Kingussie Flood Study

Baseline Modelling

31 August 2020

Quality information

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1. Introduction

AECOM have been commissioned by The Highland Council (THC) to undertake a Flood Study in Kingussie, Scotland. Kingussie is in close proximity to two watercourses; the River Spey lies to the south of the town and the Gynack Burn runs through the centre. Frequent flooding from both these sources has affected Kingussie and the surrounding area and this Flood Study aims to develop an understanding of the baseline flood mechanisms and associated damages.

Previous studies have been undertaken by AECOM (formerly URS) on behalf of THC in 2012 and 2015 to investigate flood risk in Kingussie and to develop options for alleviating it. These studies contained hydraulic modelling elements of both the upstream catchment as well as through the town.

Since the previous Flood Studies were undertaken, the baseline conditions in the upstream catchment have changed due to the construction of a Hydro power scheme on Loch Gynack, which as well as providing a power source, also provides a secondary benefit of flood attenuation. This Flood Study aims to assess the impact of this flood attenuation on peak flows in combination with a more detailed modelling approach through town so that an updated understanding of baseline flood risk can be established.

As part of this stage of the Flood Study, a baseline damage assessment will also be undertaken to establish the likely costs associated with the current flood risk. The economic assessment is not included in this report.

Understanding the baseline flood conditions and economics will allow an informed decision to be made regarding progression of the Flood Study to an optioneering stage.

2. Project Background

The study area is outlined in Figure 2-1 below and encompasses the town of Kingussie. The upstream catchment that contains the Loch Gynack hydro power scheme, is not within the study area for assessing flood risk but will be modelled to determine flows into the study area. The purpose of this study is to identify areas at risk in Kingussie from fluvial flooding during current day and climate change scenarios.

The main fluvial flood risk in the study area is from the Gynack Burn which originates upstream in rural land before running through the centre of Kingussie and joining with the River Spey downstream of the town. Whilst much of the catchment is rural in nature, there are several hydropower schemes located upstream of Kingussie. All but one of these schemes take water from the Gynack Burn and return it to the watercourse immediately downstream, maintaining the flood mechanism and peak timings. However one of the schemes diverts flow from the Gynack Burn and temporarily stores it in Loch Gynack and by doing so, provides peak flow attenuation, affecting both the peak flow and timings of a flood event.

Previous Flood Studies set out to investigate how the Gynack Loch Hydropower Scheme could affect peak flows through Kingussie. At the time of the most recent previous study (2015), the scheme had not been constructed and was in the initial design stage. Indicative details such as weir lengths and crests were provided by Pitmain Estate and used to construct a 1D hydraulic model of the lateral weir, diversion, loch and outfall structure. Full details of the scheme can be found in Section 2.3.

The scheme has now been constructed and the construction drawings have been provided by THC. These more detailed dimensions and elevations have been used to update the existing hydro scheme model now that the finer details have been resolved. Other minor changes to the model as a result of updated information has also been undertaken to improve stability.

For the purposes of this study, the modelling has been split into 2 parts. The following has been adopted;

- 1D model of the upstream diversion channel and Loch Gynack to the confluence with the River Spey from the previous 2015 Flood Study but with minor adjustments. Whilst this model extended to the Spey, the section through town was in 1D only and based on older information so therefore not appropriate for use in this study. There are two separate models, one with the hydropower scheme included and one without. This model is used to determine inflows into the town model below .Flow from these models was extracted above town to be used as the inflow into the new 1D/2D model;

- Newly created 1D/2D model throughout the town created for this Flood study, extending from Old Distillery Road, 300m upstream of High Street to the confluence with the River Spey.

Full details of how these models were constructed and how they interact can be found in Section 5.

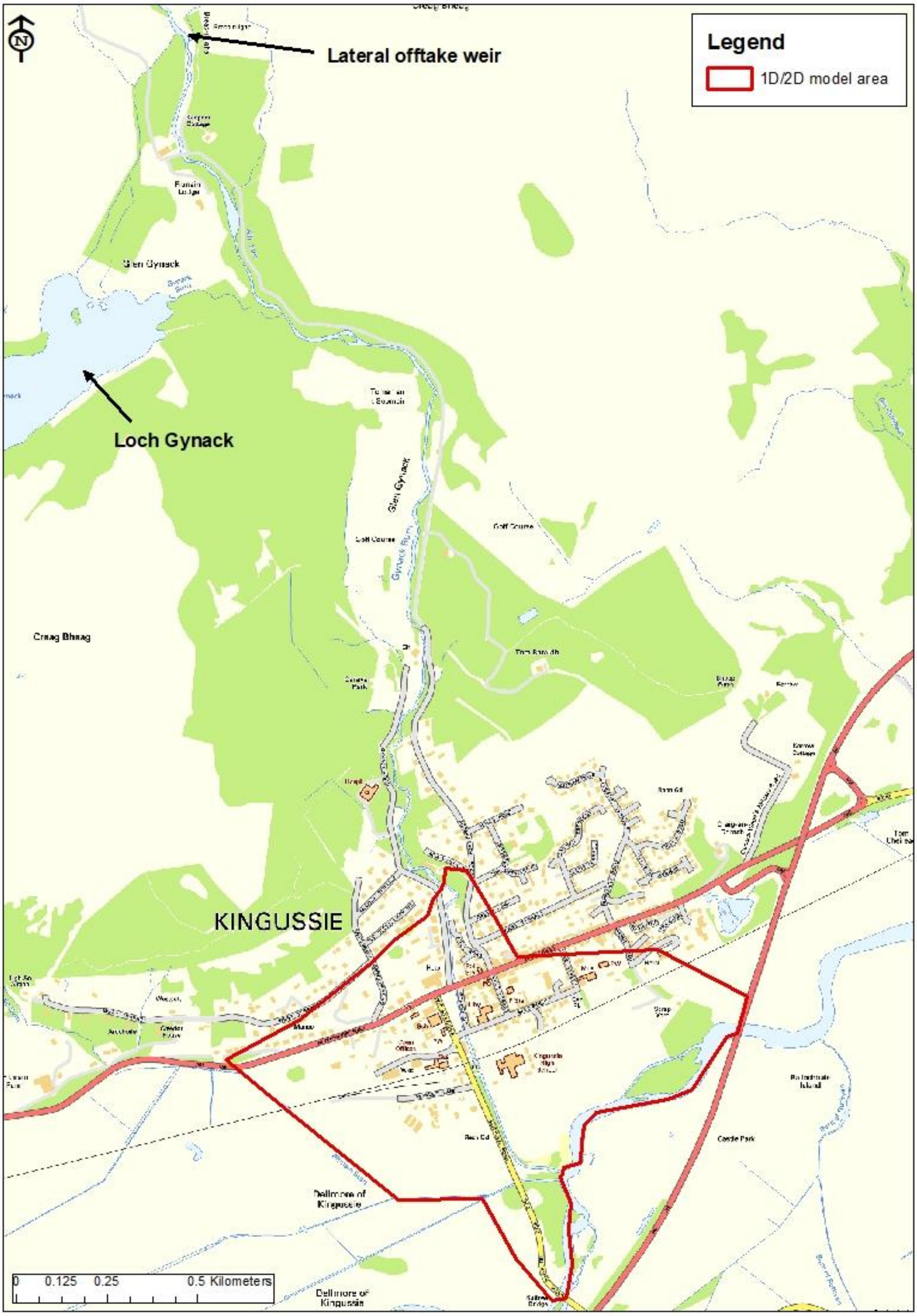

Figure 2-1: Study area

2.1 Site Visit

A site walkover was undertaken in July 2019 to establish general topography and constraints on and around the Gynack Burn. This assessment extended through town to the confluence with the River Spey. It was not possible to view the upstream elements of Loch Gynack Hydro Scheme at the time of the visit. During the walkover, a review of possible flood flow routes and assessment of the viability of potential options was also undertaken.

Upstream of Kingussie, around the golf course, the channel is seen to be incised with a natural profile. There are several sections where the watercourse has cut into the bedrock, forming waterfalls and pools. Along the entire upstream reach from the golf course to the town, the bed material is either bedrock or stones of various sizes, with small 5cm diameter stones as well as much larger 0.5m+ diameter material. Banks are lightly vegetated around the watercourse and treelined further up the bank.

The Gynack Burn through town is canalised but maintains a semi natural profile and riverbanks for the majority. Some sections of the banks have been reinforced with gabion baskets, primarily upstream of the railway bridge. At the time of the visit, the banks were vegetated with scrub, ferns and some larger trees. Bed material was seen to generally consist of small to medium smooth stones. Upstream of bridges, deposits of these stones were observed within the channel, forming small islands. This was particularly noticeable at the railway bridge. Bed material has also been dredged from the watercourse at various locations, primarily upstream of structures, and some of this material has been deposited on the banks.

Downstream of Kingussie, between the town and the confluence with the River Spey, the channel is canalised along the B970, with lightly vegetated banks and small to medium sized bed material. As the watercourse approaches the River Spey, the channel forms a more natural profile and is seen to vary its course frequently due to the active nature of the watercourse. Bed material deposits are built up along either side of the watercourse with minimal vegetation in some parts and denser trees and shrubs in others. An embankment runs along a significant reach of the left hand bank to protect agricultural land south of the High School.

There are a total of 4 bridge crossings through Kingussie, High Street, Spey Street, the railway line and an access bridge to the High School. These bridges vary significantly in their capacities, with soffit levels above bed level ranging from 0.7m to 2.1m at the time of survey. The bridges with the lowest soffit clearance are the railway bridge and school access bridge. It should be noted that sediment deposition upstream of bridges is a known issue and capacities of the bridges change frequently.

A gauge was noted on the watercourse upstream of the Spey Street Bridge. This gauge is level only.

Photographs can be found in Appendix A.

2.2 Historic Flooding and SEPA flood maps

Fluvial flooding in and around Kingussie is predicted by the SEPA online Flood Risk Management Maps[1] (FRM maps) from both the Gynack Burn and the River Spey. Water is shown to exit the Gynack Burn upstream of the High Street Bridge as well as other locations around Spey Street and the railway bridge. This flow is seen to extend southwards, affecting roads, properties and the railway line, before joining floodwater from the River Spey. The River Spey is seen to inundate large portions of the floodplain to the south of Kingussie, extending up to the High School.

The SEPA floodmaps are backed up with the historic flood reports set out in The Flood Risk Management Strategy as well as anecdotal accounts from SEPA and THC, where flooding has been noted at properties, community facilities, agricultural land and transport networks. Fluvial flooding has caused particular issues on Spey Street, Gynack Street, the railway line and at the High School. Anecdotal and photographic evidence has shown that blockage of structures, both from sediment and from woody debris, plays a significant role in flooding in Kingussie, with all three of the lower structures, Spey Street, railway line and school access bridge frequently becoming blocked.

SEPA and THC have provided the following records:

- November 2019 – Gynack Burn burst its banks, causing flooding and the railway line to close;
- July 2019 – railway line closed;

[1] http://map.sepa.org.uk/floodmap/map.htm

- December 2015 – Railway line closed;
- January 2015 – Station Road flooded and the railway line was closed;
- August 2014 – Ex-hurricane Bertha – flooding to several roads and properties: Silverfjord Hotel, Station Road, Spey Street, Kingussie High School and the bowling green;
- January 2008 – flooding from High Street Bridge to Spey Street Bridge making the road impassable;
- December 2006 – Flooding upstream of all 3 bridges flooding Spey Street, Gynack Street, Market Lane, Ruthven Road and Kingussie High School;
- January 2005 – flooding on Spey Street making it impassable. Properties on Gynack Street, Spey Street and Kingussie High School were all threatened;
- January 1989 and February 1990- Levels in the River Spey reached 224.27m and 223.87m respectively, flooding fields and part of Kingussie.

Photographs of some past flood events can be seen in Appendix B.

2.3 Hydropower scheme

Pitmain Estates have installed a hydropower scheme in the upstream reach of the Gynack Burn, part of which includes a diversion channel which was installed in conjunction with THC. This scheme diverts water from the main channel by means of a lateral weir arrangement. Flow then travels down the diversion channel to Loch Gynack where it is attenuated by an outfall weir before being used for energy generation. Levels in excess of the outfall weir are discharged back into the Gynack Burn via a small channel.

This scheme was primarily implemented for energy generation but a secondary benefit of flood peak attenuation is also realised through the diversion of flows into Loch Gynack. This diversion may be able to impact both peak flow as well as peak timing.

Due to bank erosion on the diversion channel, the hydropower scheme is currently not operational and is therefore also not attenuating peak flows. Bank erosion protection is currently being designed and for the purposes of this study, the hydropower scheme is assumed to be operational. A sensitivity test will be undertaken to assess the impact should the scheme not be operational.

Drawings of the scheme can be found in Appendix C. Figure 2-2 displays a schematisation of the hydropower scheme.

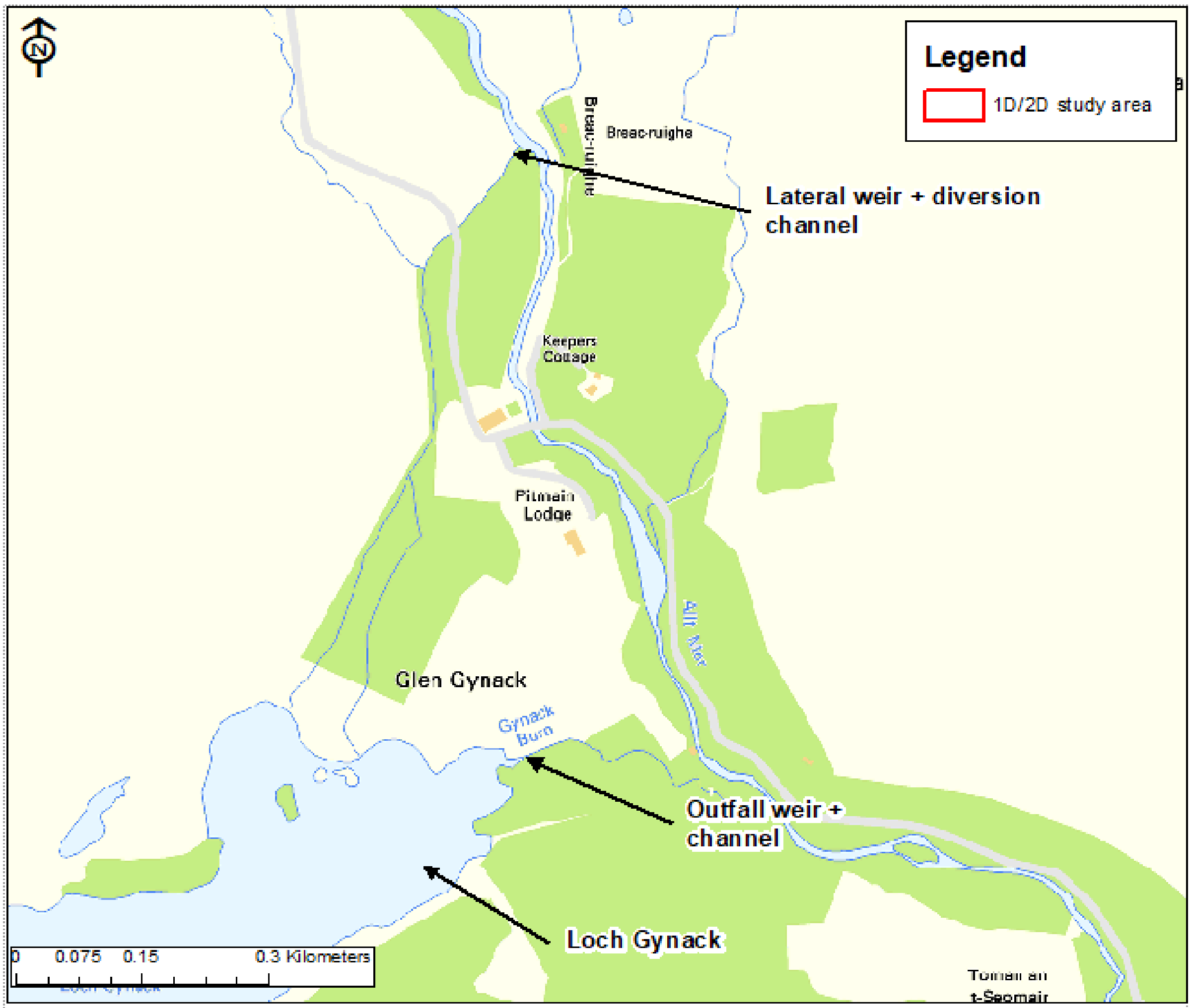

Figure 2-2: Schematisation of the hydropower scheme

3. Fluvial Hydrological Assessment

Given previous studies had been undertaken in the area, they were first assessed to determine whether the findings were suitable for use within this study. After discussions with SEPA, it was agreed that the hydrology undertaken in the 2015 FRA was appropriate for use in this study. The delineated subcatchments for the Gynack Burn catchment, along with their catchment descriptors and the FEH Rainfall Runoff derived peaks at the confluence with the River Spey for reconciliation purposes were therefore used within this study.

As the hydropower scheme model has been updated from the 2015 study, small amendments were made to the subcatchment's SPR values so that reconciliation of flows to the 2015 peaks at the confluence with the Spey could be achieved. Climate change was also updated in line with current guidance.

Below is a summary of the hydrology used in this study. Full details can be found in *'Kingussie Flood Study Update, 2015'.*

3.1 Methodology overview

The Flood Estimation Handbook (FEH) gives guidance on rainfall and river flood frequency estimation in the UK and also provides methods for assessing the rarity of notable rainfalls or floods. A number of methods of flood estimation are presented, including the FEH statistical method and the FEH rainfall-runoff method. Subsequent publications have presented the ReFH and ReFH 2 rainfall-runoff method, updating the FEH rainfall-runoff method.

The statistical method consists of two parts; estimation of the median annual flood (QMED), i.e. the flood event with an annual exceedance probability of 50% (1 in 2 year return period), and the derivation of a pooled or single-site growth curve. The growth curve is then multiplied by the QMED estimate to provide a flood frequency curve for the subject site for a range of AEP events.

This method, undertaken using WINFAP software, relies on deriving a representative growth curve for the subject site from a pooled group of hydrologically similar catchments for which there is gauged information. This means that the accuracy of the method and resulting flow estimate depends on there being a sufficient number of similar catchments contained in the gauging station database. Similarity is judged using a distance measure derived from the difference in floodplain extent (FPEXT), rainfall (SAAR) and catchment area (AREA) between the subject site and the gauging station sites. The method assumes that the flood statistics within the periods of record in the pooling group are representative of the flooding regime in the future, i.e. that the data is stationary. However, the method is based on actual observed flood data, and is therefore considered to be more robust than the more conceptual rainfall-runoff methods for the majority of cases.

The best estimate of QMED is determined using flood data at the site if such local data exists. Alternatively, if no such data exists, QMED can be estimated from FEH catchment descriptors and improved by data transfer from a suitably hydrologically similar donor gauge.

When the 2015 hydrology was undertaken, ReFH2 had just been released and was not accepted by SEPA due to the lack of Scottish and smaller catchments. Therefore, the FEH rainfall-runoff method was undertaken for comparison with the Statistical analysis. SEPA have agreed that for this study, the REFH2 method was not required to be undertaken.

Given the size of the catchment to the confluence with the river Spey is 22km^2, both the statistical and rainfall-runoff methods were suitable and both were undertaken for comparison. Flow estimates for the whole catchment were determined at the downstream extent of the study area for flow reconciliation purposes. A range of return periods were required. These included the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1% AEP events.

The chosen method would produce peak flow estimates at the downstream extent of the model that could then be used to reconcile the various subcatchment inflows. Reconciliation is a useful means of establishing flows as estimates are based on the overall larger catchment, rather than the smaller subcatchments, which reduces uncertainty in the outputs.

Throughout this report, flooding events will be described in terms of their Annual Exceedance Probability (AEP). Table 3-1 sets out how these AEP events correspond to flood return periods.

Table 3-1: AEP and return period equivalent

Annual Exceedance Probability (AEP) event	**Return Period**
50%	2
20%	5
10%	10
4%	25
2%	50
1%	100
0.5%	200
0.2%	500
0.1%	1000

3.2 Catchment descriptors

In the 2015 Study, the catchment descriptors were obtained from the FEH CD-ROM. Table 3-2 displays the key catchment descriptors of the Gynack Burn to the confluence with the River Spey.

Further details regarding the catchment and it's descriptors can be found in the 2015 report.

Table 3-2: FEH catchment descriptors to confluence with River Spey

Catchment parameters	**Total catchment descriptors**
NGR	*275700,800550*
AREA	*21.85*
ALTBAR	*567*
ASPBAR	*136*
ASPVAR	*0.4*
BFIHOST	*0.413*
DPLBAR	*6.19*
DPSBAR	*180.8*
FARL	*0.95*
LDP	*10.37*
PROPWET	*0.68*
SAAR	*1230*
SAAR4170	*1206*
SPRHOST	*56.96*
URBEXT1990	*0.0003*

3.3 Total catchment hydrology

Table 3-3 displays the 2015 Flood Study peak flows established using the Statistical and Rainfall-runoff methods.

The rainfall-runoff method was found to produce the higher of the two estimates. Given the relatively small size of the catchment, and therefore lack of similar catchments within the Statistical analysis, as well as the attenuation upstream, the FEH RR method was deemed appropriate. This approach was confirmed by SEPA for use in this study.

The FEH RR peaks were therefore used to reconcile the subcatchment flows at the downstream extent of the model.

Table 3-3: Peak flow estimation from the 2015 Flood Study to the downstream extent of the Gynack Burn

Annual Exceedance Probability (AEP) event	**Statistical Analysis Peaks (m^3/s)**	**FEH R-R Peaks (m^3/s)**
50%	12.67	**14.59**
20%	16.78	**20.33**
10%	19.72	**24.49**
4%	23.93	**30.58**
2%	27.52	**36.06**
1%	31.55	**41.28**
0.5%	36.11	**46.93**
0.2%	43.09	**57.16**
0.1%	49.22	**67.20**

3.4 Climate change

Whilst the original current day hydrology was deemed suitable for use in this study, climate change uplifts had to be reassessed due to updated research and guidance.

The United Kingdom Climate Projections 2018 (UKCP18) dataset was published in December 2018 and outlines updated probabilistic projections of climate change impact for the 2020's, 2050's and 2080's based on various emissions scenarios and probability percentiles. United Kingdom Climate Projections (UKCP09) is a previous version of the projections and has been superseded by the 2018 projections.

Outlined in their Flood Modelling Guidance for Responsible Authorities, SEPA commissioned CEH to undertake a study assessing Scottish catchments vulnerability to climate change. Within this study the UKCP09 uplift projections were run through models to provide flow uplifts for hydraulic basins. This exercise has not however been undertaken using the UKCP18 data. It is therefore still appropriate to consider using uplift values from the CEH report in Flood Studies.

SEPA have also published guidance on climate change allowances for Flood Risk Assessments for new developments. Whilst the guidance for Flood Studies applies a more adaptive approach to climate change uplift, rather than set values as specified for FRAs, it is useful to understand the uplifts applied across all guidance to gather a complete picture.

Based on SEPA's FRA guidance, an uplift of 24% flow or 35% rainfall is recommended for the area around Kingussie. Given the size of the catchment, below 30km^2, the FRA guidance recommends than rainfall be uplifted so the flow uplift can be discounted in this case. For comparison, the CEH report, which is based on UKCP09 data, states uplifts of 24% and 33% for the 67th and 90th percentile high emission scenario 2080s respectively. It should be noted that the CEH report figures are uplifts on flow rather than rainfall so is not directly comparable.

For the purpose of this flood study, a 35% uplift in rainfall, in line with SEPA's FRA guidance, has been adopted for the climate change scenario which is comparable to a 90th percentile high emission uplift. This is considered to be a relatively conservative uplift. As a further sensitivity check, a 20% uplift in flow will be applied as set out in SEPA modelling guidance.

3.5 Fluvial sub-catchment hydrology

Within the 2015 modelling exercise, subcatchment inflows were applied to several points in the model rather than applying the full catchment flow at the upstream extent. Applying the full catchment flow at the upstream extent of the model was considered to be overly conservative and would mean that the effects of the hydropower diversion scheme could not be properly assessed.

The hydrological assessment discussed Section 3.2 and 3.3 was undertaken for the total catchment of the Gynack Burn to the downstream boundary of the model. These peak flows were calculated so that the subcatchment flows could be reconciled in the model, to match this downstream peak estimate.

The following sections outline the reconciliation process which was undertaken again in this Flood Study due to the changes in some of the elements of the hydropower model.

3.5.1 Delineation and representation

Subcatchments were defined in the previous 2015 study and remained unaltered within this study. Figure 3-1 displays the subcatchments that feed into the model.

A total of 5 subcatchments were identified. Some of these subcatchments were watercourses such as the Allt à Bhreac-ruighe and some were runoff areas with no associated watercourse. The runoff areas were identified as separate subcatchments to allow flow to be added to specific sections in the model so that flow was not overrepresented in the upper portions.

In the previous 2015 Flood Study, catchment descriptors were downloaded for the tributary areas from the FEH CD-ROM. Runoff area descriptors were established using an intermediate catchment assessment.

Each subcatchment was represented using an FEH unit which provided both the peak flow for each subcatchment as well as hydrograph shape.

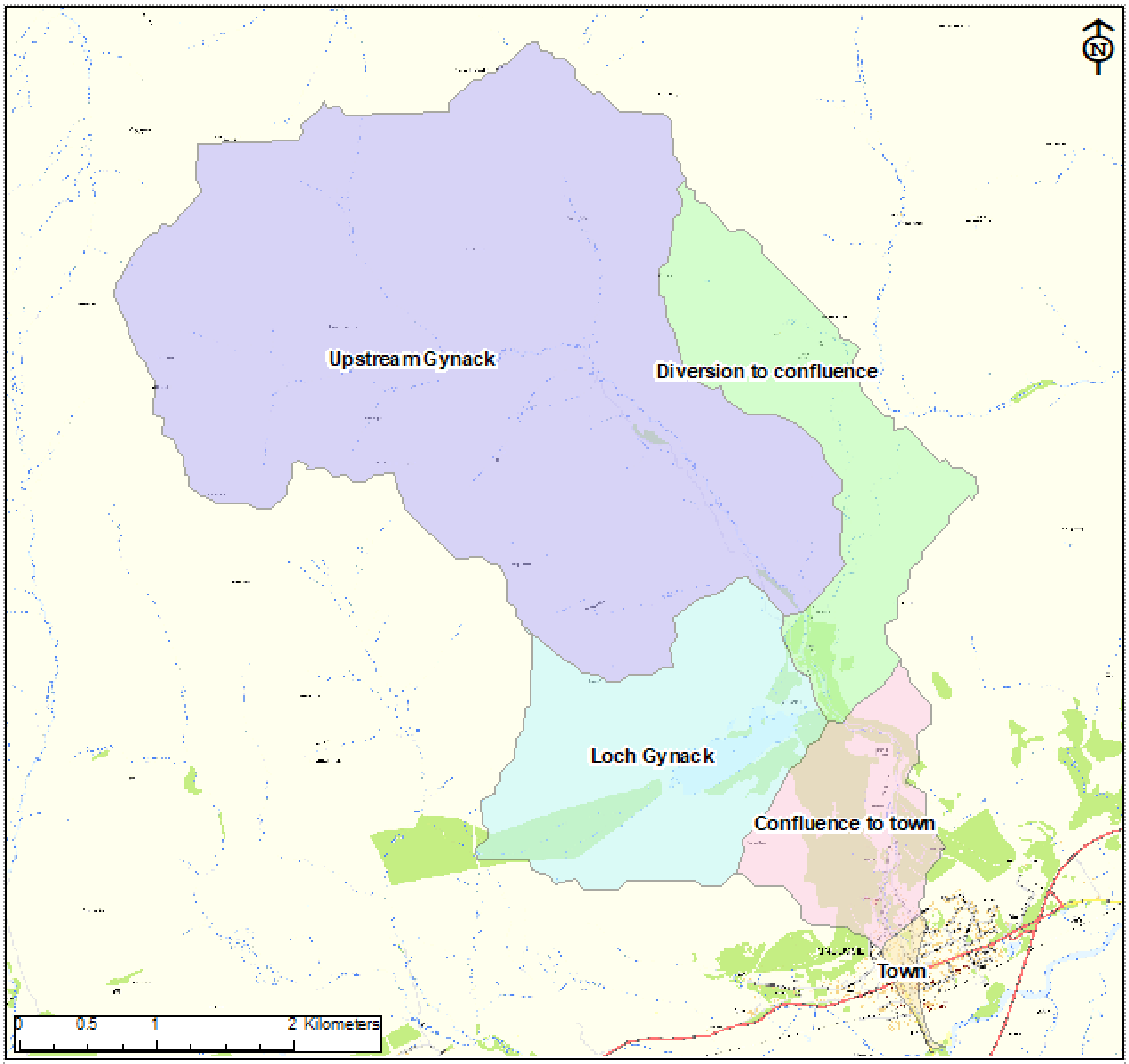

Figure 3-1: Subcatchments and inflow locations into model

3.5.2 ReFH2 reconciliation

The FEH subcatchment inflows were iteratively scaled and run within the 1D upstream baseline model (no hydropower scheme) by modifying the SPRHOST values by the same percentage across all subcatchments, until the flow at the downstream extent of the model matched the peak flow estimates outlined in section 3.3.

This resulted in the FEH SPR values being adjusted by between 10% and 18.5% from the downloaded descriptors. Table 3-4 displays the percentage change in SPR values from default and resultant peak flow at the confluence with the Spey. Once adjusted, these descriptors were used for the upstream mode, with and without the hydropower scheme, which would both be used to determine inflows into the 1D/2D model of the town developed for this Flood Study. It should be noted that the upstream inflows excluding the hydropower scheme were to be used as a sensitivity check and that the model that includes the hydropower scheme generated the baseline flows for the 1D/2D model throughout town.

Table 3-4: Sub catchment ReFH2 inflow uplifts

AEP event %	% decrease of default SPR value to match downstream flow estimate	Resultant peak flows at downstream extent of model (m^3/s) to match FEH flows
50%	10	14.6
20%	13	20.4
10%	13	24.4
4%	14	30.5
2%	14	36.2
1%	15	41.4
0.5%	17	47.0
0.2%	17	57.1
0.1%	18.5	67.2

3.6 Flood Study inflows

The flow hydrographs at section GYNA01_1016 of the upstream hydropower scheme model were extracted and used as the inflow to the separate 1D/2D model that was constructed as part of this Flood Study. This node was selected as it was the furthest surveyed upstream section in the 1D/2D model and all flow was within channel. Table 3-5 displays the flows that will be used in this Flood Study.

Table 3-5: Peak flows to be used in the modelling exercise

AEP event %	Peak flows into the 1D/2D model (m^3/s)
50%	11.84
20%	16.73
10%	20.21
4%	25.29
2%	30.43
1%	34.79
0.5%	40.20
0.5% + CC	47.58
0.2%	50.26
0.1%	59.47
0.1% + CC	70.51

4. Joint probability

4.1 Run matrix

The Gynack Burn flows into the River Spey downstream of Kingussie. Water levels in the River Spey have the potential to affect water levels in the Gynack Burn, and therefore increase flooding in Kingussie; the worst-case situation being concurrent peak flow and matched return periods in both watercourses.

Because of the significant difference in catchment areas, the storm duration that results in the largest peak flows on the Gynack Burn is likely to be significantly shorter than the River Spey. Flood events on the River Spey will arise from longer duration, and therefore less intense, rainfall than the short duration (likely spatially limited) high intensity rainfall that would give rise to the highest flows in the Gynack Burn. This means that it is relatively unlikely that a similar return period event would occur on both watercourses at the same time and also relatively unlikely that the peaks would be concurrent. Whilst event matching is unlikely, it is important to explore the effect of the downstream boundary further so that appropriate levels are applied.

An analysis of joint probability of coincidence in peaks would require gauged data on all watercourses. However, as this data is not available on the Gynack Burn, a sensitivity assessment will be undertaken using a range of simulations to determine how levels in the Gynack Burn are influenced by levels in the River Spey.

The below simulations were run as they covered the extremes of the scenarios. The Gynack 50% AEP/Spey 0.5% AEP was not run after assessing the Gynack 50%/Spey 3.33% AEP run.

Low flow in Gynack Burn	High flow in Gynack Burn
• $\text{Gynack}_{50\%}$ x $\text{Spey}_{\text{bankfull}}$	• $\text{Gynack}_{0.5\%}$ x $\text{Spey}_{\text{bankfull}}$
• $\text{Gynack}_{50\%}$ x $\text{Spey}_{3.33\%}$	• $\text{Gynack}_{0.5\%}$ x $\text{Spey}_{3.33\%}$
	• $\text{Gynack}_{0.5\%}$ x $\text{Spey}_{0.5\%}$

The results of the above simulations were compared to establish whether water levels in the River Spey impacted water level in the Gynack Burn during both a lower and higher event.

4.2 River Spey levels

As no new survey was undertaken on the River Spey as part of this Flood Study, the channel was not modelled in 1D and flow was not applied to the watercourse. Instead, water levels for the River Spey were taken from the A9 1D/2D model, provided by Fairhurst. These levels were provided between 500m upstream of Ruthven Road and the A9 crossing downstream at regular cross section spacing for the 3.33% and 0.5% AEP events. A level to represent bank full was also derived from the LiDAR.

Approximately 1.5km of the River Spey was included in the 2D element of the model and water levels were seen to vary. For that reason, 2 levels on the River Spey were selected from the Fairhurst levels; one at the upstream extent and one at the confluence with the Gynack Burn. These levels were then applied along the length of the Spey, with the Gynack Burn dictating where one level stopped and one level began as shown in Figure 4-1.

Figure 4-1: River Spey level boundaries

4.3 Joint probability conclusions

When assessing the 0.5% AEP event on the Gynack Burn, changing the downstream boundary on the River Spey for the 3 events outlined in section 4.1, was found only to impact on the Gynack water levels up to cross section 18, 70m downstream of Kingussie High School. Water levels were found to match upstream of section 18 regardless of levels on the River Spey.

Equally, when assessing the 50% AEP event on the Gynack, water levels were found to only be influenced downstream of section 19, which is 150m downstream of Kingussie High School, when altering the River Spey level between a bankfull and 3.33% AEP event. Levels upstream of section 19 were unaffected regardless of levels on the River Spey.

Based on these findings, it was concluded that water levels on the River Spey did not affect water levels on the Gynack throughout the town and therefore did not affect flooding within Kingussie which is the main focus of this study. It was deemed to appropriate to apply bankfull levels on the River Spey for all modelled return periods on the Gynack Burn.

Floodmaps of the Spey only levels can be found in Appendix H.

5. Hydraulic modelling

The modelling has been split into 2 elements; an existing model that includes the upstream hydropower scheme and Loch Gynack to the confluence with the Spey from the previous 2015 Flood Study, and the newly created 1D/2D model throughout the town created for this Flood study.

The existing upstream hydropower model is taken from the 2015 study with some adjustments to model elements such as the lateral weir and to the SPRHOST values as part of the reconciliation process. The flow hydrographs of this model were extracted just upstream of Kingussie for all AEP events and were used as the inflow to the new linked 1D/2D model through town.

The following sections outline what has been undertaken in the modelling exercise.

5.1 Existing Upstream Hydropower Model

The existing model of the catchment, including the hydropower scheme, was updated as part of this modelling exercise to provide the inflows for the model through town. The previous model had been developed before the scheme had been constructed and was therefore based on the best available information at the time. Construction drawings of the weir arrangement and bypass channel have since been made available and were used to set structure and channel dimensions within this Flood Study.

The hydrology was reconciled again as part of this Flood Study due to the modelling alterations in the scheme as outlined in Section 3.

The following amendments were made to the upstream hydropower scheme model and were based on the drawings set out in Appendix C:

- Diversion channel geometry was updated around the lateral weir structure so as not to affect the split in flows;
- Diversion lateral weir – The two weirs that make up this structure were updated based on the new design. Previously, the weirs had been entered as a single level. The construction drawings detail both weirs with varying levels to accommodate normal flow and flood conditions. The sluice structure on the offtake weir was also adjusted to align with the construction drawings;
- Outfall structure length at Loch Gynack was amended slightly;
- The sections downstream of the Loch Gynack outfall weir were also updated based on survey of the area. The wide flat floodplain was extended so that it did not glasswall, artificially raising water levels downstream of the weir, which would affect flow over the outfall weir.

The remaining elements of the model such as the channel sections and the floodplain remained the same. It was clear in the model review that some of these sections were dummy sections and did not accurately represent the channel shape. However, given the purpose of this model, the capacity of the channel was not as critical as chainage and the attenuation provision.

5.2 1D/2D Town Model Schematisation

A single hydraulic model has been constructed of the Gynack Burn through Kingussie and a small section of the River Spey for this Flood Study. This model consists of a one dimension element representing the Gynack Burn river channel built in Flood Modeller and a two dimensional element representing the floodplain and River Spey constructed in Tuflow. Both of these are industry standard hydrodynamic modelling software

5.2.1 One dimensional channel model

A one dimensional model of the Gynack Burn was constructed using surveyed river cross sections and inline structures. The topographic survey can be found in Appendix D. Cross sections, structures and a long section can be found in Appendix E. The survey was undertaken as part of this study and was used to represent the channel geometry and to define the top of bank at each surveyed section. The model consists of 22 surveyed river sections and 5 bridges with between 20-80m spacing throughout the reach as the channel was relatively uniform. All structures in the modelled reach were included in the model, both upstream and downstream faces were surveyed.

The upstream extent of the model on the Gynack Burn is located 300m upstream of the High Street bridge. In choosing this upstream location, flooding throughout town could be fully assessed as all out of bank flow was contained in the channel. The 1D model extends to the confluence with the River Spey, Section labelling can be seen in Figure 5-1 and will be referenced later in the report to describe flood risk at certain locations.

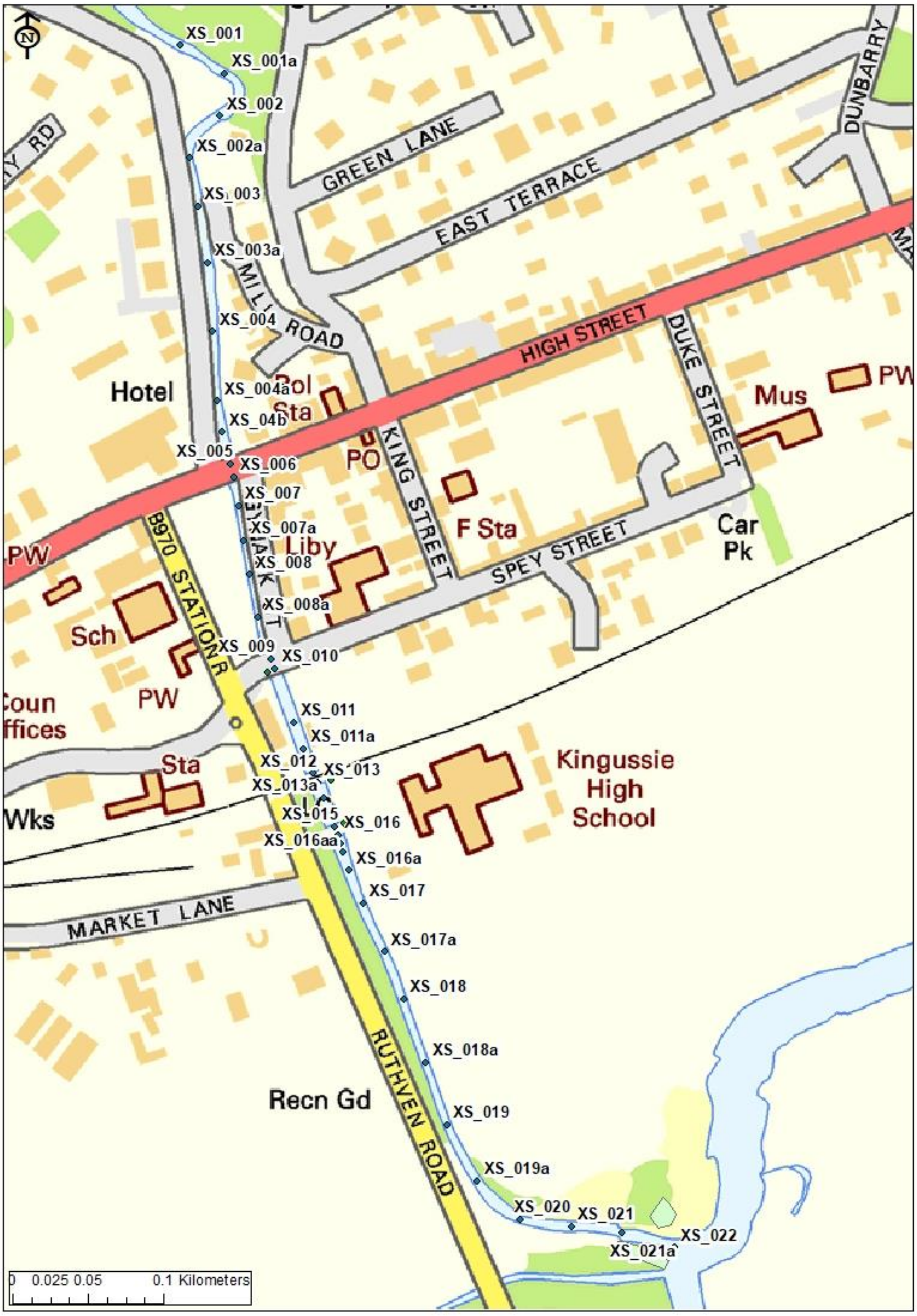

Figure 5-1: 1D node locations

The inflow hydrograph, as calculated in Section 3, was applied at XS_001 as shown in Figure 5-1. The downstream boundary was set as a Head-Time boundary that represented the water level in the River Spey. Full details of the joint probability assessment that informed the selection of water levels on the River Spey can be found in Section 4.

Channel and bank Manning's 'n' roughness values were selected based on photographs and the site visit. The channel is seen to vary from relatively natural in the upstream reaches and towards the River Spey to artificially straightened and lined throughout sections of the town. Due to the very stony nature of the channel bed, with large obstructions in some locations, roughness was generally set at 0.055. Only minor sections of floodplain and banks were represented in the 1D model. Long grass and reed banks were set at 0.045, denser vegetated banks set at 0.06 and artificial banks at 0.04.

5.2.2 Two dimensional flood plain model

The 1D channel was linked to a 2D domain (ground surface model) to model the overland flood mechanisms. The 2D hydraulic model contained the following elements:

- Ground surface using 1m LiDAR Digital Terrain Model (DTM);
- 1D/2D links to allow free flow between the river channel and floodplain based on surveyed top of bank elevations from survey and LiDAR;
- Roughness layer depicting different surfaces based on OS Mastermap data representing buildings (n = 0.5), roads (n= 0.025), wooded areas (n=0.08), industrial site (n=0.045), scrub (n=0.055), sand (n=0.025), railway embankment (n=0.04) and grassland (n= 0.035);
- Downstream boundary – a Head-Time boundary was applied along the middle of the River Spey channel to represent the water level in this watercourse. Further details of how this level was derived can be found in Section 4;
- Buildings are represented by a roughness of 0.5;
- Further LiDAR refinements around bridge decks to better represent the topography. The bridge decks were not represented in the LiDAR and instead represented the channel. This was amended using survey data so that flow over decks could occur.

5.2.3 Ground truthing

Ground truthing of the 1m LiDAR used to represent the 2D floodplain was undertaken using surveyed top of bank levels throughout town. This exercise was undertaken to ensure that the LiDAR provided a reasonable representation of the ground surface from which the 2D flow mechanisms and floodmaps would be generated.

In channel survey levels and levels around bridges were removed from the assessment as these were likely to be inaccurately represented in the LiDAR due to the resolution of the data and the inability for channel beds to be picked up accurately.

Due to the extent of the survey (cross sections only) there were relatively few points on the floodplain that could be compared. Points were taken along the reach on both the left and right bank. A total of 28 points were compared and the differences between the LiDAR and the surveyed levels were found to range between 240mm higher and 558mm lower that the surveyed levels. Whilst the most significant differences were noted throughout the reach, they were mainly focussed around the left hand bank downstream of the High School. This is an open rural area where banks are continuously moving and sediment is built up to form an embankment. Whilst Lidar levels may not be entirely representative in this area, it does not influence flood mechanisms or flood receptors in town which is the main purpose of this Flood Study.

The majority of LiDAR points, 86%, are within 200mm of the surveyed levels. Details of the ground truthing exercise are shown in Table 5-1Figure 5-1. Based on this assessment, the LiDAR is considered to be a reasonable representation of the ground surface and suitable for modelling at this stage of the Flood Study. If a scheme is progressed from this study, additional topographic survey may be required to improve representation in localised areas, specifically around top of banks.

Table 5-1: Results of ground truthing (LiDAR vs topographic survey)

	Number of points out of the total points tested	Percentage
LiDAR more than 200mm higher than the survey	1 / 28	3.6%
LiDAR between 100 – 200mm higher than the survey	2 / 28	7.2%
LiDAR within 100mm of the survey	19 / 28	68%
LiDAR between 100 – 200mm lower than the survey	3 / 28	10.6%
LiDAR more than 200mm lower than the survey	3 / 28	10.6%

5.2.4 Model runs parameters

The 2D domain was set at a 4m grid size. This was deemed appropriate as the majority of the study area was rural or open space and there were few complex alley ways or walled off details that required a finer resolution.

The 1D/2D model was run unsteady, i.e. time varying flow, for the required events set out in Section 3. This allowed for the flood progression to be fully assessed in both the 1D channel and the 2D floodplain. A 1 second 1D timestep and 2 second 2D timestep were used for all simulations.

Model parameters were kept as default.

5.3 Model amendments – creating a new baseline

In the absence of gauged data, it is standard practice in hydraulic modelling exercises to build the model using surveyed information and then test a range of parameters to determine model sensitivity. Generally, the model constructed from surveyed information gives a good indication of flood mechanisms and frequency and confidence can be improved through the use of sensitivity testing.

However, on running both a high and low frequency event, it was apparent that the model based on survey information was not replicating the type of flooding that has been seen in Kingussie or replicating the level gauge data at Spey Street. This was considered to be because of the significant role that sediment deposition plays during a flood event. This blockage mechanism around structures was not picked up in the survey and this resulted in significantly less flooding than expected. What would typically be classified as the 'baseline' model required amending to allow for a more realistic representation of reality.

Several simulation tests were undertaken with the aim of creating a new baseline model. These tests were based on anecdotal evidence such as railway closures and photographs pre and post events. The level gauge data was also used to estimate a 50% AEP water level. This was done by taking a level that occurred twice in the 4 year record before the hydropower scheme was installed and comparing it with the bank full level at this location as bank full is a crude indication of the 50% AEP event. This is a basic assumption but provides an approximate level to aim for in the absence of better data. This level equated to 228.8mAOD at Spey Street and was used as a level to match to when assessing the 50% AEP runs within this section.

5.3.1 Blockage of bridges

Bridge blockage is a known issue in Kingussie. The 3 lower bridges; Spey Street, the railway bridge and the school access bridge frequently become blocked during flood events with both sediment and woody debris. Given the channel is dredged after a flood event, and that the survey represents a fixed point in time, the survey is likely to be over representing the capacity of the bridges.

The following tests were undertaken to establish if improvements to the baseline could be made.

5.3.1.1 Blockage by difference in survey

There have been numerous studies undertaken in Kingussie resulting in 3 separate surveys of the Gynack Burn. These are dated 2004, 2015 and 2019. Each survey has cross sections located at the same location and they can therefore be compared with the aim of establishing a pattern or range in bed level variation. Whilst this information may be useful in establishing a likely range, it is understood that it is unlikely to pick up the true range in bed level as the maximum and minimum levels are unlikely to have been captured in any of the 3 surveys.

When comparing the levels at the upstream face of the 3 downstream bridges, it was found that levels ranged by between 300-400mm, with the 2004 survey having the highest bed levels and the 2015 survey having the lowest bed levels. Information was provided by Network Rail in relation to dredging activity in the Gynack Burn but accounts did not tie up well with flood events and survey dates and a pattern could not be established.

This 300-400mm difference in the surveyed level may also be backed up by the level gauge data. During the August 2014 event, water level was seen to return to post flood level that was 300mm higher than the pre flood level which could suggest a raise in the bed level and may add confidence to the range in bed level estimate.

The bridges in the model were blocked by the equivalent of a 300-400mm increase in bed level to establish if this matched the bank full level (228.8mAOD) at the gauge. The 50% AEP event was run and levels upstream of Spey Street bridge were approximately 500mm lower than bank full. It was not considered that this level of blockage was representative of the type of mechanism that occurs in reality. This may be due to incorrect bed level increase or the fact that other debris, such as trees, causes additional blockage that is not registered in the surveyed bed levels.

5.3.1.2 Blockage to match 50% AEP gauge level

Given that a blockage equating to 300-400mm increase in bed level was not found to be sufficient to achieve the 50% AEP event level upstream of Spey Street, blockages at the 3 bridges were increased iteratively until the desired level upstream of Spey Street was achieved. The same percentage was applied to each bridge as there was insufficient evidence to allow for tailored blockage at each.

The level of blockage required equated to 54% for all 3 bridges.

5.3.2 Channel capacity

Given that sedimentation is a known issue, an alternative modelling method to bridge blockage is reducing the channel capacity along a certain reach.

The build-up of sediment primarily affects the bed level but channel width is somewhat altered too. Based on anecdotal accounts and historical dredging information from Network Rail, sediment is a particular issue between Spey Street Bridge and the High School Bridge, where gradients are shallower and bridge openings are located in close proximity. It should be noted that the bed level is not uniformly raised along this reach. Instead, bed levels post flood are seen to be raised upstream of structures but lowered downstream of structures as material is scoured out due to increased velocities through the bridges.

To investigate how sediment deposition affects channel capacity and therefore flooding, a simulation was undertaken whereby bed levels were raised by 300-400mm between Spey Street and High School Bridge to represent deposition after a flood event, noting that this is conservative as areas would also likely to be scoured. A simulation was also run whereby the bridges were blocked by a percentage that represented a 300-400mm bed level raise, leaving the channel as surveyed. Blocking bridges is a more simplistic approach to representing the sediment deposition but may be a reasonable representation depending on the mechanism of flooding.

When comparing the raised bed and blocked bridge simulations, there was found to be relatively minor differences in water levels at the peak of the 50% AEP event and therefore minimal difference in out of bank flooding.

This demonstrates that the flooding mechanism is controlled by the backwater effect at the bridges and their reduced capacity rather than a general reduction in channel capacity. It is also considered more appropriate to model the sediment deposition as bridge blockages as raising the bed level is likely to overestimate the reduction in channel capacity as some of the channel would be scoured.

5.3.3 New baseline conclusions

For the purposes of this study, a blockage of 54% was applied to Spey Street bridge, the railway bridge, and the access bridge to the High School to form the new baseline.

This is not a conventional approach to baseline model generation; however, it was considered to more accurately represent the observed flooding and anticipated levels at the gauge. Applying a blockage to the surveyed bridges also ties in with anecdotal and recorded accounts of blockage caused by sediment and woody debris at all 3 structures. Photographs of the blockages can be seen in Appendix B.

Discussions with SEPA were undertaken prior to finalisation of the new baseline scenario to establish if any additional elements were worth considering and to ascertain whether SEPA were happy with the analysis done for this stage of the study. SEPA identified several sensitivity test that had either been already run and if not, were included in the testing. After AECOM's second correspondence, SEPA confirmed they had no further comments and that the approach appears reasonable and proportional to this stage of the study. Correspondence can be found in Appendix F.

5.4 Verification

There is no rainfall or flow gauge data on the Gynack Burn, with only a level gauge at Spey Street so it is not possible to accurately run a calibration simulation. A verification exercise has therefore been undertaken using the August 2014 event as the most anecdotal data is held for this event.

In order to explore the likely magnitude of the August 2014 event, the event rainfall at nearest rainfall gauge at Tromie Bridge was requested from SEPA. The rainfall proceeding the flood event was entered into the FEH Web Service magnitude generator to establish the likely magnitude of the flood event. The results of this analysis showed that the event at Tromie Bridge was likely to around a 2.5%AEP event. This is a much more frequent event than is considered to have occurred on the Gynack Burn. This is likely because the gauge does not adequately pick up rainfall events on the Gynack Burn catchment as that catchment is much higher and steeper, and therefore likely receives different rainfall events. This assumption is backed up when considering the SAAR values. Tromie Bridge has a SAAR or 807 and the Gynack Burn catchment has a SAAR of 1230, demonstrating that the Gynack catchment is much wetter than Tromie Bridge.

Whilst not possible to accurately pinpoint the magnitude of the event on the Gynack Burn, it has been estimated as between a 2% and 1% AEP event based on time stamped photographs of the event and the known time of peak at the gauge at Spey Street. This is based primarily on levels observed on the downstream face of High Street bridge and those upstream of Spey Street bridge in the hydraulic model.

The 2% and 1% events, pre hydropower scheme as it had yet to be installed, were run through the model with the blockage applied as derived in Section 5.3. Both of these flows were found to largely replicate flood levels seen at the High Street Bridge and Spey Street as well as the general flood extents throughout town.

One area where extents and mechanisms were found to not match was the park on the right hand back upstream of Spey Street. Much less water was spilling in the model than was seen to during the August 2014 event. It was noted that during the event, matted grass and debris accumulated on the left hand bank upstream of Spey Street and acted as a raised bank as seen in Figure 5-2. A simulation was run that raised the left hand bank by 400mm, along a 50m stretch upstream of Spey Street to represent the barrier caused by the matted material. This simulation produced flood extents that were more similar to observed conditions in the park. Flow was seen to spill over the right hand bank into the park which matched the photographs taken of the event immediately after the peak.

Another explanation as to why the modelled event was not replicating reality upstream of Spey Street in the park is that the top of bank may have changed or not been accurately represented by the LiDAR. If further investigation was to be carried out, additional topographic survey could be gathered in this area to potentially improve the model.

Whilst useful in understanding how the model behaved when compared to a real event, it is not proposed that this artificial raising of the left hand bank should be carried forward to form part of the baseline as it could not be guaranteed to form during all flood events. Other than the area around the park, the model was found to replicate flooding well based on the available photos and this improves confidence in the model outputs.

Figure 5-2: Photograph from the August 2014 event

5.5 Sensitivity analysis

No level-flow gauge data was available for Kingussie so a full calibration exercise could not be undertaken. It should be noted that there is a level gauge at Spey Street bridge and this information in tandem with anecdotal accounts and photographs has been used to improve the representation of flooding in the model. Full details can be found in Section 5.3.

Whilst the model has been improved to reflect reality, it is still important to understand how changes in inherently uncertain hydraulic model parameters would affect model results.

The aim is to understand the range of model results that could be obtained with variation of these parameters. The intention is not to evaluate an accuracy range or otherwise quantify uncertainty; but to give an indication of the influence certain parameters have and identify if there are significant or disproportionate influences.

The model parameters tested were:

- Flow,
- Manning's Roughness,
- Froude tolerance;
- Bridge parameters;
- Structure Blockages;
- Removal of hydropower scheme.

5.5.1 Flow

5.5.1.1 SEPA recommended uplift of 20%

SEPA recommend in their modelling guidance technical note, that model sensitivity to flow be tested with a 20% increase for the 10% AEP and 0.5% AEP events.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix G.

Increasing the flow by 20% increased the 10% AEP event channel water levels by up to 140mm and the 0.5% AEP event channel water levels by up to 210mm. These maximum increases are located upstream of High Street Bridge. Levels are seen to vary less with an increase in flow in both AEP events downstream of High Street Bridge, with increases in the order of 70mm.

During the 10% AEP event, flood extent is seen to marginally increase with an uplift in flow. Increases in extent are observed throughout town, with a small area of additional flooding located on the right hand bank downstream of Spey Street. Floodplain depths are increased between 10-60mm.

Floodplain extents are again not seen to vary significantly with an increase in flow in the 0.5% AEP event and no new areas of flooding are noted. Depths are seen to increase by between 10-80mm.

Whilst channel water levels were seen to rise upstream of High Street Bridge, this flow is still contained in channel and does not increase flooding in town. Due to the increased in flow, out of bank spill occurs earlier in the event, flooding the same areas as the baseline simulation, before entering into the River Spey flood extent. The topography of the area allows flow to drain north to south and an increase in flow does not result in a significant increase in flooding through town. Key receptors are noted to have minimal increases in flood depth for both events.

The flows used in the baseline model are deemed to be appropriate as they are based on best practice methodologies. It is recommended that uncertainty in design flows are addressed by adoption of an appropriate freeboard allowance if a scheme is considered.

5.5.1.2 Manning’s roughness

In line with SEPA’s modelling guidance Manning’s ‘n’ roughness was increased by 40% in both the 1D channel and 2D floodplain for the 10% and 0.5% AEP events.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 2 Appendix G.

Increasing the roughness by 40% in the fluvial simulations increased the 10% AEP and 0.5% AEP event channel water levels by up to 280mm and 350mm and respectively. This increase was noted primarily upstream of High Street Bridge.

During the fluvial simulations, the 10% AEP event flood extent was seen to increase marginally, with the only new area of flooding on the right hand bank downstream of Spey Street Bridge. Flood depths were seen to increase by between 10mm and 50mm when roughness was uplifted. Flood extents were also seen to increase marginally in the 0.5% AEP event but with no new areas of flooding. Depths were seen to increase by between 10mm and 60mm when roughness was uplifted.

Reasonable increases in channel depths are not seen to correspond to large increases in flooding throughout Kingussie. The 1D model is seen to be moderately sensitive to changes in roughness but key receptors are not found be significantly influenced. The roughness values used in the baseline model are deemed to be appropriate as they are based on channel type and geometry and uplifting them is not found to significantly affect floodplain model results. It is recommended that uncertainty in channel and floodplain roughness is addressed by adoption of an appropriate freeboard allowance if a scheme is considered.

5.5.1.3 Froude limit

Altering the Froude limit tolerances within the run IEF file was assessed to establish if the model was sensitive to a change in this parameter given the steep nature of the catchment. The default Froude limits which have been used in the baseline simulations are 0.75 -0.9. Within this sensitivity test, these limits were changed to 0.85 and 1 to alter when the model would calculate the change between supercritical and subcritical flow.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 3 Appendix G.

Increasing the Froude limits increased the 10% AEP and 0.5% AEP event channel water levels by up to 30mm and 75mm and respectively. This increase was noted upstream of High Street Bridge in the steeper sections of the model and was not found to affect the reach downstream of High Street Bridge.

Flood extents are not affected with this change in 1D parameter.

Whilst the watercourse is relatively steep, supercritical flow (Froude number >1) is not experienced up to the 0.5% AEP event which is likely to be the main reason that a change in Froude tolerances had limited effect on the model results. The model was not found to be sensitive to an uplift in Froude limit and no further action is required.

5.5.1.4 Bridge parameters

Altering the bridge calibration coefficient was undertaken to establish how sensitive the model was to changes in the bridge equations applied at structures. The default value of 1 means that full bridge equations are applied and a value of 0 disables the effect of the bridge. A value of 0.7 was applied to all 4 bridges in the model for this sensitivity test and compared with the baseline results which had the default value of 1.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 4 Appendix G.

Decreasing the effect of the bridge decreased water levels for the 10% AEP and 0.5% AEP events by up to 8mm and 35mm and respectively. This decrease was noted upstream of High Street Bridge and was not found to affect the reach downstream of High Street Bridge.

Flood extents are not affected with this change in bridge parameter.

The model was not found to be sensitive to a change in bridge parameters and no further action is required.

5.5.1.5 Blockages

Blockage scenarios were tested for the 10% and 0.5% AEP events to assess the impacts on flooding should a structure become partially blocked during a flood event. A total of 4 structures are located in the reach through Kingussie and have the potential to cause increased flooding if they became blocked. There are anecdotal accounts of blockage at the three downstream structures, however none have been noted at the High Street Bridge. For completeness, this structure will still be included in the assessment.

Sediment deposition is a significant problem in Kingussie and the baseline scenario created and tested in Section 5.3 already contains a blockage element to align with anecdotal flood accounts. This is what forms the 'final' baseline. The purpose of this further blockage sensitivity testing detailed in this section is to establish how a blockage larger than that estimated to occur during a flood event would affect flooding at key receptors and to identify structures at particular risk of blockage.

Structures were modelled as partially blocked to 50% of the flow area (on top of the existing blockage applied as part of the new baseline) by reducing cross sectional area. This blockage scenario is considered conservative.

This exercise aims to understand the impact of further blockage and does not indicate that it is likely to occur.

Each blockage scenario was run separately, assuming that a significant blockage would not occur on 2 structures at once. It should be noted that from anecdotal accounts that several of the structures can block at once but this has already been applied to the baseline model and it was considered appropriate to block one structure at a time for this sensitivity. Whilst extremely unlikely to occur, for completeness, a simulation was also run whereby all structures were blocked by this further 50%.

Blockage locations are shown in Figure 5-3. Tabulated results with changes to channel water elevations at various locations are displayed in Table 5 & 6 Appendix G.

Figure 5-3: Blockage locations

During blockage scenario 1 at High Street, flood depths in channel were raised upstream of High Street Bridge by around 1m in the 10% AEP event and 1.5m in the 05% AEP event. Water levels elsewhere in the 1D network were not affected in the 10% AEP event and are seen to decrease by approximately 100mm in the 0.5% AEP event due to increased out of bank flow upstream.

In the 2D floodplain, no difference was noted in the 10% AEP event. During the 0.5% AEP event, a new area of flooding upstream of Spey Street on the left bank is caused by the increased channel water levels. Elsewhere there are very minor increases and decreases in the order of 10-20mm.

During blockage scenario 2 at Spey Street, flood depths in channel were raised upstream of Spey Street by around 120mm in the 10% AEP event and 50mm in the 05% AEP event. Due to increased water levels upstream of Spey Street, and therefore increased out of bank spill, water levels downstream of Spey Street were reduced by approximately 100mm in both the 10% AEP and 0.5% AEP events.

In the 2D floodplain, slight increases in levels of around 10-60mm around Spey Street were observed at the 10% AEP event. During the 0.5% AEP event, there are very minor increases and decreases in the order of 5-50mm.

During blockage scenario 3 at the railway, flood depths in channel were raised upstream of the rail bridge by around 100mm in the 10% AEP event and 50mm in the 05% AEP event. Due to increased water levels upstream of the railway bridge, and therefore increased out of bank spill, water levels downstream of the railway bridge were reduced by approximately 250mm in the 10% AEP event and 300mm in the 0.5% AEP event.

In the 2D floodplain, slight increases in levels of around 5-50mm around the bowling green, Ruthven Road and the High School were observed at the 10% AEP event. During the 0.5% AEP event, there are very minor increases and decreases in the order of 5-20mm.

During blockage scenario 4 at the High School, flood depths in channel were raised upstream of the High School bridge by around 500mm in the 10% AEP event and 250mm in the 0.5% AEP event. Water levels were also increased upstream of the rail bridge by around 50mm in both events due to backwater affect. Due to increased water levels upstream of the High School bridge, and therefore increased out of bank spill, water levels downstream of the bridge were reduced by approximately 100mm in the 10% AEP event and 150mm in the 0.5% AEP event.

In the 2D floodplain, slight increases in levels of around 5-40mm around the bowling green, Ruthven Road and the High School were observed at the 10% AEP event. During the 0.5% AEP event, there are very minor increases and decreases in the order of 5-40mm.

During the blockage scenario whereby all bridges were blocked, flood depths in channel were raised upstream of all structures by between 50mm and 900mm in the 10% AEP event and between 50mm and 1500mm in the 0.5% AEP event. The largest increase was seen upstream of High Street bridge and the lowest observed at the railway bridge, where the 0.5% AEP event actually showed a reduction in water level due to increased spill upstream. Due to increased spill upstream of the High School bridge, water levels downstream of the High School bridge were reduced by approximately 200mm in the 10% AEP event and 250mm in the 0.5% AEP event

In the 2D floodplain, increases in levels of around 50-200mm around the bowling green, Ruthven Road and the High School were observed at the 10% AEP event. During the 0.5% AEP event, there are very minor increases and decreases in the order of 50mm, with an additional new area of flooding upstream of High Street bridge.

This sensitivity analysis is not an analysis on the likelihood of blockage, but an assessment of the severity of flooding impacts should a blockage occur at a particular structure. Due to the topography of Kingussie, increased out of bank flow as a result of blockage was not found to cause significant increases in floodplain depths as water drained to the Spey floodplain. It was also found that no one structure was overly sensitive to blockage.

The model is not found to be sensitive to increases blockage and no further action is required.

5.5.1.6 Removal of hydropower scheme

Given that the hydropower scheme attenuates the peak of a flood event, the impact of the scheme being out of operation was investigated as this information could feed into any future flood scheme design.

Table 5-2 displays the peak flows entering the town model with and without the hydropower scheme. The with scheme model show that the scheme reduces the peak flow by between 10-15%. Tabulated results with changes to channel water elevations at various locations are displayed in Table 7 Appendix G.

Table 5-2: Peak flows with and without hydropower scheme.

	With Scheme (baseline) peak flow (m^3/s)	Without Scheme peak flow (m^3/s)	Difference (m^3/s)
50% AEP event	11.84	14.59	2.75
2% AEP event	30.43	36.18	5.75
1% AEP event	34.79	41.38	6.59
0.5% AEP event	40.2	47.03	6.83

A 10-15% reduction in peak flow is seen to affect water levels downstream throughout Kingussie.

During a 50% AEP event, water levels in channel are increased by 100mm on average, with the largest increase experienced upstream of Spey Street of 400mm. The flood extent is seen to differ in small pockets around the High School, Market Lane and the railway, with increases in depth in the order of 10-30mm.

During a 0.5% AEP event, water levels in channel are increased by 100mm on average, with the largest increase experienced downstream of High Street bridge of 150mm. This increase in channel water level means that flow exists the channel earlier in an event. However due to the topography of Kingussie, the flood extent is not seen to be altered, with very minor differences in flood depth of between 5- 10mm.

Whilst little differences is observed in peak extents and depths between events, it should be noted that the hydropower scheme does result in lower flows so will reduce frequency of flooding at smaller events.

Whilst some minor differences are noted in flood depths and extents when comparing return periods, they are not considered to be significant and the standard of protection and scheme could provide would not be altered significantly. The risk of the hydropower scheme not being operational could be built into the freeboard allowance should a flood scheme be considered.

6. Results

6.1 Baseline

The results discussed in this section are based on the updated baseline model that was derived after additional testing. This equates to a 54% blockage being applied to the 3 structures through town to replicate the flooding seen in Kingussie.

During the 0.5% AEP event, flooding first occurs upstream of the Railway bridge approximately 2 hours before the peak in the event. This flow travels in both directions along the railway line before spilling into the High School and the low land south of the bowling green to the east and onto Ruthven Road to the west. During this event, depths are greatest on the land around the bowling green and at the High School, where they are in the order of 300-700mm. Out of bank flow is then seen to occur upstream of Spey Street Bridge on the left hand bank, flowing along Spey Street as well as crossing the open land adjacent to the bowling green. The flow along Spey Street is relatively shallow, averaging 90mm, and is seen to reach as far as Kingussie Parish Church, before travelling south, under the railway line around the wastewater treatment works. These floodwaters then combine with flooding on the Spey floodplain. Around the same time as flooding on the left hand bank at Spey Street, water exits the channel on the right hand bank at the park and flows towards the Silverfjord hotel, railway station and industrial areas around Market Lane to depths ranging from 10-200mm. Floodwaters again flow southwards towards the Spey floodplain.

At the peak of the event, the flood extents are seen to cover much of the High School, Spey Street, the bowling green and adjacent land and Ruthven road as well as the railway station and Market Street. Minimal flooding is noted upstream of Spey Street.

A level equivalent of bank full in the Spey was applied for all model runs. Full details of the sensitivity testing used to determine a suitable level in the Spey can be found in Section 4. Flooding from the Spey extends into the floodplain, filling low lying areas to the south of Kingussie. It is not seen to affect flooding in the Gynack Burn and does not affect any properties or the railway line.

The 0.5% AEP event flood extent is shown in Figure 6-1. A full range of flood maps can be seen in Appendix H. Tabulated results can be found in Table in Appendix G.

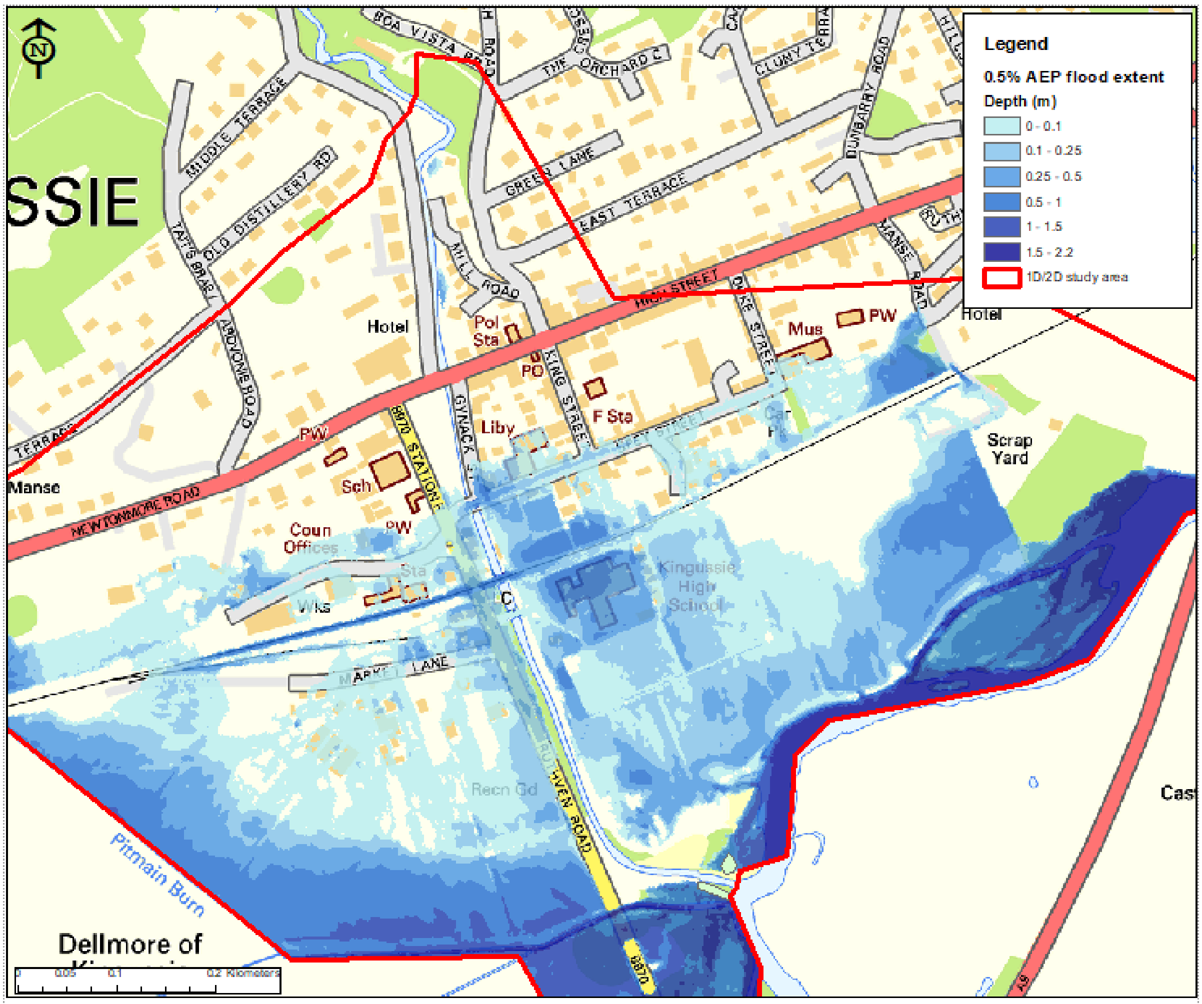

Figure 6-1: 0.5% AEP fluvial flood event

The 0.5% AEP event plus climate change follows the same flood mechanisms as the 0.5% AEP present day event, albeit with an increase in flood depths. Maximum depths of up to 900mm are noted in the area around the bowling green and the High School. More marginal increases are noted elsewhere resulting in a slight increase in flood extent. No new areas of flooding are noted.

During the 0.1% AEP current day and climate change events, flooding is observed on the left hand bank upstream of High Street. This flow exits around Mill Road, crosses High Street and inundates areas behind Gynack Street.

During higher frequency events, flooding first occurs upstream of the railway bridge during the 50% AEP event and spreads east and west along the railway, inundating areas around the bowling green, High School and Ruthven Road in the same manner as the 0.5% AEP event, albeit to lesser depths. Flooding occurs upstream of Spey Street on the left hand bank from the 20% AEP event, affecting Spey Street and land adjacent to the bowling green. Flooding on the right bank upstream of Spey Street at the park occurs from the 4% AEP event, affecting areas around the Silverfjord Hotel, Ruthven Road and the railway station. Flooding during these more frequent events is generally shallow with the exception of the area around the bowling green and the High School.

Based on anecdotal evidence, the modelled flooding seen in these higher frequency events may be an overestimation. This relates to the way in which the baseline has been created, using the standardised blockage of 54% to tie in with the gauge at Spey Street in the absence of more detailed sediment deposition and gauged data. By matching the level at the Spey Street gauge, blockage of the downstream structures may be overestimated and result in potentially increased early flooding around the railway. The representation of the baseline scenario is however considered appropriate for this stage of the study given the lack of recorded data and generally shows shallow depths of less that 100mm.

7. Conclusions

AECOM have been commissioned by The Highland Council to undertake a Flood Study in Kingussie, Scotland. Kingussie is in close proximity to two watercourses, the River Spey lies to the south of the town and the Gynack Burn runs through the centre. Frequent flooding from both these sources has affected Kingussie and the surrounding area and this Flood Study aims to develop an understanding of the baseline flood mechanisms and associated damages.

Existing studies have been undertaken in Kingussie and some of these elements, such as the 2015 model of the upstream catchment, were amended and used within this study.

7.1 Model inflows

The modelling in this study was broken into 2 parts. The upstream catchment, including the hydropower scheme, was represented by a previous 1D model from 2015 with some minor adjustments based on up to date construction drawings and additional reconciliation of the flows. This model was run with and without the hydropower scheme and provided the inflows for the 1D/2D model of the town that was developed for this Flood Study.

7.1.1 Upstream model hydrology

In agreement with SEPA, peak flows at the confluence with the River Spey were taken from the 2015 Flood study as well as the catchment delineations and descriptors that fed into the upstream model.

In the 2015 study, a statistical and FEH rainfall-runoff analysis were both undertaken to the confluence with the River Spey to provide a flow to reconcile the subcatchments to. The rainfall-runoff method was found to produce the higher of the two estimates. Given the relatively small size of the catchment, and the attenuation upstream, the FEH RR method was deemed appropriate. This approach was confirmed by SEPA for use in this study. A climate change uplift of a 35% increase in rainfall was applied in accordance with SEPA guidance.

Due to the changes in the 1D model, such as improved schematisation of the lateral weir arrangement, the reconciliation process had to be undertaken again by iteratively changing the SPRHOST values in the hydrology unit so that the downstream flow in the model would match the FEH rainfall-runoff derived peaks.

7.1.2 Town model

The flow hydrographs at section GYNA01_1016 of the upstream hydropower scheme model were extracted and used as the inflow to the separate 1D/2D model that was constructed as part of this Flood Study. This node was selected as it was the furthest surveyed upstream section in the 1D/2D model and all flow was within channel.

7.1.3 Joint probability

The Gynack Burn flows into the River Spey downstream of Kingussie. Water levels in the River Spey have the potential to affect water levels in the Gynack Burn, and therefore increase flooding in Kingussie; the worst-case situation being concurrent peak flow and matched return periods in both watercourses. However, due to the significant difference in catchment area, it is deemed extremely unlikely that the peaks and AEP events would be matched.

An analysis of joint probability of coincidence in peaks would require gauged data on all watercourses. As this data is not available on the Gynack Burn, a sensitivity assessment was undertaken using a range of simulations to determine how levels in the Gynack Burn are influenced by levels in the River Spey.

It was found that levels on the River Spey did not influence levels in the Gynack Burn sufficiently far enough upstream to alter flood mechanisms in town. A level equivalent to bank full was applied for all events on the Gynack Burn.

7.2 Hydraulic modelling

7.2.1 Existing upstream hydropower model

The previous model had been developed before the hydropower scheme had been constructed and was therefore based on the best available information at the time. Construction drawings of the weir arrangement and bypass channel have since been made available and were used to set structure and channel dimensions within this Flood Study.

The hydrology was reconciled again as part of this Flood Study due to the modelling alterations in the scheme. The downstream peak flows established in the 2015 Study were used in the reconciliation process as agreed with SEPA.

The existing model of the upstream catchment, with and without the hydropower scheme was updated as part of this modelling exercise to provide the inflows for the 1D/2D model through town developed for this Flood Study.

7.2.2 1D/2D town model

A single 1D/2D hydraulic model has been constructed of the Gynack Burn through Kingussie and a small section of the River Spey for this Flood Study. This model consists of a one dimension element representing the Gynack Burn river channel built in Flood modeller and a two dimensional element representing the floodplain and River Spey constructed in Tuflow. Both of which are industry standard hydrodynamic modelling software

A one dimensional model of the Gynack Burn was constructed using surveyed river cross sections and inline structures. The model consists of 22 surveyed river sections and 5 bridges. Channel and bank Manning's 'n' roughness values were selected based on photographs and the site visit. The upstream extent of the model is located 300m upstream of the High Street bridge so that all flow was contained in bank. This is where the inflow hydrographs, derived from the upstream hydropower model, were applied. The 1D model extends to the confluence with the River Spey, where an HT boundary was applied. A joint probability assessment of flows on the Gynack Burn and the Spey was undertaken and details can be found in Section 4.

A 2D representation of the floodplain within Kingussie was linked to the 1D channel and constructed using LiDAR, 1D/2D links of the riverbanks, roughness layers and DTM modifications where necessary. The LiDAR was ground truthed against surveyed points and found to be reasonably representative. Levels in the River Spey were applied as 2D boundaries and levels were established through the joint probability exercise.

7.2.3 New baseline

In the absence of gauged data, it is standard practice in hydraulic modelling exercises to build the model using surveyed information and then test a range of parameters to determine model sensitivity. Generally, the model constructed from surveyed information gives a good indication of flood mechanisms and frequency and confidence can be improved through sensitivity testing.

However, on running both a high and low frequency event, it was apparent that the model based on survey information was not replicating observed flooding in Kingussie or replicating the level gauge data at Spey Street. This was considered to be because of the significant role that sediment deposition plays during a flood event which reduces the capacity of the structures.

Several simulation tests were undertaken with the aim of creating a new baseline model. These tests were based on anecdotal evidence such as railway closures and photographs pre and post events. Whilst crude, a level of 228.8mAOD at Spey Street was established as being approximately a 50% AEP level and was used as a level to match to throughout this testing. The following simulations were undertaken with the aim of developing an updated baseline that was more representative of flood conditions:

- Bridges blocked by a percentage equivalent to the difference in bed level between the 3 surveys (300-400mm);
- Bridges iteratively blocked to match the required level (228.8mAOD);
- Channel capacity reduced (bed raised by 300-400mm) along the reach from Spey Street to the High School.

Blocking the bridges by a percentage equivalent to the difference in surveyed bed levels was found to result in water levels at the Spey Street gauge much lower than expected, indicating that blockage during a flood event was likely higher. Raising the bed level between Spey Street and the school access bridge by 300-400mm was also found to produce lower water levels than expected.

It was found that a 54% blockage applied to all 3 bridges resulted in the desired level at the guage. For the purposes of this study, a blockage of 54% was applied to Spey Street, the railway bridge, and the access bridge to the High School to form the new baseline. This is not a conventional approach to baseline model generation;

however it was considered to more accurately represent the observed flooding and anticipated levels at the gauge. Applying a blockage to the surveyed bridges also ties in with anecdotal and recorded accounts of blockage caused by sediment and woody debris at all 3 structures

7.2.4 Sensitivity testing and verification

A full range of sensitivity tests were undertaken including flow, roughness, bridge parameters, Froude tolerances, bridge blockage and removal of the hydropower scheme.

Changes to parameters such as roughness, flow and removal of the hydropower scheme were found to result in flooding earlier in an event. However, generally, the model was not found to be sensitive to changes in parameters which can be largely attributed to the topography of Kingussie, allowing additional flood water to flow into the River Spey floodplain rather than increasing flooding within the town.

Due to lack of gauged data, a full calibration exercise could not be undertaken. However, the verification exercise demonstrated that the model replicated the flooding observed during the August 2014 event reasonably well which improves confidence in the model.

7.3 Baseline flood risk

During the 0.5% AEP event, flooding first occurs upstream of the railway bridge approximately 2 hours before the peak in the event. This flow travels in both directions along the railway line before spilling into the High School and the low land south of the bowling green to the east and onto Ruthven Road to the west. During this event, depths are greatest on the land around the bowling green and at the High School, where they are in the order of 300-700mm. Out of bank flow is then seen to occur upstream of Spey Street Bridge on the left hand bank, flowing along Spey Street as well as crossing the open land adjacent to the bowling green. The flow along Spey Street is relatively shallow, averaging 90mm, and is seen to reach as far as Kingussie Parish Church, before travelling south, under the railway line around the wastewater treatment works. These floodwaters then combine with flooding on the Spey floodplain. Around the same time as flooding on the left hand bank at Spey Street, water exits the channel on the right hand back at the park and flows towards the Silverfjord hotel, the railway station and industrial areas around Market Lane to depths ranging from 10-200mm. Floodwaters again flow southwards towards the Spey floodplain.

At the peak of the event, the flood extents are seen to cover much of the High School, Spey Street, the bowling green and adjacent land and Ruthven road as well as the railway station and Market Street. Minimal flooding is noted upstream of Spey Street.

A level equivalent of bank full in the Spey was applied for all model runs. Full details of the sensitivity testing used to determine a suitable level in the Spey can be found in Section 4. Flooding from the Spey extends into the floodplain, filling low lying areas to the south of Kingussie. It is not seen to affect any properties or the railway line.

The 0.5% AEP event plus climate change follows the same flood mechanisms as the 0.5% AEP present day event, albeit with an increase in flood depths. Maximum depths of up to 900mm are noted in the area around the bowling green and the High School. More marginal increases are noted elsewhere resulting in a slight increase in flood extent.

During higher frequency events, flooding first occurs upstream of the railway bridge during the 50% AEP event and spreads east and west along the railway, inundating areas around the bowling green, High School and Ruthven Road in the same manner as the 0.5% AEP event. Flooding occurs upstream of Spey Street on the left hand bank from the 20% AEP event, affecting Spey Street and land adjacent to the bowling green. Flooding on the right bank upstream of Spey Street occurs from the 4% AEP event, affecting areas around the railway station.

8. Next Steps

An economic damage assessment has been undertaken to establish the likely costs of the current flooding in Kingussie. The findings of both the baseline flooding report and the economic report allow for a detailed understanding of current flooding and associated costs, which will inform whether a flood protection scheme is likely to be viable or not. If a scheme is considered to be potentially viable the next stage would be to undertake a long list to short list selection using the baseline conditions set out in this study.

The baseline flood study has shown that the transport of coarse sediment through Kingussie has a notable effect on flood levels and the subsequent extent of out of bank flooding affecting the town. Given that any flood protection works are likely to be heavily focussed towards sediment management, it is strongly recommended that a sediment transport study be undertaken as a next stage of the project. The aim of the study would be to gain an understanding of the volume and rate of transportation of material delivered to Kingussie and would involve the following tasks:

- Fluvial audit survey of the river by an experienced geomorphologist, identifying sources and sinks of coarse sediment in the system.
- Sediment sampling to record the size grading of the material in the river.
- Sediment modelling, to quantify zones of sediment erosion, transport and deposition.
- Combine flood maps and sediment zones to identify sediment risk areas.
- Link sediment management with flood risk and WFD objectives.
- Identify sustainable sediment management options.

Appendix A – Site photographs

Appendix B – August 2014 flood event photos

Appendix C – Hydropower scheme

Appendix D – Topographic survey

Appendix E – Hydraulic model build

Appendix F – SEPA correspondence

Appendix G – Model results

Appendix H – Floodmaps