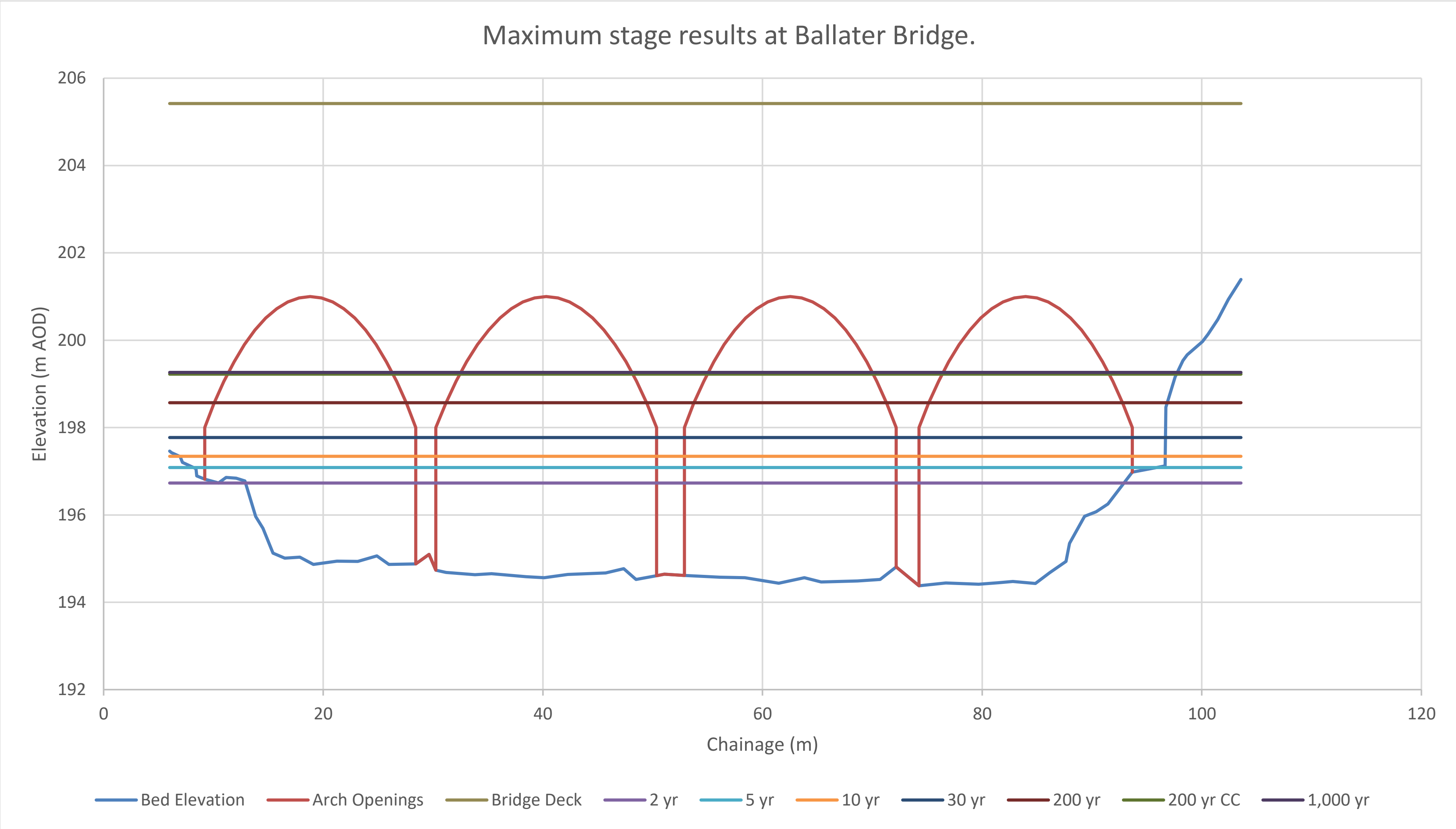

Figure 4.10. Maximum water stage results at Ballater Bridge.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This report summarises the approach to a hydrological assessment of the River Dee and River Muick catchments at Ballater, and the subsequent hydraulic modelling of these watercourses in the area. Ultimately, the purpose of the hydraulic modelling exercise was to assess the flood risk to the Ballater area and gain a better understanding of the flood flow routes activated under the different flood return intervals assessed. This will enable a more informed decision of the appropriate flood management options proposed.

The hydrological assessment applied three methodologies: the FEH and ReFH rainfall-runoff methods, and the WINFAP statistical. There are NRFA gauges on both the Dee and Muick that were considered as part of the assessment. Whilst the resulting WINFAP peak flow estimates were felt to be most accurate and all three methods produced results that were generally consistent with each other, the ReFH estimates were ultimately used for the modelling, as these were generally higher, and given the flood sensitive nature of the area, it was decided that a conservative approach to hydrological estimation would be most appropriate for this assessment.

The hydraulic modelling was carried out using a combined 1D/2D approach, with Flood Modeller and TUFLOW Classic software. This was at the request of the client, and to be compared with existing flood risk modelling carried out by SEPA, using the same approach. However, during the course of the project, it was confirmed that SEPA's model and associated results could not be shared for use during this study. Even so, the 1D/2D approach was still applied.

The results indicate that Ballater is at high risk of flooding from the River Dee, with the 1 in 2 year event encroaching on residential areas to the south of the village, and the 1 in 10 year and upwards events posing significant flood risk to certain areas within the town. The main flow routes extend from the Dee within the upstream section of the study site to the west of Ballater, overtopping the banks and flowing eastwards across the floodplain, re-entering the channel to the east of the town.

5.2 RECOMMENDATIONS

The 1D/2D approach does present a significant limitation in representation of the most dynamic, mobile section of the Dee as it flows to the south of Ballater near the River Muick confluence. The 1D model sections apply an average velocity and depth across the entire cross section and cannot capture the more nuanced nature of the flow through braided channels and alluvial bars. The 1D approach also means that the sections of river between cross-sections is interpolated, based on the cross-section data, and so localised variations in topography may not be represented accurately. This is especially prevalent in this southern section of the Dee, with the presence of mobile alluvial deposition which cannot be easily accounted for in a fixed 1D model.

Whilst the model approach was determined appropriate for this stage of the project (i.e. concept design), as the project progresses and design modelling is required, cbec recommends application of a fully 2D model, which will better representation of the complex nature of the channel and alluvial barforms to the southern area of the site. The 2D approach would also allow for variance in velocities and depths across the braided channels. The approach is also more agile, being faster to update with new channel and floodplain information, in the event that the model has to be updated at any time as a result of significant channel change. cbec has successfully applied fully 2D modelling to many similar sites and found the approach gives a more accurate representation of channel conditions, which in turn provides additional confidence when developing design options.

As such, it is recommended that a fully 2D approach (using industry-standard software, such as HEC-RAS or TUFLOW FV/HPC) be adopted for assessment of future designs.

cbec eco-engineering UK Ltd

Suite MF04, Marr House

Beechwood Business Park North

Inverness

IV2 3BW

01463 718831