Spey Catchment Initiative

River Spey

Hydraulic/Hydrological assessment and modelling, and identification of restoration options for the upper Spey floodplain

FINAL

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Executive Summary

Kaya Consulting Limited was commissioned by the Spey Catchment Initiative to undertake a Hydrological and Modelling Study of a ~15km reach of the River Spey between Spey Dam and the River Truim.

The work includes the estimation of river flows, the development of a hydraulic model of the River Spey, flood mapping and the identification of high-level options for restoration of the floodplain. The findings of the study will be used by Spey Catchment Initiative, and other supporting organisations, to make further investigations into potential restoration options.

Efforts have been made to provide a report in “Plain English”, with this main report aiming to provide key information and results with more technical documents attached to the Appendices.

A community liaison meeting was organised. Attendees provided key information, such as the location of breaches in embankments & locations where waters tend to overtop the embankments. This information was used to inform the study. (See **Section 2**).

Key supporting data was acquired from a number of sources to support this assessment. A topographical survey was commissioned covering the River Spey from the Spey Dam to close to the confluence of the River Spey with the River Truim. A number of walkovers were undertaken by key staff members to support the development of the river model and help identify strategic restoration interventions. Sediment sampling was undertaken along the River Spey and a review of previous sediment sampling by Gilvear was undertaken. The results suggest that the River Spey suffers from sediment starvation. Historical, geological and environmental information has been reviewed to help characterise the catchment and obtain an understanding of the River Spey. (See **Section 3**).

A review of the available hydrological information was undertaken. A review of the Spey Dam was undertaken, including data provided by the dam operator and previous studies undertaken by others. Observed data was compared to key flood events that were noted during the community liaison meeting. A reservoir model was developed to convert the observed water levels in the Spey Dam to flows for the key observed events. It was noted that the reservoir model is a simplified representation of how the Spey Dam works. In reality, there are a large number of variables and inputs and outputs, making it difficult to develop a model that fully represents all of these parameters. The model, therefore, is useful for providing flood flow estimates for individual recorded events but does not fully replicate how the dam works. Work was undertaken to predict peak “design flows”. Other hydrological information is also provided including flow estimates for the Mashie Dam and other tributaries. (See **Section 4**).

A Climate Change review was undertaken using local data for this part of the River Spey available from the UK Climate Projections 2018 portal. Precipitation rate anomaly (%) data was reviewed for various emissions scenarios to identify trends. The results suggest that regardless of the emissions scenario and timeframe there is projected to be an increase in occurrences of extreme precipitation, regardless of season. On average the summer months in the study area will become drier but there will be occurrences of extreme precipitation, greater than seen currently. Wetter more extreme weather is projected during the wetter months of the year. Results depend on the emissions scenario and what data (Seasonal, monthly, etc) is chosen. Climate change estimates made using the data from the UK

Climate Projections 2018 portal are generally lower than the conservative values recommended by SEPA for flood studies.

One of the main components of the study was the development of a river model of the River Spey. An initial preliminary model was developed to help inform the river topographical and walkover survey. Following on from this, a more detailed model was developed using information from the various surveys. The model was developed using standard river modelling software and key features such as bridges and embankments were represented in the model. The model was run for key observed events (“real” events for which we have data). The model results show a good relationship for flood extents, flood timings and flow mechanisms based on the observed data.

Model results are provided, including flood maps, a review of flood timings, velocities and other key information. Sediment modelling was undertaken to get a better understanding of sediment transport processes. (See **Section 5**). This work has helped us gain a better overall understanding of the predicted flood extents, flood levels and depths, and flood mechanisms that occur in this reach of the River Spey and help us better understand the impact of the changes to the channel/floodplain morphology.

The model results and other aforementioned supporting information from this study were used to identify 5 key restoration options/interventions. These include smaller options such as a floodplain scrape, to large-scale restoration at Cluny Estate. Proposals to reconnect meanders and floodplains were also put forward. Generally, the options put forward are based on a “natural flood management” (NFM) philosophy of returning the river to a more natural course by removing obstructions to flow. The majority of the options have the potential to increase flood storage, encourage groundwater recharge and create habitat or increase the variability of habitat.

A simple options appraisal was also undertaken to identify if certain options provided more benefits than others.

The results suggested that Options 2 and 5 would provide the most benefit considering the work entailed. It is recommended this is discussed with all stakeholders, however, as they may have a different view on the “benefits” of each option.

A discussion is provided on dredging and sediment and dam management to provide context.

More work could be undertaken to further evaluate/test the various aforementioned options by refining the detailed model that has been developed specifically for this study. The model could also be further improved in the future as more data becomes available, such as the refining the calibration.

Abbreviations

CEH	Centre for Ecology & Hydrology (UK Hydrology Research organization)
EA	Environment Agency (Environmental Regulator in England)
DTM	Digital Terrain Model (Topographical data, See LiDAR below)
FEH	Flood Estimation Handbook (Standard Methods for calculating river flows in UK)
LiDAR	Light Detection and Ranging data (Topographical data collected from aerial surveys)
NPF4	National Planning Framework 4 (Current Scottish Planning Policy)
NRFA	National River Flow Archive (Depositary of river information across the UK from gauging stations)
mAOD	Metres Above Ordnance Datum
OS	Ordnance Survey (UK Map authority)
SEPA	Scottish Environment Protection Agency (Environmental Regulator in Scotland)
SuDS	Sustainable (urban) Drainage Systems (Sometimes SUDS)

Glossary

Aggradation	Increase in land elevation, normally in a river system, from the deposition of sediment.
“Backing-up” or Backwater effect	A rise in water elevation caused by an obstruction such as a bridge opening that restricts the conveyance capacity of the channel.
Biodiversity Net Gain (BNG)	A strategy to contribute to the recovery of nature while developing land. Communities and land owners could earn credits by restoring areas along the River Spey.
Catchment	The area that drains into a river.
Confluence	Location where two rivers meet.
Conveyance	The ability of the channel to move (convey) the water
Cross-section	A plot (graph) showing the ground elevation across a river from one side of the watercourse to the other, including bed levels.
Ecosystem	A living community of interacting animals and plants. A “home” to these animals and plants.
Embankment (Also Bund)	A man-made earth structure. Normally trapezoidal in shape, wider at the bottom than the top.
Flood Defence	A structure, or combination of structures, normally walls or embankments, that provide protection to certain areas
Floodplain	An area of land over which water flows or is stored during a flood event.
Flow (also called Discharge)	The amount of water (volume) that passes a specific point on a watercourse over a given period of time. Rates are normally measured in Cubic metres per second (m^3/s)
Geomorphology	Processes of erosion, deposition and sediment transport that impact the physical form of a river and the surrounding area
Hydrograph	A graph showing the flow over time at a given location on the watercourse.
Hydrological Model	A model that estimates the river flow based on the rainfall falling into the catchment, amongst other factors and losses.
Hydraulic Model (River Model)	A model that represents the river and converts the flows (from the Hydrological Model) into water levels, showing where flooding would occur.
Natural Flood Management (NFM)	A selection of flood management techniques that aim to work with natural processes to manage flood risk.
Overland flow pathway	A route (pathway) that water takes once it has spilled out of the river channel. Often they will run along roads or depressions.

Return period	The inverse of probability (generally expressed in percent), it gives the estimated time interval between events of a similar size or intensity. For example, the return period of a flood might be 200 years; otherwise expressed as its probability of occurrence being 1/200, or 0.5% in any given year. This does not mean that if a flood with such a return period occurs, then the next will occur in about two hundred years' time - instead, it means that, in any given year, there is a 0.5% chance that it will happen, regardless of when the last similar event occured.
Riparian **(Riparian Zone)**	The area immediately adjacent to the riverbank. Often including vegetation that forms next to the river.
Runoff	The proportion of rainfall that does not infiltrate into the ground and instead makes its way towards watercourses.
Stage	Stage is a term for “Water Level” in a watercourse or waterbody
Surcharge	Bridges and culverts can only convey a limited amount of water. When they can no longer work efficiently, they “surcharge” although they can continue to convey flows until flows overtop the deck/top of the structure.

1 Introduction

1.1 Study Background

Kaya Consulting Limited was commissioned by Spey Catchment Initiative to undertake a Hydrological and Modelling Study of a ~15km reach of the River Spey between Spey Dam and the River Truim.

The modelling will support the development of outline proposals for restoration of this reach of the River Spey. The overall aim is to restore the connection between the River Spey and its natural floodplain to provide benefits with respect to both the environment and flood risk attenuation.

This reach of the River Spey was historically subjected to engineering works both for the generation of hydropower and to increase agricultural productivity. The Spey Dam, and a second smaller dam, were constructed in around 1942/1943 as an addition to the Lochaber Scheme, part of a hydro scheme to generate electricity for the aluminium factory at Lochaber. This scheme restricts both flows and sediment being carried downstream, impacting on the natural flow regime and transport of sediment. Numerous agricultural embankments separate the river from its floodplain, with embankments also compartmentalising the floodplain areas.

Restoring the River Spey and its floodplain to a more natural condition has the potential for multiple benefits such as natural flood management (NFM) and habitat improvement, as well as adding to climate change resilience and improved amenity for the community. The study will also be used to engage with local landowners/managers and the community.

1.1 Aims & Objectives

The overarching aim of this study is to identify between 4 and 6 key interventions for river restoration along this reach of the River Spey.

To achieve this aim Spey Catchment Initiative suggested dividing the work into 6 stages. These are shown in **Table 1-1**.

Table 1-1: 6 Stages of the Project

NO	TASK	ADDRESSED IN SECTION
1	Project Initiation Meeting & Project Scoping	**Section 1/2**
2	Landowner/Community Liaison	**Section 2**
3	Field Surveys & Data Gathering	**Section 3**
4	Hydraulic Modelling & Generation of Restoration Options	**Sections 4-6**
5	Presentation of the project to the PM Team	**Throughout report**
6	Final Report	**Throughout report**

To meet the above the following work has been undertaken:

- A topographical survey of the River Spey and embankments.
- A geomorphological survey, including sediment sampling.
- A hydrology/modelling walkover.

- A hydrological assessment, considering available hydrometric data.
- The development of a river model to represent the study reach of the River Spey.
- Review of the modelling to identify interventions/restoration options.

1.1 Study Reach & Description

The study reach is an area of the River Spey of approximately 15km from the Spey Dam and the River Truim (**Figure 1-1**). This reach of the River Spey was historically subjected to engineering works both for the generation of hydropower and to increase agricultural productivity.

The Spey Dam, and a second smaller dam, were constructed in around 1942/1943 as an addition to the Lochaber Scheme, part of a hydro scheme to generate electricity for the aluminium factory at Lochaber. This scheme restricts both flows and sediment being carried downstream, impacting on the natural flow regime and transport of sediment.

The construction of embankments and other drainage improvements were undertaken along the River Spey as early as the 1750's close to Kingussie to support an increase in agricultural production. These measures were soon extended across much of the surrounding area including the study reach. The embankments and drainage measures maximised available agricultural land but removed the connection between the River Spey and its floodplain, reducing flood storage but also altering the natural hydro-geomorphological processes and negatively impacting on the natural river and wetland habitats.

Figure 1-1: Study Area and Important features

The study reach is therefore now characterised by controlled low flows conditions, with lower flows compared to what would have passed downstream historically. The hydraulic control has changed the natural pattern of flows in the river and reduced high (non-flood) flows, resulting in a reduction in the diversity of channel morphology and habitat and contributed to local sediment accumulation in sections of the channel downstream of tributary inflows. In contrast, in the reach downstream of Spey Dam the channel can be sediment-starved as bedload sediment is trapped in the reservoir.

2 Community Liaison Meeting

Prior to commencing fieldwork, a community liaison meeting was organised to enable discussion with local landowners and to obtain information on this reach of the River Spey The meeting was held in February 2023 at Laggan Village Hall. Kaya Consulting was also provided with a letter from a local community member who could not attend the meeting and a series of letters and documents describing previous work/comments.

The meeting was led by the Spey Catchment Initiative, supported by key team members from Kaya Consulting.

The meeting had a good turnout with a large number of local landowners and community members attending the meeting to provide local knowledge and voice their opinions.

Attendees provided key information, such as the location of breaches in embankments and locations where waters tend to overtop the embankments. This information was used to inform the site walkover, topographical survey and the modelling. The most important of these key locations are marked on **Figure 2-1**.

Attendees indicated that the river channel has become blocked over time in places, with a gravel island, for example, having built up over a period of approximately 12-years at approximately NGR 259915 793828 (**Figure 2-1**). Flood waters spill north upstream of the gravel island, around the location of the ford, and flow around the gravel island. Flooding of the road in this location occurs and the field to the north of the gravel island also floods. The General Wades Military Road that gives access to Dalchully House was also noted to be liable to flood, restricting access to Dalchully House.

One member of the community noted that flooding of the fields to the south of Gergask occurs approximately twice a year. Flood waters reach approximately 20m to the south of house number 7. The resident noted that flooding historically occurred after periods of snow melt.

A member of the community noted that the fields to the north of the River Spey to the south of Gaskbeg, a little downstream of Laggan bridge and the disused pit flood relatively frequently. Information on where the flooding starts from and extends to was provided. Further downstream, but still on the Gaskbeg land (south of Balgown War Memorial), it was noted that the area between the River Spey and the raised embankments floods, but it is rare that the embankment itself is overtopped.

The community voiced a number of more general concerns and noted that the River Spey and agricultural ditches are heavily sedimented in places and require dredging. Dredging of the river used to take place frequently but this is not the case now and sediment has built up. It was emphasised that deepening should not take place, only maintenance to remove sediment and vegetation. It was noted that the construction of the Spey Dam has changed the flows in the River Spey. A community member, who has lived in the area for a long time, suggested that the dam has resulted in there being more smaller floods than before the construction of the dam but that there have been fewer large floods. The importance of flooding was brought up. It was accepted that flooding helps keep the water moving, cleaning out the river and streams. It was noted that erosion occurs along the River Spey, particularly, in the location of trees, which likely exacerbate the erosion. Consideration should be given to removing some trees.

A representative from NatureScot attended the community liaison meeting. They noted that there was a Strathspey Wetland and Waders Initiative (SWWI) project to create Wader Scrapes in the fields to the north of the River Spey close to the aforementioned gravel island. Wader Scrapes are small wetland areas formed by shallow depressions with gently sloping edges, which seasonally hold water. They are attractive to wildlife such as invertebrates and can provide important feeding areas for breeding wading birds. The SWWI project objectives are to benefit breeding waders, which are declining across the UK. Scrapes are one of many actions which can be taken to benefit waders. NatureScot noted that this area is very important for breeding waders, and if options are proposed for this area, NatureScot should be further consulted for advice.

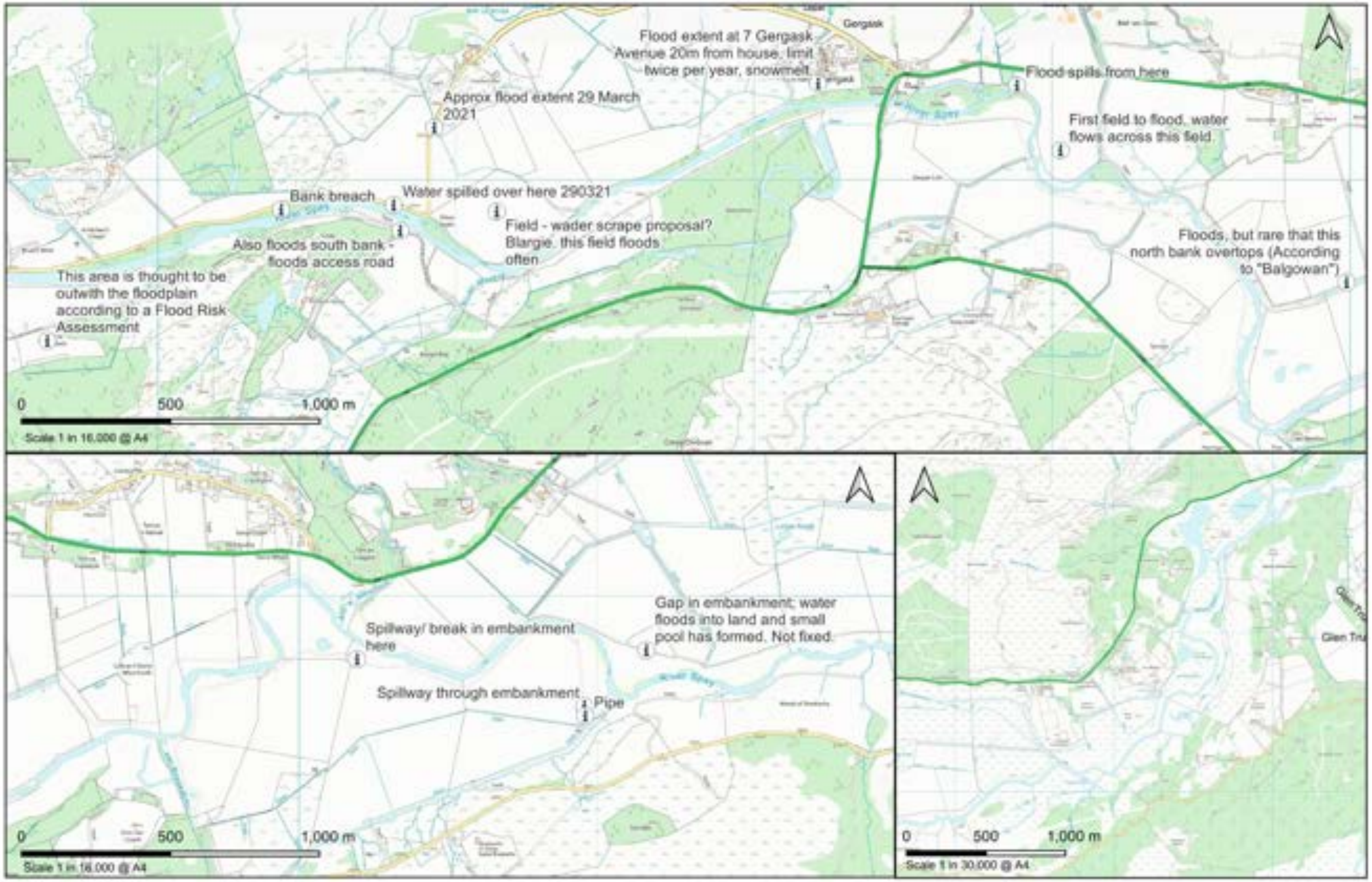
Photos of flooding were provided by the various attendees which helped confirm three dates where flooding had occurred. These were 19/09/18, 10/12/19 and 29/03/21. This allows comparison with the local observed data (rainfall, river levels). A video, taken from an ATV, of flooding along the road between the Spey Dam and Gergask, for the latter event, helps confirm the approximate extent of flooding for this period and was useful for calibrating the modelling work.

Key locations of breaches in embankments and where flooding occurs, based on the above discussion, are provided in **Figure 2-1**. This information has been used to feed into the surveys undertaken but also to support the river modelling.

Documents viewed at the meeting include a "Flooding in Badenoch & Strathspey" report dated 1990 and undertaken by Cuthbertson and Partners (Now part of AECOM); a report on Aggradation within the Upper Spey SSSI (David Gilvear of University of Stirling, 2000); a number of letters from various organisations (SNH, now NatureScot; The Highland Council, Transport Scotland and a number of letters from the community to MSPs and similar important people) dated 2011 and 2012 regarding the removal of a gravel bar a short distance downstream of Laggan Bridge to reduce flood risk following an embankment breach and flooding of the link across Laggan Bridge; A letter dated 30th November 2011 from famers and crofters to Rio Tinto Alcan UK (Now Alvance) regarding flooding that occurred; A response letter from Rio Tinto Alcan UK (Now Alvance) explaining that they did not alter their control procedures during this flood event; A follow-up letter from Gaskbeg Farm regarding flooding that occurred in May, considered unusual by the community, with further suggestions for amending control procedures at the dam to permit slightly higher water levels in the River Spey in the winter months while perhaps maintaining the lower water levels in the River Spey during the summer months, alongside some newspaper articles.

Some information on dredging, and why it is not common practice nowadays, is provided in **Section 6.4**.

Figure 2-1: Key information provided by the community at the liaison meeting.



3 Data Collection, Field Surveys & Review

To support the undertaking of this study it was necessary to obtain a selection of key data from a variety of sources. Information on the acquired data is provided in the following sections.

3.1 Topographical Survey

A topographical survey was commissioned and undertaken by a Mick McWilliam Chartered Land Surveyors. As part of this survey 66 River Spey cross-sections were surveyed alongside the top-of-bank of all important embankments that run adjacent to the river. Key bridges over the River Spey were also surveyed, alongside a number of structures on the aforementioned embankments, such as culverts/pipes etc.

The topographical survey was undertaken to Ordnance Datum. The survey was obtained by walking the area and wading the river in places, but a waterborne vehicle was also used to obtain bed levels on the River Spey, where it was too deep to wade.

The topographical survey was extensive and was undertaken over a period of approximately 6 weeks.

3.2 LiDAR Digital Terrain Data

Light Detection and Ranging (LiDAR) is a method for undertaking spatial measurements by targeting an object/surface with a laser and measuring the time for the reflected light to return to the receiver. In the context of terrain data, an aeroplane is flown over and area and LiDAR is used to measure the ground elevation, providing topographical data over a wide area.

Phase 1 LiDAR for Scotland is available for the area surrounding River Spey. This data was commissioned by the Scottish Government in response to the Flood Risk Management Act (2009). This LiDAR was collected between March 2011 and May 2012. The data is provided with a 1m horizontal resolution.

The Scottish Government has since commissioned further areas of Scotland, but this has not covered the study area.

This Phase 1 LiDAR data has been used in the river model developed for this study. It is thought to be a suitable representation of the study area because there have not been significant changes since the data was collected in 2011/2012.

Key data, such as embankments, embankment breaches and the river channel have been surveyed as part of the topographical survey.

3.3 Mapping, GIS & other supporting data

A selection of Ordnance Survey mapping was purchased to support this study. This included the 1:10:000 VectorMap Local and the 1 in 50:000 mapping.

Kaya Consulting were provided with approximate landowner boundaries at the community liaison meeting. This data was converted into a suitable GIS format to support the fieldwork.

3.4 Site Walkovers

A number of site visits were undertaken by relevant specialists to support this assessment. These included site visits to the study area but also areas upstream and downstream of the study area.

These included the following summarised in **Table 3-1**. This does not include the topographical survey which was undertaken over a period of approximately 6 weeks when weather and flow conditions permitted.

Table 3-1: Information on Site Walkovers

WALKOVER DESCRIPTION	INDIVIDUAL	DATE
Pre-Community Liaison Meeting Drive by	Geomorphologist	01/02/23
Hydrology/Modelling Walkover	Hydrologist & Modeller	16/02/23
Sediment Sampling & Geomorphology	Geomorphologist & Hydrologist	08/03/23
Sediment Sampling & Geomorphology - 2	Geomorphologist & Hydrologist	18/04/23

A photographic record and plan showing the location of photos taken is provide in **Appendix B**. This shows key photos for the study, but the full suite of photographs taken as part of the study will be provided separately.

A photographic record of the watercourses, structures and relevant properties was made to support the development of a river model and help consider possible flood mitigation works.

3.5 Historical Information

Three key dated flood events were identified as part of the Community Liaison Meeting. These are shown in **Table 3-2.**

Table 3-2: Recorded Historical Flood Events

LOCATION	DATES	DETAILS
Coul & Blargie Farms (North bank of the River Spey)	19/09/18	The dam overtopped on this date. Water spilled out of the north bank at two main locations/breaks, spilling over the road into fields. Flows spilled across field east of road at bend (to the north of gravel island). Livestock has to be moved and sheep rescued.
Coul & Blargie Farms	10/12/19	Similar to above. Less severe. Flooding at the corner of the road at the gravel island.
Coul & Blargie Farms	29/03/21	Similar flood event to that that occurred on the 19/09/18. Video provided by the farms' owner, showing flood extents and depths. Flood waters reached 2/3 of the way up the road north towards Blargie Farm.

These three events all occurred in the upper part of the study area within the Coul Farm/ Blargie Farm area, approximately halfway between the bridge over the River Spey near Crathie and Laggan Bridge. The two locations where flooding started from are marked in **Figure 3-1** in **Section 3**. The provision of dates means that observed data on the River Spey can be used to help calibrate the results of the river model.

Additional flood information was provided at the community liaison meeting. Locations are marked on **Figure 2-1**. However, dates were not always available so this information can only be used as a guide rather than the calibrate the modelling.

3.6 Historical Mapping

Historical mapping of the River Spey and the surrounding area is available via the National Library of Scotland website (NLS, 2023). This service provides a number of georeferenced maps via a portal that can be overlain with current mapping sources, in addition to older mapping that has not yet been georeferenced.

The following maps were inspected to identify possible changes to the River Spey over the years. Inspected mapping includes, among others:

- OS 1 inch, 1885-1900;
- OS 25 inch, 1892-1914 (Partial Coverage);
- OS 6 inch, 1888-1913;
- OS 1:10,560, 1949-1969;
- OS 1:1,250/1:1,2500, 1944-1967 (Partial Coverage);
- OS 1 inch 1945-1948;
- Present day digital OS mapping and aerial imagery.

A review of these historic maps shows some localised changes to the morphology of the River Spey since the construction of the Spey Dam in 1942/1943, although the main stem channel remains in approximately the same position.

Maps from prior to the construction of the Spey Dam show a wider channel, in places, with more active meanders, bars and bends. After the construction of the Spey Dam some sinuous reaches of the channel have become straighter and narrower. Moreover, pre-construction, certain areas of the channel exhibited a more braided morphology where this is no longer the case.

The construction of embankments and other drainage improvements were undertaken along the River Spey as early as the 1750's close to Kingussie. Embankments further upstream at the study area are thought to have been constructed soon afterwards. There are no Ordnance Survey maps that predate the construction of the embankments along the study area. The only detailed map that predates the construction of the embankments is the Roy Military Survey of Scotland Map (1747-1755). This detailed map was surveyed using circumferentors, rather than triangulation, and was not undertaken to a consistent scale. This means it is not possible to directly compare this map to later Ordnance Survey mapping. However, it is clear from this map that the River Spey was historically much more sinuous with a number of islands along the study reach. For example, at the confluence with the River Mashie and a short distance upstream of the Laggan Bridge. The reach between Laggan Bridge and Uvie Farm is represented as particularly meandering.

Laggan Bridge is marked on the earliest Ordnance Survey maps, surveyed in 1870. This map also shows the current day road network suggesting there has not been much change with respect to infrastructure. The obvious exceptions are the two bridges over the River Spey a short distance downstream of the Spey Dam. These will have been constructed to replace a previous bridge a little further upstream when the Spey Dam was constructed. **Figure 3-1** shows the Ordnance Survey One Inch 1945-1948 map from before the Spey Dam and Mashie Dam were constructed.

Figure 3-1: Historic Ordnance Survey OS One Inch 1945-1948

3.7 Hydrometric Data

Hydrometric data was obtained from two key sources: Alvance British Aluminium (Hereafter Alvance) and SEPA. We would like to take the opportunity to thank them for providing this data.

Alvance British Aluminium, owners and operators of the Spey and Mashie Dams, were contacted to obtain relevant hydrometric data. Alvance provided some of the long-term data they collect such as abstractions taken from the Spey and Mashie Dams and monitored water levels in the Spey Dam. Some monthly rainfall data at the Glenshero Gauge was also provided, alongside daily average compensation flow data permitted to leave the Spey Dam. Alvance also provided some additional information, when requested, such as details of the Spey Dam spillway. This data was provided in spreadsheet format.

The above information was useful to get an understanding of the operation of the Spey Dam.

Much of SEPA's data can be downloaded from their API website. There are two gauging stations within this reach of the River Spey. The River Spey @ Spey Dam gauge and the River Spey @ Invertruim river gauge. The former gauge, which monitors water levels in the Spey Dam Reservoir, is only used for measuring water levels. The latter gauge receives more attention from SEPA and the measured water levels can be converted to flows using a stage-discharge equation. The River Spey @ Invertruim gauge also forms part of the National River Flow Archive (NFRA) and can be used in the FEH WINFAP software, for estimating flood flows.

Hourly observed water level data was downloaded from both gauging stations for the past 5 years for comparison with flood events that were described by the local community at the meeting. Observed flows were also downloaded from the River Spey @ Invertruim gauging station. Key data for the River Spey @ Invertruim gauging station was also downloaded from the NRFA.

SEPA also operate a rainfall gauge at Spey Dam. Hourly, daily, monthly and annual data was downloaded and reviewed.

The client provided a number of previous reports relevant to this study. A 2014 CRESS Report on the River Mashie provided some further clarification of the workings of the Mashie Dam. A 2000 report by Dr David Gilvear of the University of Stirling "An Assessment of Reported Aggradation Within The Upper Spey SSSI" also provides key hydrological information.

3.8 Geological Review

A review of the geology along the study reach was undertaken to obtain a general understanding of the geology. The review concentrates on areas of the study area close to the River Spey and is not exhaustive.

The British Geological Survey (BGS) GeoIndex provides BGS and other geology-related datasets available across the UK. This was used to review the geology along the study reach.

The area between Spey Dam and Balgowan is predominantly underlain by bedrock of the Glen Banchor subgroup. Between Balgown and a little upstream of the confluence with the River Truim the bedrock is predominantly Loch Laggan Psammite. At the River Truim confluence the bedrock is predominantly Torr Na Truim Semipelite.

Superficial deposits along the entire river reach are noted as being predominantly alluvium, of clay, silt sand and gravel. At the Cluny Estate, Breakachy Farm and Glentruim Farm, some areas of peat are identified. Some raised areas further from the River Spey are marked as being of Glaciofluvial Ice Contact Deposits. This includes parts of Laggan, Gaskbeg, Balgowan, Crathie and close to Jock's Spot Cottage. Areas of glaciofluvial sheet deposits are present between Uvie Farm and the River Truim. Further from the river to the north and south of the Glaciofluvial deposits there are some areas of hummocky (moundy) glacial deposits of sand, gravel and boulders. Other areas are composed of Devensian till.

The BGS GeoIndex also identifies some of the embankments that run alongside the River Spey as "artificial ground".

The BGS GeoIndex identifies a number of mines and quarries (14) within the wider area. These are all generally setback from the River Spey. Most are identified as gravel pits. There are or were pits/quarries at Crathie (2 pits), Drumgask, Gaskbeg, Balgowan (2 pits), Auchmore (2 pits) and at A' Ghlaic, close to Craig Dhu House. There is also a pit marked at Shirrabeg/Sherrabeg to the south of the Spey Dam.

Water wells are identified at Balgowan and Spey Dam.

There are few borehole log records in this area, as is typical for rural areas. There are a number of logs around Laggan Bridge, although some are not available to view online. A review of the available logs around Laggan Bridge suggests this area is underlain by a mixture of gravel and sand with some silt, in line with the description of alluvium. Some peaty layers were also identified.

3.9 Environmental Review

An environmental review was undertaken to identify key aspects of the local ecology, landscape, cultural heritage and how this might impact the potential for restoration options. The review concentrates on areas of the study area close to the River Spey and is not exhaustive.

This area is underlain by a low productively aquifer with small amounts of groundwater in the near surface weathered zone and secondary fractures, with virtually all flow being through fractures and discontinuities.

The River Spey is identified as both a Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) for biological reasons. NatureScot consider the River Spey to represent a variety of freshwater and riparian habitats including beds of shingle, gravel, sand and silt, islands, fringing woodlands and marshes. Its populations of Atlantic salmon, sea lamprey, freshwater pearl mussel and otter are considered to be of national and European importance. It is for this reason that the River Spey is designated a SSSI and a SAC.

Creag Dhubh, a hill to the north Creag Dhubh Lodge, is also classified as a SSSI for biological reasons (Woodland)

A number of woodland areas adjacent to the River Spey are part of the Ancient Woodland Inventory of Scotland. This includes some areas to the east and west of Balgowan, Coille Chluanaidh, Coille Na Creige Duibhe and Tom Na Moine to the north of the River Spey, alongside Coille Chatlaig, the Woods of Breaknachy, Creagan An Fhithich and Woods of Glentruim to the south of the River Spey.

There is a single Scheduled Monument in this area of the River Spey noted as Dun-Da-Lamb Fort, which lies raised up on the hill to the south of the Spey Dam. There are no Battlefields or World Heritage Sites.

There are over 100 Historic Environment Records along the study reach of the River Spey. This includes many historical features that vary in importance from General Wade's Military Road to old cemeteries such as Pol Na Bracha and other dykes, buildings and tracks.

3.10 Geomorphological & Sediment Survey

A walkover survey of the reach (fluvial audit[1]) was undertaken on the 8th of March and the 18th of April 2023 by two geomorphologist/hydrologists from Kaya Consulting. Weather conditions were very cold, dry and sunny at the time of the surveys. The preceding few weeks had been fairly dry in Scotland, hence flows and water levels were low. A visual survey of the study reach was also undertaken on 1 February 2023 by a geomorphologist and hydrologist from Kaya, accompanied by Duncan Ferguson from the Spey Fishery Board.

Sediment sampling was undertaken at 12 locations on the study reach to categorize the main sediment sizes on the bed (see **Figure 3-2** and **Appendix D-2** for locations). Locations for sediment sampling were chosen to correspond with survey cross-section locations where possible, at locations where management inventions may be recommended, and areas where active bars or sediment accumulations were present. The locations also broadly correspond to the sediment sample sites of the Gilvear (2000) study (see **Appendix D-2**). Sediment analysis was undertaken on site using standard Wolman counts (100 clasts per sample location).

Wolman counts are a method of measuring the size of material on a stream bed. The approach was first proposed by Wolman (1954) who suggested collecting at least 100 pebbles and measuring their size (B-axis). Hey and Thorn (1983) developed a 'gravelometer' which increased the speed and accuracy of determining particle sizes and Bevenger and King (1995) suggested sampling 'at toe point' as you walk along the stream zig-zagging from left to right bank.

A fluvial audit was carried out on the reach upstream of Laggan, where point observations on flow type and main surface sediment type were recorded at each point location. Locations of 'trash' lines were also noted during the audit, which give indications of recent flood extents; these will be used to help calibrate the flood model. The initial results of the fluvial audit, walkover survey and sediment analysis are summarised in **Appendix D** and described in the following sections.

The classification of sediment type is based on the Wentworth (1922) grain size classification (see **Figure 3-3** below) where boulders are >256mm and cobbles >64mm. **Appendix D-4** shows that the surface sediment within the reach upstream of Laggan tended to be characterised by boulder and cobble sized sediment.

[1] See https://www.sepa.org.uk/media/103943/appendix-fluvial-audit-method.pdf & https://www.sepa.org.uk/media/152207/wat_sg_30.pdf for details of the fluvial audit method.

Figure 3-2: Sediment Sample Location Map

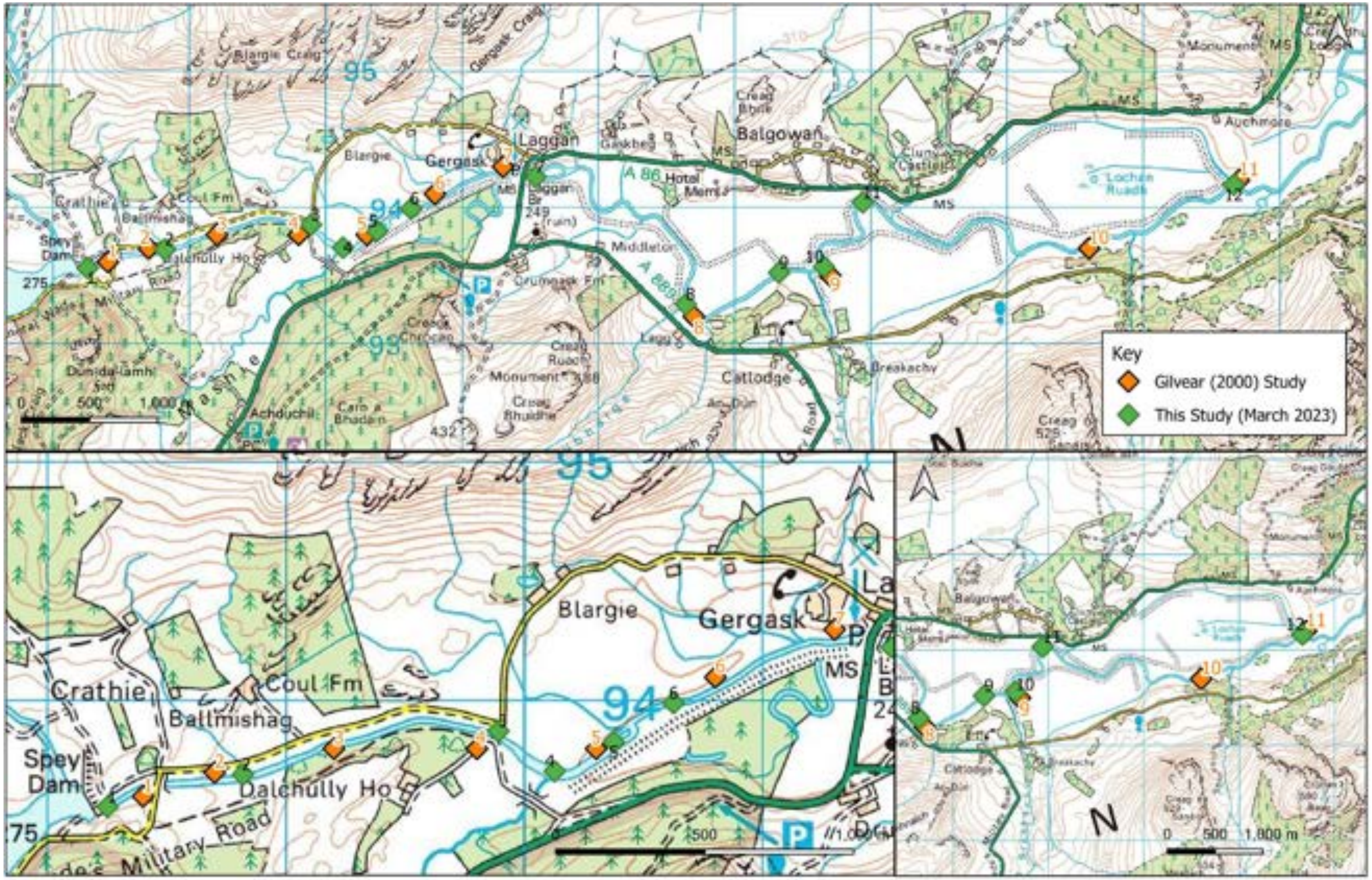


Figure 3-3: Wentworth (1922) Grain Size Classification

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	Gravel
	64		-6.0	Pebble	Gravel
	4		-2.0	Granule	Gravel
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	Sand
1/2	0.50	500	1.0	Medium sand	Sand
1/4	0.25	250	2.0	Fine sand	Sand
1/8	0.125	125	3.0	Very fine sand	Sand
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	Silt
1/64	0.0156	15.6	6.0	Fine silt	Silt
1/128	0.0078	7.8	7.0	Very fine silt	Silt
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

Definition of sediment grain sizes as defined by Wentworth (1922). A Scale of Grade and Class Terms for Clastic Sediment, The Journal of Geology.

3.10.1 Sediment Sampling and Results

Results of the sediment sampling and photographs at each sampling location are provided in **Appendix D** and summarised in **Table 3-3**. Grain size percentiles are given for the D10, D50 and D90, where D*i* denotes the grain size where *i* percent of all grains are equal to or smaller than this specific length. The D50 is frequently employed for hydraulic calculations because the equivalent grain size is considered to characterize the material particularly during equal mobility conditions in a river (e.g. Church, 2006). The modal class is also provided in **Table 3-3** to allow comparison with sediment samples collected by Gilvear (2000). The modal class represents the class interval with the highest frequency.

It is noted that the gravelometer used for this study has a maximum size of 180mm (18cm) so does not account for larger cobbles and boulders. Surface sediment on the medial and lateral bars tended to be boulders (>256mm) or larger cobbles (>180mm) (see **Figure D-4**) which were not recorded by the Wolman counts.

The results show that there is considerable variation in bed sediment size with the D50 ranging from 3mm (at the downstream sample site 12, where the bed was in an area of fine gravel/sand) to up to 86mm (at sample site 1 immediately downstream of the Spey Dam). The downstream sample sites (samples 9 – 12) have a bimodal distribution with fines (<2mm) and small gravels being the modal classes.

Table 3-3: Summary of sediment sizes in reach (March 2023)

Sample Location	D10 (mm)	D50 (mm)	D90 (mm)	Modal class
1	14	**86**	159	128 - 180
2	26	**71**	145	64 - 90
3	10	**26**	117	11 - 16
4	24	**48**	94	45 - 64
5	17	**41**	101	22 - 32
6	10	**58**	141	64 90
7	24	**48**	94	45-64
8	11	**39**	88	45-64
9	<2	**6**	19	<2 & 5.6 - 8
10	<2	**40**	104	<2 & 45-64
11	<2	**27**	79	<2 & 45-64
12	<2	**3**	51	<2 & 2.8-4
D50 is the median particle size (i.e. 50% of the clasts in the sample are equal to or smaller than the D50) D10 - 10% of the clasts in the sample are equal to or smaller than the D10 D90 - 90% of the clasts in the sample are equal to or smaller than the D90				

As a comparison Gilvear (2000) sediment data are reproduced in **Table 3-4**. It is clear that the sediment sampled in March/April 2023 tended to be finer than Gilvear (2000) reported. It is also evident that Gilvear's gravelometer sampled up to 256mm sizes and may represent the coarser end of the distribution better. The sand bed is consistent over both sampling periods for the downstream sample sites.

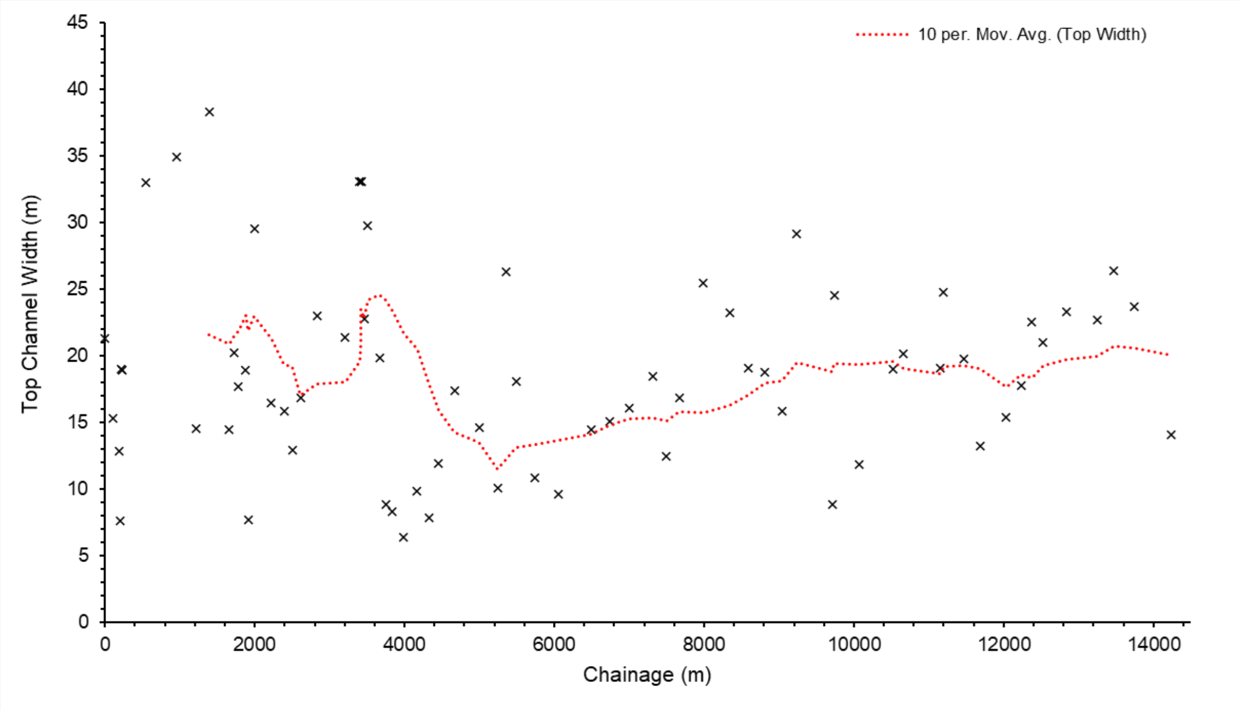
Table 3-4: Gilvear (2000) sediment sampling results

Sample Location	Bed material	Modal size (mm)	Maximum (mm)	Minimum (mm)
1	Boulder	256	>256	45
2	Boulder	180	256	63
3	Boulder	180	256	90
4	Gravel	128	180	45
5	Gravel	128	256	32
6	Gravel	128	256	32
7	Gravel	90	180	32
8	Gravel	45	128	16
9	Sand	Sand Bed	Sand Bed	Sand Bed
10	Sand	Sand Bed	Sand Bed	Sand Bed
11	Sand	Sand Bed	Sand Bed	Sand Bed

3.10.2 Geomorphology of Reach

The geomorphology of the study reach has been modified by the presence of embankments which are present along most of the study reach and also by the impacts of flow regulation and sediment starvation as a result of the Spey Dam. Over most of the study reach the Spey flows in one main channel with embankments close to (or slightly set-back) from the channel. The variation in the active channel width down the study reach is shown in **Figure 3-4**.

Figure 3-4: Variation in Active Channel Width (m) in Study Reach



There are limited active gravel bars and medial bars/islands in the study reach. The majority of the bars are well-vegetated and appear to be relatively stable.

Gilvear's (2000) study details channel morphological changes in the River Spey from 1942-2000 following the impoundment of the river at the Spey Dam. The dam effectively starves the downstream reach of sediment as no sediment can pass the dam. In addition, the dam has a hydrological effect, such that flows are reduced in the main stem of the Spey, resulting in less stream power and less sediment transport capability. This leads to a morphological response as the channel responds to the new flow and sediment regime downstream of the dam.

Immediately downstream of the dam, there is erosion of sediment and bed degradation leaving coarser sediment on the bed and removing fines as a result of a process known as clearwater erosion. This process relates to the fact that when flows competent to transport the channel boundary materials occur, sediment is lost from the river reach. With a reduction in flood magnitudes and stage, vegetation encroachment may occur on fluvial surfaces such as bars and bank faces. Further downstream of a dam within a regulated river, and below significant sized tributaries entering the mainstem channel (which transport the same volume of sediment as before into a river less able to move it), channel capacity reduction has been observed as a typical response to the reduction in flood magnitudes.

Gilvear's detailed morphological study showed that the channel capacity of the Spey has been reduced due to a combination of width reduction, aggradation (Sedimentation) of the bed, and vegetation colonization of tributary confluence bars, lateral bars and medial islands. Gilvear (2000) presents the following aggradation model for the River Spey in the study reach:

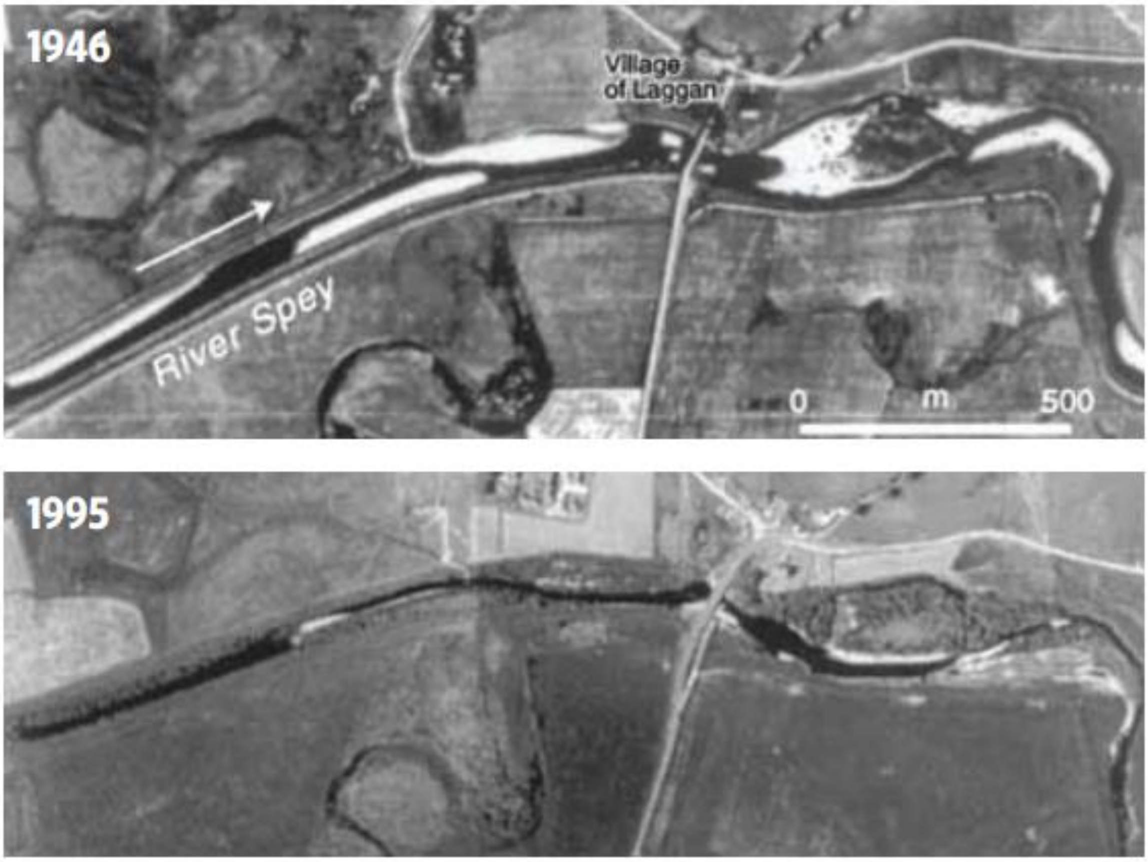
"For 1km downstream of the dam, clearwater erosion has resulted in the formation of a coarse bed but no significant channel change is apparent. Downstream of the River Mashie confluence, during the period 1942 to 1965 tributary confluence bars formed and the first stage of bench development occurred as unregulated tributary sediments were redistributed along the river. By 2000, the channel bench is

well developed and wooded, resulting in a much narrower channel than occurred prior to regulation. Mid channel bars and point bars are also well vegetated with mature trees present.

Downstream as far as Newtonmore, gravel accumulations at tributary confluences and the early stages of bench development are apparent in 2000. Where benches are present they are vegetated but are not yet wooded. This may reflect their young age but also the fact that grazing by deer is possible in most areas. This reach is therefore still adjusting to the imposed flow and sediment transport regime and is likely to undergo further adjustment over the next few decades."

Aerial imagery presented in **Figure 3-5** clearly shows the decrease in active, unvegetated sediment, vegetation colonisation of bars and narrowing of the active channel that has occurred between 1946 and 1995.

Figure 3-5: The River Spey at Laggan Bridge (1946 and 1995)



The upper River Spey at Laggan, 5 km downstream of Spey Dam in 1946 (four years after dam construction) and in 1995. Narrowing of the channel and stabilisation of previously active gravel bars are linked to a history of upstream flow regulation and straightening (© Centre for River Ecosystem Science).

Source: CREW (2013) Scottish Rivers Handbook: A guide to the physical character of Scotland's rivers, available online at [scottish rivers handbook web.pdf (crew.ac.uk)]

Gilvear (2000) also presents a comparison of repeat cross-section surveys of the Spey, with 5 cross-sections surveyed close to Blargie and 5 close to Laggan. These were surveyed in 1927 and 1999 (see Figure 18 in Gilvear 2000). Within the Laggan reach comparison of the sections show a marked and consistent change. Marked aggradation of the south bank of the river has occurred with between 0.50 and 0.75 metres of deposition equivalent to between 33% and 80% of the original channel depth (Gilvear, 2000). This is consistent with the development of a channel bench as observed on the aerial photographs. The 2000 river channel is thus substantially narrower and a little deeper than at the time of the 1927 survey (Gilvear, 2000). Cross-section surveys taken in 2023 for this study will be compared to the 1927 and 1999 sections, where possible. However, it is noted that the sections reported by Gilvear are not surveyed to m Above Ordnance Datum (m AOD), but use an arbitrary datum and the exact locations are currently unknown.

Gilvear (2000) notes the implications of aggradation of the study reach are:

- the capacity of the river to convey large floods has been reduced. This reduction may affect flood magnitudes with a recurrence interval of 1 or 2 years. Gilvear notes that this could have led to a greater frequency of over-topping of the flood-embankments independent of any trends in flood discharges, but comments that this fact cannot be substantiated.
- the aggradation will have impacted the ecology of the river. Most notably channel narrowing will have reduced significantly pool and riffle habitat availability.

Observations from the geomorphology walkover surveys for this study confirm the lack of active sediment within the main stem channel of the Spey and the vegetation colonisation of medial, lateral and tributary bars. Narrowing of the main stem channel and aggradation of the bed downstream of the tributaries appears to have occurred, as per Gilvear's observations. In addition, the embankments prevent out of bank flooding occurring in the reach, which will in turn lead to increased aggradation within the main channel.

3.11 .Previous Studies & Review

A number of previous studies have been undertaken that cover the study reach of the River Spey. While most are not "flood studies", many provide important supporting information, such as information on changes to the geomorphology, flow regime and aquatic habitat since the construction of the Spey Dam.

Dr David Gilvear of the University of Stirling authored a journal paper entitled "Patterns of channel adjustment to impoundment of the upper River Spey, Scotland (1942–2000)". This paper details changes to river channel morphology over 60 years since the impoundment of the River Spey by the Spey Dam. It explains that tributary confluence bars were formed followed by bench development and the vegetation colonisation on formed benches and gravel bars. The paper also highlights that since impoundment the River Spey has experience a marked change in flow regime. Flow regulation has reduced the frequency of small flows (of less than 50m^3/s) and the capacity of the river to convey large floods has been reduced by the changes to the river channel morphology (see discussion in **Section 3.10.2** above).

This paper is likely based on the report that Dr Gilvear undertook in 2000 for Scottish Natural Heritage entitled " An assessment of reported Aggradation within the Upper Spey SSSI". This report provides details of the geomorphological change of the Upper Spey since the development the Spey Dam and included sediment sampling, a literature review and hydrological assessment. Gilvear's work is summarised in the geomorphological description of the reach in **Section 3.10.2** above.

Michael J Morgan undertook a dissertation at the University of Edinburgh on introducing sediment back into the River Mashie. It details that the Mashie has been starved of sediment since the introduction of the Mashie Dam and has suffered from a significant reduction in flows. The paper concludes that a sediment reintroduction plan is viable and cost-effective. However, it stressed uncertainties in how much sediment should be introduced and how far this sediment might disperse over time.

EnviroCentre undertook a study in 2021 for the Spey Fishery Board entitled “River Spey Abstractions 2021, Water Resources Management Now and Implications for the Future”. This is an update to a report dated from 2008. The report concluded that the natural mean flow in the Spey is reduced by up to 66% by abstractions. It made recommendations to reduce the loss of water transferred out of the catchment as well as land management measures to re-connect the rivers with their natural floodplains and allow floodwater to drain naturally back into the underlying sands and gravels.

In 2010 a study of the River Mashie was undertaken by CRESS (University of Stirling). The study included a literature review and desk study alongside a detailed fluvial audit including a geomorphological survey. This report explains that due to the construction of the Mashie Dam there are significant geomorphological changes downstream, with no sediment replenishment having resulted in the gravel dominated bed becoming sand along much of the lower reach. The study also outlines some options for restoration of the River Mashie including re-meandering, gravel augmentation and removal of Sitka Spruce.

4 Hydrological Assessment

A Hydrological Assessment is a study to estimate river flows based on available data.

The River Spey has a catchment area draining to the Spey Dam of approximately 176km², at the head of the study area, rising to approximately 400km², close to the downstream reach of the study area. The land use upstream of the Spey Dam is considered to be predominantly Heathland & Moorland or Rough Pasture, with some areas of Woodlands. Downstream of this point Arable Land and Woodlands become more prominent along the line of the River Spey.

Both the River Spey and River Mashie are artificially influenced by the Spey Dam and Mashie Dam, meaning river flows (but also river morphology, hydroecology, etc) do not correspond with their "natural" regime. This makes it difficult to estimate "flood" river flows for this study reach, at least using standard methods. Many of the tributaries of the River Spey are also used for hydropower generation, meaning water is abstracted from the watercourses.

Hydrometric data was obtained to help support this assessment. Refer to the Hydrological Assessment Report (**Appendix C**) for technical details of the hydrology. A simplified overview is provided below.

4.1 Spey Dam – Overview

The operation of Spey Dam impacts flows in the River Spey downstream of the dam. Hydrometry data for the Spey Dam is collected as a single daily average value (i.e., no sub-daily flow variations are recorded). However, the daily average flow leaving the Spey Dam does not vary significantly, with discharges controlled by sluice gates and managed to provide a regulated compensation flow to maintain environmental flow conditions in the river. The normal compensation flow (combination of the compensation flow plus fish pass flow is 50 Cusecs equivalent to 1.42 m³/s. On a minimum of 22 occasions throughout the calendar year Alvance are obliged to release double this flow over a 24 hour period (freshets) giving a discharge of 100 cusecs or 2.83 m³/s. While there might be some minor variation, flows leaving the dam during each day will be relatively consistent based on the number of gates open and the reservoir water level.

Flows downstream of the Spey Dam increase when water levels in the reservoir exceed 880 feet Above Ordnance Datum (268.2mAOD) and overtop the spillway. This spillway measures 92.96m wide with side walls approximately 2m high. According to the report by Gilvear (2000) the spillway rating curve, that converts water level to flow is $Q = 3.42 * 305H^{1.5}$, based on Imperial units, where H is the depth over the weir crest and Q is the flow rate. This rating curve was converted to metric allowing the water level data from the SEPA Spey Dam gauging station to be converted to a discharge (flow).

The Spey Dam abstracts a maximum of 21.97 m³/s from the River Spey to send to Loch Laggan, according to a Gilvear (2000). This is corroborated by abstraction data provided by Alvance which suggests a maximum abstraction rate of 776 cubic feet per second, which is equivalent to 21.97 m³/s. The average abstraction rate between 2020 and 2022, based on data provided by Alvance and excluding missing data, is 13.95 m³/s.

4.2 Spey Dam – Overtopping

The Spey Dam overtops the spillway once water levels in the reservoir exceed 268.2 mAOD. The observed water levels in the reservoir were interrogated and events where the water level had risen up to the level of the spillway and not overtopped and events that had only just exceeded the spillway level were compared to rainfall data from the SEPA gauge at Spey Dam. Efforts were made to identify single "isolated" events where antecedent conditions in the reservoir would not skew the results.

The review of data from between 2003 and 2022 suggested that the spillway had overtopped in April 2006 from approximately 28.5mm of rainfall and in December 2017 from approximately 24mm of rainfall. However, there were a number of occasions where rainfall depths of over 30mm had fallen, and no spilling had taken place. According to the review, the Spey Dam would overtop once 40mm or so rain had fallen. This suggests that the Spey Dam can, in certain circumstances, store something equivalent to a 30-year short duration storm (4 hours) but would only store a 1-year long duration storm (12-hours) based on ReFH2 rainfall runoff model.

This would seem to correspond with the observed water level data for the Spey Dams which suggests that water spilled over the spillway on average 4 times a year, between 2009 and 2022. In some years there were 13 overtopping events (2011 and 2020) and in some years only two overtopping events occurred (2012 and 2017). Most of the events where the spillway overtopped occurred during storms that lasted longer than a day.

The Spey Dam reservoir is capable of storing water from relatively severe short storms but becomes overwhelmed in less severe but longer storm events. During smaller flood events the Dam can store a large percentage of the water in the event, significantly impacting the flow rate and flow volume passing downstream. However, for large flood events (multi-day or produced by low return period rainfall) the Dam will store water early in the flood event but will pass the peak of the flood flow of the event, which will pass (with some reduction/attenuation) down the Spey.

4.3 Spey Dam – Reservoir Model

A Reservoir-Routing model was developed to represent the Spey Dam, based on available information. This model represents the storage and attenuation provided by the reservoir. It is composed of inputs (rainfall) and outputs (flows, water levels and the abstraction for the Alvance plant). The spillway was represented in the model using the Stage-Discharge relationship for this structure provided in the Gilvear (2000) report. Technical details of this model are provided in **Appendix C**.

It should be noted that the model is a simplified representation of how the Spey Dam works. In reality, there are a large number of variables (rainfall, antecedent reservoir conditions, abstraction rates, reservoir operating procedures, infrastructure, etc) and it is difficult to develop a model that fully represents all of these aspects. The model, therefore, is useful for providing flow estimates but does not fully replicate how the dam works.

According to the Gilvear report (2000) it is Alvance operational policy to maintain the Spey Dam at the lowest possible water levels, compatible with the requirements of meeting minimum statutory discharges to the River Spey. This means the reservoir is often kept at lower water levels, although in periods of heavy consistent rainfall or a consecutive series of storms, the reservoir is likely to fill up.

The Reservoir-Routing model was developed to represent a low water level, although a higher starting water level was also tested as part of the sensitivity analysis.

A series of storms of different durations and return periods were run through the model. These used the FEH Rainfall-Runoff model for rainfall inputs.

The results suggest that the “critical storm” depends on the return period. For example, for a 10-year return period storm the critical storm, leading to the highest peak flow, is estimated to be an 18-hour storm. This reduces to a 14-hour storm for the 50-year return period event and to a 12-hour storm for the 200-year return period event. Longer storm durations result in lower flow peaks. However, it should be noted that the longer storms still pass more volume of water downstream. Therefore, the critical storm for the reservoir is not necessarily the critical storm for flooding along the River Spey corridor downstream of the Spey Dam.

The Reservoir-Routing modelling predicts that the Spey Dam has capacity to attenuate flows discharging downstream.

For example, in shorter duration, smaller return period storms, the model predicts that the Spey Dam could attenuate the event with no flows overtopping the spillway. This includes events up to a 3-hour 2-year storm, with longer storm durations and larger return periods predicted to overtop the spillway. Even in events where the spillway is overtopped the Spey Dam will provide attenuation. For example, the 4-hour 2-year return period storm is predicted to generate a peak flow of approximately 119.0 m^3/s. Allowing for the compensation flow of approximately 2.83 m^3/s, which is still permitted to leave the reservoir, the spillway overtopping flow of 27 m^3/s and the abstraction of approximately 21.97 m^3/s, approximately 56% of the peak is stored or abstracted (52 m^3/s). The 4-hour 10-year storm is predicted to generate a peak flow of 166.7 m^3/s. Allowing for the compensation flow of approximately 2.83m^3/s, spillway overtopping flow of 76.7 m^3/s and the abstraction of approximately 21.97 m^3/s approximately 39% of the peak is stored or abstracted (65.19 m^3/s). The 4-hour 50-year storm is predicted to generate a peak flow of 245.6 m^3/s. Allowing for the compensation flow of approximately 2.8 m^3/s, spillway overtopping flow of 156.1 m^3/s and abstraction rate of 21.97 m^3/s approximately 26% of the peak is stored or abstracted (64.7 m^3/s). The percentage of the peak flood stored/abstracted reduces as the return period and storm duration increases. By the 12-hour 50-year storm, for example, there is no attenuation (of the peak flow) provided, although the Spey Dam still stores some water because an approximate 1-hour delay (lag) is provided in the peak downstream of the dam.

The attenuation provided by the reservoir is significantly less than that predicted previously by Cuthbertsons and Partners (now AECOM) in 1990. The difference is likely due to the increase in rainfall estimates since 1990. The percentages stored used above include the compensation flow and assume the maximum flow is being abstracted for use by the operator. It may be that the previous study did not use these values or used different calculations for the storage calculation.

The results of the reservoir modelling predict that the reservoir can store the entirety of short duration low return period storms and flows not increasing downstream. In larger events, the peak flow is attenuated, reducing the impact on flooding downstream. Even in quite large return period, long duration storms the Spey Dam provides a lag in the hydrograph, delaying the flood.

4.4 Spey Dam – Recorded Events

Three key, dated flood events were identified as part of the Community Liaison Meeting. These occurred on 19/09/18, 10/12/19 and 29/03/21. Photos and videos were provided for these events and water levels in the Spey Dam are available for these time periods. This means these three flood events are useful for calibration of the River Model.

To input the three events into the reservoir model, however, the events need to be converted to a flow hydrograph. The stage-discharge curve for the Spey Dam spillway is provided in the report by Gilvear (2000) and so this can be used to convert the water level to a flow, once the units are converted from imperial to metric. This can be calculated through an amended version of Reservoir-Routing model (with other abstractions and compensatory flow removed).

Running the model predicts the flood event on 19th September 2018 to have peaked at flows of approximately 124 m³/s, with the event on the 10th December 2019 being composed of two successive peaks of approximately 102 m³/s and 128 m³/s. The flood event on the 29th March 2021 has the largest peak of approximately 147 m³/s. These estimates include the compensation flow that is always released from the dam.

These events can be compared to the observed peak flows at the Spey @ Invertruim gauging station. The results suggest that the peak flows are consistently lower at the downstream gauging station than at the dam. This suggests that considerable storage/attenuation is provided in the study reach of the River Spey. For example, peak flows at the Spey @ Invertruim gauging station on the 29th March 2021 were measured at approximately 115 m³/s. The release from the Spey Dam is approximately 147 m³/s. This is a difference of approximately 27 m³/s not including the additional flows discharged via the tributaries of the River Spey between the Spey Dam and Spey @ Invertruim gauging station.

Comparing the three events to peak flows at the Spey @ Invertruim gauging station against the available growth curve suggests that all three events are relatively small return periods of between approximately 1 in 1.5 and 1 in 2.5 years with the 29th March 2021 flood event being the largest return period event.

4.5 Spey – Design Flows

The “design flows” are peak river flow estimates for key return period events (Or Annual Exceedance Probability AEP events). These design flows can then be used in the modelling to provide flood maps for each return period. This then allows a comparison between locations for the same return period. A 1 in 2 -year return period is a smaller event with an AEP of 50% (50% likelihood of occurring in any one year). A 1 in 50-year return period is a larger event with an AEP of 2%.
The design flows for the River Spey are difficult to estimate due to the impact of the Spey and Mashie Dams and the floodplain storage within the Spey valley.

Design flows at the SEPA Invertruim gauging station can be calculated through statistical analysis of observed data. Design flows for the River Spey at the Invertruim Gauging Station are provided in **Table 4-1**. These are based on the results of the FEH Single Site method using WINFAP software using observed data from the gauge and so are thought to be representative estimates. For events greater than the 1 in 50-year return period the flows are extrapolated from the available data, but this is standard procedure.

Table 4-1: Design Flows for the River Spey @ Invertruim Gauging Station

Return Period	Invertruim Design Flow (m³/s)
1 in 1-Year	43.29
1 in 2-Year	105.85
1 in 3-Year	123.31
1 in 4-Year	134.32
1 in 5-Year	142.36
1 in 10-Year	166.81
1 in 20-Year	191.69
1 in 25-Year	199.84
1 in 30-Year	206.72

1 in 50-Year	226.51
1 in 75-Year	243.02
1 in 100-Year	255.20
1 in 200-Year	286.21

Efforts were made to develop a simple relationship between the design flows at the SEPA Invertruim gauging staging and the Spey Dam observed data to back-calculate design flows in this manner. However, a review of this suggests that there is not a good direct relationship between the flows at the two gauges. This is likely due to the other tributaries (River Mashie & River Truim, amongst others) responding differently during events, alongside other factors such as the storage within the floodplain between the Spey Dam and Invertruim.

The simpler back-calculations did identify a trend. They suggest that for smaller return period events of approximately a 1 in 2 -year return period (such as the modelled observed events) peak flows are much higher at the Spey Dam than at the Invertruim Gauge. However, for larger return period events, such as an event that occurred on the 5th December 2015, roughly equivalent to a 1 in 20/25 year event, the peak flows are much closer, suggesting that in bigger flood events the floodplain storage provides less attenuation as a proportion of the total flow. In other words, the floodplain along the study reach has a finite storage capacity that attenuates smaller return periods but is drowned out in larger return period events.

Therefore, for the purpose of this assessment a representation of smaller flood events (approximately. 1 in 2 to 1 in 5-year events) are based on the observed flood events in 2021 and 2019 for which there is observed flood data. These events will be used to calibrate the flood model and to identify key flood flow mechanisms that can guide the choice of restoration interventions. These will be the key events for this study which focuses on river restoration and communication to stakeholder through the use of frequently occurring events which impact farming and which landowners have direct experience.

The model will also be run for a representative extreme event where the 1 in 200-year storm event is run through the Spey Dam reservoir-routing model and peak 1 in 200-year flows are estimated for the other contributing watercourses.

This is based on the assessment presented above and is likely a simplification of the hydrological processes during such a large event and the resultant flood map should not be considered an accurate 200-year flood extent (to replace SEPA indicative flood maps of the area). Rather it is developed as a representative extreme event that can be used to test the flood model, provide an indication of flood extents and depths for such an event and be used for future testing of restoration interventions.

4.6 Mashie Dam – Overview

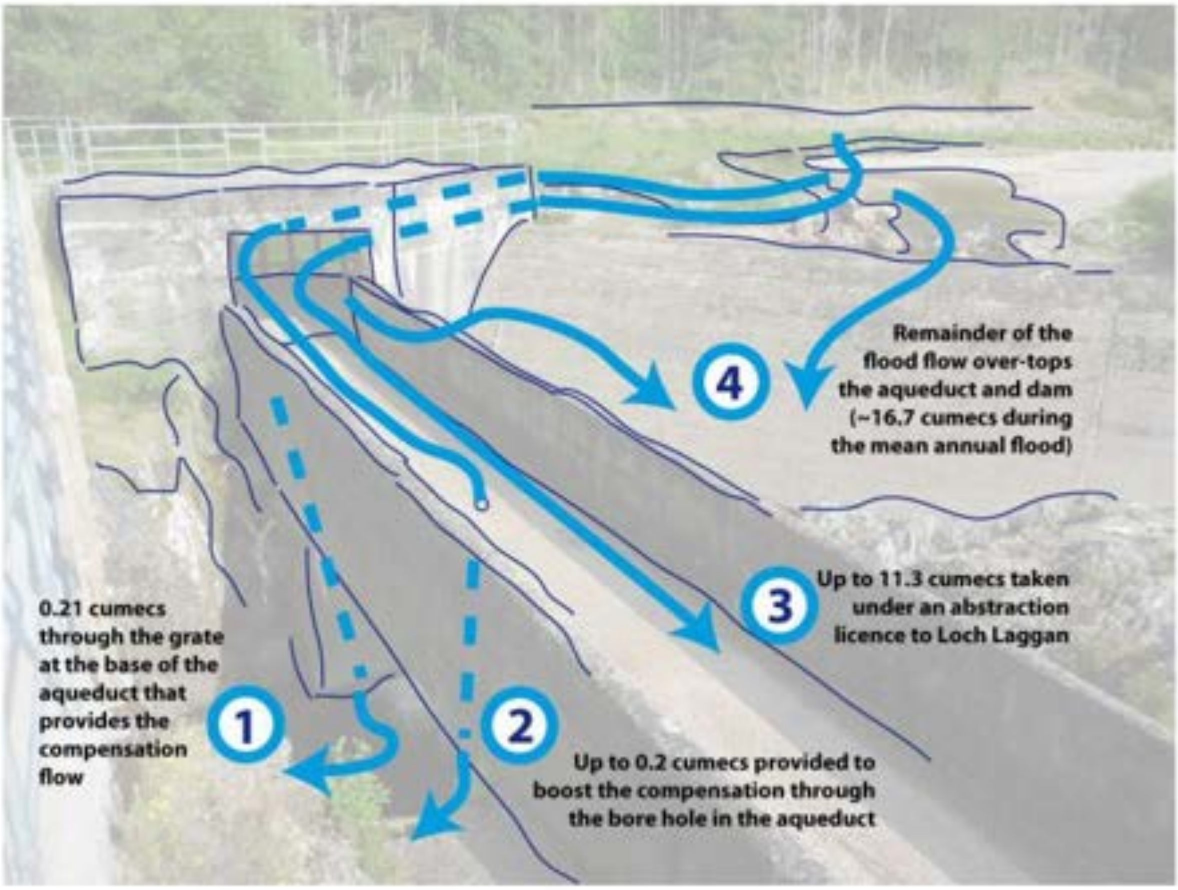
Compared to the Spey Dam, the Mashie Dam is a much smaller structure located on the River Mashie at approximately NN 587 911. The structure is effectively a dam with aqueduct that diverts much of the flow in the River Mashie into Loch Laggan. A previous CRESS study (2010) on the River Mashie provides a detailed assessment of the Mashie Dam control.

The aqueduct can abstract up to 11.3 m^3/s from the River Mashie, with two compensatory flows provided through a grate at the base of the aqueduct (0.21 m^3/s) and a further 0.2 m^3/s via a “hole” in the aqueduct itself. Flows in excess of the capacity of the aqueduct overtop the dam (and aqueduct) and spill back into the River Mashie.

This means that between approximately 0 m³/s and 11.71 m³/s, only a maximum of 0.41 m³/s is discharged into the River Mashie downstream of the Mashie Dam. Once flows upstream of the Mashie Dam exceed this flow, the flows in excess of the 11.71 m³/s are returned to the River Mashie.

This is represented in **Figure 4-1**, taken from the CRESS study.

Figure 4-1: Schematic of Mashie Dam taken from CRESS Study (2010)



4.7 Mashie Dam – Design Flows

Design flows were estimated using the ReFH2 method. This method was chosen as it permits the input of observed rainfall data (such as that available from the Spey Dam rainfall gauge) to estimate river flows. This was used to obtain flows to add to the modelling for the observed events (See **Section 5**).

The CINI value (catchment wetness) was adjusted to match with the observed data at the gauging station on the River Spey at Invertruim, because it was noted that the standard ReFH2 parameters were overpredicting flows.

The 11.71 m³/s abstraction (see above) has been removed from the values in **Table 4-2**.

Table 4-2: Design Flows for the River Mashie (With abstraction removed)

Return Period	Mashie Design Flow (m³/s)
1 in 1-Year	0.90

1 in 2-year	2.82
1 in 5-year	9.48
1 in 10-year	14.32
1 in 30-year	22.40
1 in 50-year	26.39
1 in 75-year	29.70
1 in 100-year	32.12
1 in 200-year	38.17
1 in 1000-year	53.78

4.8 Other Tributaries – Catchments & Design Flows

There are a number of additional tributaries discharging into the River Spey within the study reach. This includes a number of watercourses such as the Allt Breakachy, Allt na Cubhaige, Allt Dobhrain and An t Eileach alongside smaller unnamed watercourses and the larger River Truim. Design flows for all of these watercourses were estimated using the same approach as for the River Mashie, using the ReFH2 method with parameters adjusted to better represent the River Spey catchment. These peak flows were estimated for both the observed recorded events (See **Section 5**) and different return periods.

The design flows are provided in **Appendix C**.

4.9 Climate Change

Scotland's climate is changing. Since the late 1800's the world has warmed, with snow and ice diminishing, resulting in rising sea levels. Over the past few decades Scotland has become warmer with rainfall patterns shifting and sea levels rising. The scale of change will depend on the rate in which global greenhouse gas emissions continue to increase and whether levels can be got under control.

It is anticipated that, as time passes, Scotland will experience more extreme rainfall and associated flooding alongside more frequent heatwaves. For this reason, hydrological and modelling studies often incorporate an allowance for climate change to illustrate potential future flooding.

SEPA provide climate change allowances for use in Flood Risk Assessments and Flood Studies. These allowances are for the year 2100 and are generally considered to be "conservative" allowances to account for a number of unknowns with respect to future climate change. The peak river flow allowance for the River Spey, in the North Highland River Basin is 34%.

The SEPA climate change allowances are based on a 2021 paper (Kay, A.L., Rudd, A.C., Fry, M., Nash, G., Allen, S. 2021. *Climate change impacts on peak river flows: combining national-scale hydrological modelling and probabilistic projections.* Climate Risk Management 31) which uses the most recent UK Climate Projections 2018 (UKCP18) data alongside additional catchment-based hydrological models.

Spey Catchment Initiative asked that careful consideration is given to climate change. It was decided to undertake a review of climate change data for the study area.

4.10 Climate Change Review

A review of climate change data for the study area was undertaken. The UK Climate Projections 2018 (UKCP18) data is freely available to all via an online web portal. Projections for both land and marine are provided in both data format, alongside plots and plumes. Data is available at a variety of scales, from 60km to 2.2km and for a number of emissions scenarios.
Following a review of the available data it was decided to obtain and assess precipitation rate anomaly (%) projections covering a 25km area, representing the study area of the River Spey, for the RCP 6.0 and RCP 8.5 emissions scenarios. A baseline of 1981-2010 was used. This is the period to which the climate change projections are compared to.

The RCP 6.0 emissions scenario represents an increase in temperature of 2.8 degrees by 2081-2100. This is an “Intermediate” stabilization pathway (higher medium) emissions scenario which assumes that a range of technologies and strategies will be employed to stabilize total radiative forcing at 6.0 W/m^2 by 2100. In simple terms, this is considered to be a plausible climate change scenario, assuming efforts are made to reduce global warming. Because this emissions scenario assumes some mitigation measures will be put in place to reduce global warming, the 2080s value for precipitation are sometimes lower than the 2050s values.

The RCP 8.5 emissions scenario represents an increase in temperature of 4.3 degrees by 2081-2100. This is a “high” stabilization pathway (high) emissions scenario which assumes a more-or-less “business as usual” approach, with little effort made to reduce global warming.

The projected data was obtained and downloaded for the four seasons for both RCP 6.0 and RCP 8.0 for the 2050s and 2080s period. This provides projected data for medium and high emissions scenarios up to both the 2050s and 2080s. The months of December and July were also reviewed separately. This data was reviewed and 95^{th} percentiles and 50^{th} percentiles calculated. The 95^{th} percentile provides a representation of the maximum increase in precipitation, discarding the top 5% of values to remove data “spikes”. The 50^{th} percentile represents a middle value in which 50% of the data are lower than this value and 50% are equal or higher than this value. It is equivalent to the mean, in most instances, and similar (although not equal) to an average value. It is referred to as “mean” here for simplicity.

A review of the projections suggests the following:

- Regardless of emissions scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s) there is projected to be an increase in occurrences of extreme precipitation, regardless of season.
- Mean precipitation will decrease in the summer season regardless of emissions scenario (RCP 6.0 or RCP 8.5). This is projected to continue to decrease from the 2050s and 2080s. The decrease is projected to reach -6% (by 2050s) and -15% (by 2080s) under RCP 6.0 or -10% (by 2050s) to -20% (by 2080s). However, there will still be an increase in occurrences of extreme precipitation in the summer season of up 14% under RCP 8.5.
- This is not the case for the Autumn season. Mean precipitation is projected to increase to 2% (by 2050s) and 3% (by 2080s) under RCP 6.0 to 3% (by 2050s) and 5% (by 2080s) under RCP 8.5.
- Winter and Spring are projected to be less impacted in changes to mean precipitation. By the 2050s mean precipitation is predicted to increase slightly by between 0.3% and 1.2% under the RCP 6.0 and RCP 8.5 scenarios. By the 2080s this begins to change, with the mean precipitation projected to decrease in Spring regardless of emissions scenario and decrease in winter under RCP 6.0, while increasing marginally (0.2%) under the RCP 8.5 scenario.

- The greatest increases in extreme precipitation are projected to occur in the wettest months of Autumn. Increases of up to 16% are projected by the 2080s under RCP 6.0. Increases of up to 22% are projected by the 2080s under RCP 8.5
- There is projected to be an increase in occurrences of extreme precipitation in the month of December regardless of emission scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s). Under the RCP 6.0 emissions scenario increases of 22% are projected (by 2050s) rising to 25% (by 2080s). Under the RCP 8.5 emissions scenario increases of 27% are projected (by 2050s) rising to 35% (by 2080s).
- Mean precipitation in December is also projected to increase slightly regardless of emissions scenario and timeframe. Under RCP 6.0 mean precipitation is projected to increase by 4% (by 2050s) reducing to 2% (by 2080s). Under RCP 8.5 mean precipitation is projected to increase by 6% (by 2050s) rising to 7% (by 2080s).
- There is projected to be an increase in occurrences of extreme precipitation in the month of July regardless of emission scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s). Under the RCP 6.0 emissions scenario increases of 24% are projected (by 2050s) rising to 25% (by 2080s). Under the RCP 8.5 emissions scenario increases of 27% are projected (by 2050s) rising to 35% (by 2080s).
- Mean precipitation in July, however, is projected to decrease regardless of emissions scenario and timeframe. Under RCP 6.0 mean precipitation is projected to decrease by -6% (by 2050s) and -15% (by 2080s). Under RCP 8.5 mean precipitation is projected to decrease by -9% (by 2050s) and -21% (by 2080s).

4.11 Climate Change – Summary

Climate projections from the UK Climate Projections 2018 (UKCP18) portal were obtained and reviewed representing the study area of the River Spey.

A review of projections suggests the following:

- Regardless of emissions scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s) there is projected to be an increase in occurrences of extreme precipitation, regardless of season.
- Mean precipitation will decrease in the summer season regardless of emissions scenario (RCP 6.0 or RCP 8.5). However, there will still be an increase in occurrences of extreme precipitation in the summer season compared to the baseline of 1981-2010.
- The greatest increases in extreme precipitation are projected to occur in the wettest months of Autumn.
- There is projected to be an increase in occurrences of extreme precipitation in the month of December regardless of emission scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s).
- Mean precipitation in December is also projected to increase slightly regardless of emissions scenario and timeframe.
- There is projected to be an increase in occurrences of extreme precipitation in the month of July regardless of emission scenario (RCP 6.0 or RCP 8.5) and timeframe (2050s or 2080s).
- Mean precipitation in July, however, is projected to decrease regardless of emissions scenario and timeframe.

The data suggests that on average the summer months in the study area will become drier but there will be occurrences of extreme precipitation, greater than seen currently. Wetter more extreme weather is projected during the wetter months of the year.

4.12 Climate Change – Study Uplifts

The SEPA climate change allowance for the River Spey is 34%. Spey Catchment Initiative asked that careful consideration is given to climate change and consideration given to a “lower” climate change allowance that might better represent the near future. The climate change review identified a range of different potential uplifts. A seasonal precipitation uplift for Autumn of 22% was projected using the RCP 8.5 emissions scenario. This is likely lower than the SEPA allowance as it incorporates some averaging across the 3 months that represent the season, potentially removing some of the highest projections. This value was considered to be representative of a less extreme climate change scenario.

It is suggested to take both climate change allowances forward (SEPA:34% and SPEY:22%) for use in future work. To account for climate change the “Design flows” (See **Section 4.5**) are increased by the aforementioned climate changes. For example, a peak flow of 100 m^3/s would be increased to either 134 m^3/s or 122 m^3/s to account for 34% or 22% climate change.

It should be noted that climate change is controlled by numerous, constantly-changing variables and it is not possible to identify an “accurate” climate change allowance. The two climate change allowances identified here have been chosen to permit a comparison to be made.

5 River Spey Modelling

A 1D-2D model was developed to represent the study reach of the River Spey and the surrounding floodplain. The main channel of the River Spey was represented in the 1D model using cross-sections surveyed as part of a topographical survey. The wider area surrounding the River Spey was represented in a 2D model using available LiDAR DTM data supplemented by topographical survey at key locations such as along embankments and at culverts/pipes and other structures.

The 1D model is used for the River Spey itself because this uses equations to best represent channel flow. The 2D model is used for the surrounding area because this uses shallow water equations over wider areas.

5.1 Preliminary Modelling

An initial 2D-only flood model was developed for the study reach to help inform the river topographical and walkover survey. Then when the extensive topographical survey of the River Spey and the surrounding area took longer than anticipated to undertake, due to ground and weather conditions, the model was used to undertake some initial flood modelling. The model was developed in Flood Modeller Pro software covering the study reach from downstream of the River Spey up to the confluence with the River Truim. The model was run using a 5m horizontal resolution.

The model was run for two flow scenarios; a regular annual flood flow and a slightly less frequent, greater flood flow. These flows were run through the model to represent some relatively common flood events, similar to those observed over the past few years and discussed at the Community Liaison meeting. The aim was to see how the initial modelling compared with flooding observations obtained at the Community Liaison meeting.

The modelling results predicted flows spilling out of the main channel of the River Spey at key locations throughout the study reach. The predicted flood extents were compared to comments made by community members at the Community Liaison meeting. A map was developed to show the flood extents against the comments made by the community with additional notes stating whether the preliminary modelling corresponds with information provided by the community. This map was circulated to the community although no responses were received. This map is provided in **Appendix Ea**.

These initial modelling results generally correspond well with the comments provided by the community. For example, the model predicts flooding of the road that gives access to Crathie just upstream of the gravel island that sits within the River Spey channel. This corresponds with previous events, including a video provided by the community. The model also predicts flows to spill out of the north bank of the River Spey a short distance downstream of Laggan Bridge and the braided part of the channel, similar to what was described by the community. Further downstream, the preliminary model appears to be slightly less representative in places. For example, the community suggested that the land to the south of Balgowan floods via a gap in the embankment. The preliminary modelling predicts the flooding of this area to come from backing-up from the confluence of the River Spey with the Allt Dobhrain. It may be that the gap in the embankment is not suitably represented in the preliminary model, although there is also a chance that the community have misread the flood mechanisms. This will be reviewed as part of the more detailed modelling.

The results suggest that the preliminary modelling provides an acceptable representation of flood mechanisms along the River Spey, although there are places where further revisions may be required.

5.2 Detailed Model Setup

On receipt of channel survey, a detailed HEC-RAS 1D-2D hydraulic model was developed to represent the reach of the River Spey from the Spey Dam to close to the Invertruim Gauging Station.

A reach of approximately 15 km was represented using the surveyed topographic cross-sections. Interpolated cross sections were generated using the surveyed sections at regular intervals for model stability.

Spot levels were surveyed along the top of the embankments, with the resultant levels gridded and imposed onto the model terrain grid. Levels outwith the channel were taken from Phase 1 LiDAR.

The 1D model was connected to the 2D model using lateral structures set at the elevation of the surveyed embankment and bank tops. The 2D model was set up with a variable grid size of between 1 – 10m, utilising the finest resolution at the location of the embankments and tributary watercourses, and lower resolutions in the fields.

The model utilised varied friction values in the 1D cross sections. A manning's *n* of 0.035 was used in the channel, while higher roughness values (0.05 – 0.10) were applied at the channel banks, with higher values used in areas of dense vegetation. A Manning's *n* value of 0.06 was used to represent the floodplain outwith the channel. These roughness values were based on the site walkover and the aerial photography using Chow (1959) and experience as a guide.

Three bridges exist along the modelled reach and were surveyed for inclusion in the model. The first, 'Forestry Bridge', is a Bailey (truss) bridge of approximately 44.0m wide x 3.5m high, situated approximately 200m downstream of the Spey Dam. Immediately downstream is General Wade's Military Road Bridge, a Beam bridge of approximately 35m wide x 4m high, with two 0.5m wide piers. Laggan Bridge is situated approximately 3km further downstream at the A86 and consists of a Girder bridge with a concrete deck and no piers, measuring approximately 31.5m wide x 8.0m high.

Flows in the model were divided throughout the model. The main inflows were added to the head of the model, to represent flows leaving the Spey Dam. Lateral inflows were added for the main incoming tributaries, including the River Mashie, River Truim, Allt Breakachy, Allt na Cubhaige, Allt Dobhrain, An t_Eileach, but also smaller unnamed watercourses. These lateral inflows were added to the 2D model.

A normal depth boundary was added to the end of the model based on the bed slope of the last two cross-sections to permit flows to leave the model.

The model was run with an adaptive timestep of between 2 – 8 seconds. A schematic of the model components is provided in "Hydraulic Model" figures in **Appendix E1**.

5.3 Model Calibration

The model was built iteratively, starting with the 1D model before connecting the model, section by section, to the 2D model, predominantly at the location of embankments. The model was then run, and the results reviewed, and amendments made to the model to improve the representation.

The model was run for the largest recent flood event, that occurred on the 29th March 2021. It was decided to calibrate to this event first, because photos and videos from this event had been made available by the local community. A map showing the modelled flood extent against data provided by the community for the event is provided in **Appendix E2**.

5.3.1 Calibration for Downstream Flow Hydrograph

This model was run to calibrate the model using observed flows at the head of the model (Spey Dam) with observed flows at the end of the model (Spey @ Invertruim Gauging Station). Tributary inflows were generated using observed rainfall data during the event.

The results showed a good relationship between the modelled shape of the hydrograph at the Spey @ Invertruim gauging station and the observed data from this gauge. However, the model consistently overpredicted the peak flow leaving the model at the Spey @ Invertruim gauging station by approximately 27 m^3/s. A systematic review of the model inputs was undertaken, and various additional runs of the model were undertaken.

The discrepancy between the modelled inputs and outputs could not be resolved through analysis of the input and output data. The volume difference between the modelled and observed flow hydrographs could be explained by storage within the floodplain gravels along the River Spey valley. As water levels in the river rise flood waters will pass laterally from the river into the gravels that underlie the floodplain. This process is not represented in standard flood models as this process is only significant on large gravel-bed rivers such as the Spey, and even in the Spey this process would not be visible for very large flood events (e.g., 200-year flood event) as the floodplain (sub-surface) storage would be filled early in the flood event before the arrival of the flood peak. The impact of sub-storage is notable in the calibration event considered here, due to the flood being of relatively small size, where this storage effect impacts on the peak flow passing downstream.

To test this idea calculations were undertaken to quantify the storage that could be provided in these alluvial deposits. The area was calculated for floodplain adjacent to the Spey in which depths exceeded 0.3m on the 29th March 2021. An approximation of the channel depth was estimated for each of these areas. Potential storage provided was then calculated using the following equation: *Area (m^2) x Depth (m) x Porosity (Percentage voids).* The porosity of the alluvial deposits was based on standard literature to be between 15% and 50%. Assuming a porosity (voids) of 15% gives a volume stored of 1.7 x 10^6m^3; assuming a porosity of 25% gives a volume stored of 2.8 x 10^6m^3. Comparing the volume difference between the modelled flow leaving the model and the observed flow gives a value of 2.4 x 10^6m^3. This suggests that the storage within the alluvium likely fully accounts for the discrepancy between the modelled results and the observed results, particularly considering the detailed review of other model parameters which are not predicted to have a significant impact on the results.

Although this means the model overpredicts flooding compared to reality, for the calibration event, a review of the model suggests that it suitably represents overland flow pathways and flood mechanisms as observed in the calibration event, as discussed below.

5.3.2 Calibration for Flood Extent and Flow Mechanisms

The predicted flood extent for the 29th March 2021 Flood Event is provided in a series of figures named *Flood Depth with Observations 29/03/21* in **Appendix E2**. The predicted velocities in the channel and the floodplain are provided in maps named *Flood Velocity 29/03/21* also in **Appendix E3**. Percentage time inundated maps (How long areas were inundated for in percent) are also provided in **Appendix**

E4. Maps showing the flood timings (How many hours into the event that flooding occurred) are also provided in **Appendix E5** named *Flood Timings***.**

The progression of the flood is described below and represented in detail in **Table 5-1** and **Figure 5-1**. The predicted flood extents are also considered against the comments made by community members at the Community Liaison meeting. A map has been developed to show the flood extents against the comments made by the community with additional notes stating whether the preliminary modelling corresponds with information provided by the community. This map is provided in **Appendix E2** and named as *Flood Depth with Observations 29/03/21.*

During the early hours of the morning at the very beginning of the flood event, flows are predicted to remain predominantly in bank. As water levels begin to rise at around (28/03/21 03:00) some initial flooding occurs close to Ptarmigan Cottage and the meander just downstream of Laggan Bridge is activated. As flows begin to rise some initial flooding of land near Dulchally House and at Eilean Dubh is predicted to occur. At approximately (28/03/21 08:00) flows start to spill out of the left bank downstream of the meander at Laggan Bridge, activating an overland flow pathway through the fields here. This corresponds Well with comments made by the local community that this field "*is the first field to flood*". By (28/03/21 09:00) Flooding starts to occur of some of the ponds and wetlands in the downstream reach of the study reach. By (28/03/21 11:00) some flooding of Lochan Ruadh is predicted. By (28/03/2021 21:00) flood waters start to rise with greater flooding at Lochan Ruadh and Allt Granda. By (28/03/2021 23:00) flows are predicted to spill out of bank upstream of Eilean Dubh, spilling onto the road and flowing through fields in an easterly direction. This corresponds well with comments from the local community that suggest that flooding of this road occurred in this event and that the field to the east floods often. By (29/03/2021 02:30) flooding is predicted of the low-lying area to the north of Cnoc Bheithe on the left bank of the River Spey, with this area almost completed flooded. This corresponds well with the comments from the local community which suggest that this area floods but that it is "rare" for flood water to overtop the embankment that bounds this area to the north. By around this time the area around Lochan Ruadh is almost entirely flooded. By (29/03/2021 05:30) the low-lying area adjacent to the River Mashie is predicted to be almost entirely flooded. This corresponds well with comments from the local community that suggest this area floods, including the access road to Dalchully House. The maximum predicted flood extent occurs at some point between (29/03/2021 09:00) and (29/03/2021 11:00).

The maximum predicted flood extent corresponds well with comments provided by the local community. The community indicated that the flooding during the 29th March 2021 extended up to approximately (259930, 794189) which corresponds well with the predicted flood extent. The community indicated that flooding on the left bank of the River Spey reaches approximately 20m from Gergask Avenue approximately twice a year. This corresponds well with the flood extent predicted for 29th March 2021.

The above suggests that the flood extent and progression of the flood event for 29th March 2021 fits well with observations made by the community.

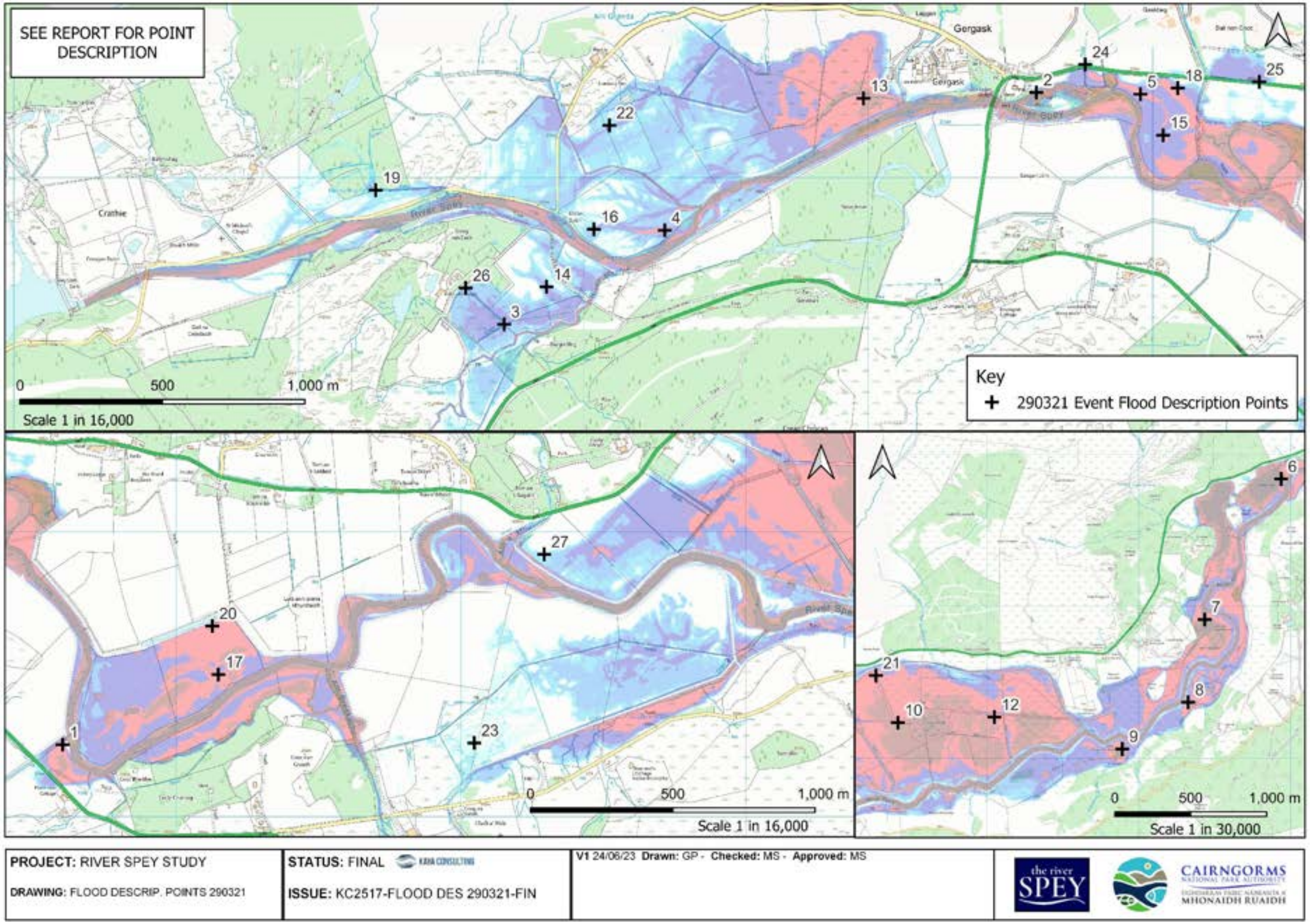
The maximum predicted flood extent (*Flood Depth 29/03/2,* **Appendix E2)** clearly shows that flooding and overland flow pathways along the study reach are heavily controlled by the agricultural embankments. These have stopped many areas from flooding (Such as Bankhouse, Sean Amar, etc) that would have otherwise flooded and have resulted in the compartmentalisation of parts at the floodplain, such as the area to the south of the Balgowan War Memorial (262731, 793884).

The progression of the flood on 29th March 2021 is described in **Table 5-1** and **Figure 5-1** provided below.

Table 5-1: Key Flood Event Description Points (See Figure 5-1)

ID	Time	Description
1	28/03/2021 03:00	Flows mostly in bank. Some initial flooding close to Ptarmigan Cottage.
2	28/03/2021 03:00	Flows mostly in bank. Meander at Laggan Bridge activated.
3	28/03/2021 05:00	Flows mostly in bank. Some flooding of land near Dulchally House from River Mashie.
4	28/03/2021 07:00	Flows start to back-up at close to Eilean Dubh, opposite River Mashie Confluence
5	28/03/2021 08:00	Flows starts to spill out of left bank downstream of Meander at Laggan Bridge to south of Gaskbeg
6	28/03/2021 09:00	Flows starts to back-up into ponds/wetlands in downstream reach downstream of Allt Dobhrain confluence with River Spey.
7	28/03/2021 09:00	Flows starts to back-up into ponds/wetlands in downstream reach downstream of Allt Dobhrain confluence with River Spey.
8	28/03/2021 09:00	Flows starts to back-up into ponds/wetlands in downstream reach downstream of Allt Dobhrain confluence with River Spey.
9	28/03/2021 09:00	Flows starts to back-up into ponds/wetlands in downstream reach downstream of Allt Dobhrain confluence with River Spey.
10	28/03/2021 11:00	Lochan Ruadh starts to flood from Tributaries
11	28/03/2021 12:00	Flood waters start to recede after initial flood peak
12	28/03/2021 21:00	As flood waters start to rise again more flooding is predicted at Lochan Radh.
13	28/03/2021 21:00	Heavy flooding of Allt Granda close to River Spey from Spey backing up.
14	28/03/2021 21:00	Backing up of River Spey into River Mashie flooding areas close to Dalchully House.
15	28/03/2021 21:00	Flooding reactivated on left bank downstream of Meander at Laggan Bridge to south of Gaskbeg
16	28/03/2021 23:00	Flows spill out of left bank at Eilean Dubh, flooding onto road and flowing through fields in an easterly direction.
17	28/03/2021 23:00	Spey spills out on left bank in low-lying area to north of Cnoc Bheithe.
18	28/03/2021 23:00	Much of area to east of Meander at Laggan flooded.
19	28/03/2021 23:00	Flows back-up into Poll na Bracha
20	29/03/2021 02:30	Area on left bank in low-lying area to north of Cnoc Bheithe is now almost completed flooded
21	29/03/2021 02:30	Lochan Ruadh almost entirely flooded from River Spey backing up.
22	29/03/2021 02:30	Area on left bank between Eilean Dubh and Gergask almost entirely flooded
23	29/03/2021 02:30	Flooding of Breachnach Farm from Tributaries overtopping bund predicted, although not necessarily from the River Spey.
24	29/03/2021 05:30	Flooding on left bank downstream of Meander at Laggan Bridge to south of Gaskbeg is flooded up to A86 at > 1 location
25	29/03/2021 05:30	Flooding on left bank downstream of Meander at Laggan Bridge to south of Gaskbeg is flooded up to A86 at >1 location
26	29/03/2021 05:30	Low-lying area adjacent to River Mashie almost entirely flooded
27	29/03/2021 09:00	Flooding at Lochan Ruadh is now extensive extending to Allt a'Mhuilinn
28	29/03/2021 14:00	Flood waters start to recede again, but surrounding area will remain wet for a long time

Figure 5-1: Key Flood Event Description Points Map (see Table 6-1)



5.4 Running Model for December 2019 Event

The predicted flood extent for the 10th December 2019 Flood Event is provided in a series of figures named *Flood Depth 10/12/19* in **Appendix E6**. This event was composed of two large peaks of approximately 102 m³/s and 128 m³/s (at the Spey Dam, excluding tributaries) and so represents a slightly smaller peak than the 2021 event, although it is composed of two peaks as opposed to one main one.

Flood mechanisms for the 2019 event are predicted to be very similar to those that occurred in 2021. A comparison flood map is provided in **Appendix E7** named as *Flood Depth Comparison*. This shows very similar maximum predicted flood extents. It should be noted that flood depths tend to be greater in the 2021 event, as would be expected for this larger peak flow event.

5.5 Modelling of Larger Flood Event

The flood model produced very good fits to observed flood extents for the calibration event, with the model appearing to represent key overland flow pathways and flood mechanisms observed (and videoed) during the event. Despite some discrepancies in flood volumes due to the storage in the sub-surface alluvium the model was considered representative of the flood conditions in the Upper Spey.

The model was then run for a larger flood event, consistent with an approximate 1 in 200-year event.

As discussed in **Section 4**, there are uncertainties associated with flood estimation in this reach due to floodplain and reservoir storage. However, the purpose of this assessment is not to provide flood maps associated with given return period flows, but rather to identify key flood mechanisms in the Upper Spey, to inform the choice of restoration interventions. The larger flood events will also be useful as the project develops to be used to test the impact of interventions on flood flows.

The 1 in 200-year event is predicted to respond in a similar manner to the flood event of the 29th March 2021, with flood mechanisms during the first 8 hours or so of the event corresponding well with this observed event. The 1 in 200-year event represents a larger flood event though and greater flooding of the area surrounding the River Spey is predicted as flows in the model increase.

As flows increase the model predicts overtopping on the right bank a short distance upstream of Laggan Bridge. Water spills over the embankment in this location and backs up into the former meander channel in this location up to depths of 2m. As flood waters rise water builds up against the A86 and then passes through the culvert under this road at the junction of the A86 and the A859 once levels reach the necessary heights. At this point flows spill through Drumgask farm meeting with existing flooding in this farmland, which occurs once flows exceed the levels of the embankment on the right bank of the River Spey approximately 600m downstream of Laggan Bridge. By the end of the flood event much of Sean Amar and Drumgask Farm are flooded.

Land to the south of Balgowan War Memorial at Gasbeg Farm is predicted to flood in the 1 in 200-year event. Water levels are predicted to overtop the embankment that protects this area once water levels exceed this threshold the farmland begins to fill up with water. Flooding is predicted to impact the entirety of the area protected by embankments from to the south of Victory Lodge through Luib an t-siorra Mhurchaidh to Tom a'Mhoid.

Flooding of Breakachy Farm from the River Spey is predicted in the 1 in 200-year event. Flows are predicted to overtop the embankment on the right bank of the watercourse a short distance downstream of the confluence of the Allt a'Mhuilinn, flooding the farmland. Flows are also predicted to overtop the right bank of the Allt Breakachy. In practice, parts of the farmland will already be flooded in such a scenario from the drains to the south of the farm.

In a 1 in 200-year event more extreme flooding is predicted throughout the modelled reach, with greater flooding at Dail na Creardaich, Cregan Dubh, Bruadh Mhór, St Michael's Chapel, areas to the south of Blargie, Gergask (Village) and Dalchully. Flood extents are only predicted to be slightly greater at Woods of Breakachy and Cluny Farm and further downstream at Toman a' Chaoruinn, Torr Uvie and Tom Na Moire.

The flood maps are provided in **Appendix E11**.

5.6 Sediment Modelling & Results

In addition to the hydraulic modelling for flood purposes, extra runs were undertaken for both shear stresses and stream power. These parameters are a good indicator of the ability of the river to transport sediment.

Bed load movement and sediment transport is a function of shear stress, for example. Stream power is the amount of energy water in a river channel is exerting on the channel sides and bed.

Runs were undertaken for the 29/03/21 flood event and a representative everyday flow based on a value between the compensatory flows released by the Spey Dam and the higher freshet flow. A flow of approximately 2.06 m^3/s was used.

5.6.1 Everyday Flow Results

Shear Stress maps for the everyday flow results are provided in **Appendix E8**.

The results of the modelling predict shear stresses to be highest in the reach between immediately downstream of the Spey Dam and Laggan Bridge. Within this reach, shear stresses are highest at channel constrictions such as just downstream of the Eilean Dubh island and at some of the narrower channel sections downstream. Regardless, shear stresses do not really exceed "medium" levels of shear stress. In wider channel sections the maximum shear stresses drop to very low values. There are some medium shear stresses at the weir immediately downstream of the Laggan Bridge. Downstream of this point shear stresses are generally low or very low, only reaching medium low and medium in areas where the channel is constrained.

Shear stresses can be used to infer areas of potential erosion (high shear stresses and/or limited sediment supply) or deposition (low shear stresses and/or abundant sediment). They can also be used to estimate the sediment sizes that will move under a given shear stress.

Using the dimensionless form of the bed shear stress equation and the Shield's parameter (see Sears *et al.,* 2010), the maximum mobilised size of particles for the flow conditions can be calculated. Based on model predictions of shear stress, the maximum particle size mobilised in an everyday flow is between 31 mm and 0.1mm, varying significantly along the reach of the river. The higher values are concentrated at the head of the model a short distance downstream of the Spey Dam, with the particle size able to be conveyed generally reducing further downstream of this point. This corresponds well with the results from the sediment sampling which suggests the sediment is finer further downstream.

Stream Power was also calculated along the River Spey based on the 1D (Channel) model results. Stream power is the rate of energy dissipation against the bed and banks of a river per unit width. It is given by the equation:

$$\Omega = \rho\ g\ Q\ S$$

where Ω is the stream power, ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s^2), Q is discharge (m^3/s), and S is the channel slope. Stream Power is given in Watts per Metre squared (Wm$^{-2)}$

Variations in stream power along a reach can indicate the channels sensitivity to erosional and depositional processes; higher values of stream power can show locations that may be prone to erosion and lower values can show stable or depositional areas.

Several academic studies have noted that a value of unit stream power between 30 and 35 W is where the transition from a stable reach to reach that is reshaping itself via erosional processes tends to occur (Bizzi and Lerner (2015), Orr *et al*., 2008).

A comparison of the results for the everyday flow event and 29/03/21 event is provided in **Appendix E10**.

In the everyday flow event stream power values are predicted to be predominantly very low and low, with some isolated areas where stream power might reach medium low values predominantly in the reach immediately downstream of the Spey Dem.

5.6.2 29/03/21 Event Results

Compared to the everyday flow results the model predicts higher maximum shear stresses for the recorded flood event that occurred on the 29th March 2021, as would be expected. While the everyday flow event remains predominantly within bank, flows spill out into the floodplain during the 29/03/21 event.

Shear stresses are predicted to be greater in the channel than in the floodplain, as would be expected. Shear stresses are predicted to be high and medium high in the reach immediately downstream of the Spey Dam. Around Eilean Dubh shear stresses begin to reduce a little towards medium levels. From around Laggan Bridge onwards shear stresses are predicted to be medium low reducing to predominantly low for much of the rest of the model reach, with isolated areas with medium and medium high shear stresses. There is a general trend that maximum predicted shear stresses reduce as one travels further downstream.

While the floodplain is dominated by low and very low shear stresses, there are certain key areas where shear stresses are a little higher. This is mainly concentrated at breaches in embankments and other areas where water is funnelled through a particular area, such as along the meander downstream of Laggan Bridge or the overland flow pathway that spills across the left bank of the River Spey just upstream of Eilean Dubh.

Using the dimensionless form of the bed shear stress equation and the Shield's parameter (see Sears *et al.,* 2010), the maximum mobilised size of particles for the flow conditions can be calculated. Based on model predictions of shear stress, the maximum particle size mobilised in the flood event on the 29th March 2021 is between 185 mm and 4mm, varying significantly along the reach of the river. The higher values are concentrated at the head of the model a short distance downstream of the Spey Dam, with the particle size able to be conveyed generally reducing further downstream of this point. For example, downstream of Laggan Bridge the maximum particle size that can be mobilised is predicted to be no more than 50mm and is often significantly lower. This suggests that some gravel coarse gravel can be mobilised immediately downstream of the Spey Dam but this ability to transport the sediment reduces quickly, and may partially explain, for example, why sediment has accumulated at Eilean Dubh, where the maximum particle size that can be mobilised is predicted to be no more than approximately 94mm. This would also explain why the bed sediment immediately downstream of the Spey Dam is quite coarse (**Sample Location 1, Section 3.10**) when the bed sediment further downstream (**Sample Locations 9, 10, 11, 12, Section 3.10**) is considerably finer.

Stream Power was also calculated along the River Spey based on the 1D (Channel) model results. Stream power is the rate of energy dissipation against the bed and banks of a river.

Variations in stream power along a reach can indicate the channels sensitivity to erosional and depositional processes; higher values of stream power can show locations that may be prone to erosion and lower values can show stable or depositional areas.

A comparison of the results for the everyday flow event and 29/03/21 event is provided in **Appendix E10**.

Stream power is predicted to be high in the reach immediately downstream of the Spey Dam. Downstream of Eilean Dubh the stream power begins to reduce a little towards medium high, medium and medium low levels. Immediately downstream of Laggan Bridge shear stresses are predicted to rise again to medium high levels before dropping to medium low, low and very low levels along the rest of the modelled reach, with very low and low levels particularly prevalent in the downstream part of the modelled reach.

5.7 Model Considerations

There is now a detailed model available of the River Spey and the surrounding floodplain. This model would be suitable for further development to support the further evaluation/testing of Options (and potentially alternative options). The model could also be further improved in the future as more data becomes available, such as the refining of the calibration.

The model itself is complex but it can be shared and revised/re-run by those who have experience of hydraulic modelling.

It is noted that there is an interaction between the river and the local groundwater table, particularly the large expanse of alluvial gravels in the river floodplain. This cannot be formally represented in most hydraulic modelling packages and so is not formally represented in the model. In reality, it is likely that lateral flow of river water into the floodplain gravels occurs during a flood event. This storage/attenuation of water in the floodplain is not fully represented in the model, which explains the discrepancy between modelled flows and actual measured flows at the downstream gauge. This is explained in detail in **Section 5.3.1**. Although this means the model will slightly overpredict flooding compared to reality, the model suitably represents overland flow pathways and flood mechanisms as observed in the calibration event of 29th March 2021 (described in detail in **Section 5.3.2** and **Appendices E2-E5)**.

Locals noted that water levels in the Spey Dam rise up and spill over General Wade's Military Road upstream of the dam, close to Glenshero Lodge. A review of the topography suggests that water could back-up into Loch Crunachdan in extreme events, but it is highly unlikely to build up sufficiently to reach Loch Laggan which lies over 50m above the ground levels at Glenshero. Model results suggest the water would only back-up sufficiently to spill over the road in extreme events This backing-up of water into Loch Crunachdan does not have an impact on the modelled observed events or the model calibration, because these models are based on observed water levels in the Spey Dam. The backing-up could have an impact on model results for the larger modelled flood events (such as the 1 in 200-year event). The impact on the results is likely to be very small and while this could contribute to the slightly overpredicted flooding (described above and see **Section 5.3.1**) the storage within the alluvial gravels is considered likely to be more important.

The model is considered to provide a suitable representation of the processes that occur along the River Spey.

6 Strategic Restoration Interventions

6.1 Restoration Overview

The Spey Catchment Initiative is aiming to reinstate a more natural functioning of the River Spey and surrounding floodplain.

The objective is to restore hydro-morphological functioning by selectively removing manmade constraints and re-connecting the Spey and major tributaries to the floodplain, allowing natural flow and sediment processes to take place. Ideally this should also encourage the establishment of re-aligned, longer and more sinuous watercourse routes across the floodplain, expand the range and quality of habitats, reduce local and downstream flood risk and retain water in the catchment for longer to encourage groundwater recharge.

The authors and stakeholders recognise the importance of farming for food production and the efforts of land managers to manage the landscape. The importance of land for farming is recognised. Most of the recommendations provided in this document are concentrated on returning the River Spey to a more natural state. This is likely to involve changes to land available for farming. It is hoped that the benefits to flooding and biodiversity, amongst other things, would outweigh the loss of productive farmland. It may be that any work can be offset by gaining Biodiversity Net Gain (BNG) credits.

The results of the community liaison meeting, data collection, surveys and initial review helped support the development of the model that represents this reach of the River Spey. The model was run with a selection of flows, including observed events and hypothetical events. The results of the modelling, together with observations from the community, existing literature and data, walkover surveys and professional experience were used to identify key locations for restoration interventions.

The restoration interventions are termed “options” here to emphasize that they are for consideration and not “final” interventions. Options could be undertaken individually or combined with other options as part of a wider plan for the river reach.

The five main options are:

- **Option 1:** Floodplain Scrape at Eilean Dubh
- **Option 2:** Reconnection of Former Meander at Sean Amar
- **Option 3:** Reconnection with Floodplain to West of Gergask
- **Option 4:** Reconnection with Floodplain south of Balgowan War Memorial
- **Option 5:** Large-scale Restoration at Cluny Estate

These are provided in relative detail and discussed in **Section 6.2**.

Discussions on dredging and sediment and dam management are provided in **Section 6.4** and **6.5**.

Figure 6-1 shows an overview of the 5 options.

6.2 Identified Restoration Options

The options described below are those that are considered to be feasible based on the results of this study. However, their feasibility should be confirmed by more detailed modelling and study. The aim is to outline a selection of different options but, for avoidance of doubt, these should not be considered the only options possible. Moreover, where an option has been put forward there are likely to be a number of alternatives that could be put forward at each location depending on the response from Spey Catchment Initiative (and other partners) and the local community. Options are numbered from upstream to downstream.

Figure 6-1: Options Overview Plan

6.2.1 Option 1 – Floodplain Scrape at Eilean Dubh

Create a small wetland feature, such as a floodplain scrape, on the land on the left bank (looking downstream) of the River Spey just downstream of the Eilean Dubh.

This could be achieved by creating a shallow pond that forms a natural low spot in the floodplain. It may also be prudent to lower bank levels a little to encourage flows to overtop into this area.

This area is predicted to flood in the observed events of 19/09/18, 10/12/19 and 29/03/21. The area is predicted to flood initial by backing up of the River Spey into the area from slightly further downstream, but also spilling over the left bank just downstream of Eilean Dubh once flows get a little higher.

Considering the local superficial geology of alluvium, the water levels in the scrape would likely also be linked to water levels in the River Spey through groundwater, so this area would be expected to remain relatively wet throughout much of the year, although this would need to be confirmed by additional testing.

Previous proposals for a similar intervention proposed the construction of a bund to protect farmland further to the north. This is not strictly necessary for the scrape to work but may have been suggested to reduce the existing risk of flooding to the farmland to the north of the option.

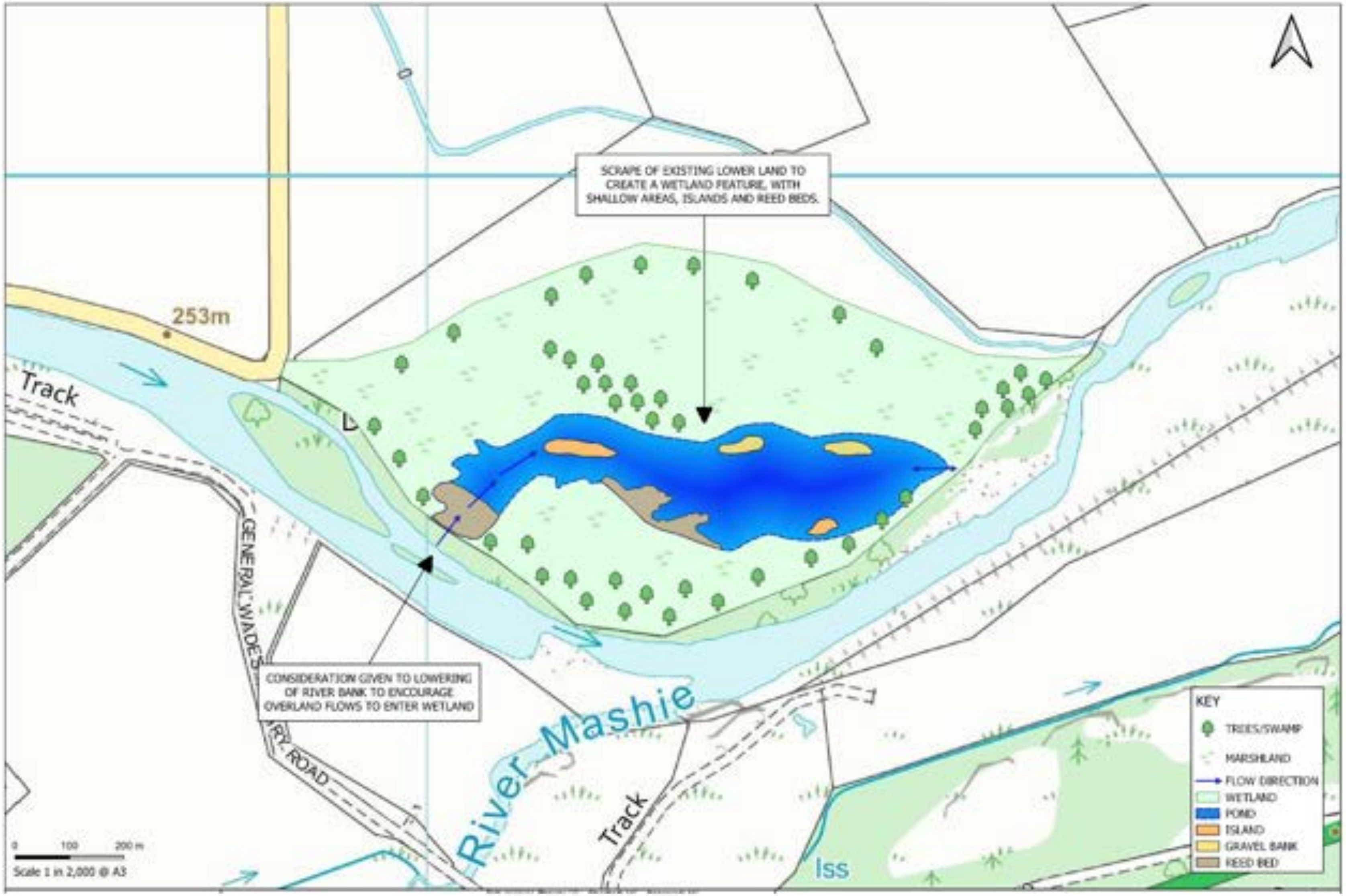
A variety of habitat could be provided by providing deep and shallow areas, islands and reed beds within the Floodplain Scrape. Trees and other suitable vegetation could also be planted within the scrape and surrounds to create more variable habitat.

Positive and negative aspects of this proposal are provided in **Table 6-1**. This table also classifies the project based on "scale" of the intervention. An outline drawing for this option is provided in **Figure 6-2.** Proposals have been suggested in line with the areas of predicted flooding as shown in the flood mapping.

Table 6-1: Option 1 – Positives & Negatives

Positives	1. Creation of habitat in the floodplain 2. Creation of floodplain storage 3. Encourage groundwater recharge 4. Local interception of surface water 5. Potential for Biodiversity Net Gain credits
Negatives	1. Some "loss" of farmland 2. Requirement for a more detailed design to confirm suitability

Figure 6-2: Option 1 Outline Drawing



6.2.2 Option 2 – Reconnection of Former Meander at Sean Amar

Breach an embankment a short distance downstream of the River Mashie on the right bank and a second breach a short distance upstream of the Laggan Bridge. This will reconnect the River Spey to its former meander at Sean Amar and effectively create a secondary channel that will activate once river flows in the River Spey reach a particular threshold.

The breaching of the embankment a short distance downstream of the River Mashie on the right bank would permit flows to spill into the former meander and take a more sinuous path through fields and woodland. Flows would discharge back into the River Spey a short distance upstream of the Laggan Bridge at the second breach.

This option would only require breaching the embankment in two locations. The bottom of the embankment appears to be lower than the left bank, in this location, meaning that flooding of this area would occur frequently if the embankment is breached down to bank level. It may be preferable to set an overtopping level and provide a plug, or similar, at the location of the breach so that the meander doesn't activate until slightly higher flows. This would need to be modelled and discussed with the Spey Catchment Initiative and the community.

While this option has not been modelled, the model results suggest that the breach of the embankment down to bank level would result in this meander activating frequently. Extensive flooding would occur in events similar to the recent observed events of 19/09/18, 10/12/19 and 29/03/21.

Due to the local topography, once flows enter this area, some water will accumulate, particularly in the low-lying existing wetted areas.

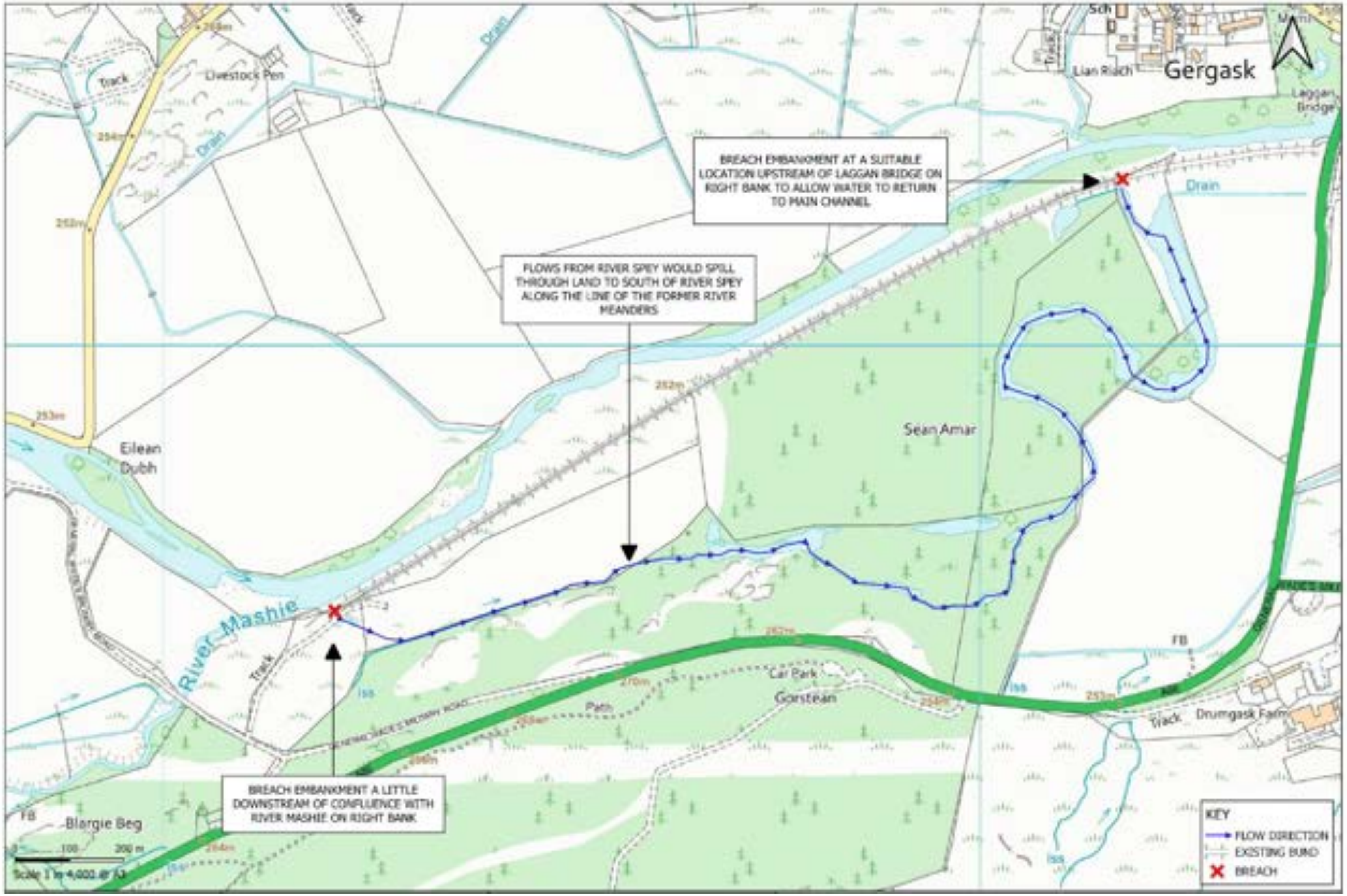
This option may have an impact on flooding of the A86 between Laggan Bridge. Additional modelling would be required to assess the impact and whether betterment can be provided over the existing situation,

Positive and negative aspects of this proposal are provided in **Table 6-2**. An outline drawing for this option is provided in **Figure 6-3.** Proposals have been suggested in line with the model results.

Table 6-2: Option 2 – Positives & Negatives

Positives	1. Creation of secondary channel 2. Creation of floodplain storage 3. Encourage groundwater recharge 4. Local interception of surface water 5. Some potential habitat creation/increase in variability 6. Potential for Biodiversity Net Gain credits
Negatives	1. Some "loss" of farmland and potentially woodland plantation 2. Recommend modelling to assess impact on Laggan Bridge/A86 3. Requirement for a more detailed design to confirm suitability

Figure 6-3: Option 2 Outline Drawing



6.2.3 Option 3 – Reconnection with Floodplain to West of Gergask

Remove an older embankment on the left bank upstream of Gergask to reconnect the River Spey with the floodplain in this area. With the removal of the embankment the River Spey itself may start to migrate north a little, creating a more sinuous channel. This might take some time to occur due to a lack of energy in the river caused by the relatively low “everyday” flows released from the Spey Dam. Larger events that exceed the capacity of the Spey Dam would be anticipated to support this. A more sinuous channel provides a greater variability of flow and riverine habitat.

The removal of the embankment could be combined with additional interventions, such as remeandering of the channel of the Allt Granda and creation of ponds, etc to improve the wetland habitat and provide additional benefits. Exact proposals would depend on how the River Spey channel responds to the removal of the embankment.

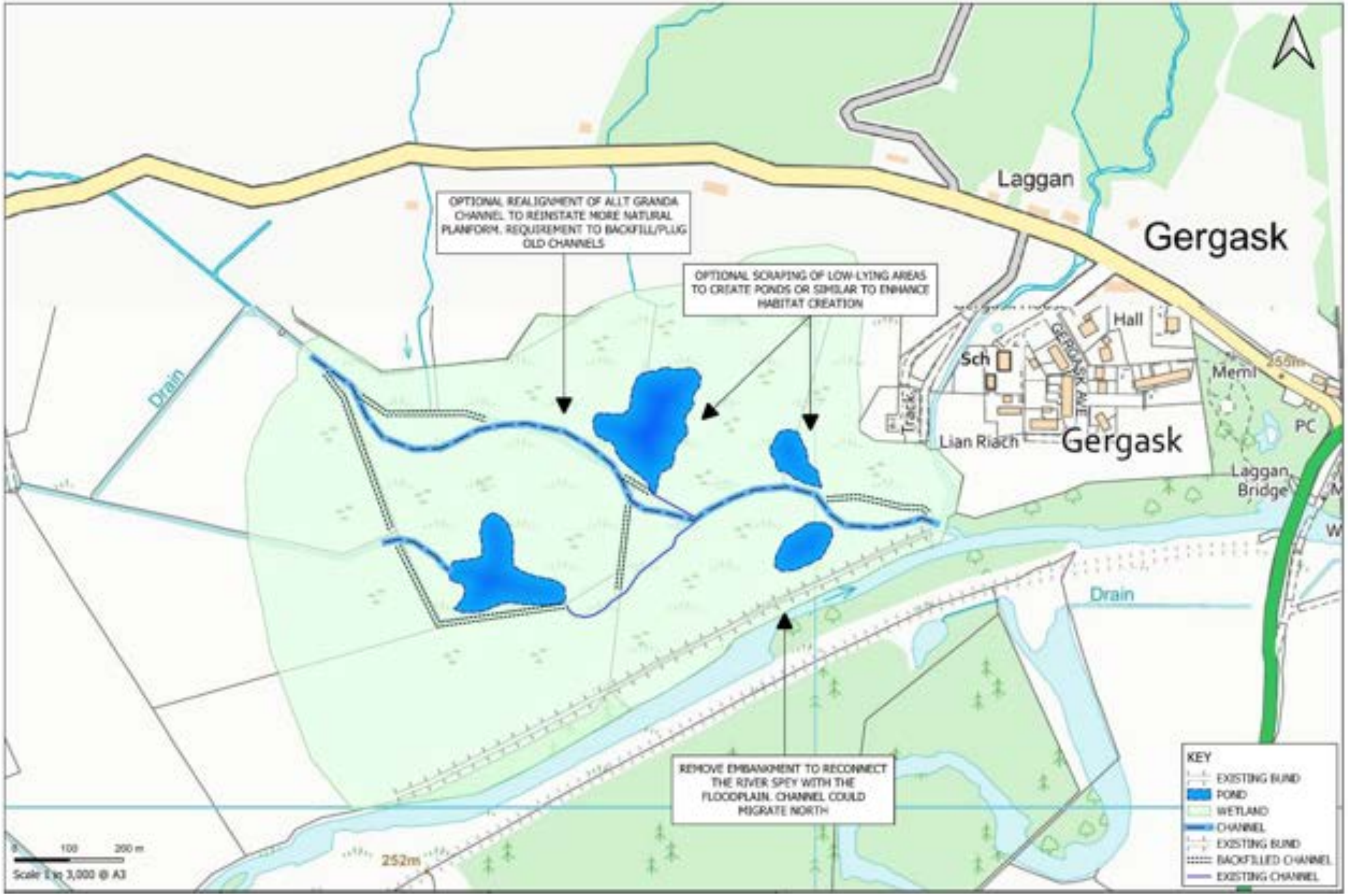
The removal of the embankment in this location would permit flows to spill into this low-lying area on the left bank of the River Spey. Modelling suggests that flows from the River Spey already back up into this area in larger events (such as the recent observed events of 19/09/18, 10/12/19 and 29/03/21) but the removal of the embankments would make this more frequent.

Positive and negative aspects of this proposal are provided in **Table 6-3.** An outline drawing for this option is provided in **Figure 6-4.** Proposals have been suggested in line with the model results.

Table 6-3: Option 3 – Positives & Negatives

Positives	1. Creation of floodplain storage 2. Encourage groundwater recharge 3. Enhance local interception of surface water 4. Habitat creation/increase in variability 5. Variability in flow regime through re-meandering of tributary 6. Increased connection between River Spey & floodplain 7. Potential for Biodiversity Net Gain credits
Negatives	1. Some “loss” of farmland but this area is wet and floods frequently anyway. 2. Recommend modelling to assess impact of removal of embankment and local flood risk to Gergask 3. Requirement for a more detailed design to confirm suitability

Figure 6-4: Option 3 Outline Drawing



6.2.4 Option 4 – Reconnection with Floodplain south of Balgowan War Memorial

Remove the embankment on the left bank of the River Spey between the Oxbow Lake upstream and land to the north of the River Spey to the north of Cnoc Bheithe. This would reconnect this area to the upstream and downstream floodplain, restoring natural processes.

The removal of this embankment would encourage flows to spill out of the River Spey channel and onto this floodplain, providing flood storage, groundwater recharge and generally creating more wet habitat. This area could continue to be grazed, although it would now flood more frequently. The alternative would be to create more of a wetland in this area by creating lower-lying areas for ponds, etc.

The removal of the embankment has not been modelled at this stage, but interrogation of the model suggests that the floodplain would activate soon after the filling of the Oxbow Lake at approximately 60 m^3/s, and would have likely become flooded in the three recent observed events of 19/09/18, 10/12/19 and 29/03/21.

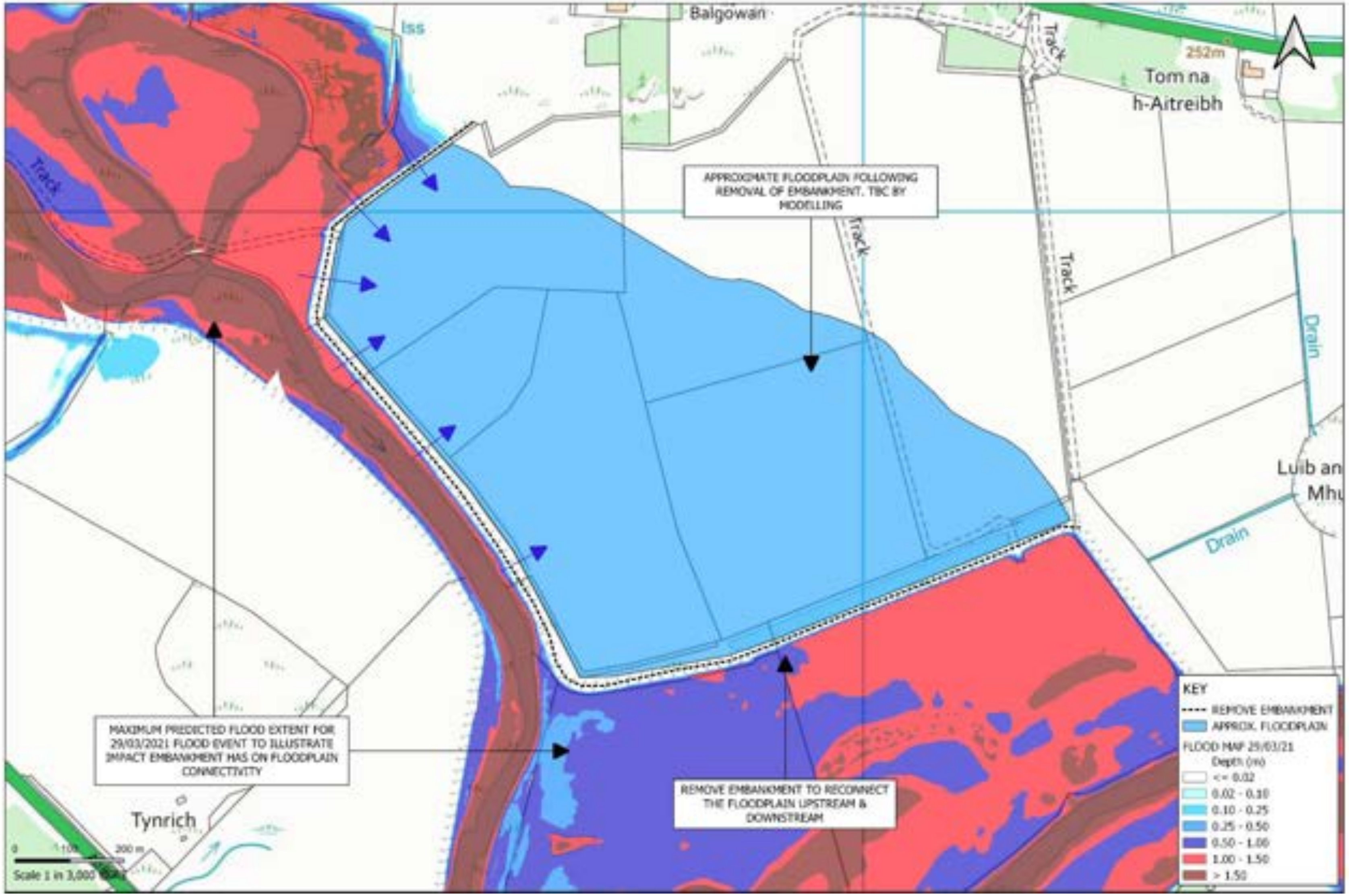
The removal of the embankment could result in some migration of the River Spey channel through this area although this depends on a number of factors.

Positive and negative aspects of this proposal are provided in **Table 6-4.** An outline drawing for this option is provided in **Figure 6-5.** Proposals have been suggested in line with the model results.

Table 6-4: Option 4 – Positives & Negatives

Positives	1. Creation of a larger area of floodplain storage 2. Encourage groundwater recharge 3. Increased connection between River Spey & floodplain 4. Potential improvements in habitat through more frequent wetting 5. Potential for Biodiversity Net Gain credits
Negatives	1. More frequent flooding of a large area of productive farmland although still possible to use the farmland 2. Recommend modelling to assess impact of removal of embankment and local flood risk to Gergask 3. Requirement for a more detailed design to confirm suitability

Figure 6-5: Option 4 Outline Drawing



6.2.5 Option 5 – Large-scale Restoration at Cluny Estate

The Cluny Estate is protected from flooding by an embankment along the left bank (north) of the River Spy. This protects an area of over 1.5km². The existing embankment has been breached in at least two location and is not heavily maintained. The land protected to the north of the embankment has been heavily-managed historically, with the Allt Dobhrain bunded and diverted around the site and a number of drains cut into the estate to drain the land. These works appear to have only been partially successful with some areas of the site seeming waterlogged from aerial photography. It seems likely that this area will have historically been a wetland that formed part of the floodplain of the River Spey.

There are a multitude of possible options here, including a large-scale restoration of the whole area to return it to a more natural state.

In the interest of simplicity, a straight-forward option has been proposed with information provided on enhancing it with further interventions.

Proposals are to breach or remove the embankment on the left bank (north) of the River Spey at the meander bend directly to the south of the Balgowan farm buildings. While this option has not been modelled the results of the modelling suggest flows would spill out at this location from approximately 60 m³/s onwards and would have likely spilled out in the three recent observed events of 19/09/18, 10/12/19 and 29/03/21. The floodwaters would spill through the Cluny Estate in an easterly direction, likely flowing through Lochan Ruadh and leaving via the existing confluence of the Allt Dobhrain with the River Spey. It may be beneficial to breach some of the embankments that cross within the Cluny Estate, although this is not strictly necessary.

This proposal would reconnect the River Spey with this floodplain, likely resulting in the creation of a clear overland flow pathway along the route of the flooding over time. This would provide benefits with respect to flood storage and groundwater recharge but also habitat related benefits through the creation of wetter areas.

This area is predicted to have flooded anyway in the recent observed events of 19/09/18, 10/12/19 and 29/03/2, due to flood waters backing up at the confluence of the Allt Dobhrain and the River Spey, but also due to the Allt Dobhrain and smaller drains being unable to discharge their flows into the River Spey when it is in spate. This option would therefore not increase the area of flooding drastically, but it would increase the frequency of flooding and result in numerous benefits.

It is likely that the farm could remain operational following the removal of the embankment. However, there is also plenty of scope to make further improvements to this area and create a large wetland and floodplain area, if the landowner is supportive. Although this will have an impact on farming this may be offset by the potential for Biodiversity Net Gain funding. Suggested additional measures could include:

- the backfilling of existing drains to encourage the area to be more like a wetland;
- Improvements to “grow” Lochan Ruadh;
- lowering of areas to create ponds and other variety of habitat;
- Planting of key plants and native species to encourage recolonisation.
- the removal or breach of the embankment bunding the Allt Dobhrain to encourage this watercourse to find a more natural path;
    - This could be combined with a more formal re-meandering of the channel;

Ultimately, this option, when combined with other suggested measures in this location could help create a large wetland area with a more natural floodplain that is better connected to the River Spey.

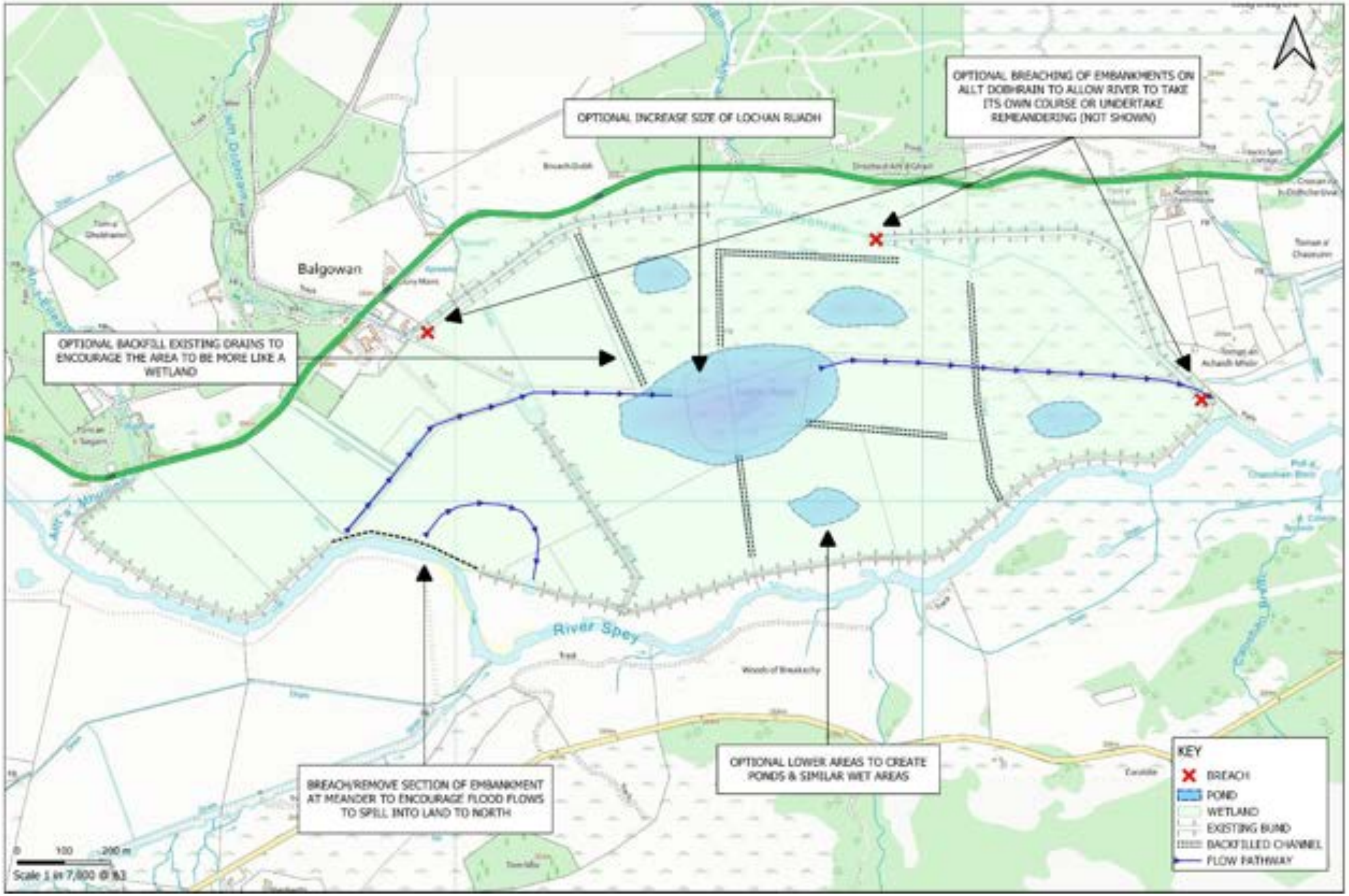
It is noted that there is an existing breach in the embankment. This is located at a high point so modelling predicts that it only activates in larger flood events and so does not provide as much benefit as the proposals discussed here.

Positive and negative aspects of this proposal are provided in **Table 6-5.** An outline drawing for this option is provided in **Figure 6-6.** Proposals have been suggested in line with the model results.

Table 6-5: Option 5 – Positives & Negatives

Positives	1. Creation of a larger area of floodplain storage 2. Encourage groundwater recharge 3. Increased connection between River Spey & floodplain 4. Potential improvements in habitat through more frequent wetting 5. Other benefits including creation of wetlands & a variety of habitat depending on what other suggested measures are taken forward at this location 6. Potential for Biodiversity Net Gain credits
Negatives	1. More frequent flooding of a large area of productive farmland although still possible to use the farmland, in some instances depending on final option 2. Recommend modelling to assess impact of removal of embankment 3. Requirement for a more detailed design to confirm suitability

Figure 6-6: Option 5 Outline Drawing



6.3 Options Appraisal

It is important to review and compare the suggested interventions/options and confirm if particular options provide clear benefits over others.

In this instance this is difficult as it depends on how one values different aspects of the options. For example, Option 2 would be relatively easy and low-cost to implement as it only really requires the breaching of an embankment in two places. However, undertaking additional interventions within this same area would provide greater benefits but would obviously require more effort. Moreover, other options may require more effort but would ultimately provide a greater benefit. This makes it difficult to rate one option over the other.

It was decided to allocate a positive number to benefits and a negative number to loss of farmland and effort required. The results are provided in **Table 6-6**. This suggests that all options provide positive benefits but that Options 2 and 5 are likely to be the most beneficial versus the loss of farmland and effort required.

Table 6-6: Summary of Options Appraisal

	HABITAT CREATION / IMPROVEMENT	FLOOD STORAGE & GROUNDWATER RECHARGE	LOSS OF FARMLAND	EFFORT REQUIRED	RATING
OPTION 1	2	1	-0.5	-1	1.5
OPTION 2	2.5	2	-1	-1	2.5
OPTION 3	3	2	-1	-2	2
OPTION 4	2	3	-1	-2	2
OPTION 5	2.5	4	-1.5	-2.5	2.5

Habitat Creation: 1 (little) to 3 (high)
Flood Storage: 1 (little) to 4 (high)
Loss of Farmland: 0 (none) to -1.5 (high)
Effort required: 1 (little) to 2.5 (high)

6.4 Dredging

Dredging is the process of removing material from a riverbed and/or banks to deepen or widen the channel and increase the conveyance capacity.

Dredging has historically been a popular option to mitigate against flooding, alongside many other “engineered” measures. However, time has shown that these methods often do not have the intended effects and result in negative impacts.

For example, dredging has some of the most severe environmental impacts of any management option. Environmentally, it has a direct impact on the physical habitat, harming the aquatic ecosystem and disrupting riverine processes. It can result in the decimation of local species, some of which will be protected, and make the watercourse more vulnerable to non-native invasive species. Dredging in the Spey is likely to result in the loss of substrate suitable for salmonid spawning.

Dredging also leads to the suspension of sediments which can lead to impacts on downstream water quality. This can also lead to the undermining of river banks and structures such as bridges, causing river banks to collapse and exposing structure foundations and reducing their structural integrity. Dredging can also increase flood risk to communities downstream by increasing the speed and volume of river flows.

Moreover, studies have determined that dredging is often one of the least efficient methods of reducing flood risk. Watercourses naturally carry sediment downstream with sediment deposition occurring in certain areas, as part of the river maintaining its “equilibrium”. Where riverbeds are dredged the rivers tend to quickly replenish these areas with the lost sediment. This means that dredging needs to be undertaken frequently to be effective. This further exacerbates the impact on the environment.

That said, studies have found that sediment management and redistribution can be beneficial in particular circumstances, such as places where the natural drainage has been altered. This is discussed below.

6.5 Sediment & Dam Management

The results of previous studies suggest that the River Spey receives a reduced sediment load due to sediment being trapped behind the Spey and Mashie Dam. This results in bank erosion downstream of the dam due to the loss of sediment from the system. Sediment that is available in the system, such as from tributaries and from eroded banks, also accumulates at confluences and in the main channel due to the reduction in flows in the main river. This can result in the formation of benches, islands and channel narrowing, reducing the capacity of the river channel.

This means that the Spey (& Mashie) Dams impact the River Spey twofold by:

- Reducing sediment load in the watercourse;
- Reducing flow variability, reducing the ability to transport sediment and resulting in sediment aggradation.

Therefore, one way to help restore the River Spey to a more natural state would be to return sediment load levels to a more natural rate and increase flow variability by varying the discharge from the Spey Dam.

A review of previous studies suggests that this would be very difficult to achieve. The Gilvear (2000) study suggests that the Spey Dam operator does not have the capability to release higher flows than that of the maximum that is currently released of approximately 2.83 m^3/s. Contact was made with Alvance, the dam operator to confirm this. Alvance obliged and undertook internal calculations to estimate a hypothetical maximum flow that could be released from the Spey Dam. They estimated that if all 14 fish pass gates were opened fully and other certain conditions met an additional 2.37 m^3/s could be released, above the existing maximum of 2.83 m^3/s. This gives a maximum theoretical release flow of 5.56 m^3/s. While close to double the flow that is released from the Spey Dam currently, this is still very low compared to the scale of the river.

Adjusting the dam operating procedures to release the higher flows up to 5.56 m^3/s and provide a more variable flow regime could provide some limited benefit to the river. However, this is unlikely to be sufficient to have a significant impact on the ability of the river to convey sediment. While there will be more variability between 0 m^3/s and 5.56 m^3/s, higher flows cannot be released from the dam until water levels exceed the overtopping level of the spillway.

As it will not be possible to provide a more variable flow regime across a range of flows there is likely to only be limited benefit to reintroducing sediment into the downstream reach, as the river does not have the capacity to carry it.

A review of the River Mashie Dam suggests that it would likely be feasible to increase the compensatory flow that is discharged downstream of the dam by providing a larger (or more) bore holes in the aqueduct, or similar. However, this is a much smaller dam and is unlikely to make up for the loss in flows from the River Spey itself.

During consultation it was noted that the dam operator is known to remove sediment from upstream of the dam approximately every 3 years.

6.6 Improvements for Fish Spawning

The identified restoration options detailed in **Section 6.2** provide a number of benefits such as flood storage, groundwater recharge, floodplain reconnection and habitat creation. Discussion in **Section 6.5** emphasises the impact that damming the River Spey has had on flow variability and sediment transport. This, alongside the construction of embankments, has changed the morphology of the river and reduced its suitability for fish spawning. There is likely to be very little that can be done to improve this unless the dams and embankments are removed or heavily modified.

As it is difficult to improve the conditions for fish spawning on the main stem of the River Spey, suggestions were made to the creation of spawning channels. These are channels, which are often created adjacent to a heavily-modified river that are designed to encourage fish spawning by replicating the ideal spawning habitats. A review of literature (Jukka et. al, 2022) suggests that these spawning channels are relatively common in Canada, from as early as the 1950s, and have been explored in Germany and Finland. Internet references were made to the Dunglass side channel in Scotland, on the River Conon. This has been restored and now acts as a site for spawning on the river (RRC, 2005).

A review of the literature suggests that a spawning channel would need to maintain a gentle bed slope of between 0.1% and 1% and velocities of approximately 0.5 m/s (D.J. Hebert, 1965).

It is possible that spawning channels could be created adjacent to this reach of the River Spey and could be incorporated as part of Options 2 or 5. We would recommend input by a fisheries specialist to help design suitable spawning habitat within the options.

6.7 Previous Improvements.

Previous efforts to provide some flood storage have been undertaken at Breakachy Farm. The embankment between the River Spey and the Feith Bhuidhe to the east of Easter Breakachy has been improved with a concrete spillway and a pipe with non-return value. It is understood that this has been designed to store water during periods of spate in the River Spey. This likely provides some benefit by attenuating flows discharging to the River Spey.

6.8 Other Considerations

No options have been proposed downstream of Poll a' Chaochain Bhric. This downstream reach is more natural, with a sinuous channel and surrounding wetland features set within a narrower valley. This means there would be less of a benefit to undertaking interventions in this area.

Spey Catchment Initiative (and partners) requested options that would provide tangible benefits but also not significantly impact on available farmland. This request is very difficult to achieve. Reconnecting the River Spey with its floodplain, providing additional flood storage, encouraging groundwater recharge, creating more habitat, etc, all generally require some additional land take. However, it should be noted that naturalising the River Spey by undertaking some of these options could reduce flood risk to other areas. Moreover, permitting more land to be used for restoring the River Spey may come under the principle of Biodiversity Net Gain, meaning that landowners may be able to benefit financially by permitting these works to go ahead. Ultimately, there will need to be a discussion with communities and landowners to move forward. It may be that hybrid options where existing embankments are set back would provide some of the benefits while maintaining areas for productive farming and generating financial assistance through Biodiversity Net Gain.

Refer to **Section 5.7** for Model Considerations.

7 Summary and Conclusions

Kaya Consulting Limited was commissioned by the Spey Catchment Initiative to undertake a Hydrological and Modelling Study of a ~15km reach of the River Spey between Spey Dam and the River Truim.

A community liaison meeting was organised with key information provided by attendees such as where flooding had occurred previously, approximate levels it had reached and locations where flooding first occurred. This information was used to inform the site walkover, topographical survey and the modelling. The information provided by the community helped support the calibration of the River Model of the River Spey and the model results show a good relationship with the observed information provided by the community.

Key supporting data was acquired from a number of sources to support this assessment. A topographical survey was commissioned. A number of walkovers were undertaken by key staff members. Historical, geological and environmental information has been reviewed. All of this information has helped support the development of a representative model of the River Spey, itself helping to identify strategic options/interventions.

A Climate Change review was undertaken using local data for this part of the River Spey available from the UK Climate Projections 2018 portal. Results depend on the emissions scenario chosen and what data is considered (Seasonal, monthly, etc). Local climate change estimates are generally lower than the conservative values recommended by SEPA. The results show that peak river flows are estimated to increase in the future, regardless of the data used to calculate this, although the magnitude of change does depend on the data chosen. It is impossible to know how much flows and water levels will increase by in the future, as this depends strongly on how successful the international community is at reducing greenhouse gas emissions.

A review of the available hydrological information was undertaken. Observed data was compared to key flood events that were noted during the community liaison meeting. A reservoir model was developed to convert the observed water levels in the Spey Dam to flows for key observed events. It is much more difficult to estimate the return periods/recurrence intervals (estimated average time period between events) for the River Spey due to the damming of the watercourse. A much more detailed assessment would be required to obtain suitable estimates.

A hydraulic model of the River Spey was developed and efforts were made to calibrate it to the observed events. The final model was run for the key observed events. Model results are provided, including flood maps, a review of flood timings, velocities and other key information. Sediment modelling was undertaken to get a better understanding of sediment transport processes. This work has helped us gain a better overall understanding of the predicted flood extents, flood levels and depths, and flood mechanisms that occur in this reach of the River Spey and help us better understand the impact of the changes to the channel/floodplain morphology.

The model results and other aforementioned supporting information from this study were used to identify 5 key restoration options/interventions. A simple options appraisal was also undertaken to identify if certain options provided more benefits than others. The results suggested that Options 2 and 5 would provide the most benefit considering the work entailed. It is recommended this is discussed with all stakeholders, however, as they may have a different view on the “benefits” of each option.

A selection of alternative options are also discussed in less detail. These were considered to be potential options but would provide fewer benefits or be complex. A discussion on dredging and sediment and dam management is also provided. This was added to help understand if changes to the way the Spey Dam is managed could help provide benefits to the reach. It was noted that the controls at the Spey Dam are limited in that only very low flows (Compared to the scale of the River Spey) can be released without water overtopping the dam.

More work could be undertaken to further evaluate/test the various aforementioned options by refining the detailed model that has been developed specifically for this study. The model could also be further improved in the future as more data becomes available, such as the refining of the calibration.

The study has helped gained a more thorough understanding of the upper River Spey from downstream of the Spey Dam to Invertruim. The results of the study have confirmed that the Spey Dam (and other features such as the Mashie Dam) have had a significant impact on the river flow regime, fluvial geomorphology, riverine habitat and sediment transport, resulting in changes to the river. Work has also been undertaken to characterise the hydrology of the River Spey using observed data and to estimate peak flood flows. A detailed model of this reach of the River Spey has been developed, based on surveyed data, and the model ran for a number of observed and theoretical flood events. This has provided a better understanding of flood mechanisms and flood extents, and illustrates the impact of the agricultural embankments. The results of the modelling have identified a number of potential restoration interventions, although the options provided in this report are not meant to be exhaustive. Discussions are required with the community and stakeholders to identified the preferred options, keeping in consideration both the positive and negative aspects of each option.

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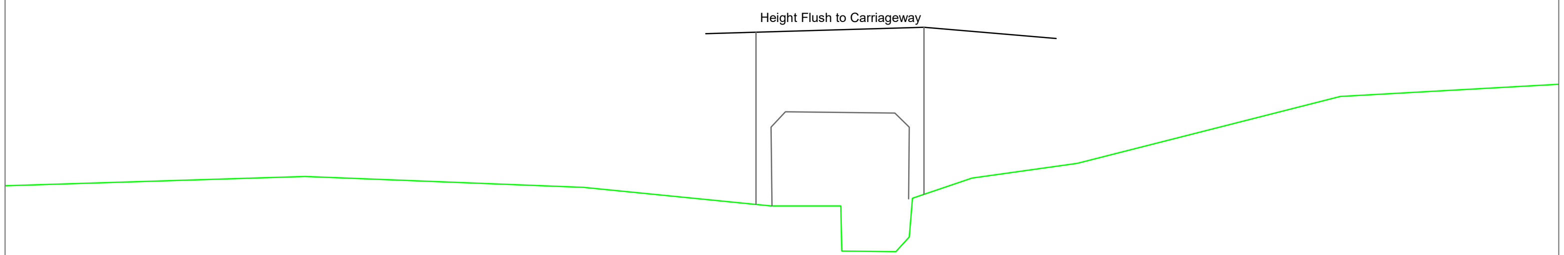
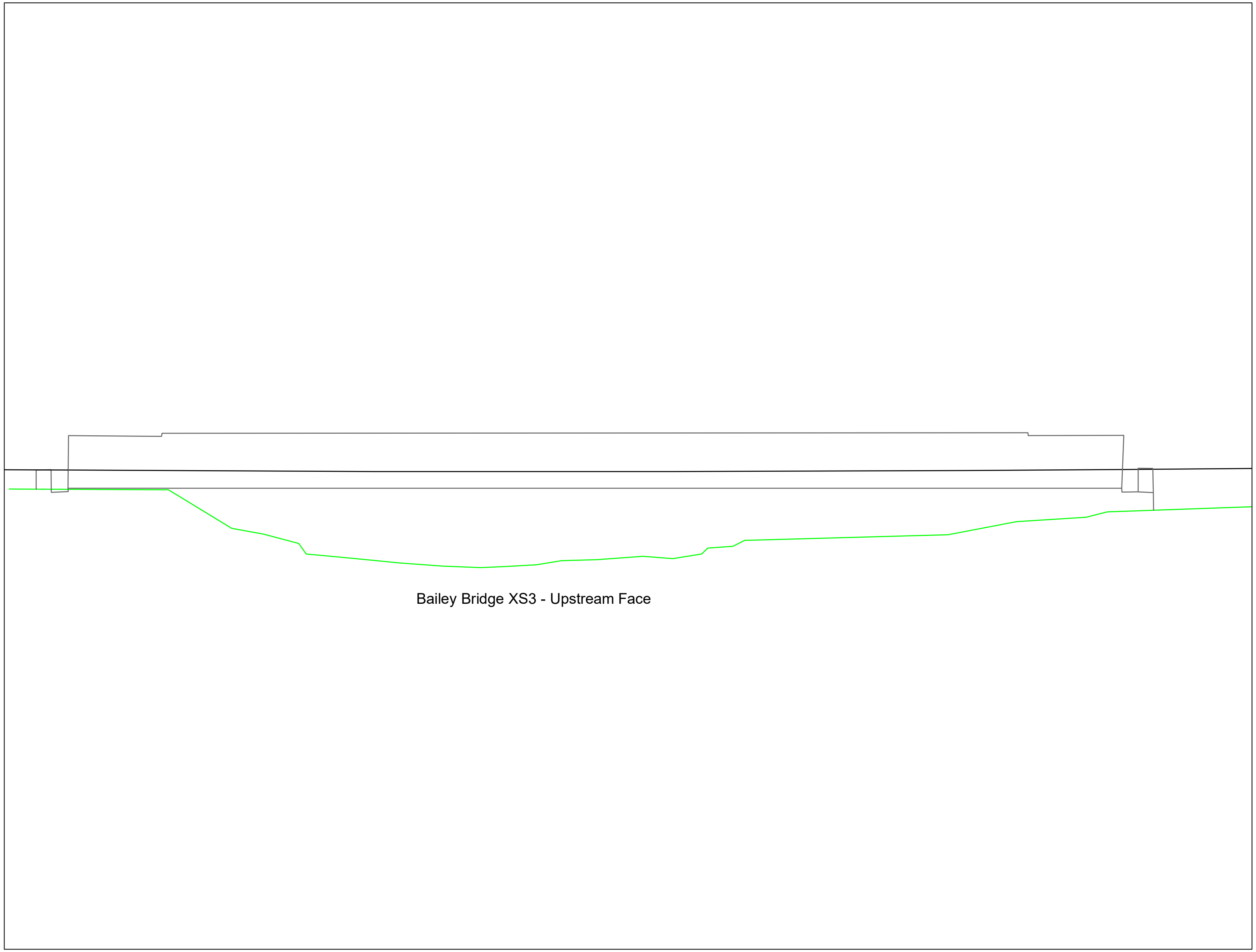
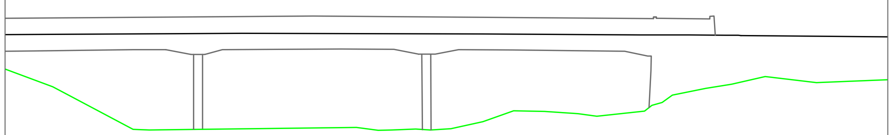
Appendix A – Topographical Survey Data



Culvert at T Junction A86/A889 - Upstream Face


Bailey Bridge XS3 - Upstream Face



General Wade's Bridge XS4 - Upstream Face

Appendix B – Walkover & Photo Record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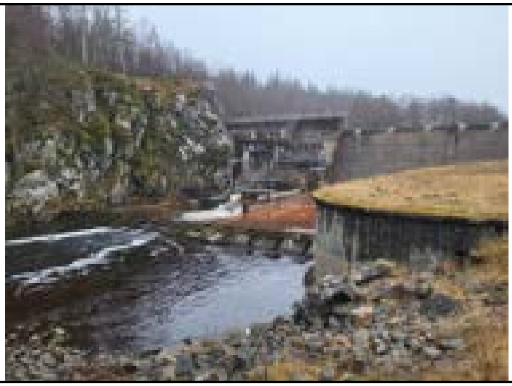
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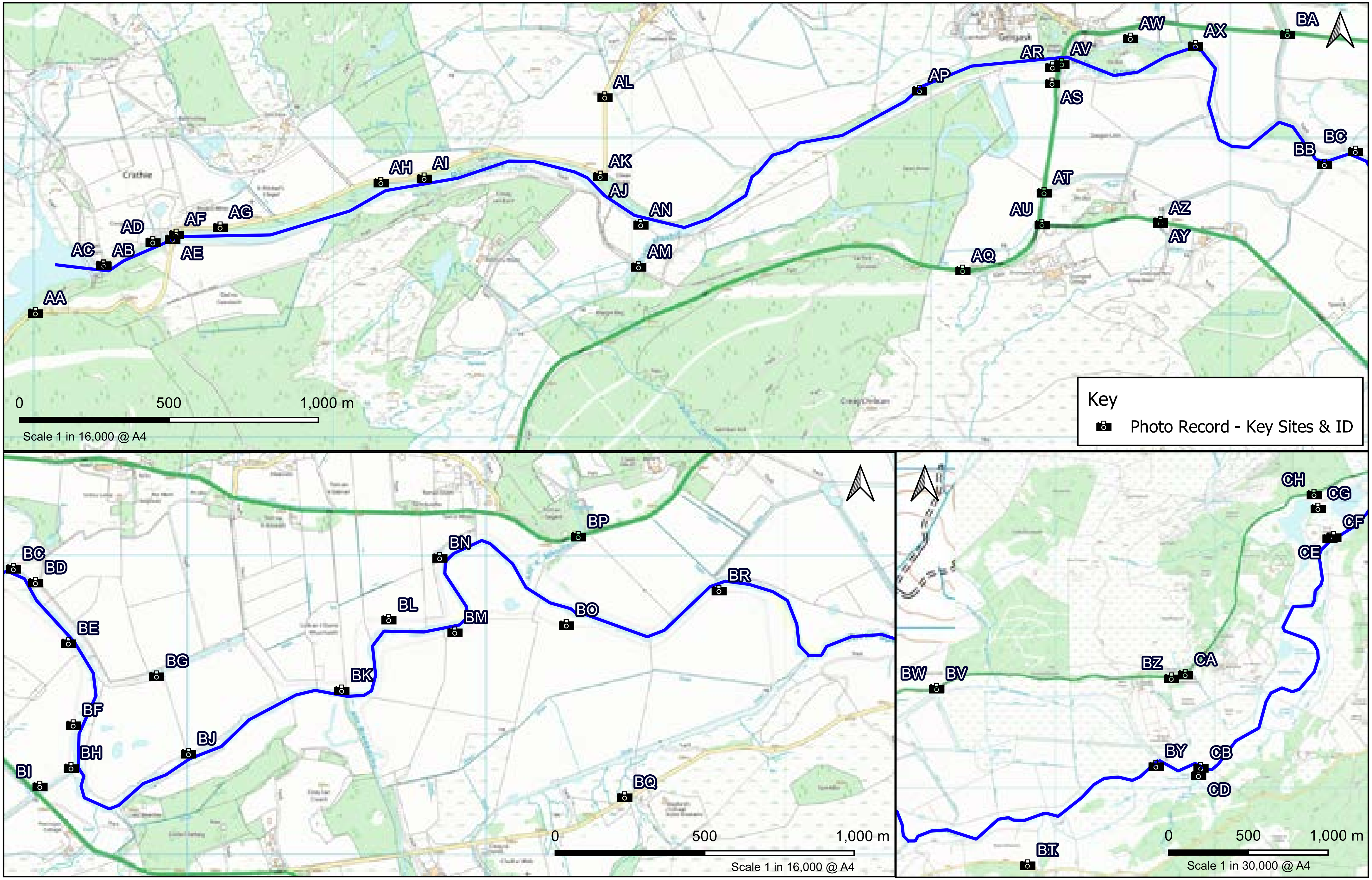


PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	**V1** 24/03/23 **Drawn:** GP - **Checked:** MS - **Approved:** MS	
DRAWING: PHOTO RECORD KEY SITES	**ISSUE:** KC2517-PHOTO KEY-FIN-V1		

Appendix C – Hydrological Assessment Appendix

Hydrology Memo

DATE: October 2023

TO: SCI

FROM: Kaya Consulting

This is the Hydrological Assessment Appendix for the Spey Study. It includes details of the following:

1. Reservoir-Routing Model details.
2. Hydrographs for 3 observed events
3. Hydrology for Spey @ Invertruim
4. Hydrology for River Mashie
5. Hydrology for other tributaries.

This document includes technical details of the work undertaken. Discussion on the work is provided in the main report.

1. Reservoir Routing Model

A Reservoir-Routing model was developed to represent the Spey Dam, based on available information. Two versions of the model were developed. 1 uses observed water levels in the Spey Dam reservoir as inputs at the top of the model; 2 uses rainfall inputs. The latter requires additional information to represent the storage provided by the reservoir.

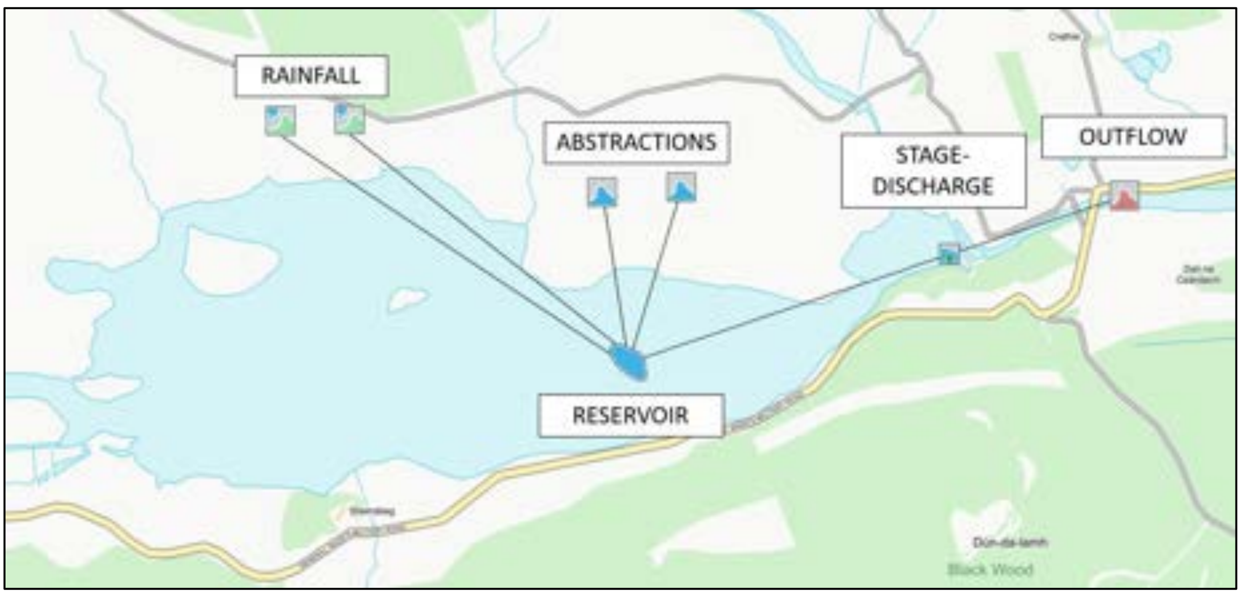
Model 1 represents observed water levels in the Spey Dam reservoir as inputs, the known stage-discharge relationship over the spillway (provided in Gilvear report but adjusted to metric) and a head-time boundary to permit flows to leave the model downstream of the spillway. It is not necessary to account for the volume of water abstracted from the dam because the observed water levels used in the model account for this. This model permits observed water levels to be added into the model and flows to be output. The model was run using a suitable timestep for the entirety of the observed events. The results of this model are thought to be representative of reality with a high confidence level in the predicted outflows.

Model 2 uses rainfall as an input to model theoretical storm events. Because these events are theoretical the water levels in the reservoir are unknown, so the reservoir is represented as a storage unit and an initial water level needs to be chosen. The spillway was represented using the known stage-discharge relationship which is connected to a head-time boundary to permit flows to leave the model downstream of the spillway. The model includes an allowance for the Spey Dam abstraction of 21.97 m^3/s and the allowance for the compensatory flow of 2.83 m^3/s. Because this model uses theoretical storms and does not represent abstractions the results are only estimations and there is a lower confidence in the model results.

A schematic of the models is provided below in **Figure 1** and **Figure 2**.

Figure 1: Reservoir-Routing Schematic – Model 1

Figure 2: Reservoir-Routing Schematic – Model 2



2. Hydrographs for 3 observed events at the Spey Dam.

The reservoir-routing model was employed to calculate the hydrographs for the three recent recorded events that occurred on 19/09/18, 10/12/19 and 29/03/21. The results are provided below in **Figures 3, 4 and 5**.

Figure 3: Flood Event – Hydrograph 19/09/2018

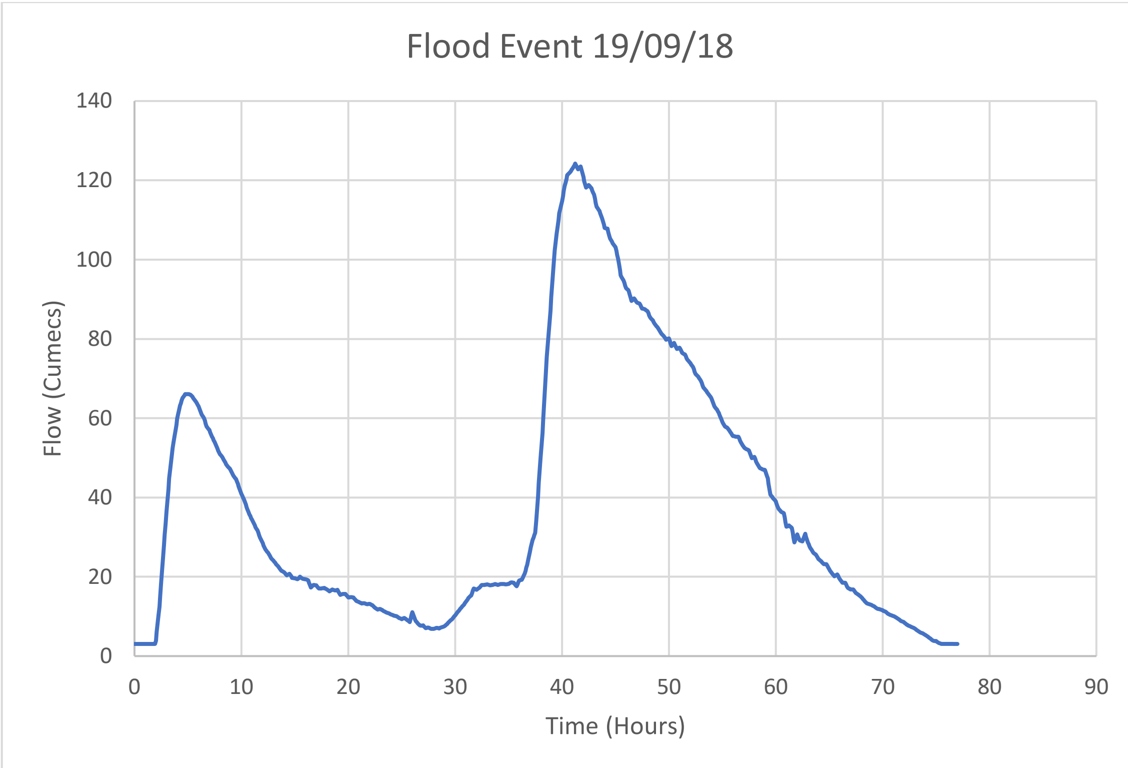


Figure 4: Flood Event – Hydrograph 10/12/2019

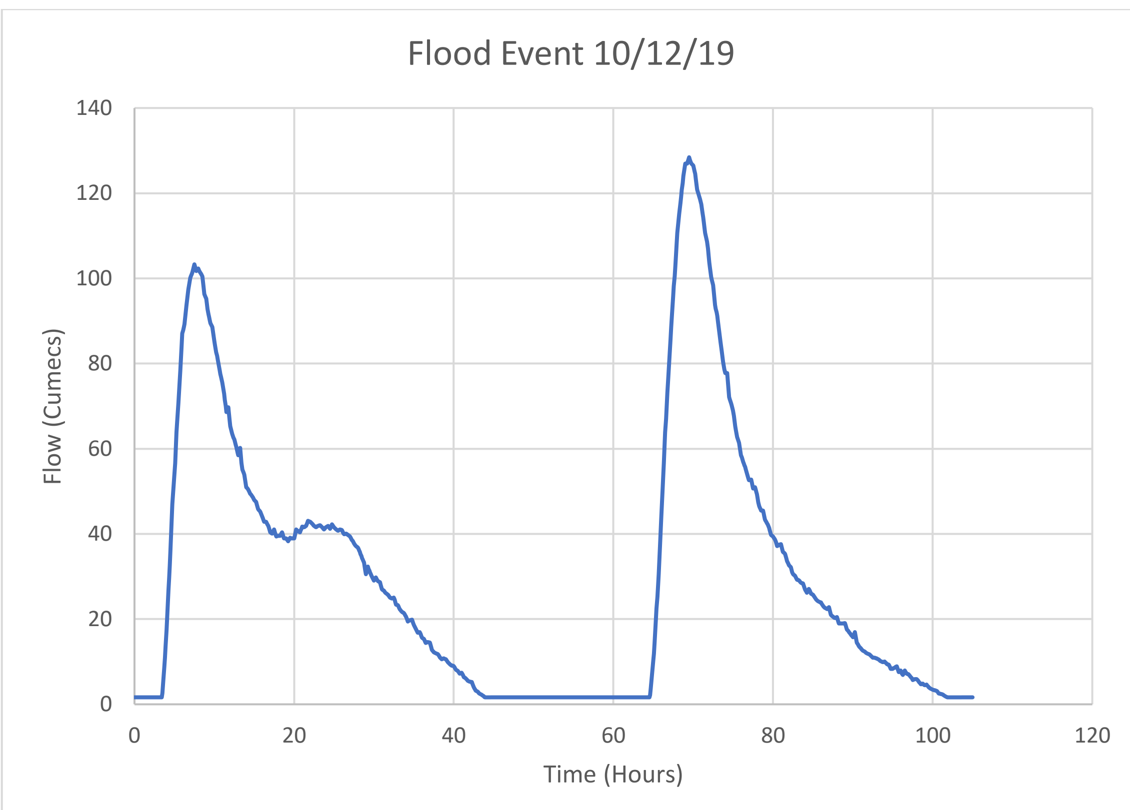
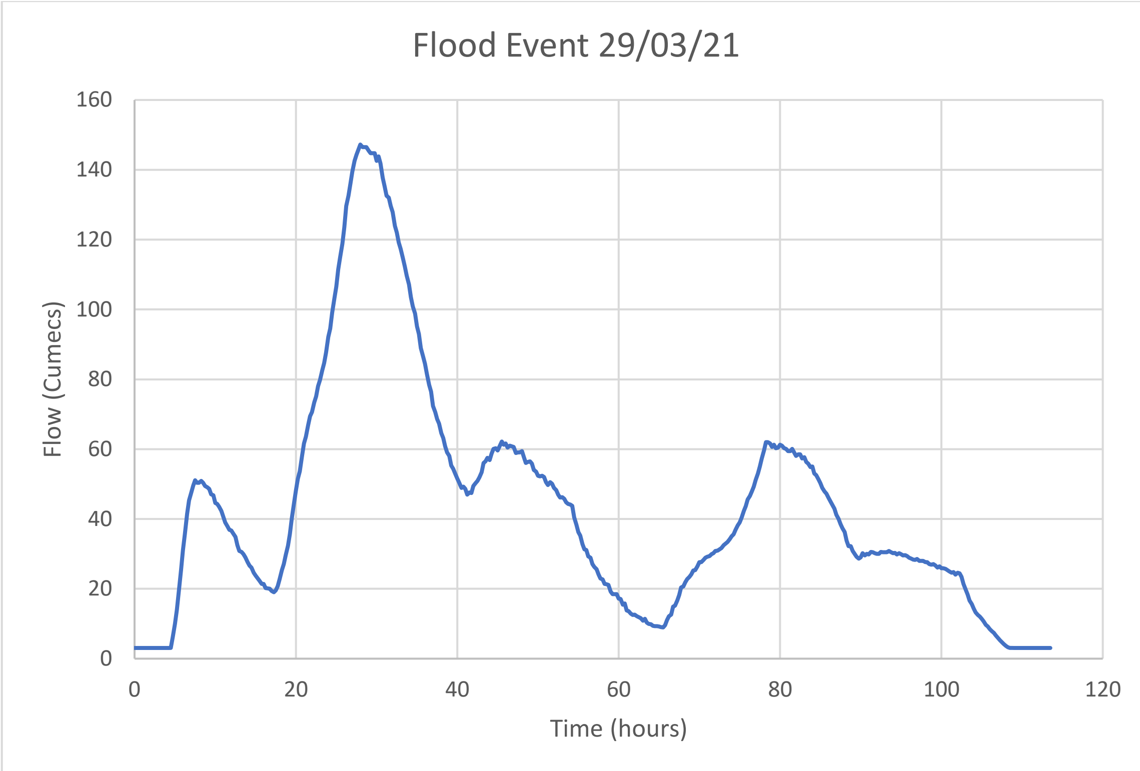


Figure 5: Flood Event – Hydrograph 29/03/2021



3. Hydrology for Spey @ Invertruim

Information on the FEH Single Site Analysis undertaken for the Spey @ Invertruim is provided below. The QMED observed, based on observed data rather than catchment descriptors was used. This is preferable where there is a gauging station. Qmed estimates are provided in **Table 1**.

Table 1: QMED Estimates for the Spey @ Invertruim

	Type	m^3/s
QMED	RURAL	212.5
QMED	URBAN	212.5
QMED	Observed	105.85

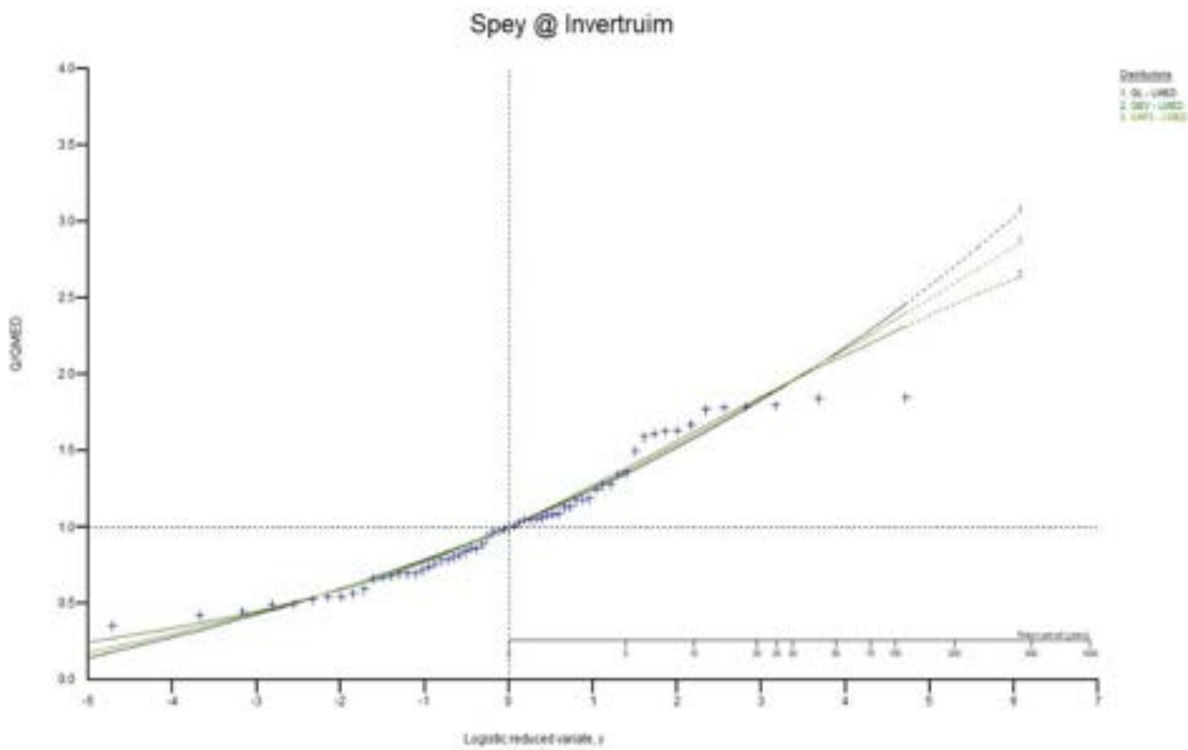
The Generalised Logistic growth curve was employed to extrapolate the data for higher return periods in line with SEPA guidance. The rating curve and peak flows are shown in **Table 2**. **Figure 6** shows the growth curve plotted.

Table 2: Peak Flows & Rating Curve for the River Spey @ Invertruim

Return Period	GL	Peak Flows (Cumecs)
1	0.409	43.29
2	1	105.85
3	1.165	123.31

4	1.269	134.32
5	1.345	142.36
10	1.576	166.81
20	1.811	191.69
25	1.888	199.84
30	1.953	206.72
50	2.14	226.51
*** 75**	2.296	243.02
*** 100**	2.411	255.20
*** 200**	2.704	286.21
*** 500**	3.13	331.30
*** 1000**	3.485	368.88

Figure 6: Growth Curve for Spey @ Invertruim Gauge



4. Hydrology for River Mashie

Design flows for the River Mashie were estimated using the ReFH2 method. This is a rainfall-runoff model suitable for smaller catchments.

The CINI value (catchment wetness) was adjusted to match with the observed data at the gauging station on the River Spey at Invertruim, because it was noted that the standard ReFH2 parameters were overpredicting flows.

The Mashie Dam extracts up to 11.71 m³/s, while permitting a maximum of 0.41 m³/s to leave the dam via two "boreholes" (Total difference of 11.3 m³/s). Once flows upstream of the Mashie Dam exceed this value, the flows in excess of the 11.71 m³/s are returned to the River Mashie.

Peak flow estimates are provided in **Table 3**.

Table 3: Estimated Peak River Mashie Flows

Return Period	Peak Flow (Ignoring Mashie Dam) (m³/s)	Peak Flows (m³/s)
1	12.20	0.90
2	14.12	2.82
5	20.78	9.48
10	25.62	14.32
30	33.70	22.40
50	37.69	26.39
75	41.00	29.70
100	43.42	32.12
200	49.47	38.17

5. Hydrology for Other Tributaries

In addition to the River Spey, there are an additional 18 model inflows from tributaries including the River Mashie, River Truim, Allt Breakachy, Allt na Cubhaige, Allt Dobhrain and An t Eileach alongside a number of unnamed watercourses. Peak design flows for the River Mashie are provided above but flows for the modelled observed events are provided below.

Flows lower than 0.2 m³/s were removed, as very low flows can lead to instabilities in the model. For this reason, some tributaries show a flow of less than 0.2 m³/s.

Flows for the observed flood events were derived using rain gauge data from the Spey Dam alongside representative FEH Catchment Descriptors obtained from the FEH web-service.

A visual depiction of the location of the tributaries is provided in **Figure 3**. Peak flow estimates are provided in **Table 4**.

Table 4: Estimated Peak Flows for Tributaries for Key Events & Return Periods

Tributary	1 in 200-year Design Event	10th Dec 2019 Event	29th March 2021 Event
	m³/s	m³/s	m³/s
1	NA	Less than 0.2	Less than 0.2
2	5.42	0.842	0.985
3	7.18	1.12	1.31
4	7.44	1.16	1.359
5	5.00	0.775	0.907
6	14.23	2.421	2.60
7	11.82	2.007	2.156
8	4.31	0.668	0.781
9 (Mashie)	38.17	1.961	2.889

10	NA	Less than 0.2	Less than 0.2
11	NA	Less than 0.2	Less than 0.2
12	9.60	1.505	1.761
13	47.13	6.426	6.811
14	7.88	1.232	1.441
15	6.13	0.950	1.116
16	2.08	0.319	0.374
17 (Truim)	110.60	34.481	29.615

Figure 7: Visual depiction of tributaries

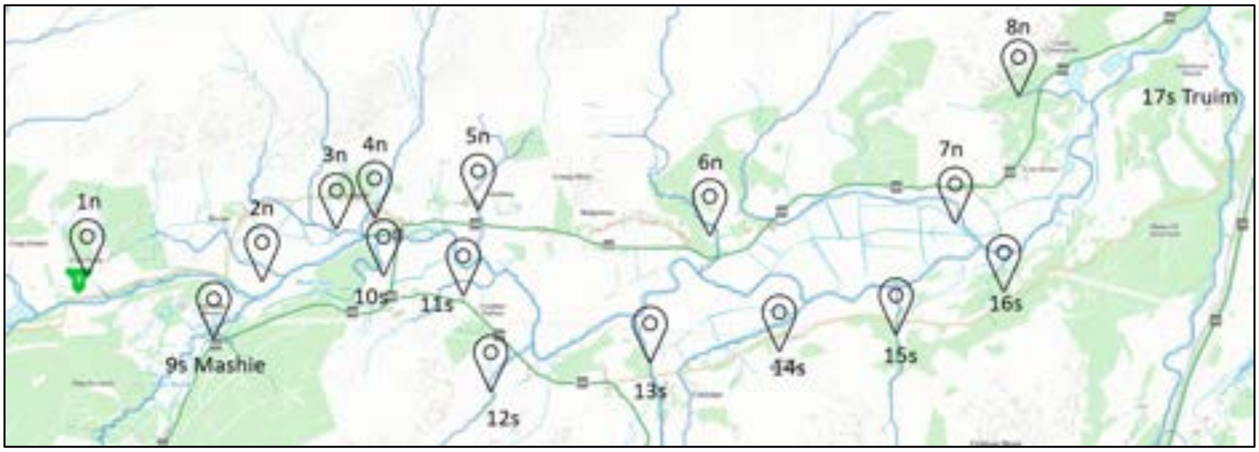


Table 5: Representative FEH Catchment Descriptors for Tributary 2.

Area (km²)	0.51
ALTBAR	319
ASPBAR	172
ASPVAR	0.76
BFIHOST	0.47
BFIHOST19	0.4
DPLBAR (km)	0.91
DPSBAR (mkm-¹)	120.7
FARL	1
LDP	1.73
PROPWET	0.83
RMED1H	8.8
RMED1D	35.8
RMED2D	49.1
SAAR (mm)	1212
SAAR4170 (mm)	1125
SPRHOST	42.23
Urbext2000	0
Urbext1990	0
URBCONC	0
URBLOC	0

Appendix D – Sediment Sampling & Maps

Wolman Count – Location 1	
View Looking Downstream	

Grainsize Designation	**Grainsize (mm)**
D10	14
D50	86
D90	159
Modal class	128-180

Wolman Count - Location 2
View from north bank looking upstream

Grainsize Designation	Grainsize (mm)
D10	26
D50	71
D90	145
Modal class	64-90

Wolman Count – Location 3	
View Upstream	View Downstream

Grainsize Designation	Grainsize (mm)
D10	10
D50	26
D90	117
Modal class	11-16

This data indicates fine gravel, compared to what is shown in photos of the location which appears to be much larger sediments – will confirm location of Wolman count in next draft.

Wolman Count – Location 4	
View Upstream	

Grainsize Designation	**Grainsize (mm)**
D10	24
D50	48
D90	94
Modal class	45-64

Wolman Count – Location 5	
View Downstream	

Grainsize Designation	Grainsize (mm)
D10	17
D50	41
D90	101
Modal class	22.6 - 32

Wolman Count – Location 6	
View Upstream	
	
Grainsize Designation	**Grainsize (mm)**
D10	10
D50	58
D90	141
Modal class	64-90

Wolman Count – Location 7	
View Upstream	

Grainsize Designation	Grainsize (mm)
D10	24
D50	9
D90	46
Modal class	128-180

Wolman Count – Location 8	
View Upstream	

Grainsize Designation	**Grainsize (mm)**
D10	11
D50	39
D90	88
Modal class	45-64

Wolman Count – Location 9	
View Upstream	

Grainsize Designation	Grainsize (mm)
D10	<2
D50	6
D90	19
Modal class	<2 & 5.6-8

Wolman Count – Location 10	
View Upstream	
	
Grainsize Designation	**Grainsize (mm)**
D10	<2
D50	40
D90	104
Modal class	<2 & 45-64

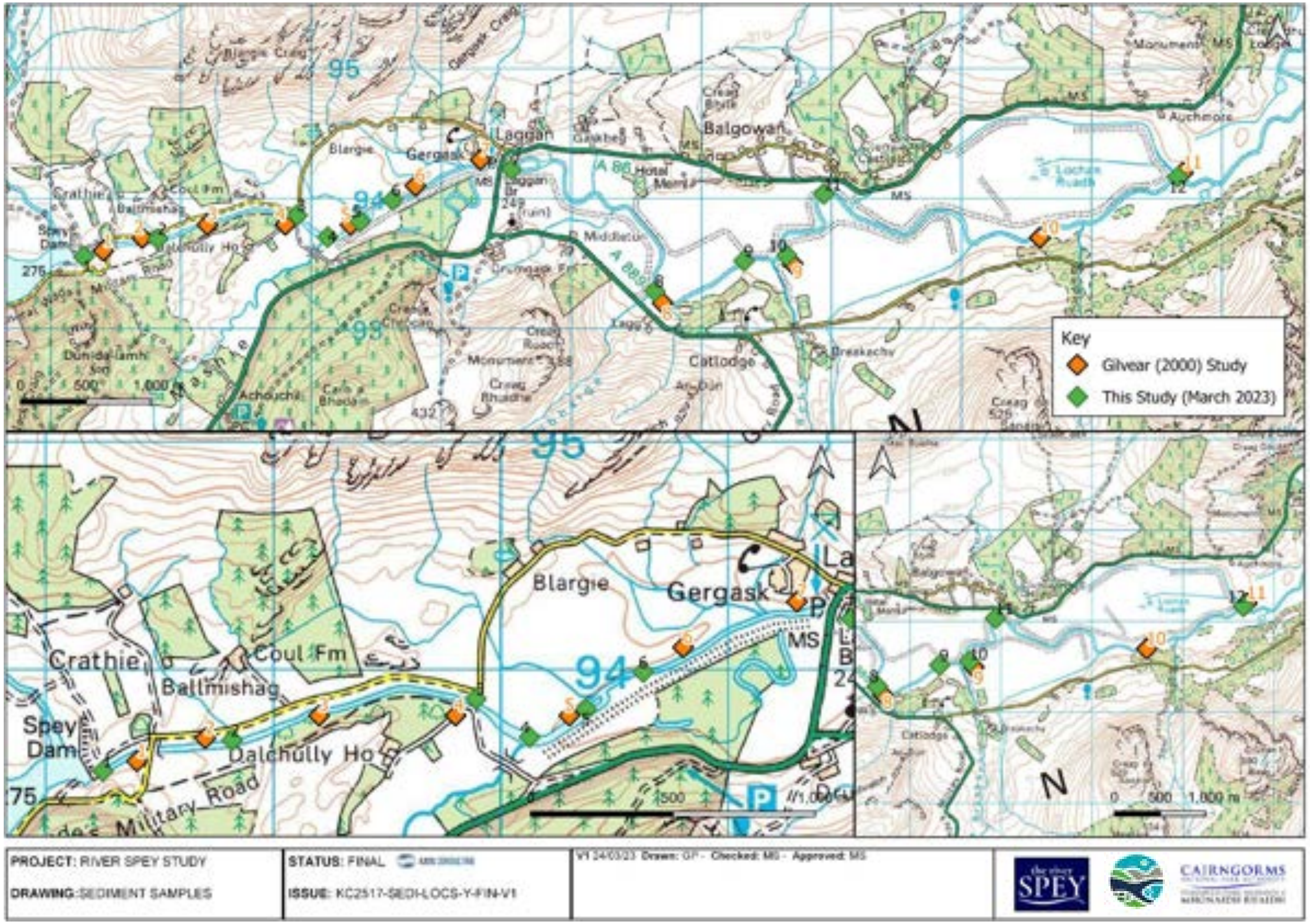
Wolman Count – Location 11	
View Upstream	

Grainsize Designation	Grainsize (mm)
D10	<2
D50	27
D90	79
Modal class	<2 & 45-64

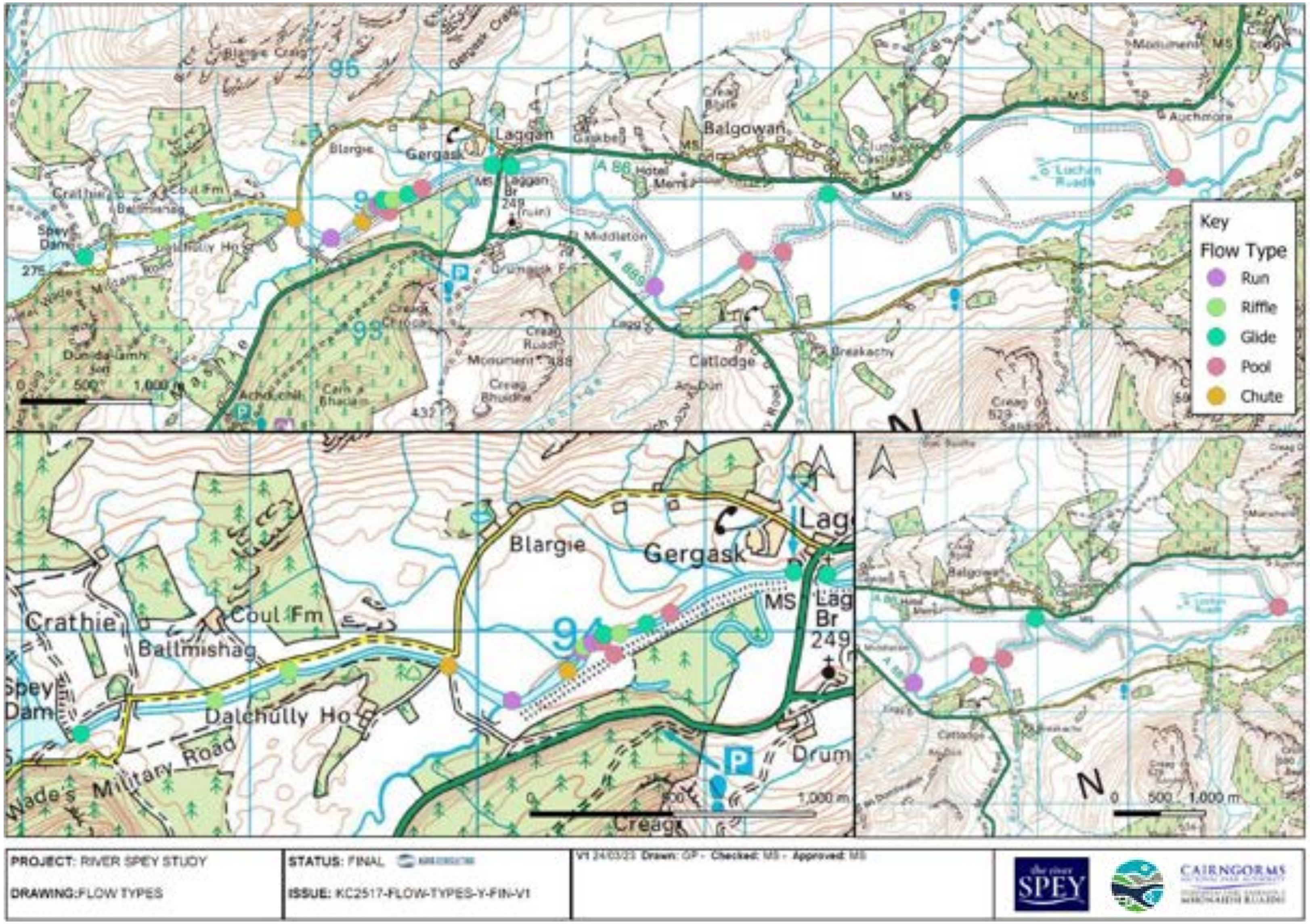
Wolman Count – Location 12	
View Upstream	

Grainsize Designation	**Grainsize (mm)**
D10	<2
D50	3
D90	51
Modal class	<2 & 2.8-4

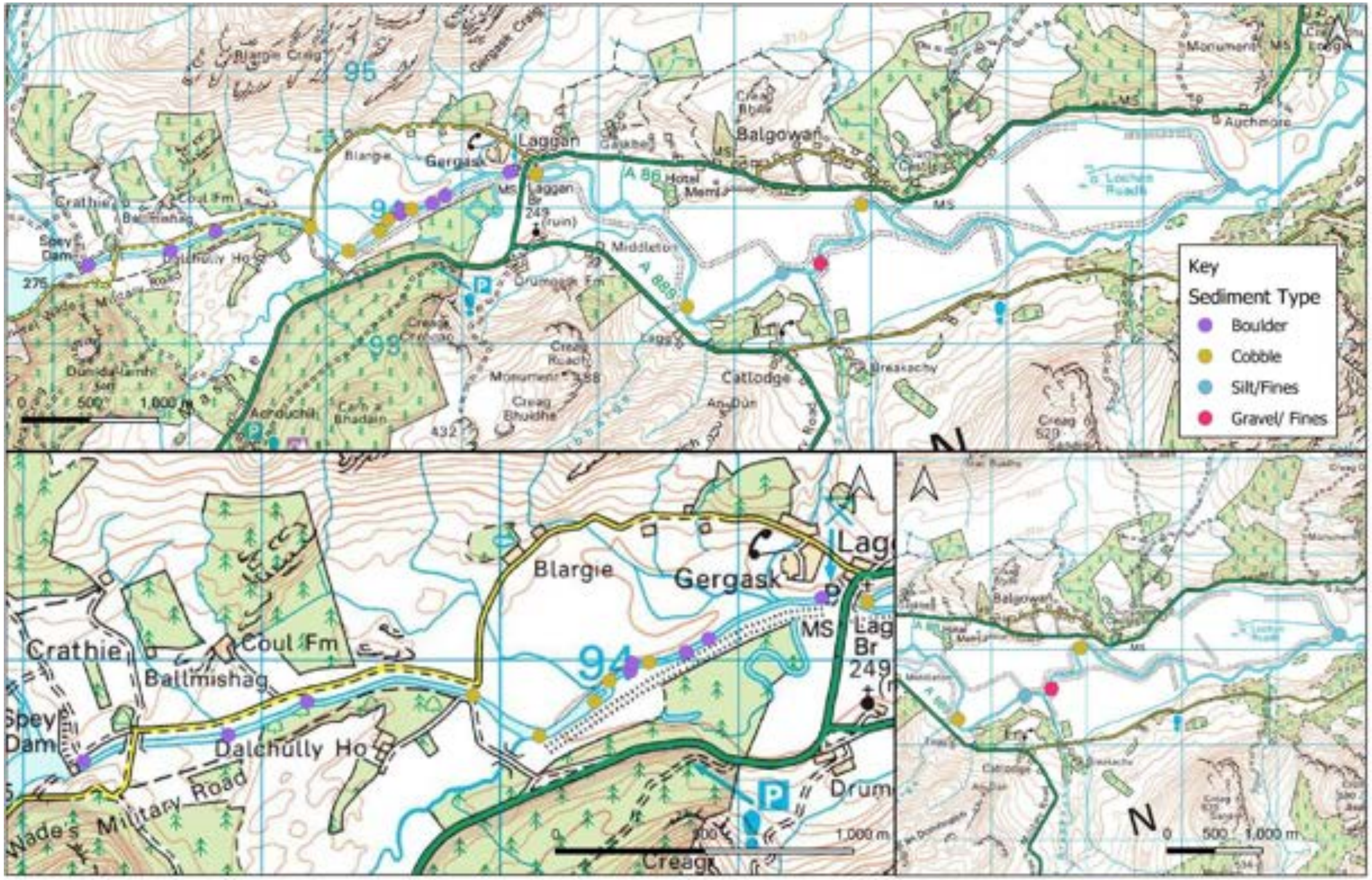
Appendix D-2: Wolman Pebble Count Locations



Appendix D-3: Fluvial Audit – Flow Regime



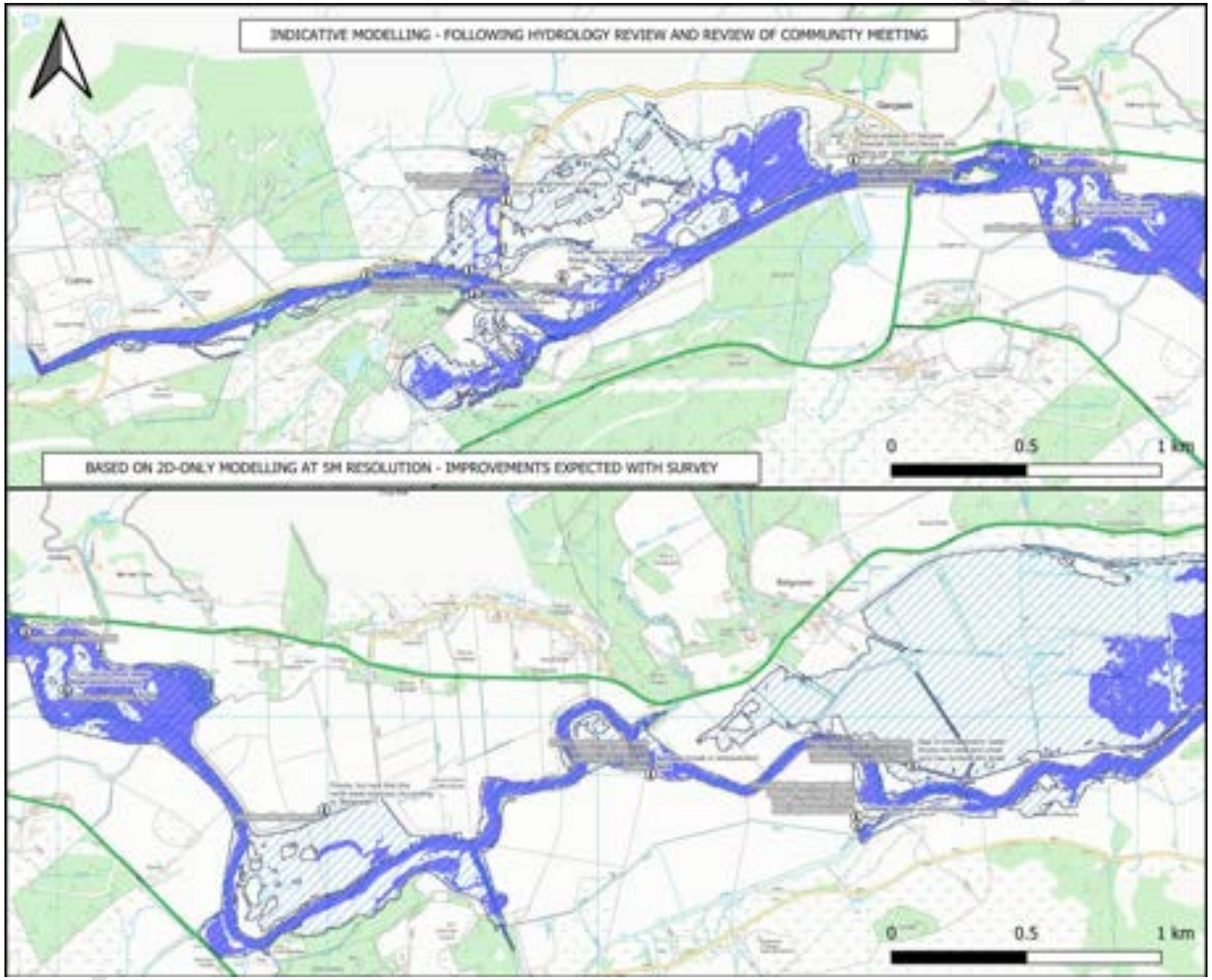
Appendix D-4: Fluvial Audit – Sediment Regime

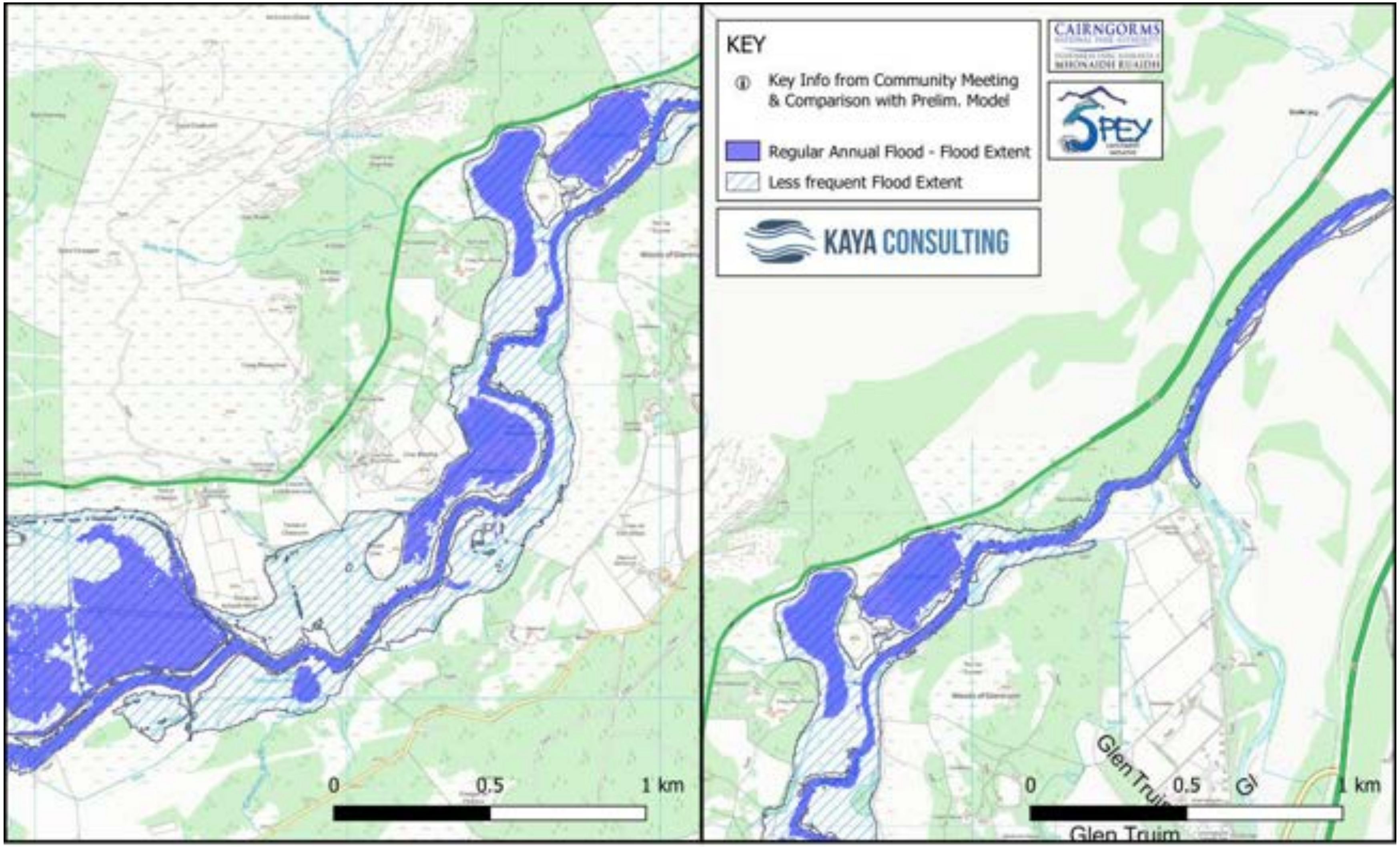


PROJECT: RIVER SPEY STUDY	STATUS: FINAL	V1 24/03/23 Drawn: GP - Checked: MS - Approved: MS
DRAWING: SEDIMENT TYPES	ISSUE: KC2517-SEDI-TYPES-Y-FIN-V1	

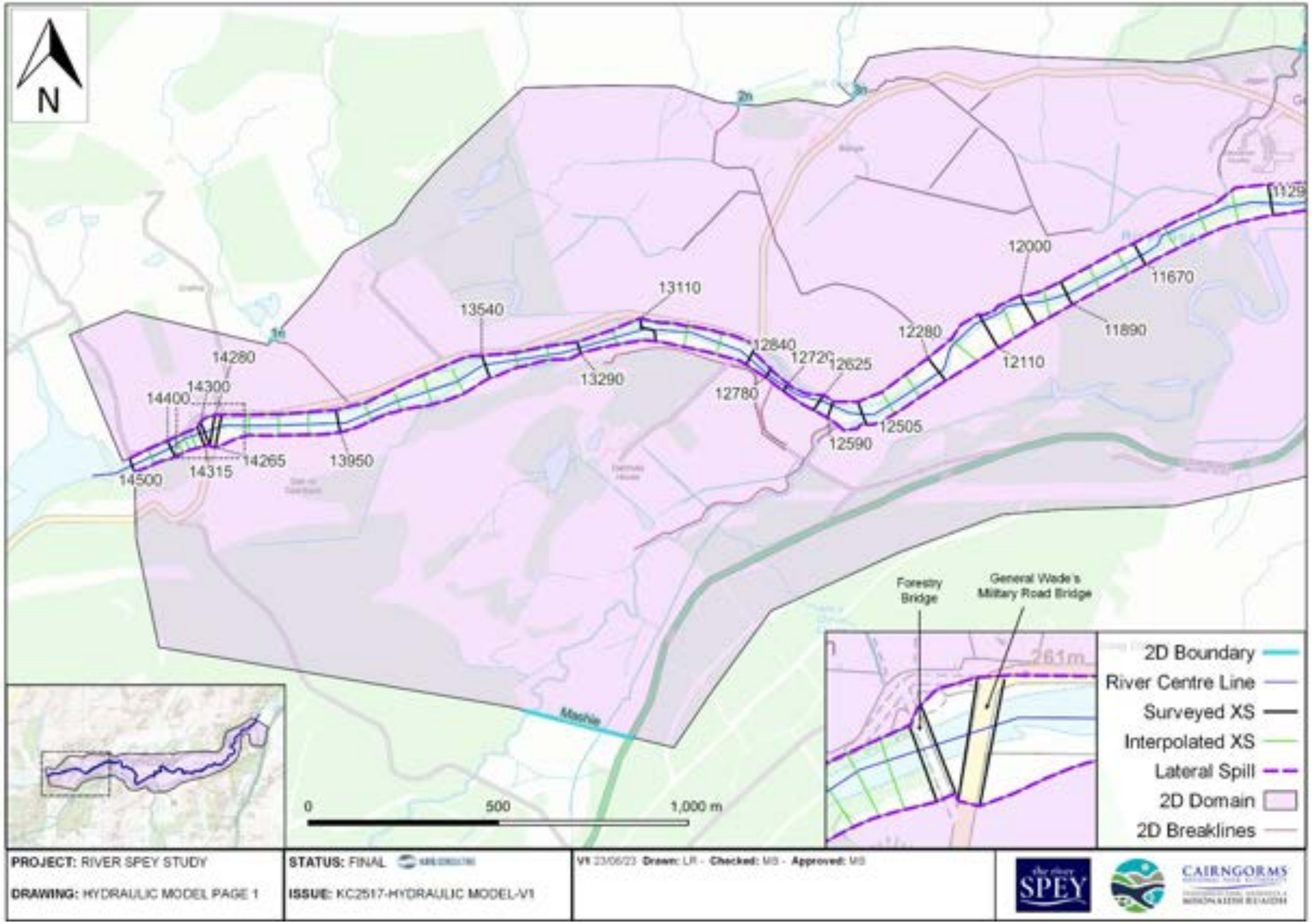
Appendix E – River Modelling Technical Appendix

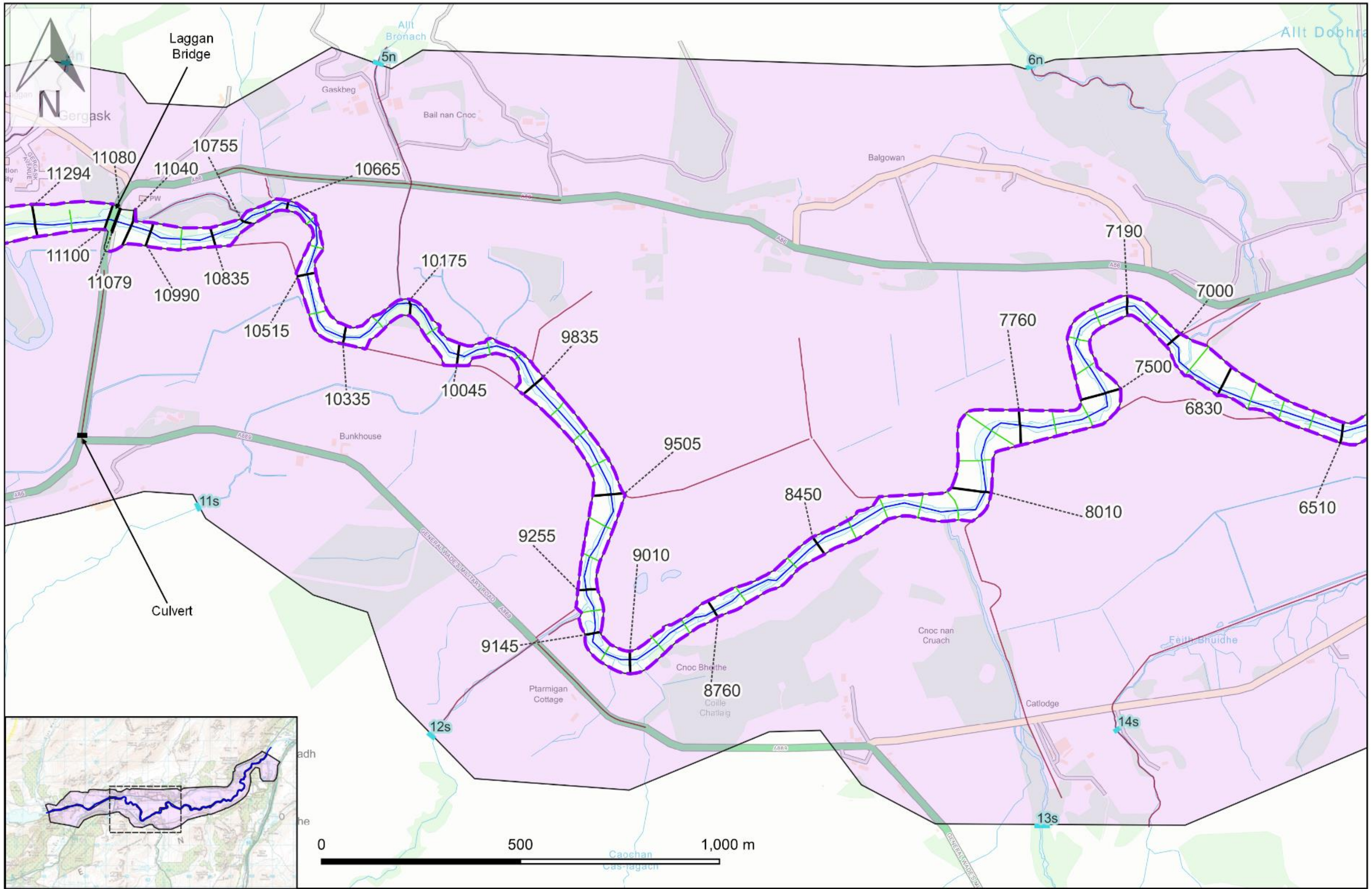
Appendix Ea: Preliminary Modelling Results



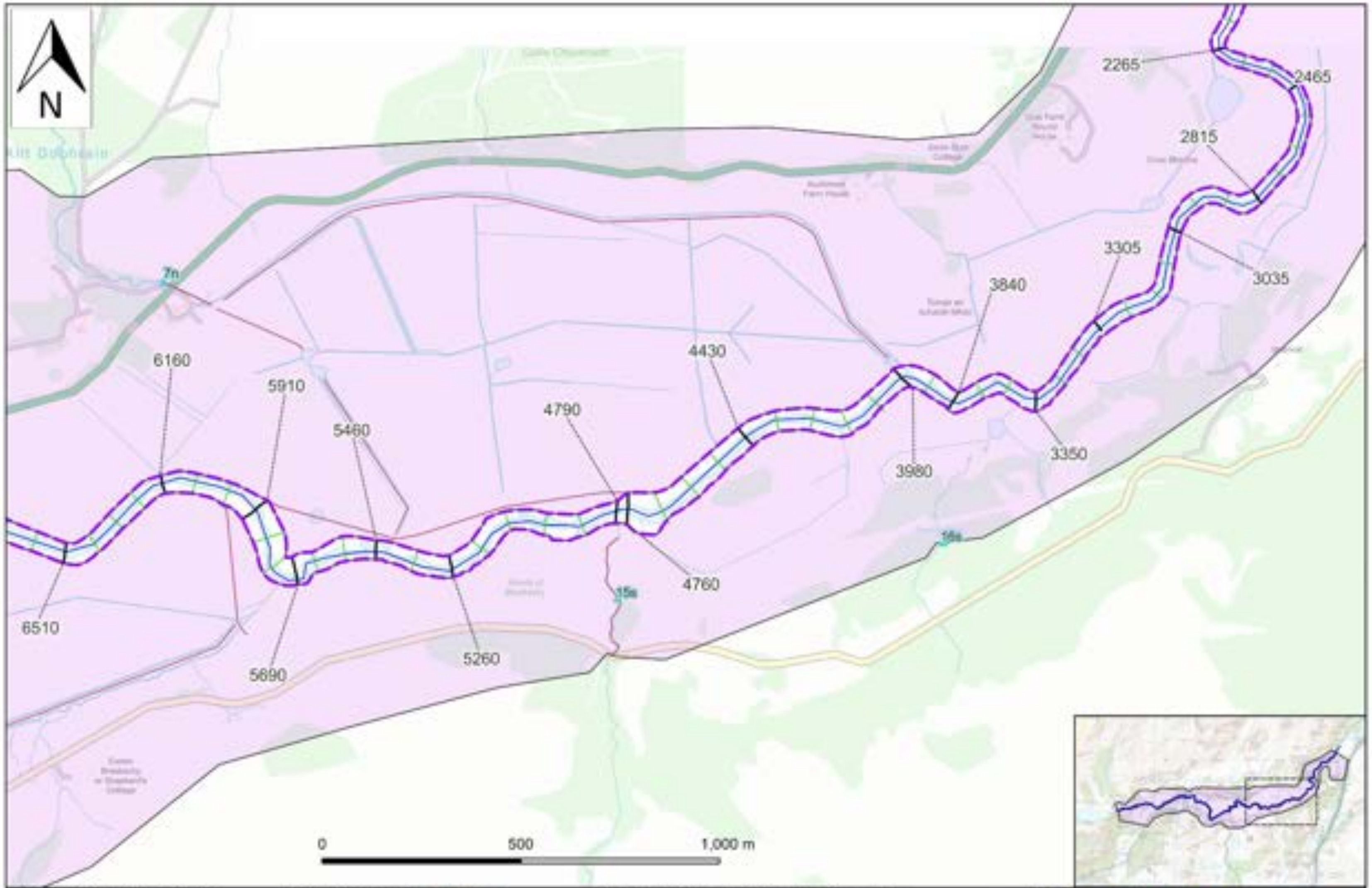

KEY
Key Info from Community Meeting & Comparison with Prelim. Model
Regular Annual Flood - Flood Extent
Less frequent Flood Extent
KAYA CONSULTING
CAIRNGORMS
0
0.5
1 km
0
0.5
1 km
Glen Truim

Appendix E1: Hydraulic Model Schematic

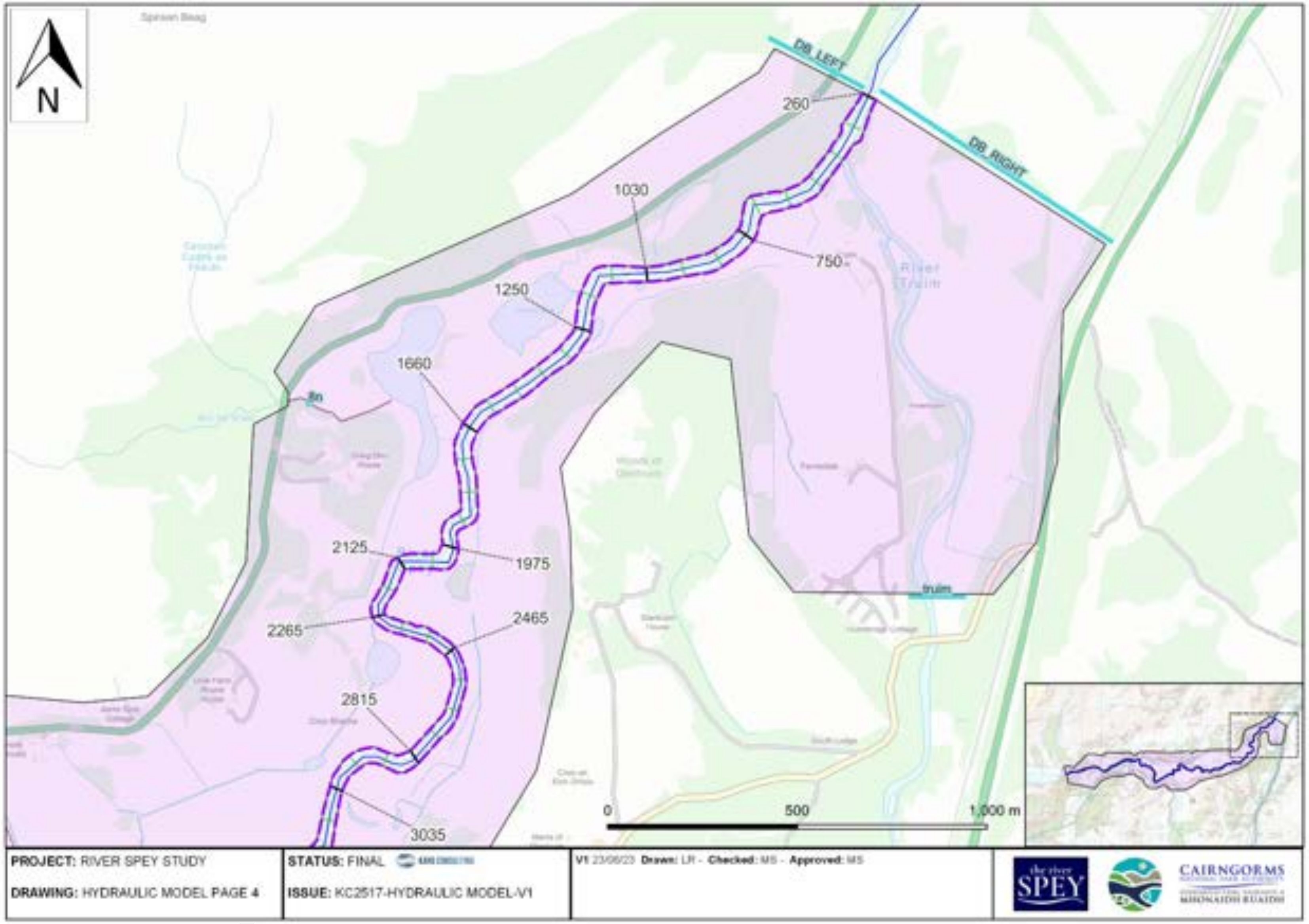




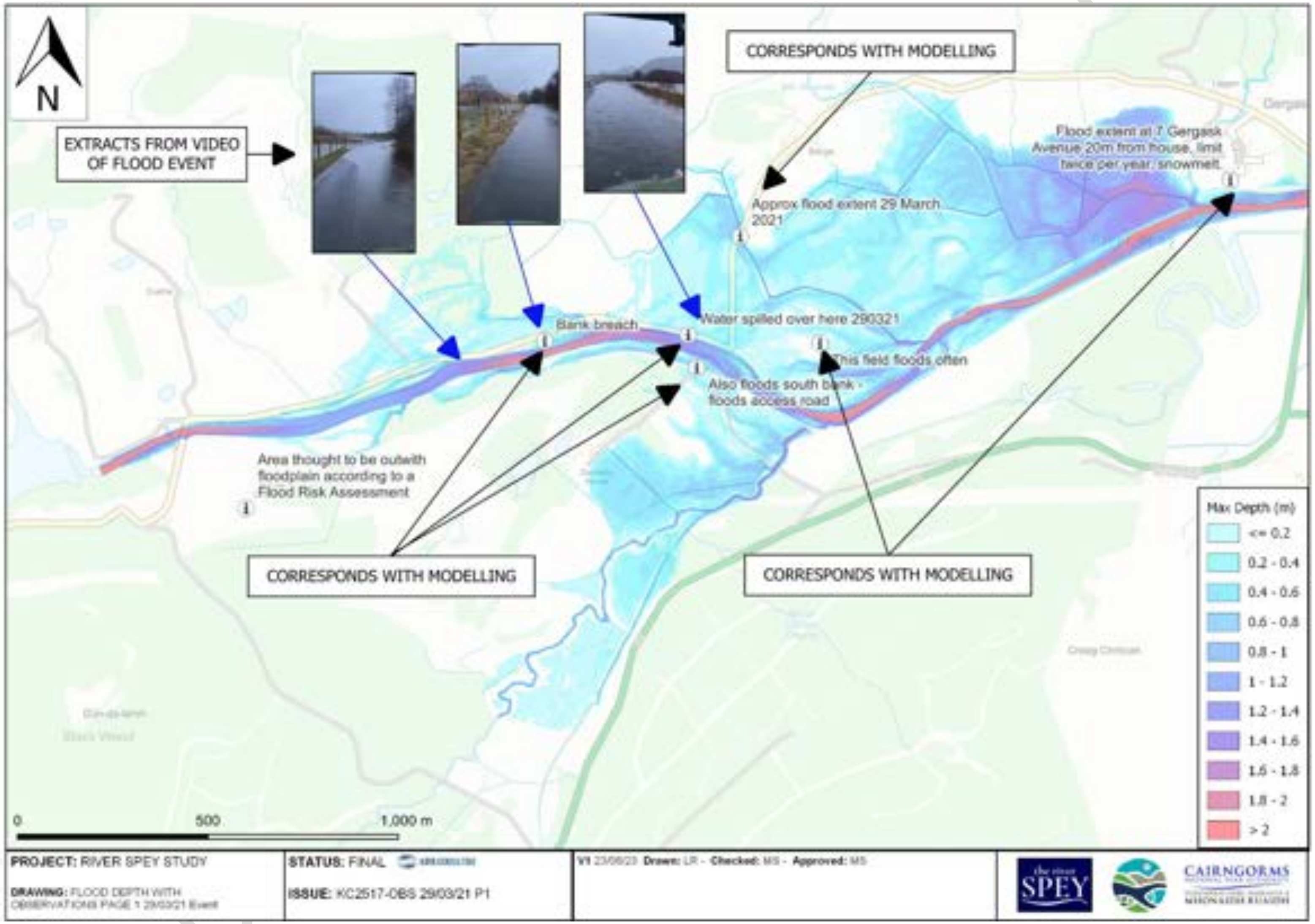
PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	**V1** 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	the river SPEY; CAIRNGORMS NATIONAL PARK AUTHORITY ÙGHDARRAS PÀIRC NÀISEANTA A' MHONAIDH RUAIDH
DRAWING: HYDRAULIC MODEL PAGE 2	**ISSUE:** KC2517-HYDRAULIC MODEL-V1		

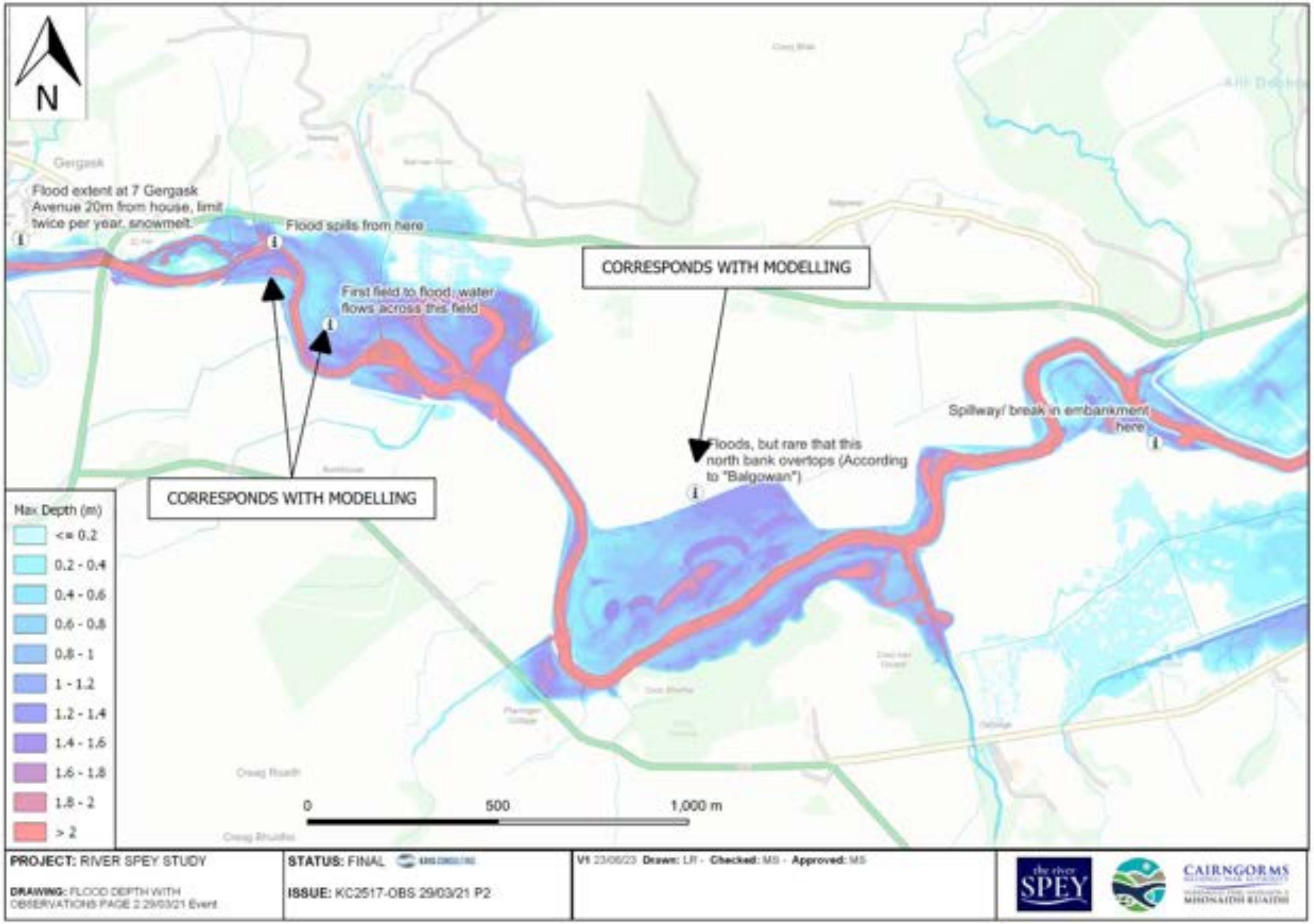


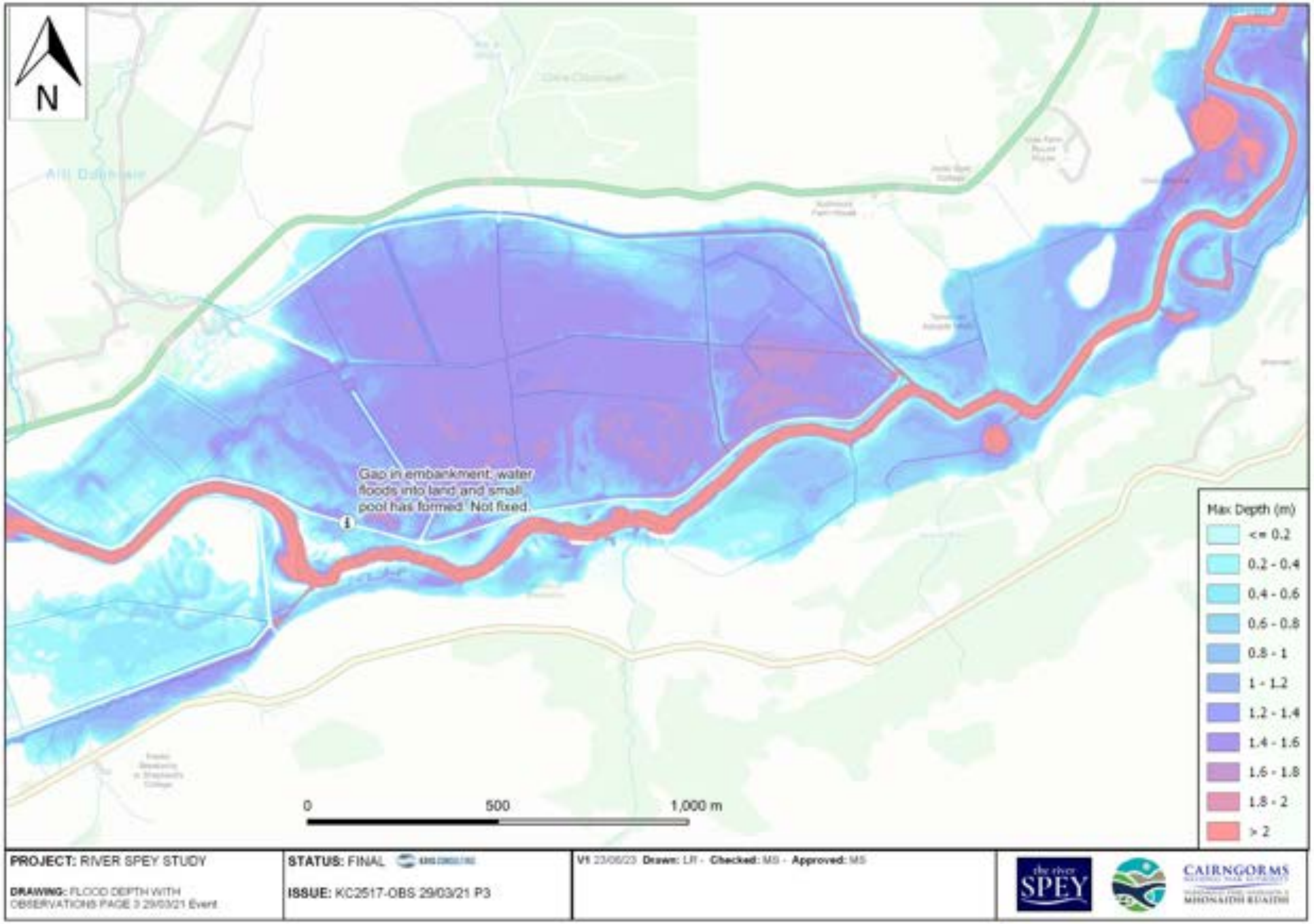
PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	
DRAWING: HYDRAULIC MODEL PAGE 3	**ISSUE:** KC2517-HYDRAULIC MODEL-V1		

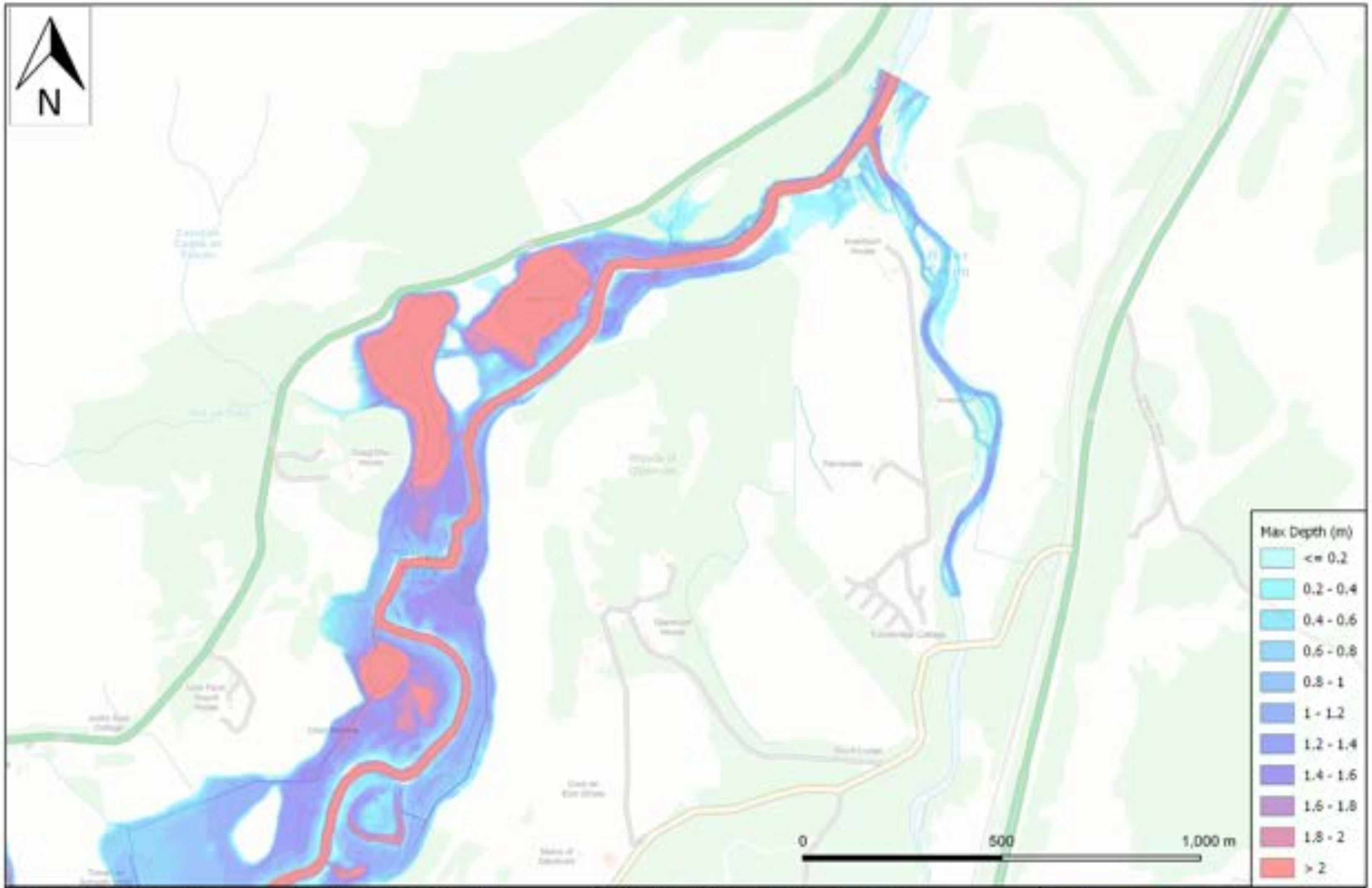

N
DB_LEFT
DB_RIGHT
260
1030
750
1250
1660
2125
1975
2265
2465
2815
3035
Truim
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: HYDRAULIC MODEL PAGE 4
STATUS: FINAL
ISSUE: KC2517-HYDRAULIC MODEL-V1
CAIRNGORMS

Appendix E2: Flood Maps for 29/03/2021 Event against Observations made from local community



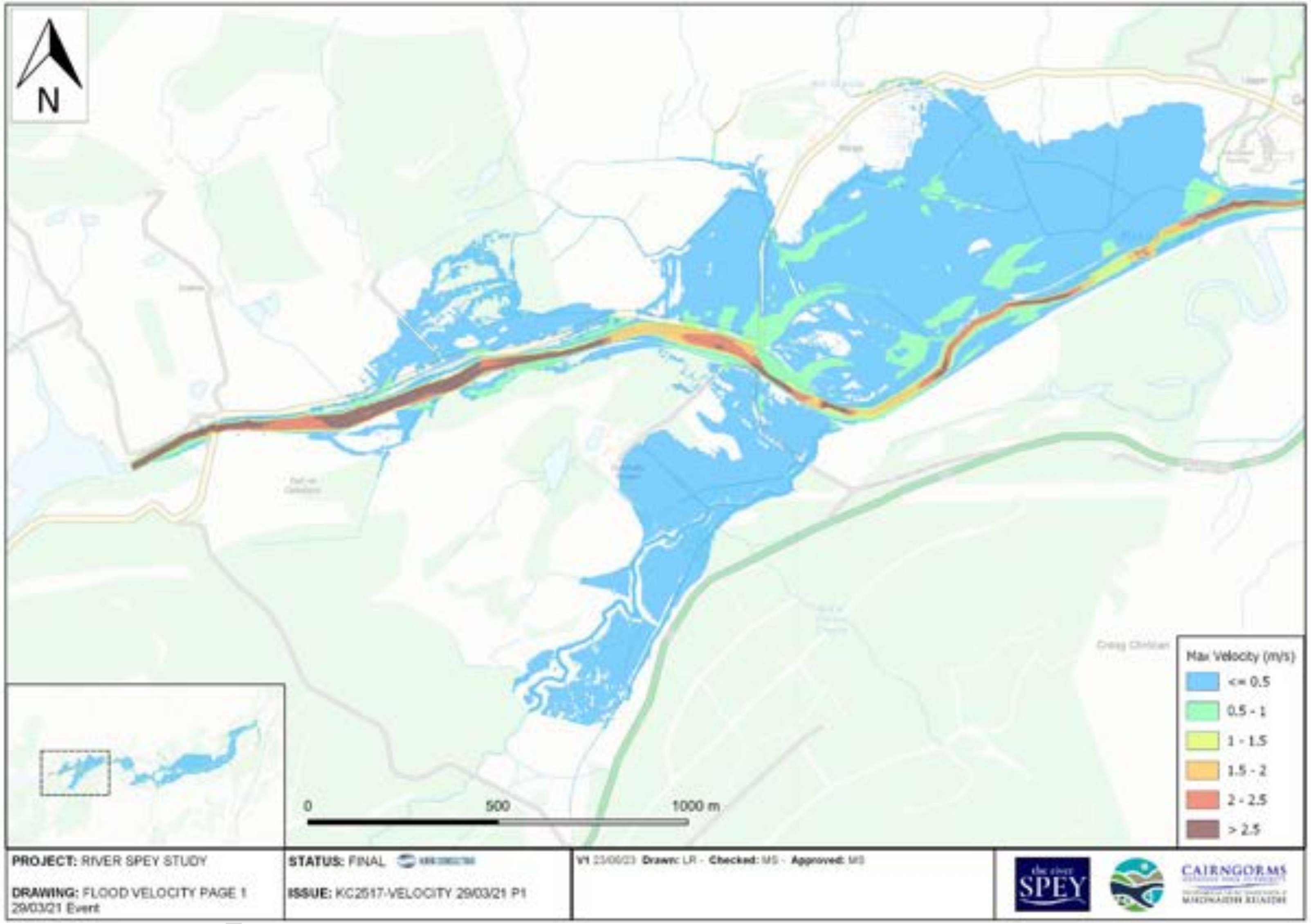

N
Gergask
Flood extent at 7 Gergask Avenue 20m from house, limit twice per year, snowmelt.
Flood spills from here
First field to flood, water flows across this field
CORRESPONDS WITH MODELLING
CORRESPONDS WITH MODELLING
Floods, but rare that this north bank overtops (According to "Balgowan")
Spillway/ break in embankment here
Max Depth (m)
<= 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
1 - 1.2
1.2 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2
> 2
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD DEPTH WITH OBSERVATIONS PAGE 2 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-OBS 29/03/21 P2
CAIRNGORMS

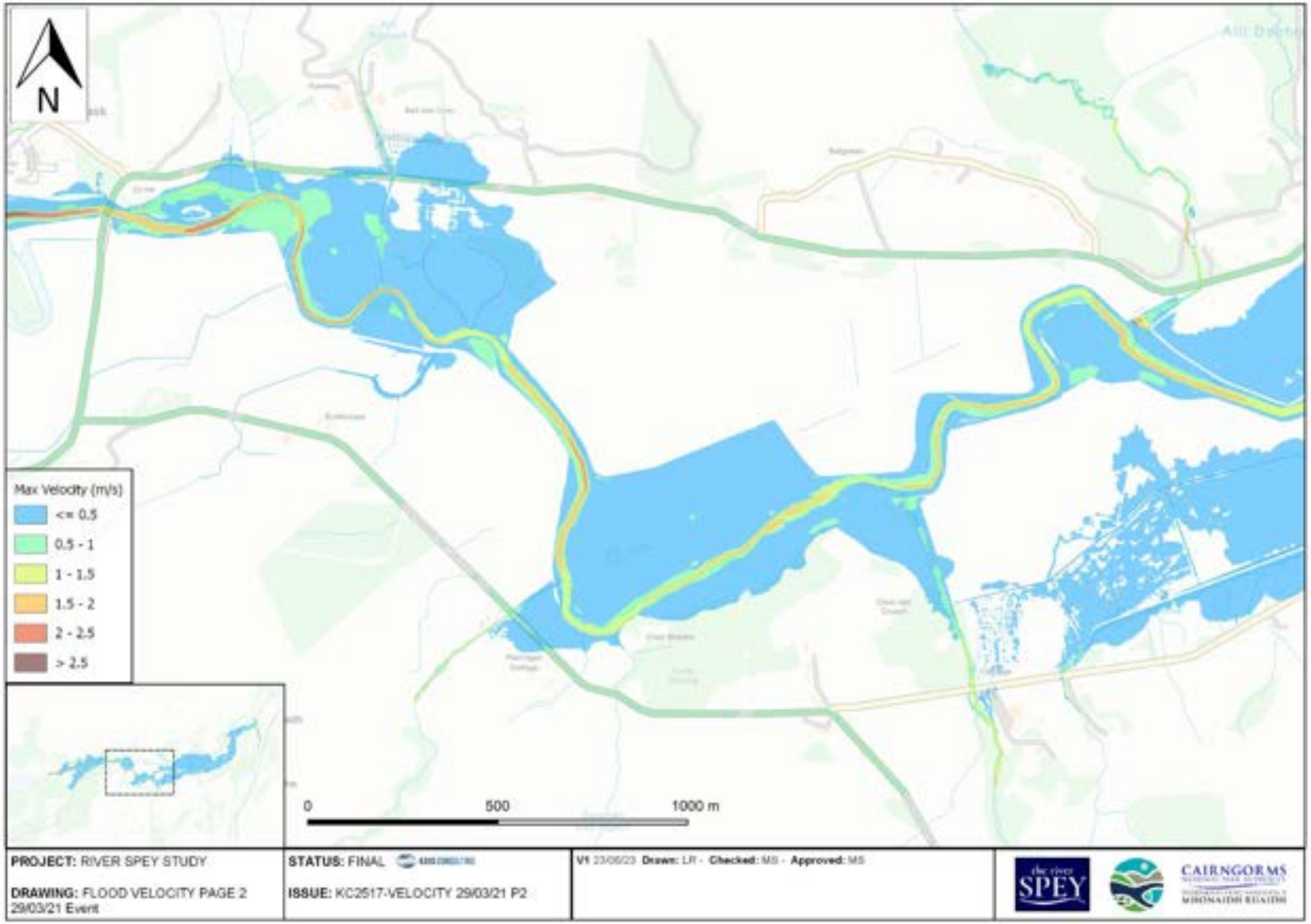

N
Gap in embankment; water floods into land and small pool has formed. Not fixed.
0
500
1,000 m
Max Depth (m)
<= 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
1 - 1.2
1.2 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2
> 2
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD DEPTH WITH OBSERVATIONS PAGE 3 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-OBS 29/03/21 P3
V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS

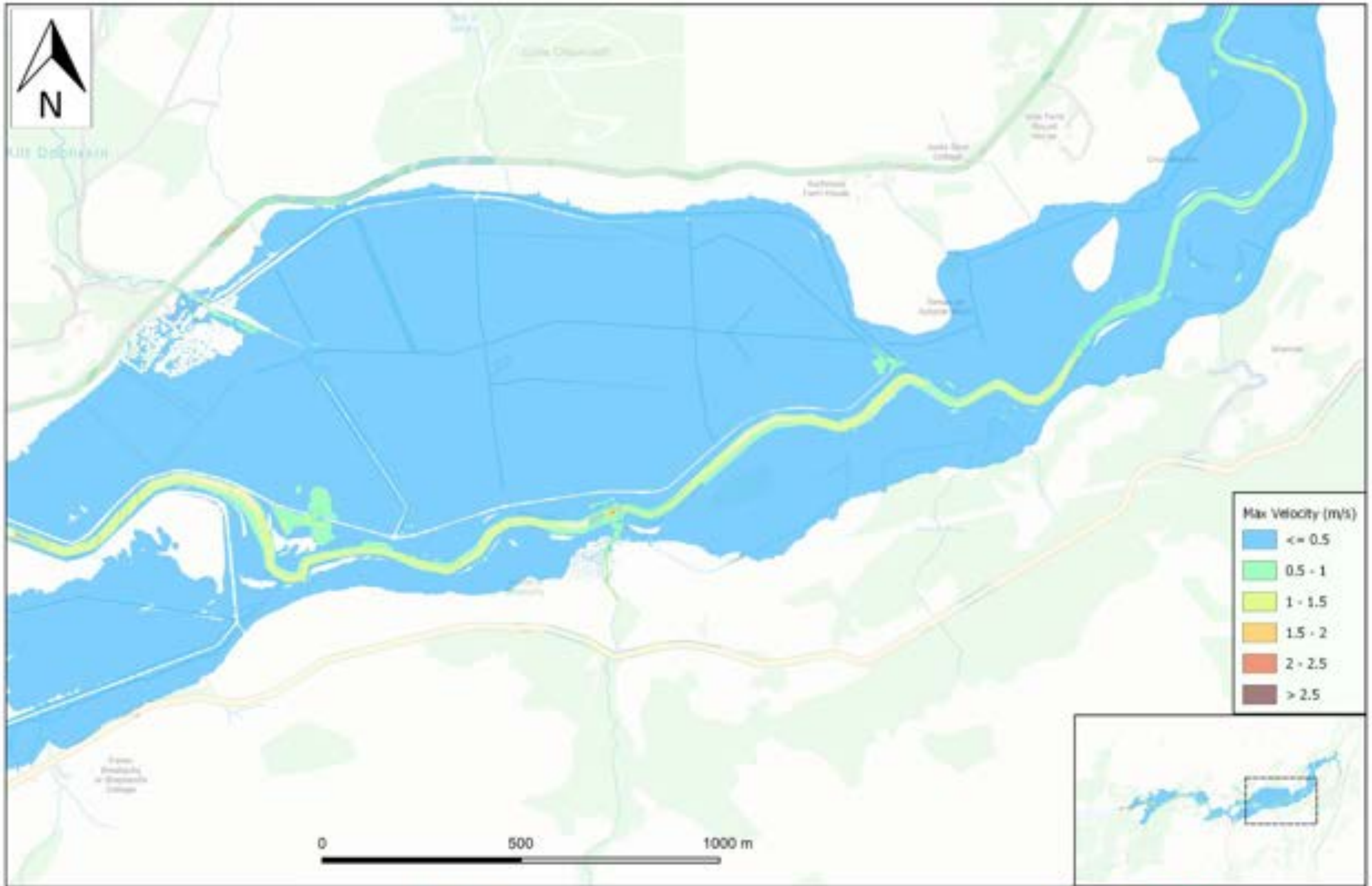


PROJECT: RIVER SPEY STUDY **DRAWING:** FLOOD DEPTH WITH OBSERVATIONS PAGE 4 29/03/21 Event	**STATUS:** FINAL **ISSUE:** KC2517-OBS 29/03/21 P4	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS

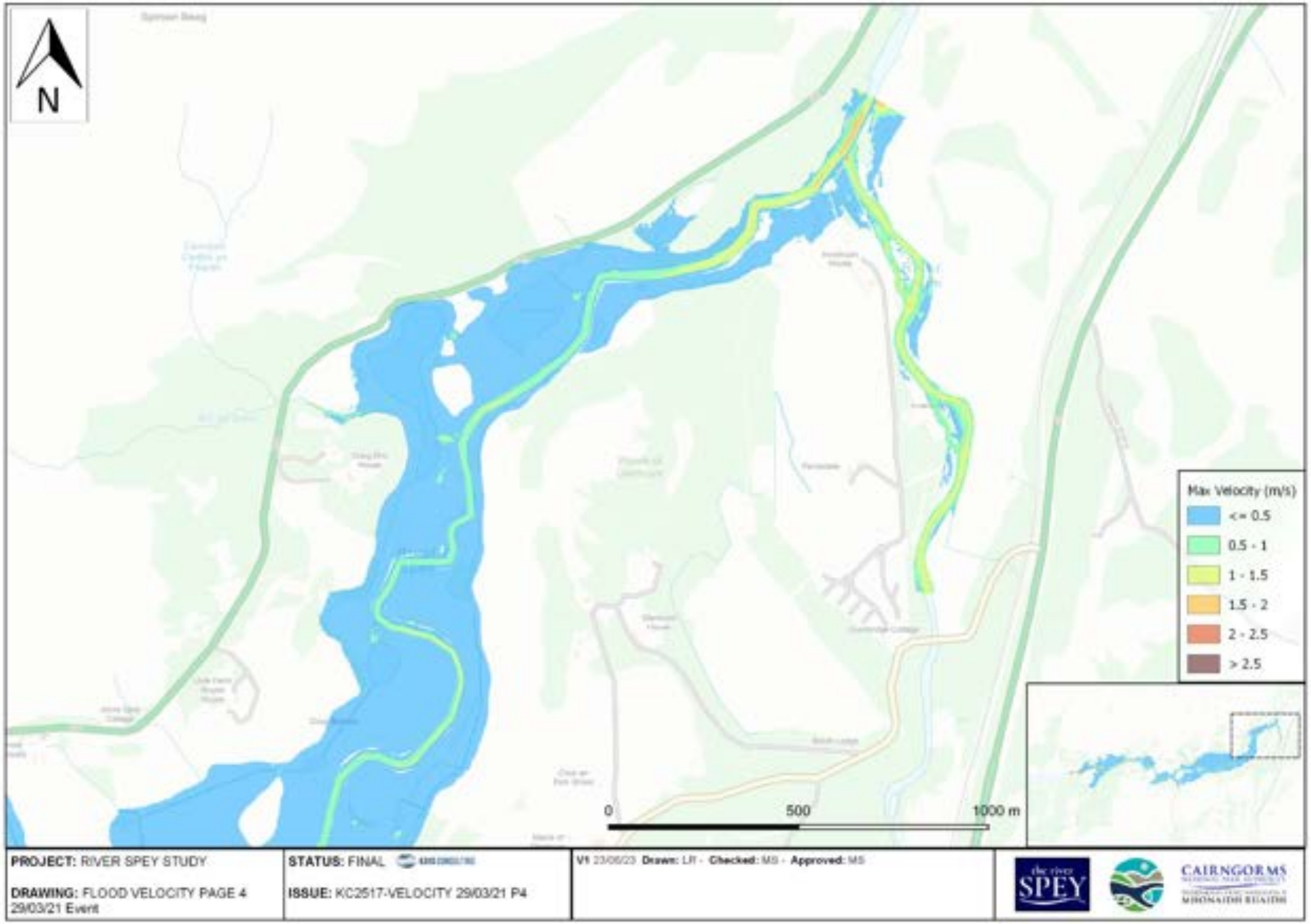
Appendix E3: Velocity Maps for the 29/03/2021 Flood Event



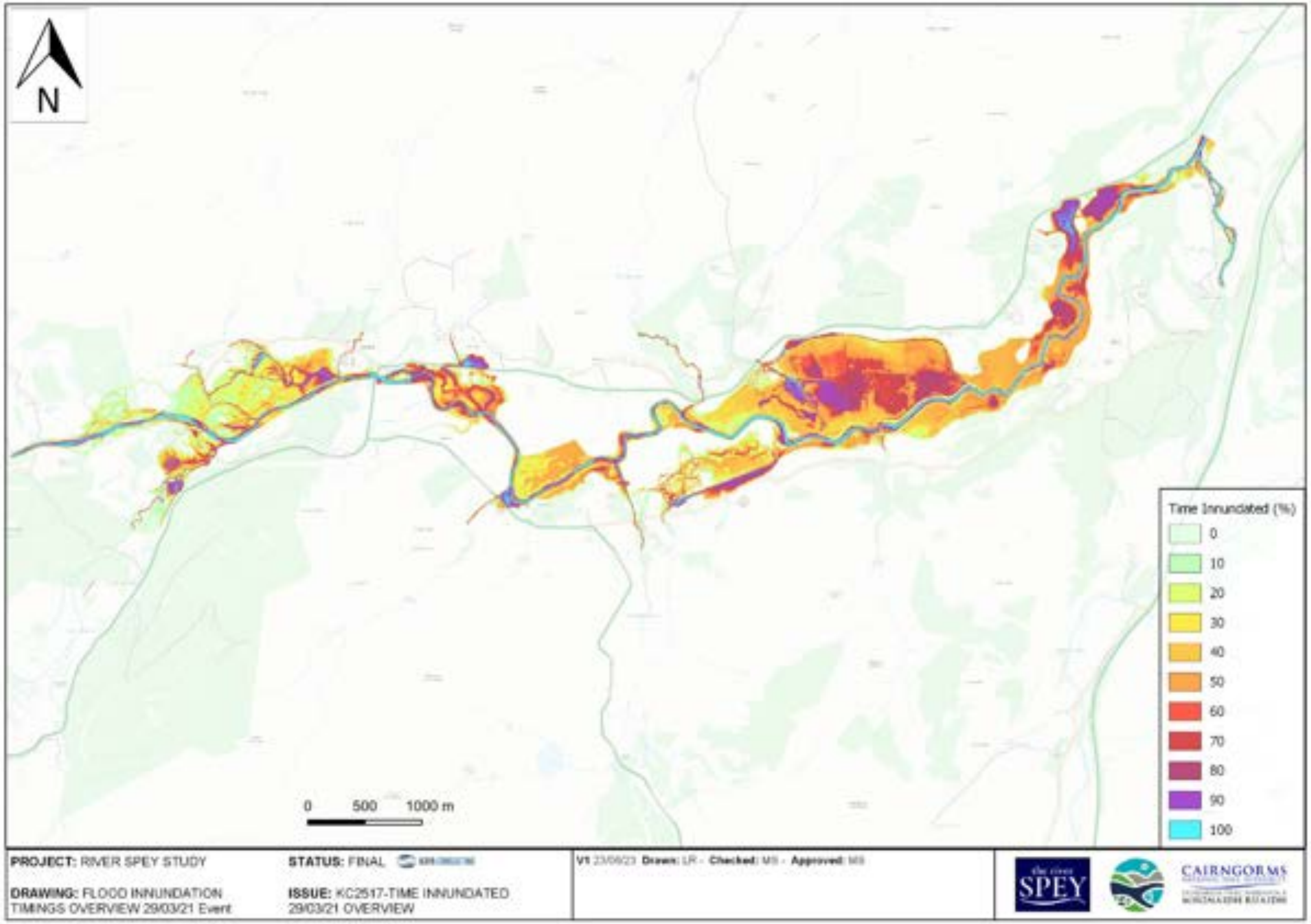

N
Max Velocity (m/s)
<= 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
> 2.5
0
500
1000 m
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD VELOCITY PAGE 2 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-VELOCITY 29/03/21 P2
CAIRNGORMS



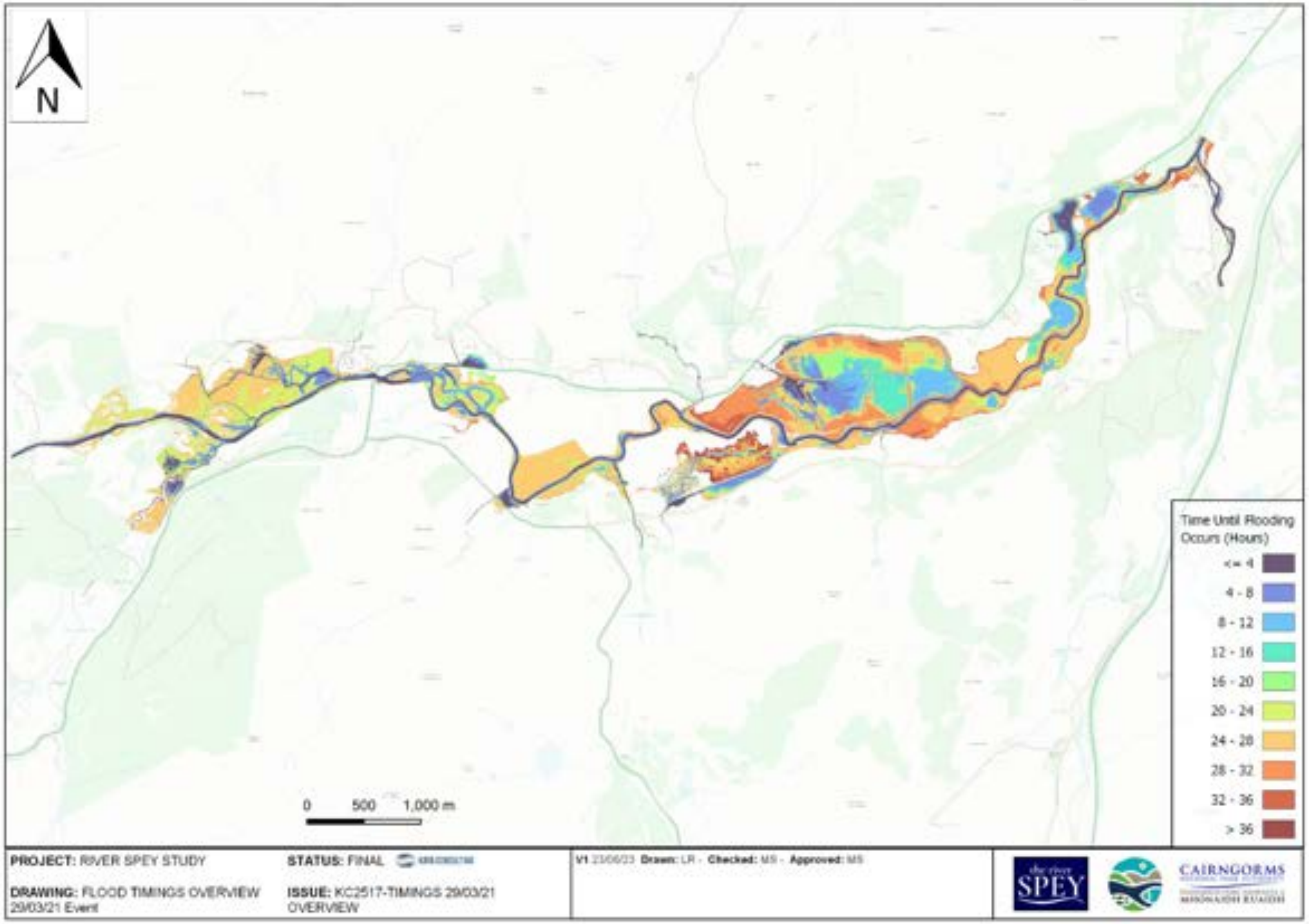
PROJECT: RIVER SPEY STUDY DRAWING: FLOOD VELOCITY PAGE 3 29/03/21 Event	STATUS: FINAL ISSUE: KC2517-VELOCITY 29/03/21 P3	V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS	

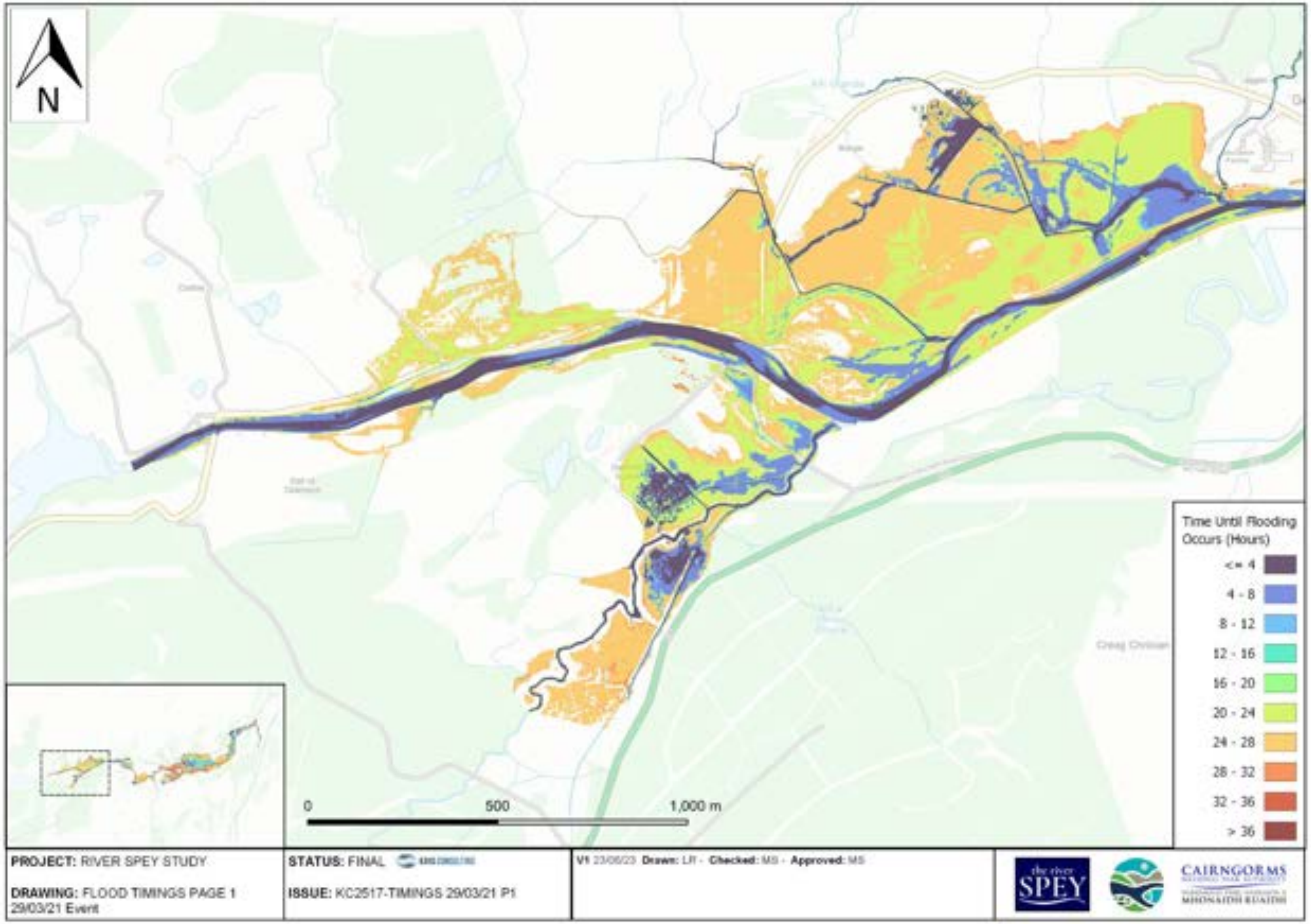

N
0
500
1000 m
Max Velocity (m/s)
<= 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
> 2.5
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD VELOCITY PAGE 4 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-VELOCITY 29/03/21 P4
V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS

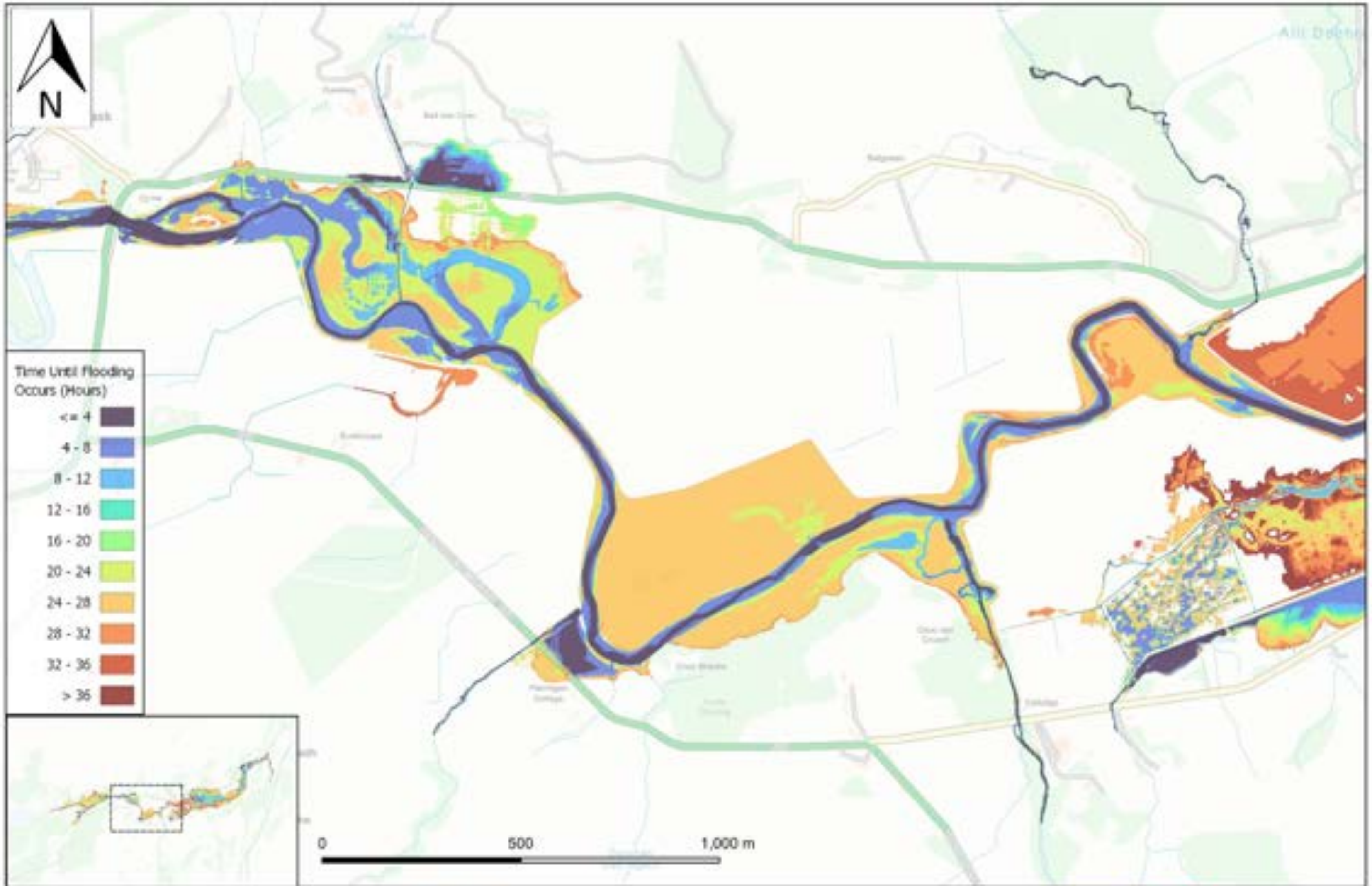
Appendix E4: Percentage Time Inundated for 29/03/21 Flood Event



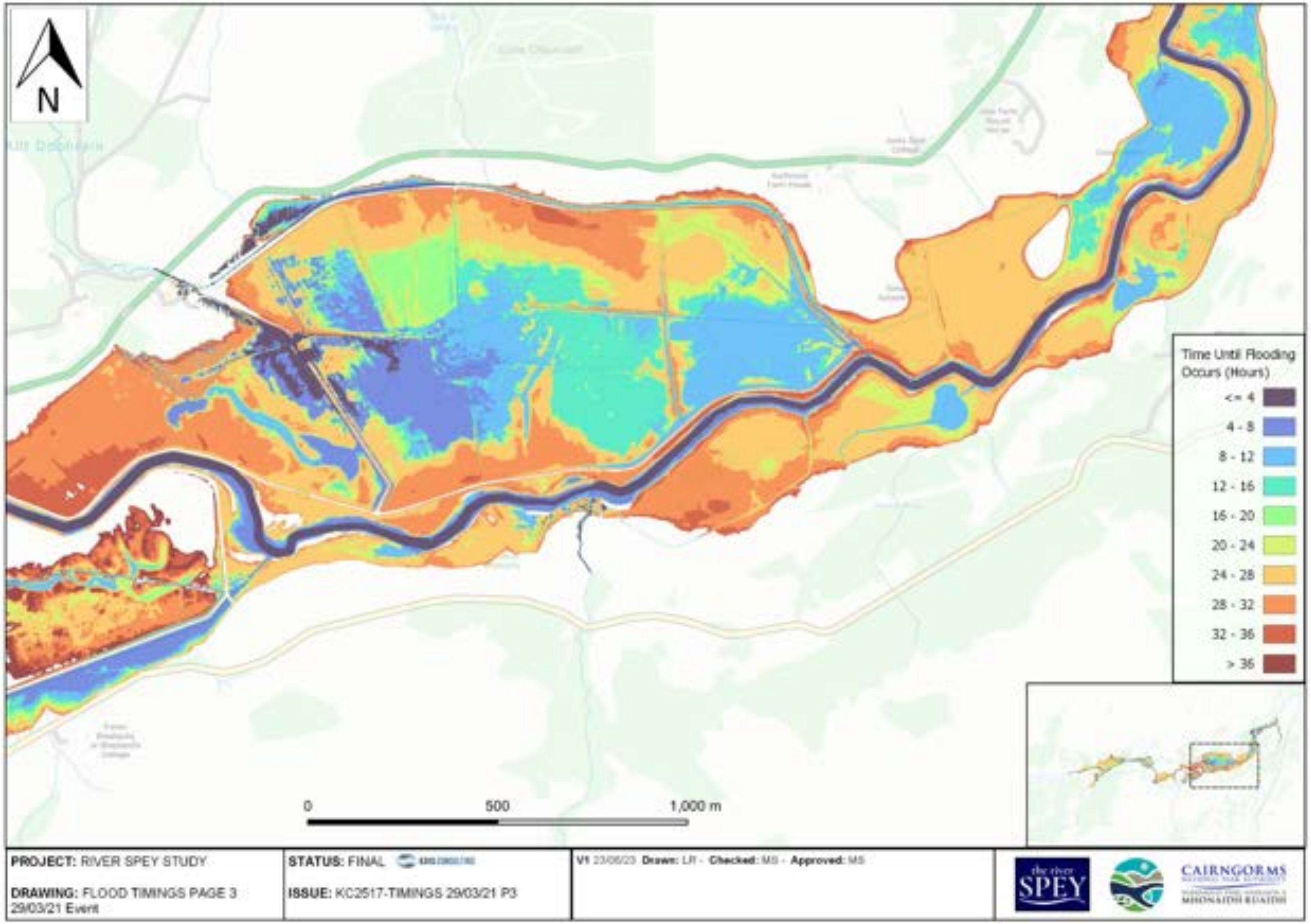
Appendix E5: Timings of Flood for 29/03/21 Flood Event

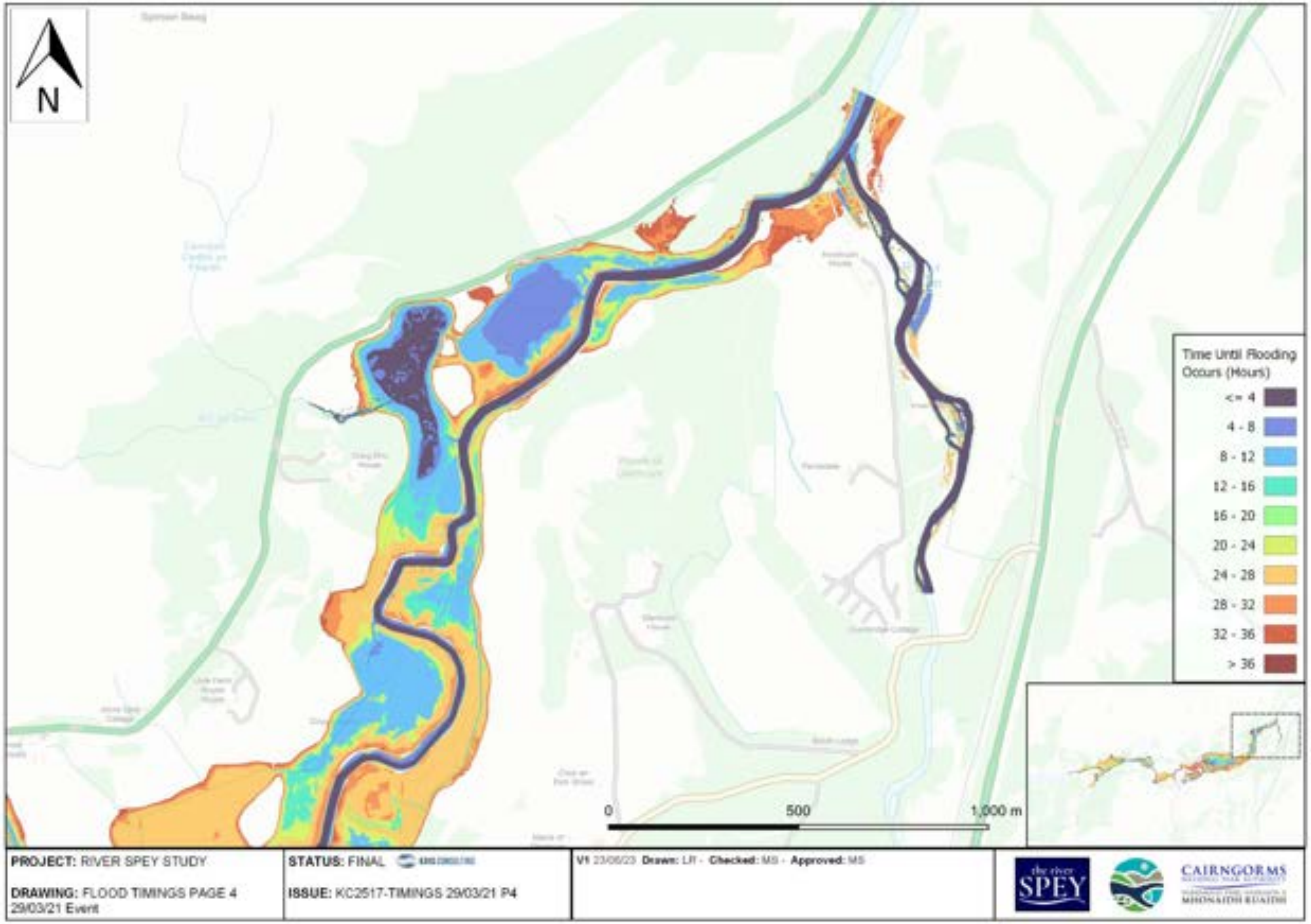



N
0
500
1,000 m
Time Until Flooding Occurs (Hours)
<= 4
4 - 8
8 - 12
12 - 16
16 - 20
20 - 24
24 - 28
28 - 32
32 - 36
> 36
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD TIMINGS PAGE 1 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-TIMINGS 29/03/21 P1
V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS

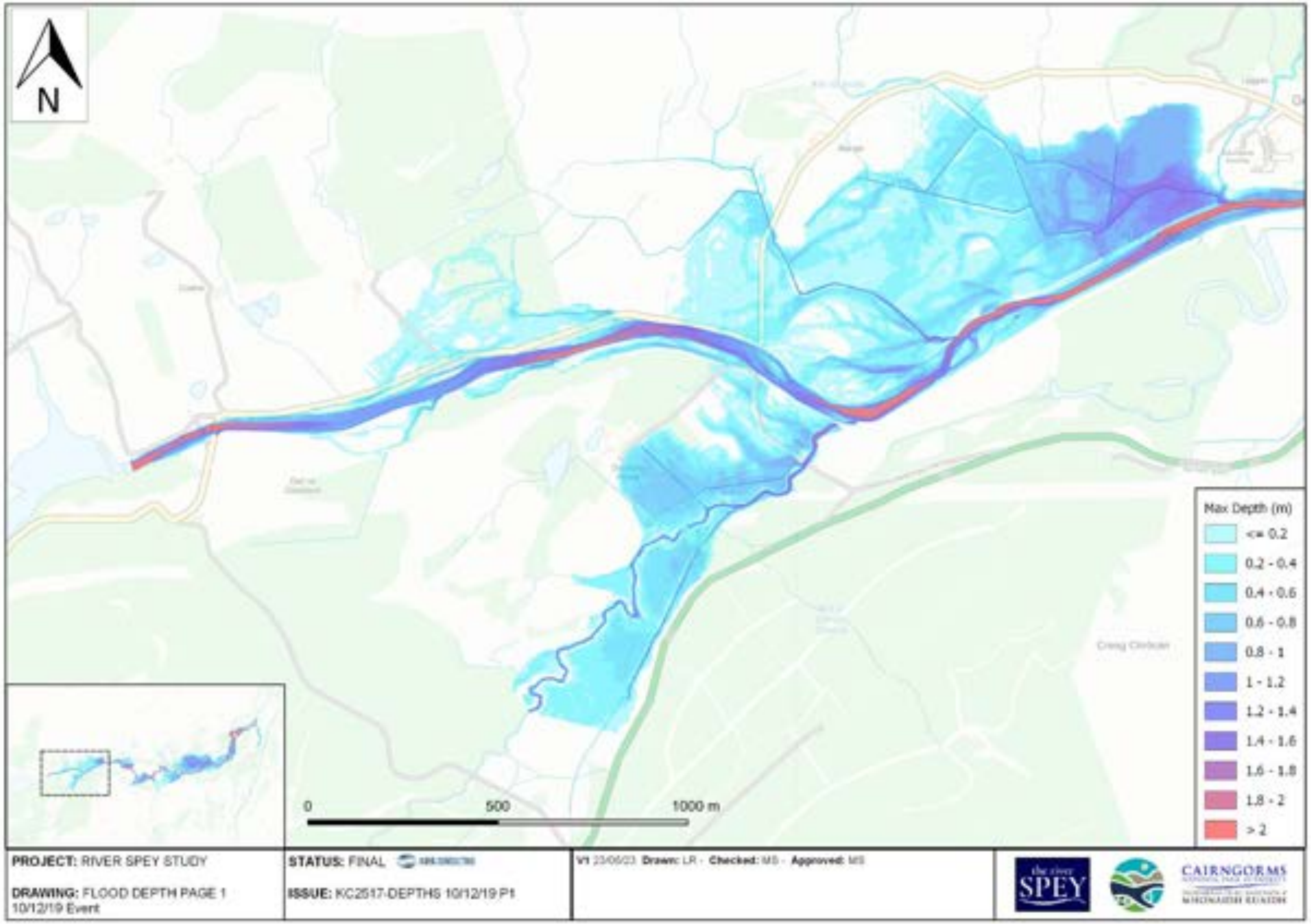


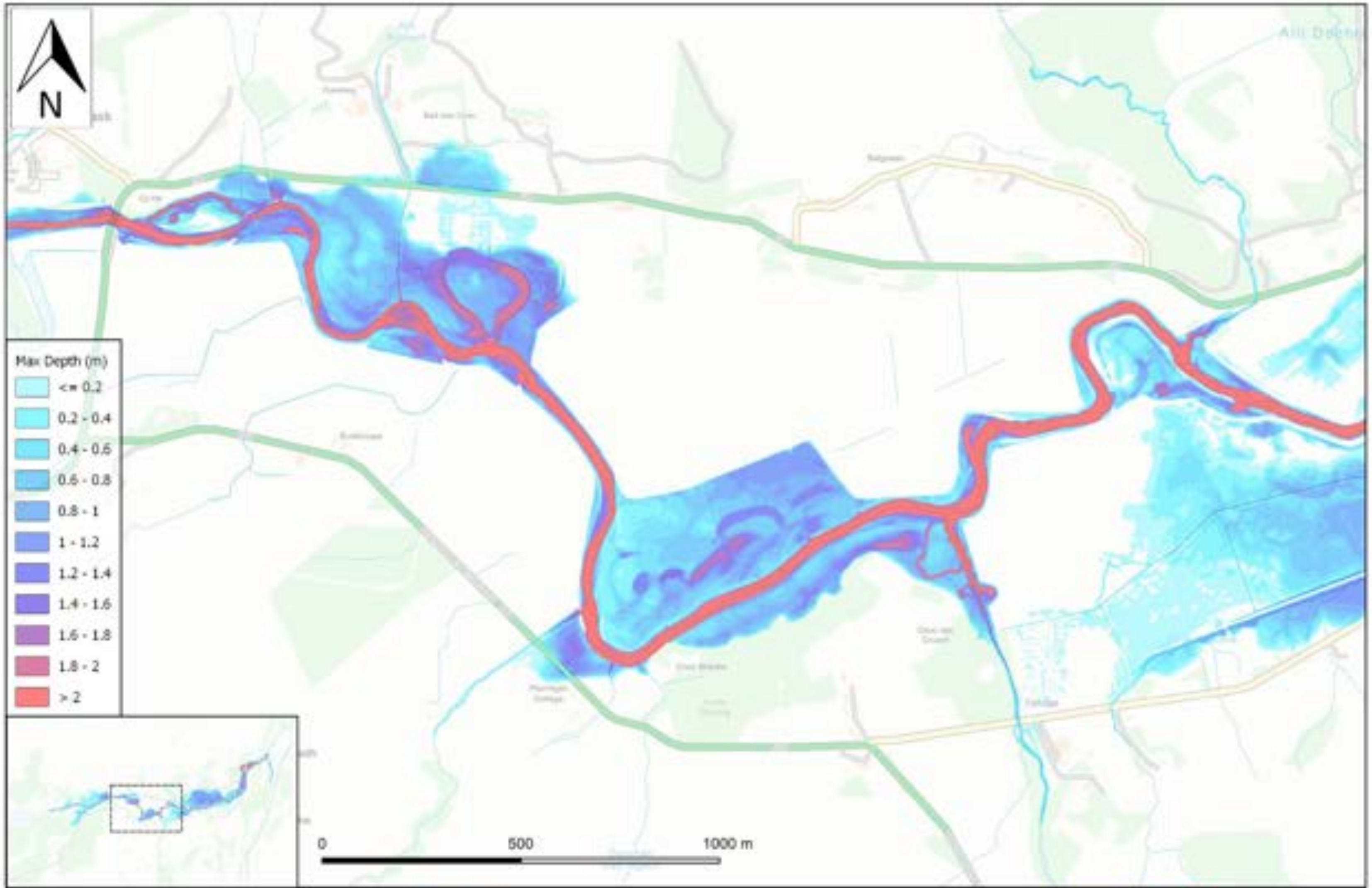
PROJECT: RIVER SPEY STUDY **DRAWING:** FLOOD TIMINGS PAGE 2 29/03/21 Event	**STATUS:** FINAL **ISSUE:** KC2517-TIMINGS 29/03/21 P2	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	


N
Time Until Flooding Occurs (Hours)
<= 4
4 - 8
8 - 12
12 - 16
16 - 20
20 - 24
24 - 28
28 - 32
32 - 36
> 36
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD TIMINGS PAGE 3 29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-TIMINGS 29/03/21 P3
CAIRNGORMS

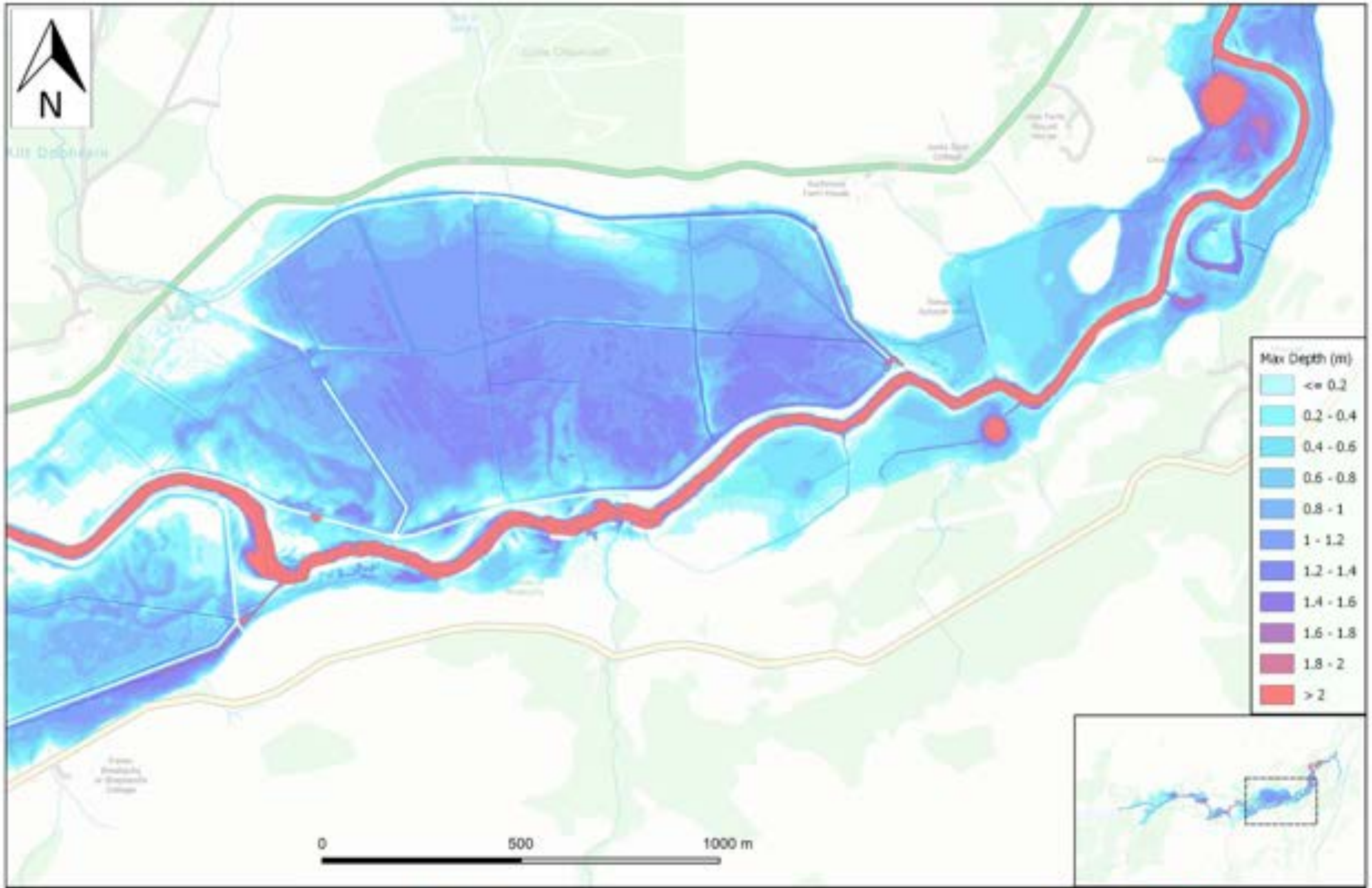

N
Time Until Flooding Occurs (Hours)
<= 4
4 - 8
8 - 12
12 - 16
16 - 20
20 - 24
24 - 28
28 - 32
32 - 36
> 36
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: FLOOD TIMINGS PAGE 4
29/03/21 Event
STATUS: FINAL
ISSUE: KC2517-TIMINGS 29/03/21 P4
V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS

Appendix E6: Flood Maps for 10/12/19 Event

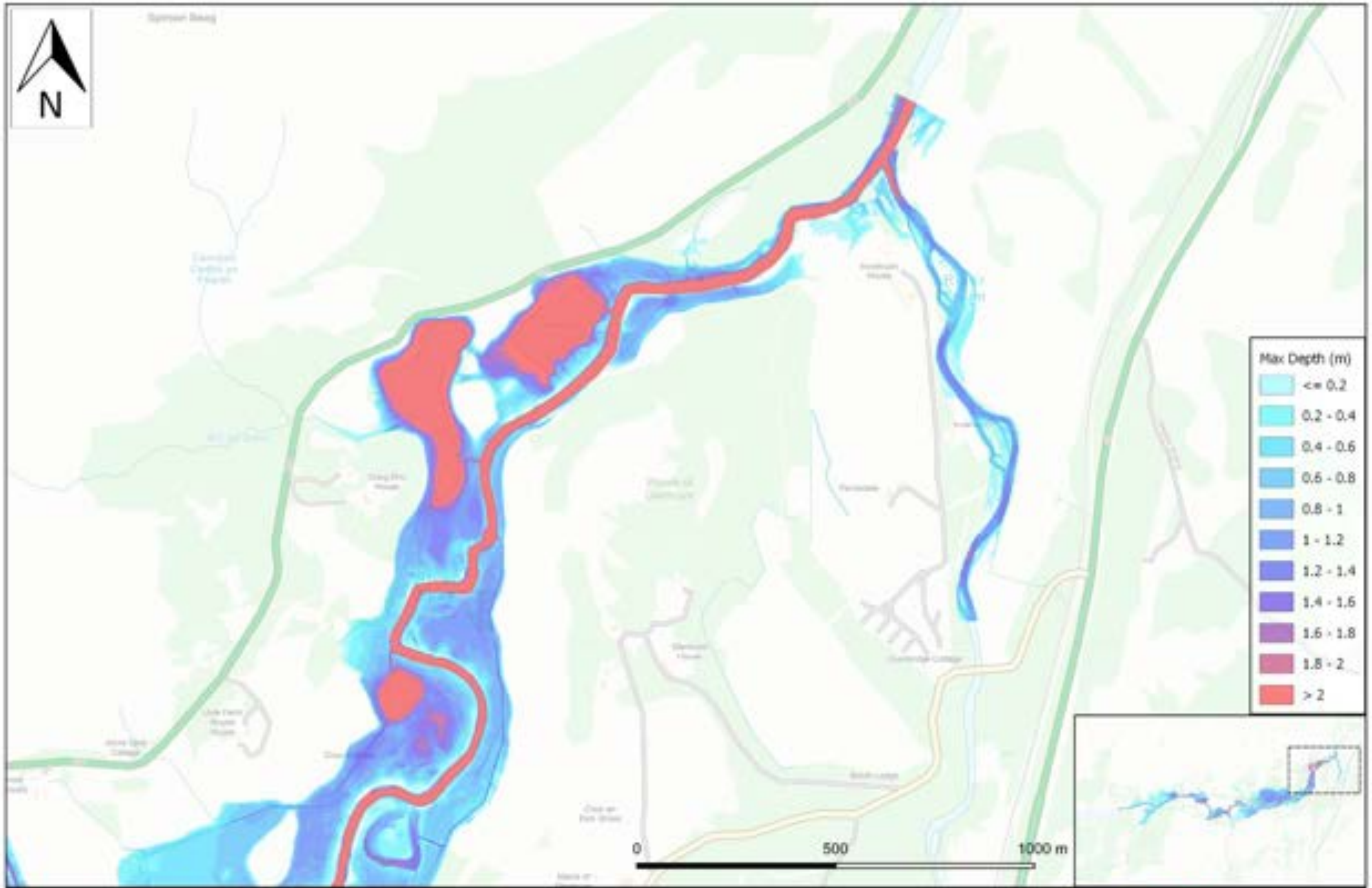




PROJECT: RIVER SPEY STUDY **DRAWING:** FLOOD DEPTH PAGE 2 10/12/19 Event	**STATUS:** FINAL **ISSUE:** KC2517-DEPTH 10/12/19 P2	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	

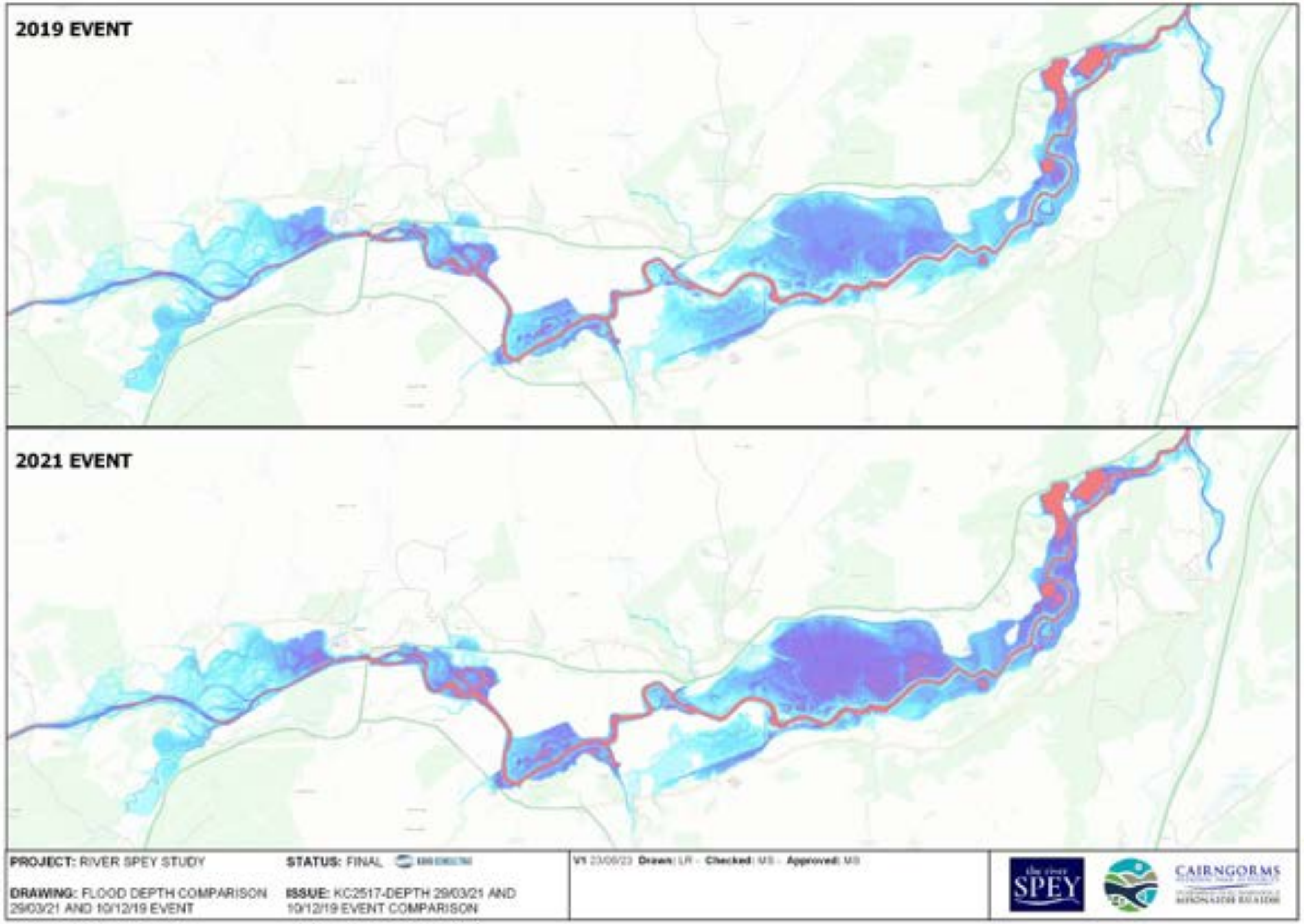


PROJECT: RIVER SPEY STUDY **DRAWING:** FLOOD DEPTH PAGE 3 10/12/19 Event	**STATUS:** FINAL **ISSUE:** KC2517-DEPTH 10/12/19 P3	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	the river SPEY · CAIRNGORMS

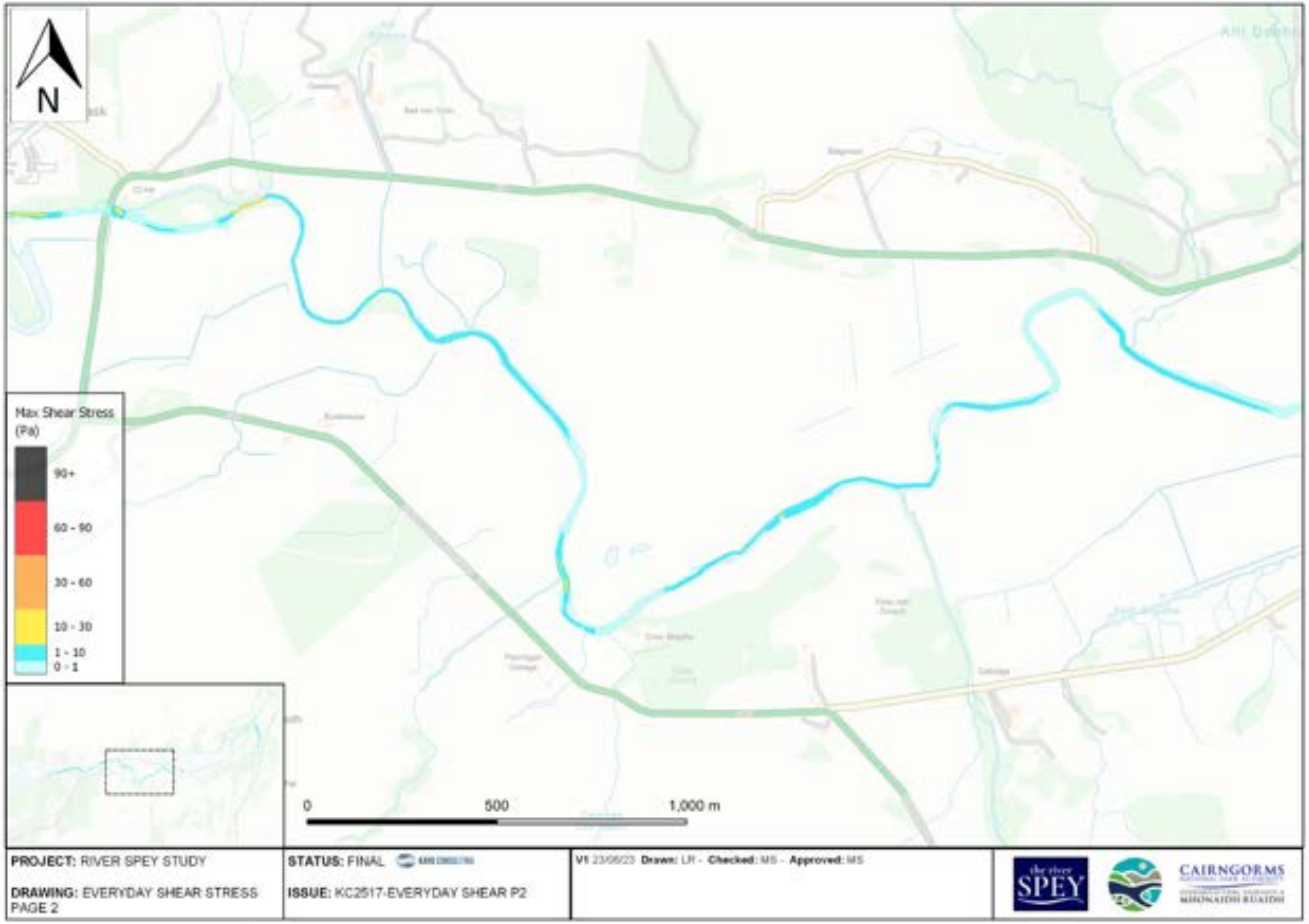


PROJECT: RIVER SPEY STUDY **DRAWING:** FLOOD DEPTH PAGE 4 10/12/19 Event	**STATUS:** FINAL **ISSUE:** KC2517-DEPTH 10/12/19 P4	**V1** 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS

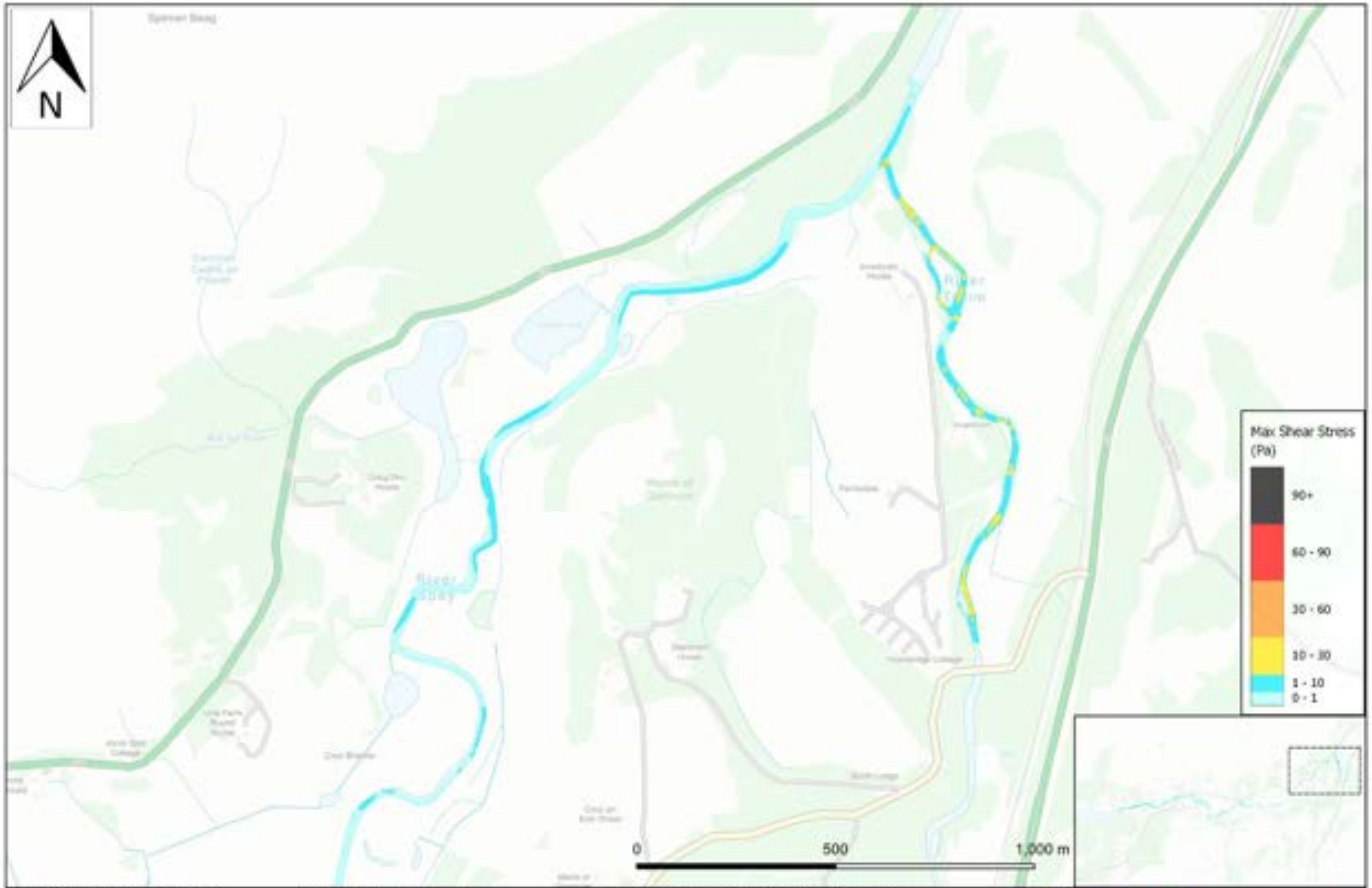
Appendix E7: Comparison Flood Maps for 10/12/19 Event and 29/03/21 Event



Appendix E8: Shear Stress Model Results for Everyday Flows

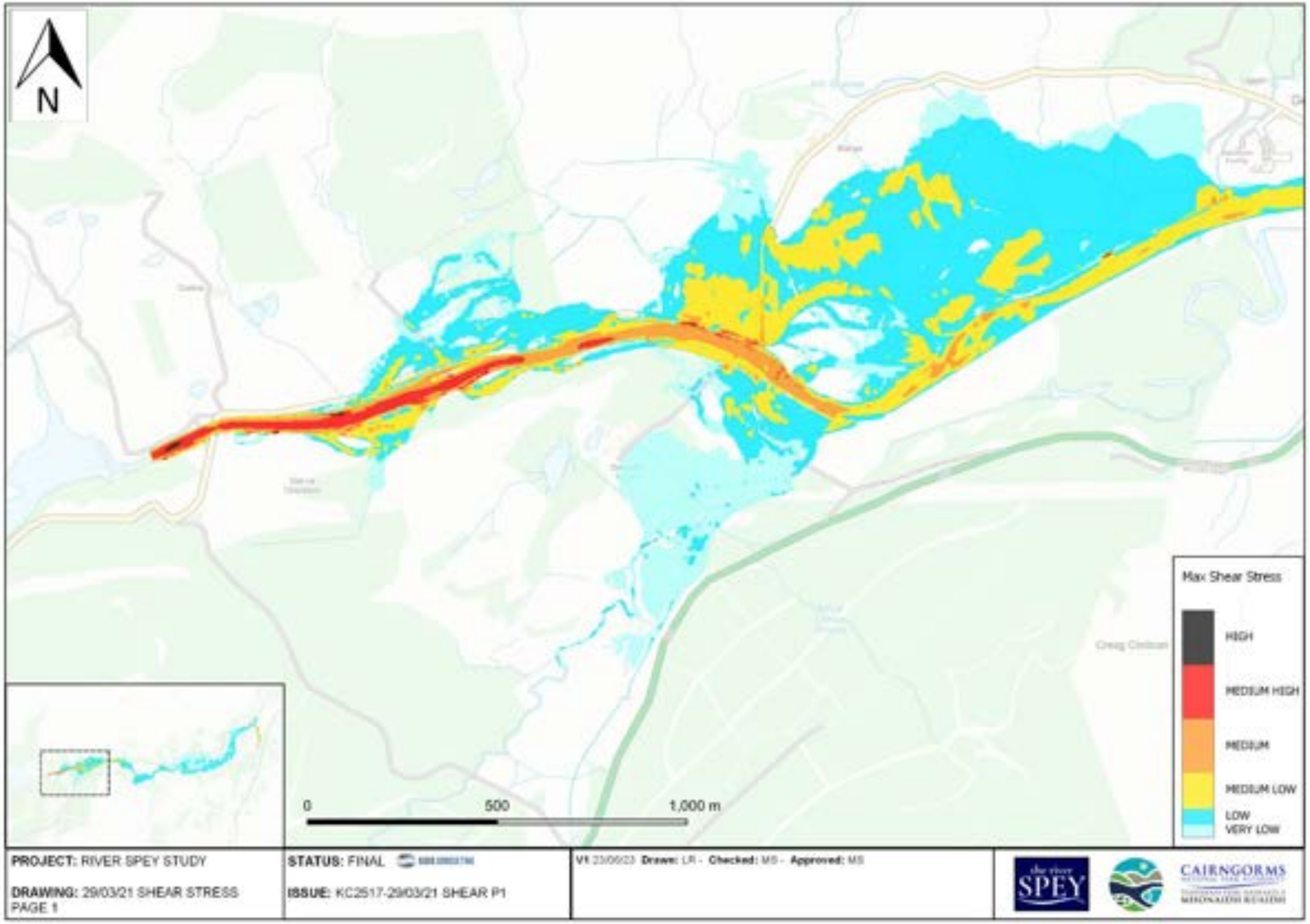

N
Max Shear Stress (Pa)
90+
60 - 90
30 - 60
10 - 30
1 - 10
0 - 1
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: EVERYDAY SHEAR STRESS PAGE 2
STATUS: FINAL
ISSUE: KC2517-EVERYDAY SHEAR P2
the river SPEY
CAIRNGORMS

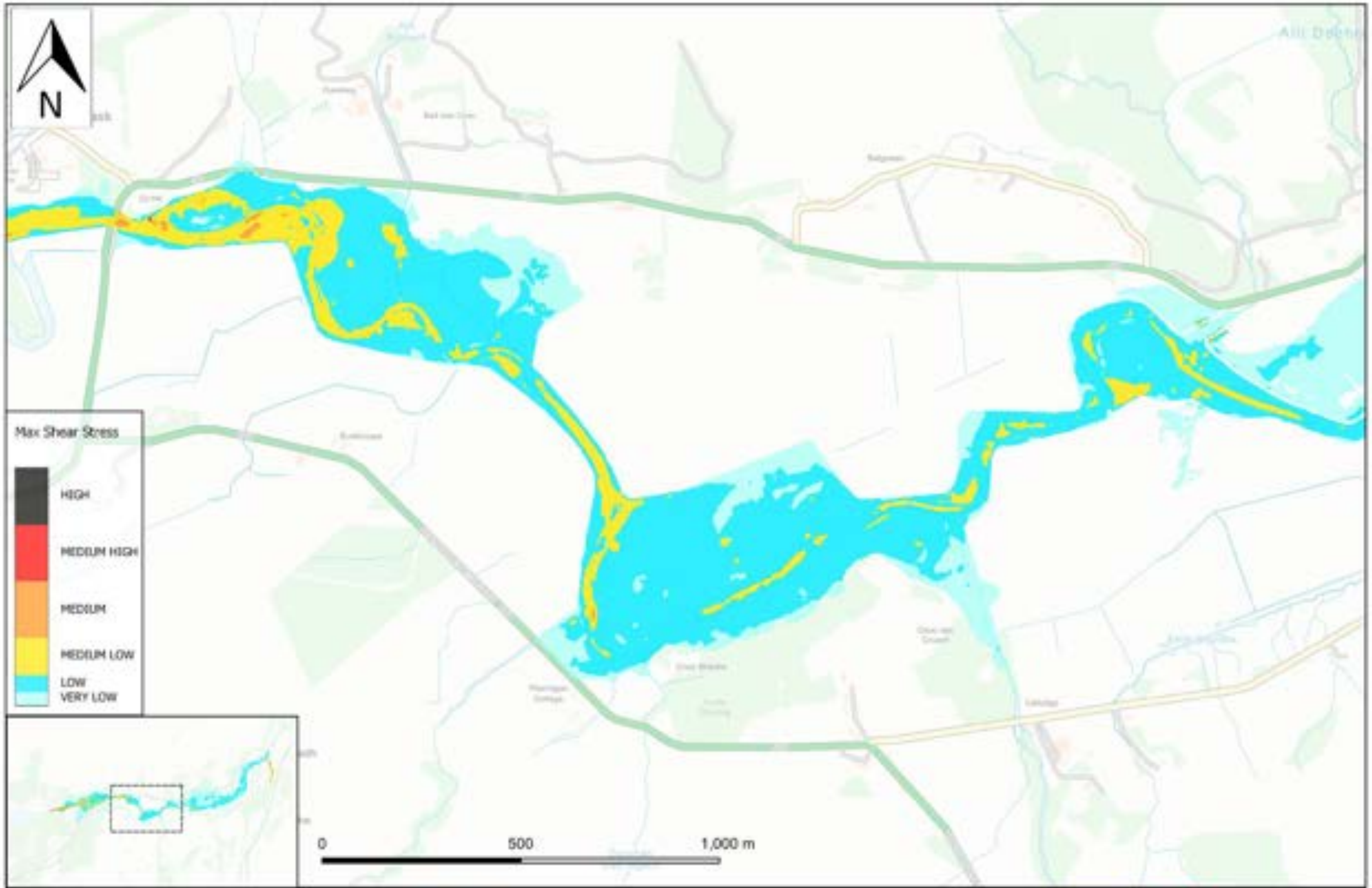

N
Max Shear Stress (Pa)
90+
60 - 90
30 - 60
10 - 30
1 - 10
0 - 1
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: EVERYDAY SHEAR STRESS PAGE 3
STATUS: FINAL
ISSUE: KC2517-EVERYDAY SHEAR P3
Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS



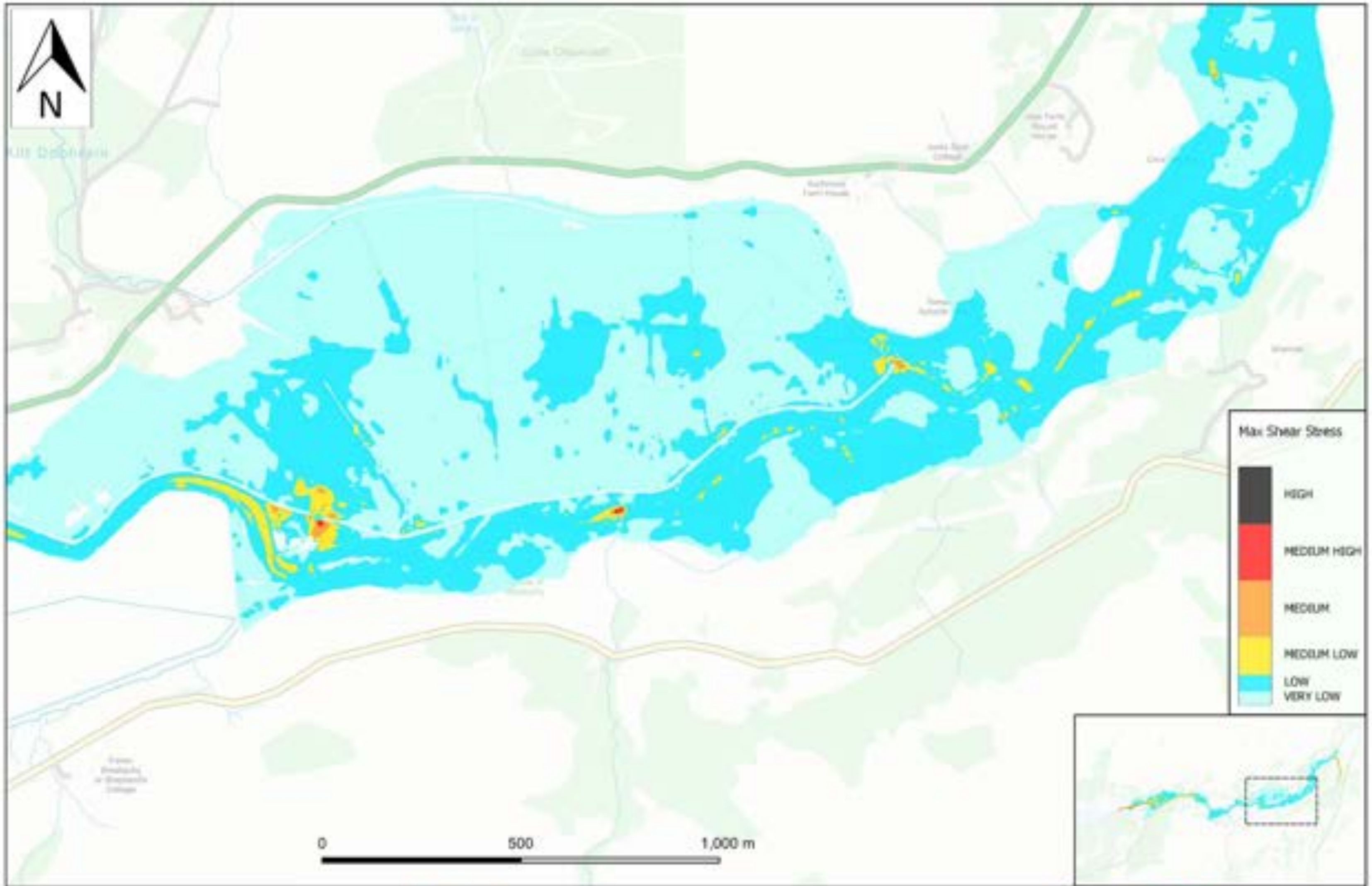
PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	
DRAWING: EVERYDAY SHEAR STRESS PAGE 4	**ISSUE:** KC2517-EVERYDAY SHEAR P4		

Appendix E9: Shear Stress Model Results for 29/03/21 Flood Event

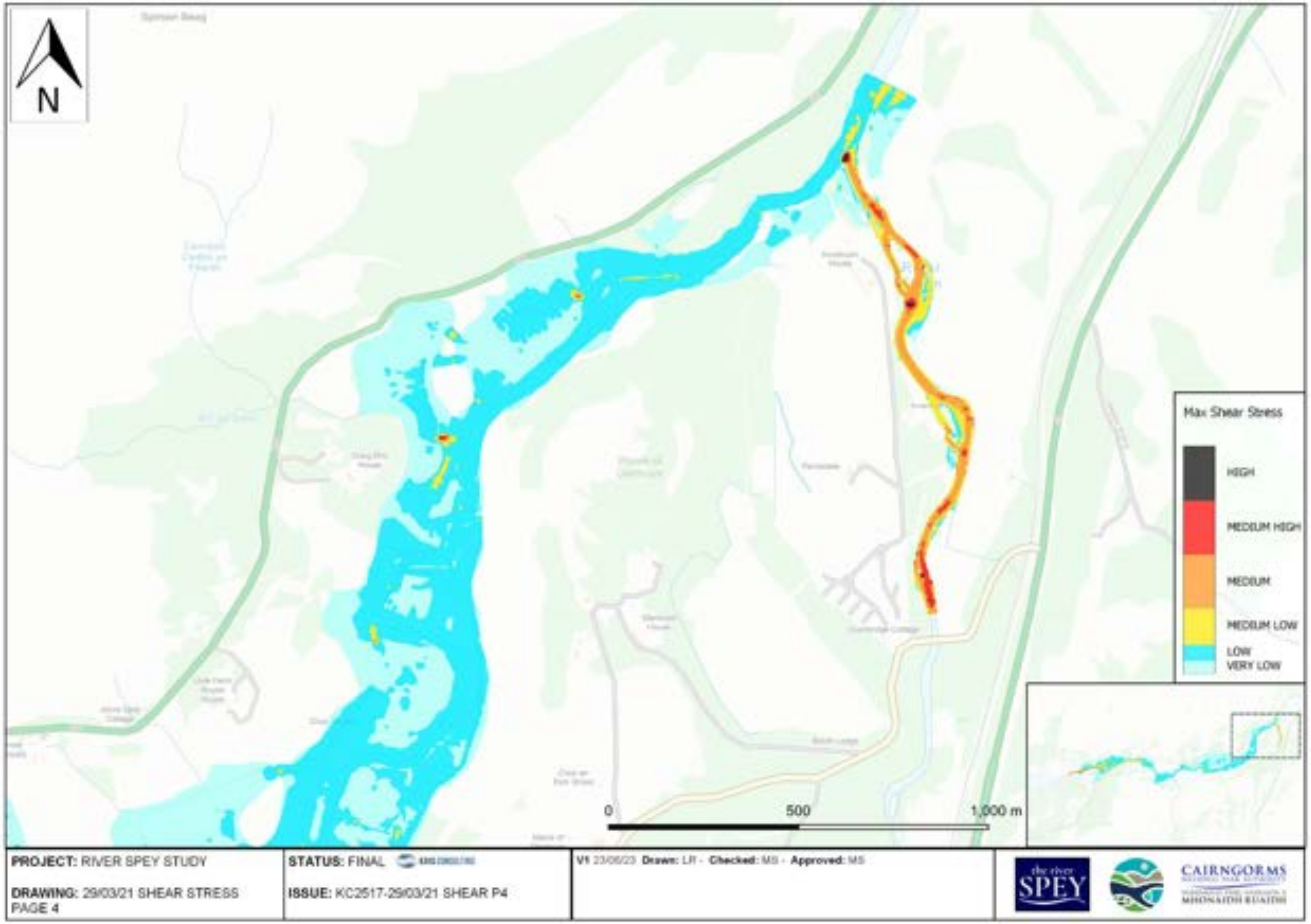




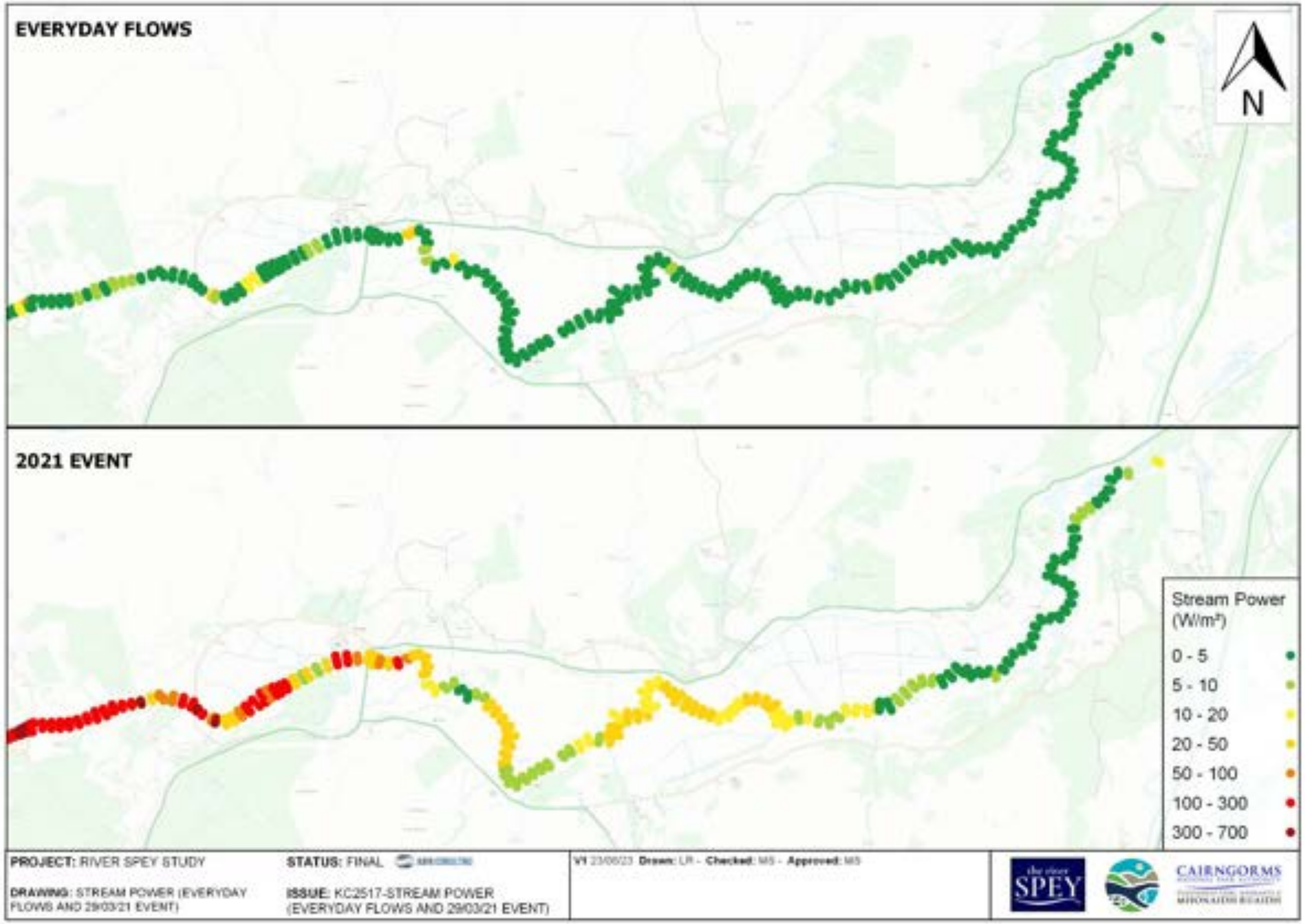
PROJECT: RIVER SPEY STUDY **DRAWING:** 29/03/21 SHEAR STRESS PAGE 2	**STATUS:** FINAL **ISSUE:** KC2517-29/03/21 SHEAR P2	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	



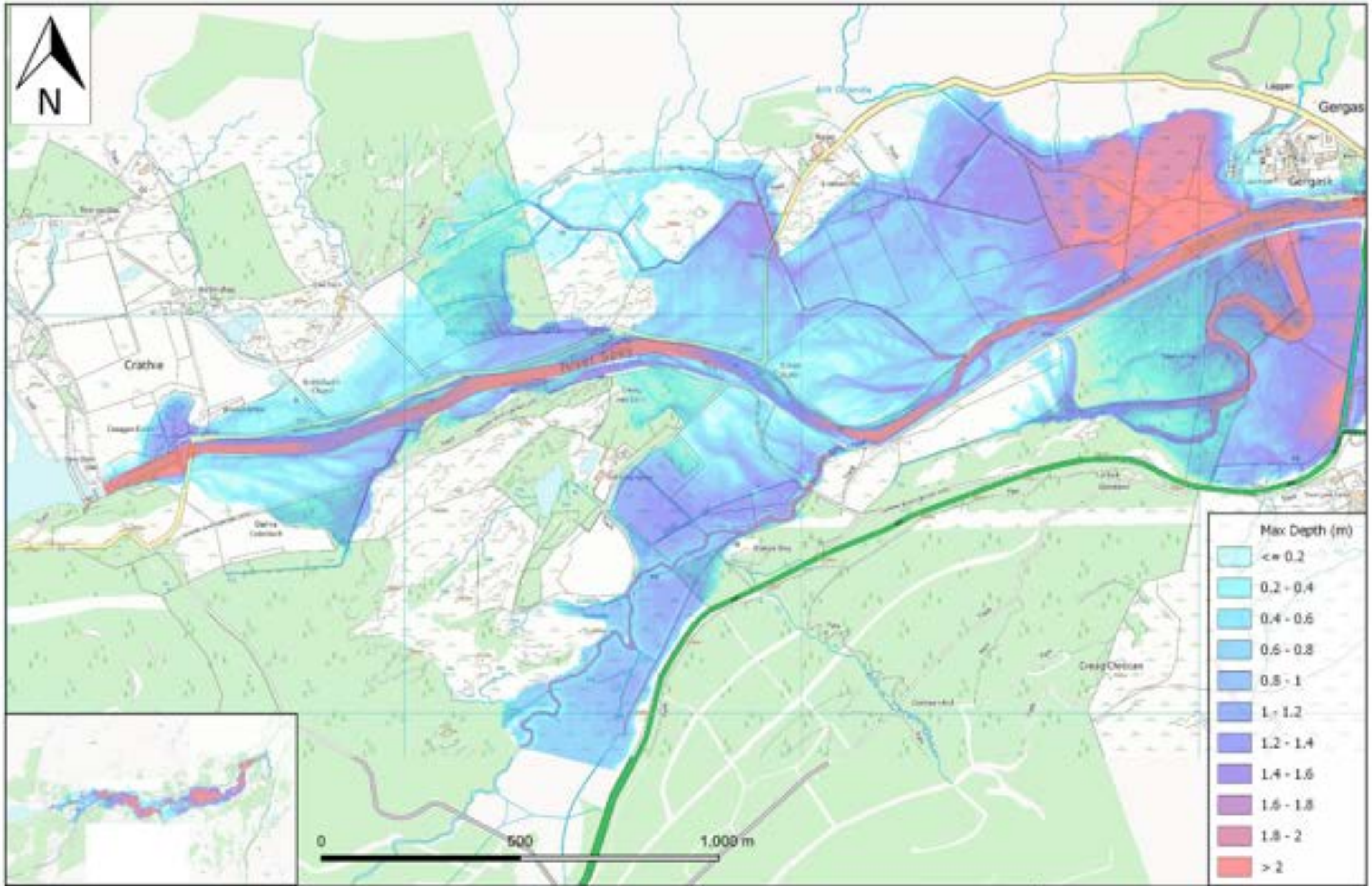
PROJECT: RIVER SPEY STUDY **DRAWING:** 29/03/21 SHEAR STRESS PAGE 3	**STATUS:** FINAL **ISSUE:** KC2517-29/03/21 SHEAR P3	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	


N
Max Shear Stress
HIGH
MEDIUM HIGH
MEDIUM
MEDIUM LOW
LOW
VERY LOW
0
500
1,000 m
PROJECT: RIVER SPEY STUDY
DRAWING: 29/03/21 SHEAR STRESS PAGE 4
STATUS: FINAL
ISSUE: KC2517-29/03/21 SHEAR P4
V1 23/06/23 Drawn: LR - Checked: MS - Approved: MS
the river SPEY
CAIRNGORMS

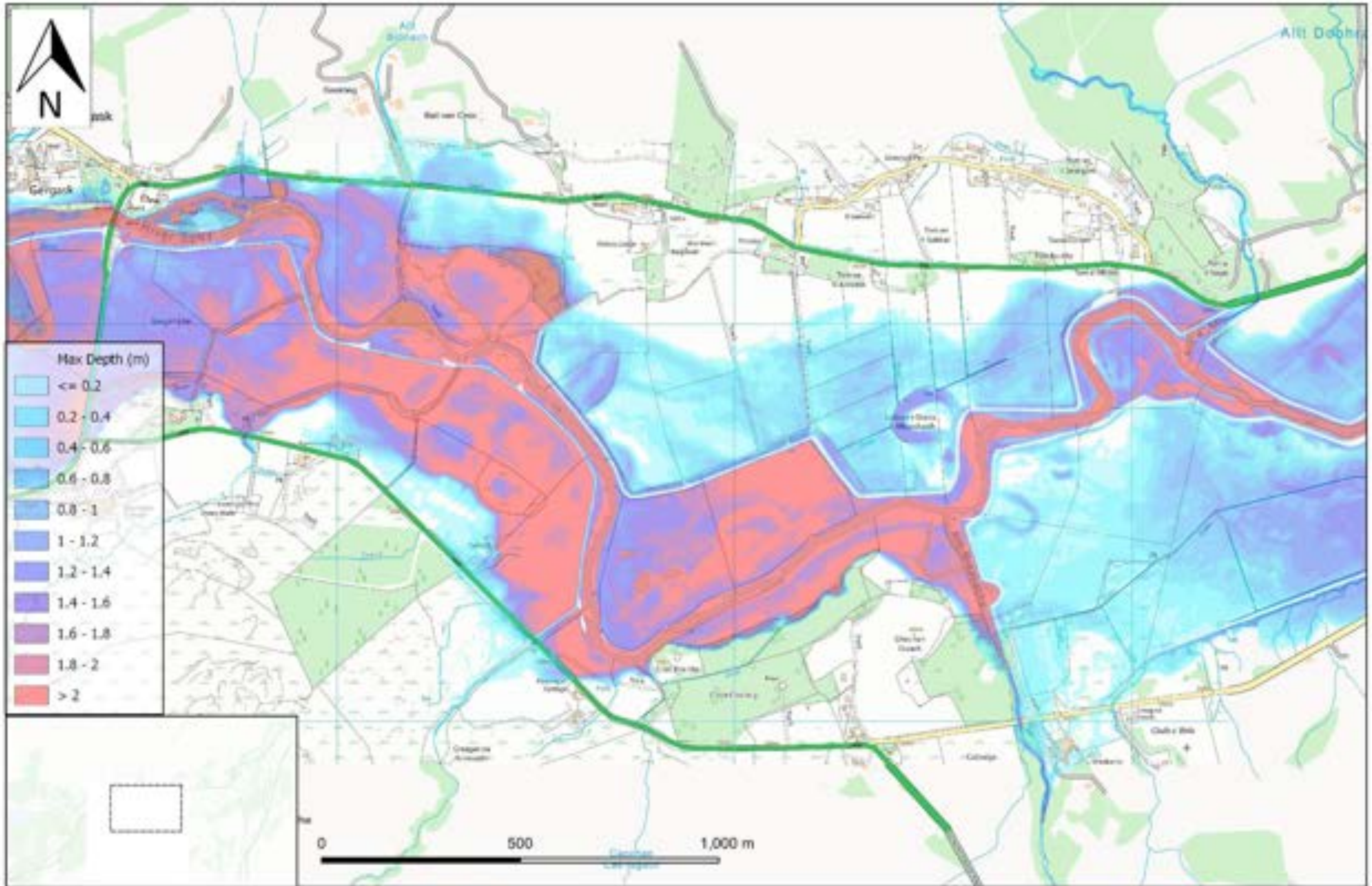
Appendix E10: Stream Power Model Results for Everyday Flows and 29/03/21 Flood Event



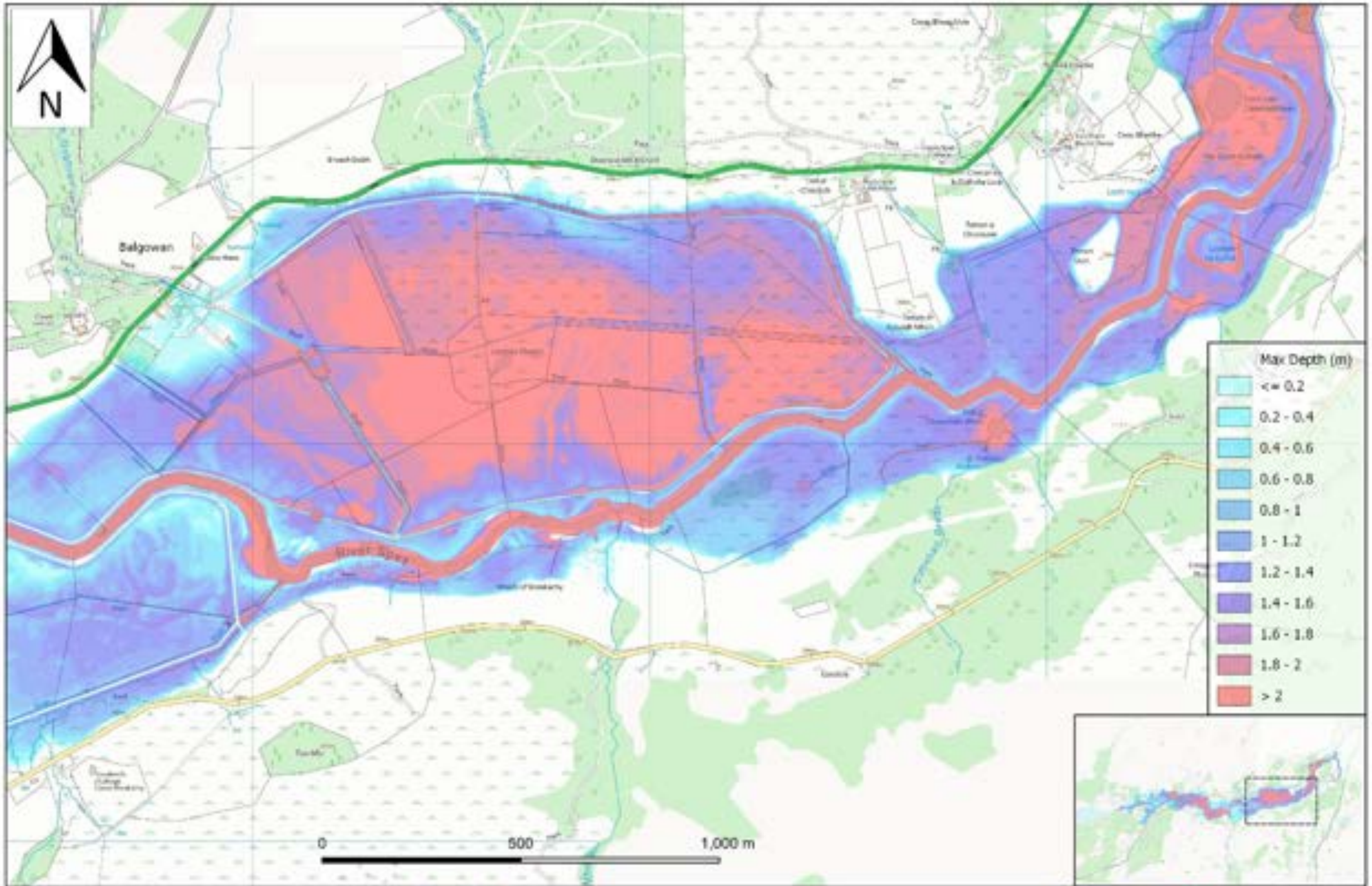
Appendix E11: 1 in 200-year Flood Maps



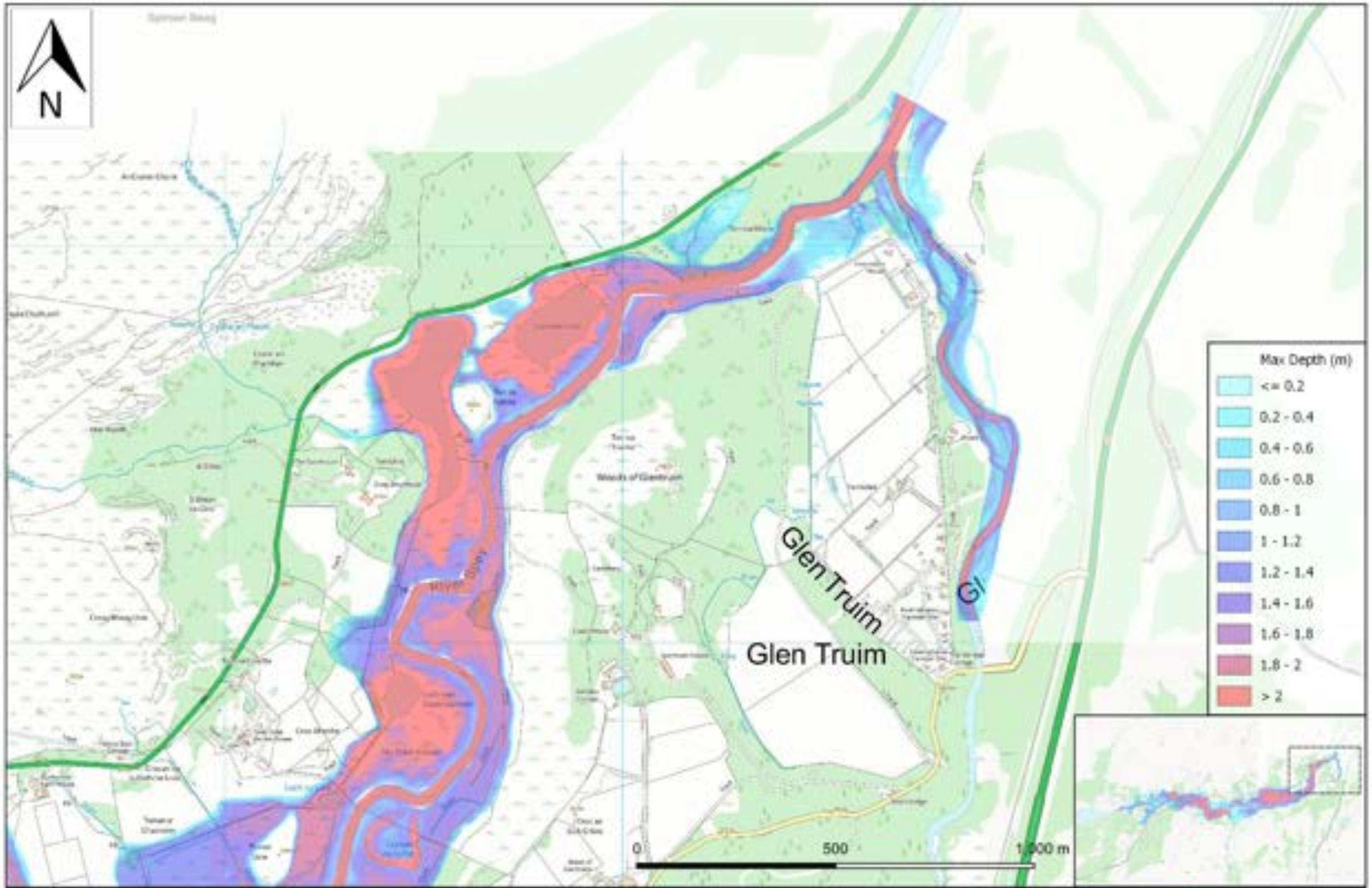
PROJECT: RIVER SPEY STUDY	STATUS: FINAL	V1 23/07/23 Drawn: LR - Checked: MS - Approved: MS	
DRAWING: FLOOD DEPTH 200-YEAR	ISSUE: KC2517-FM Q200 P1		



PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	**V1** 23/07/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS
DRAWING: FLOOD MAP 200-YEAR P2	**ISSUE:** KC2517-FM Q200 P2	



PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	V1 23/06/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS
DRAWING: FLOOD DEPTH 200-YEAR P3	**ISSUE:** KC2517-FM Q200 P3	



PROJECT: RIVER SPEY STUDY	**STATUS:** FINAL	V1 23/07/23 **Drawn:** LR - **Checked:** MS - **Approved:** MS	
DRAWING: FLOOD DEPTH 200-YEAR P4	**ISSUE:** KC2517-FM Q200 P4		