Ballater FPS Report

Hydrology Chapter

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1 HYDROLOGY

1.1 INTRODUCTION

The hydrological analysis for the Ballater Flood Protection Study focuses on the main source of flood risk to the town of Ballater in Aberdeenshire from the River Dee and its two significant tributary inflows the Rivers Gairn and Muick. All three rivers can be considered well gauged for the purposes of historical flood analysis and design flood flow estimation having long term, flood rated hydrometric gauging stations located within the reaches just upstream of Ballater. This analysis relates predominantly to these records through the use of the methodologies laid out in the Flood Estimation Handbook (FEH).

1.1.1 Catchment Review

The main Study catchments are shown in Figure 1.1 including the major tributary catchments; the River Muick and the River Gairn.

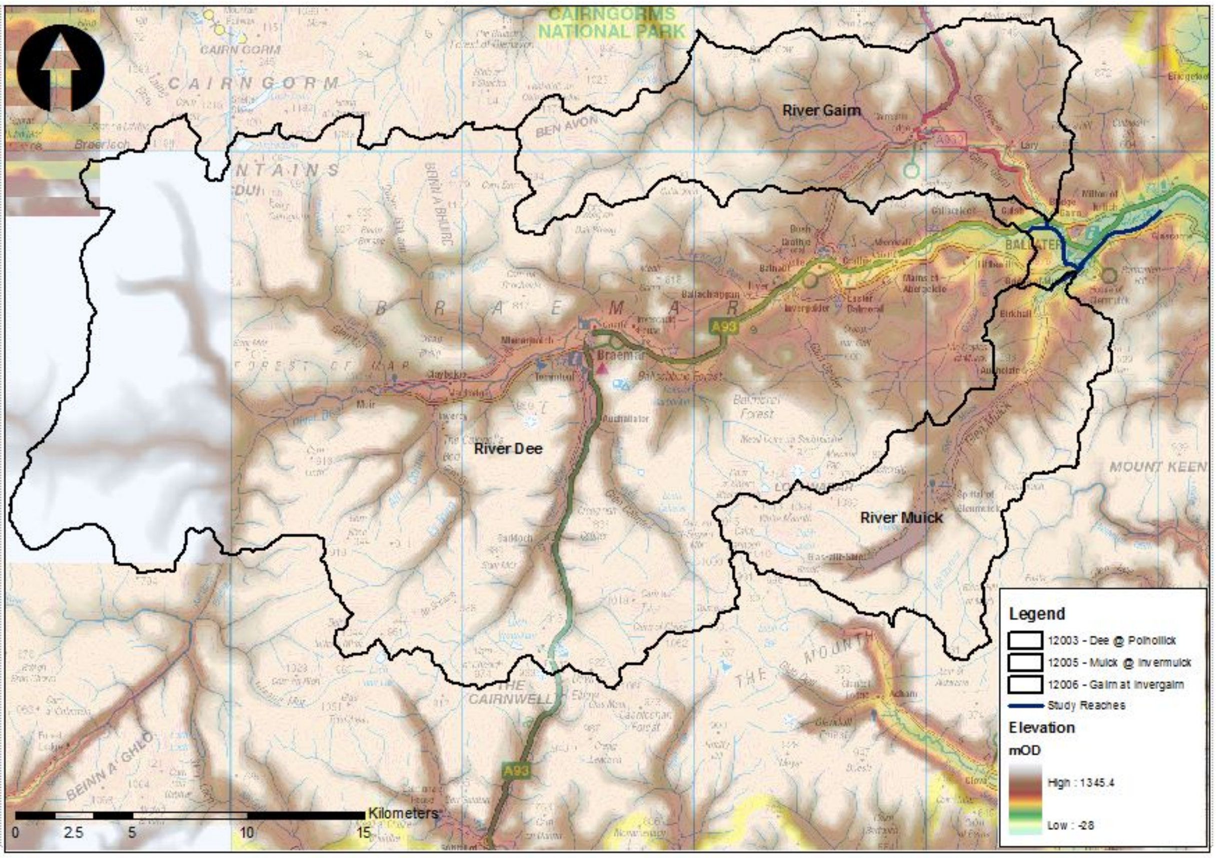


Figure 1.1 – Main Study Catchments

1.1.1.1 The River Dee Catchment

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

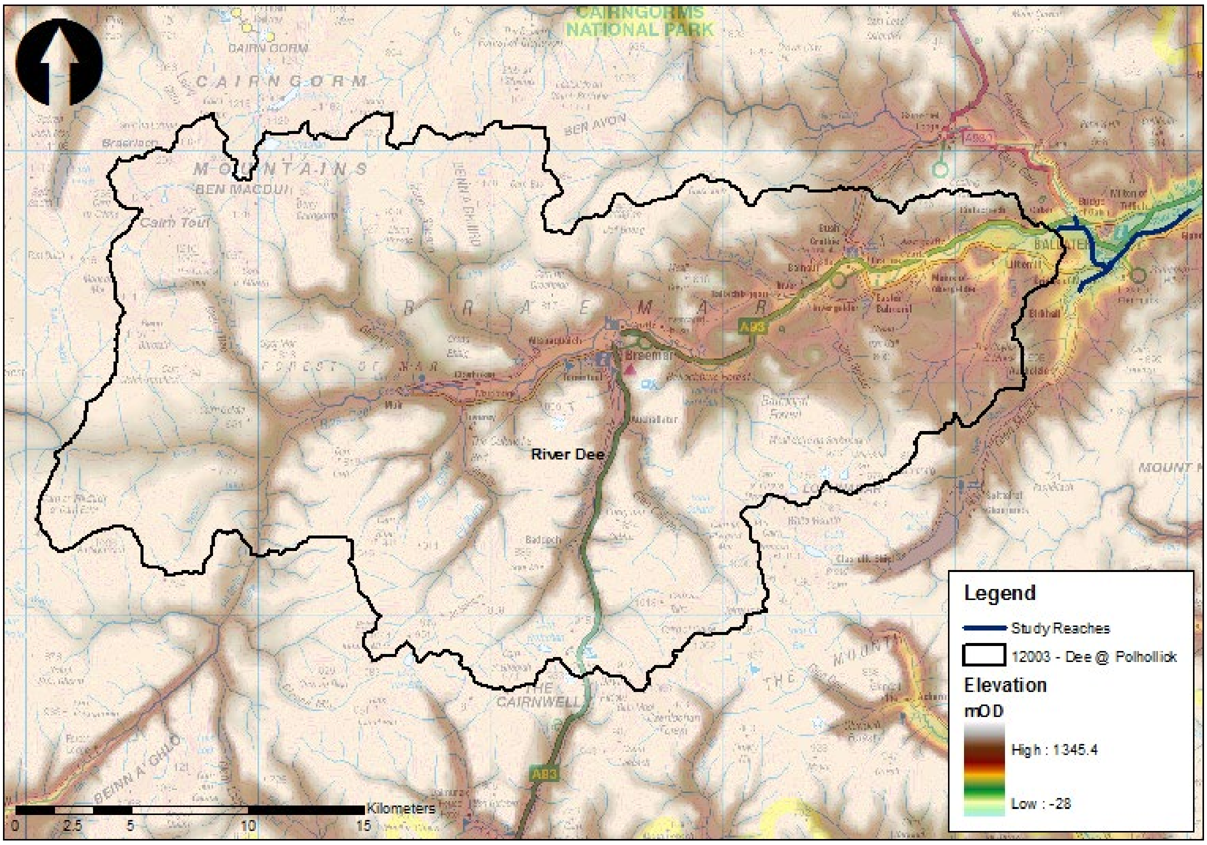


Figure 1.2 River Dee Catchment

1.1.1.2 The River Muick Catchment

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

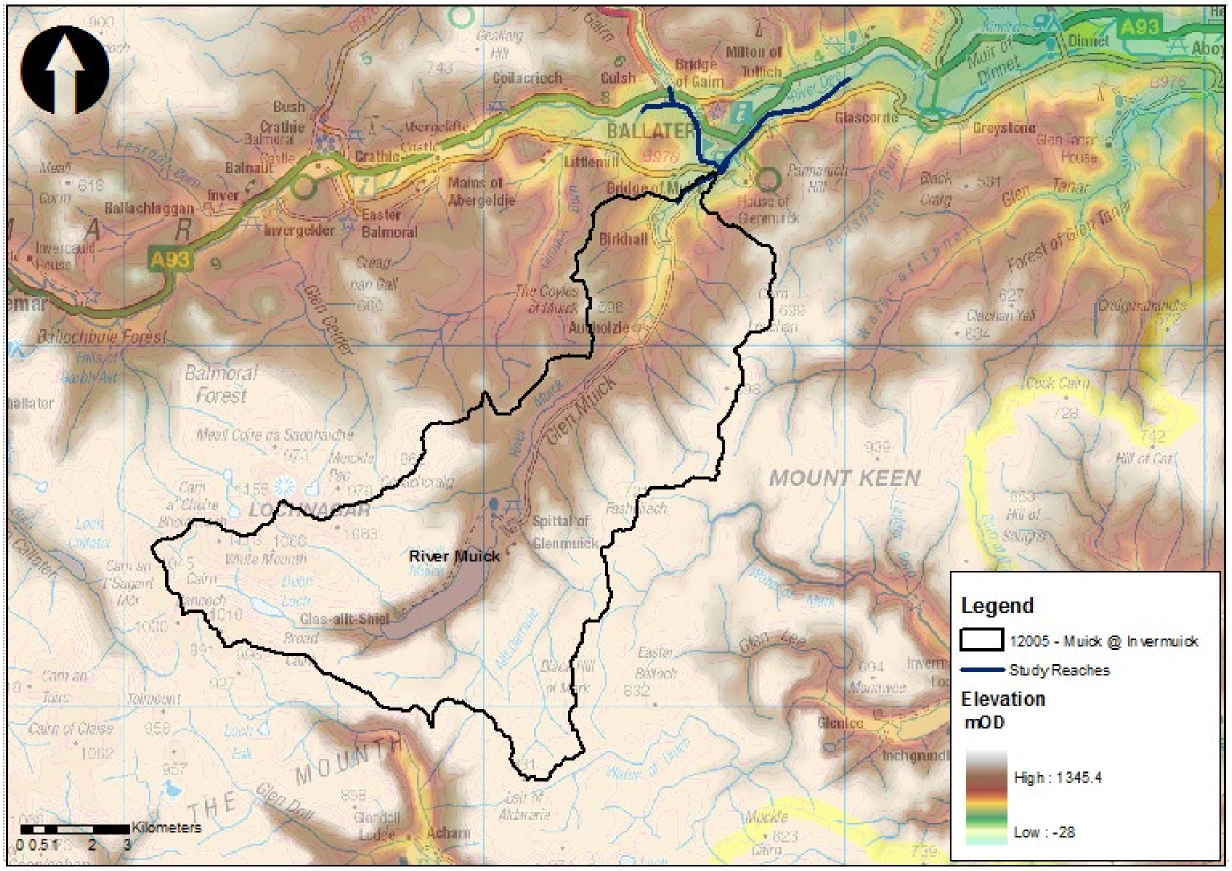


Figure 1.3 River Muick Catchment

1.1.1.3 The River Gairn Catchment

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

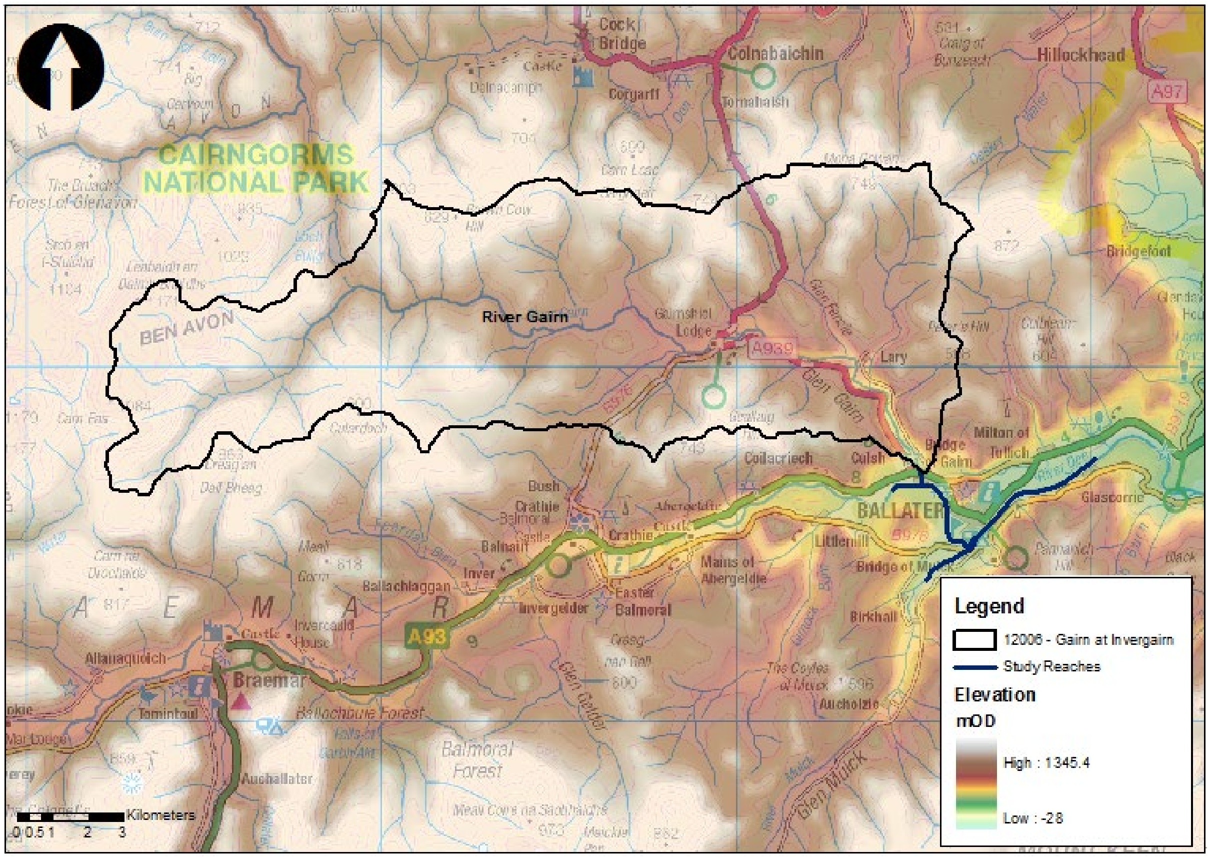


Figure 1.4 River Gairn Catchment

The main catchment descriptors for the three rivers upstream of Ballater are presented in Table 1.1. The catchment descriptor URBEXT2000 describing the urbanisation within the catchment has not been presented here despite the effect it may have on flood flows. This is because the URBEXT2000 values are all very low (<0.0007) meaning the catchments may all be treated as entirely rural for the purposes of hydrological analysis.

Table 1.1 - Summary of Main Catchment Descriptors

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

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

1.1.2 Historic Flood Events

As part of this study, RPS has reviewed historic flood records related to fluvial flooding in the Ballater area. Sources of information on events include internet searches, community magazines, consideration of the hydrometric data and a review of the Chronology of British Hydrological Events. Further information on the calibration/validation data recorded in relation to these events is provided within the hydraulic modelling chapter.

The most recent significant flood event for which records can be found in relation to the Ballater area occurred in December 2015 (Storm Frank) when the River Dee was reported as having burst its banks causing damages to Ballater Caravan Park and local businesses. This event is the largest on record at the Dee gauging station just upstream of Ballater at Polhollick. There is evidence that this area was also affected in August 2014 as the River Dee achieved the second highest level on record at the Polholick gauge on the Dee and the highest on record at the upper catchment gauging station at Mar Lodge and also at the Invergairn station on the Gairn, just upstream of Ballater. During this event the caravan park was evacuated and road closures put in place. A summary of the historic event records is shown in Table 1.2.

Table 1.2 - Summary of historic flood records in the Ballater Area

Date	Waterbody	Scale or Magnitude	Source
Aug 1829	River Dee	The Muckle Spate was a great flood in August 1829. The River Dee rose rapidly above its normal level, many bridges were washed away including the bridge at Ballater.	Chronology of British Hydrological Events website.
1877	River Dee	Reports of cellars in the lower part of Ballater were flooded.	SEPA
1920	River Dee	Ballater town and roads infrastructure were flooded. Reports mention the main cause was heavy runoff from bare fields post clear felling. The flood of 1920 was also reported to have drove the river into its old course at Inch of Culter.	SEPA / The Ballater & Crathie Eagle, Winter 2014, Issue 76, Dee Catchment partnership
Jan 1929	River Dee	Ballater town and roads infrastructure were flooded.	SEPA
1990	River Dee	Local reports are Deebank Road, Bridge Street Richmond Place and Braichlie Road were all badly flooded with water coming up through drains.	Aberdeenshire.gov.uk
1937	River Dee	The River Dee burst its bank and caused significant flooding.	Aberdeen Journals
Aug 2014	River Dee	The caravan park was closed and 150 people were evacuated from the site as well as a number of roads being closed as a result of the River Dee Flooding.	Newspaper/Youtube/SEPA
30th Dec 2015	River Dee	Footage available on Youtube indicates the River Dee burst its banks – this caused flooding to over 300 residential and commercial properties resulting in 100 residents having to be evacuated and substantial damage occurring to the Cambus O'May Bridge, a section of the A93 between Ballater and Balmoral Castle as well as the police station. An article in The Telegraph stated that it was estimated to "be the highest river level on the Dee since 1928"	Newspaper/Youtube/SEPA

Flooding occurred on the River Dee in 1829, destroying the Ballater Bridge and in 1839, the bridge at Tullich was damaged. In 1877, cellars in the lower part of Ballater were flooded, and in 1920 and 1929 the town and roads were flooded. Local reports are that in the late 1980s the bottom part of the village was badly flooded with water coming up through the drains. Deebank Road, Bridge Street Richmond Place, Braichlie Road were all affected. In 2008, surface runoff entered the Netherley Guest House at Netherley Place. In August 2014, the caravan park and a number of roads were closed due to flooding from the River Dee. As a result, 150 people were evacuated from the caravan site.

1.1.3 Available Hydrometric Data

SEPA hydrometry were consulted with regards to the available hydrometric data within the River Dee catchment. There are several flow gauges identified, however, SEPA advised caution in using certain periods of data for some of the stations. As a result, select record periods Table 1.3 were considered for inclusion in the hydrological analysis and the geographic locations of the stations are presented in Figure 1.5.

Table 1.3 – AMAX Records Used in the Analysis

Name	Station Number	QMED_AMAX	Record Period	HiFlows UK
Dee @ Polhollick	12003	302.60	1976 - 2015	YES
Muick @ Invermuick	12005	69.79	1977 - 2015	YES
Gairn @ Invergairn	12006	58.80	1978 - 2015	YES
Dee @ Woodend	12001	446.21	1929 - 2015	YES

All of the gauges above are listed in the HiFlows UK dataset, however, additional hydrometric data has been added following consultation with SEPA. These additional records received from SEPA generally extend the end of the observed record period from hydrometric year 2005 to hydrometric year 2015. Crucially this means that the record periods all included the observed peak flow from Storm Frank recorded on 30th December 2015. Crucially this event represents the largest event in three of the four gauged records (AMAX1) and the second largest for the Invergairn gauge (AMAX2) and therefore it would be expected to significantly influence the understanding of flood frequency within the catchment.

Three of the gauging stations are located just upstream of Ballater (Dee at Polhollick, Invergairn and Invermuick) and as such they represent the core stations which have been used as the basis for design flow estimation in relation to the hydraulic analysis at Ballater. The Dee at Woodend gauging station has been used for comparison of the estimated downstream flood frequency conditions in an attempt to validate the cumulative design flows at the downstream extents.

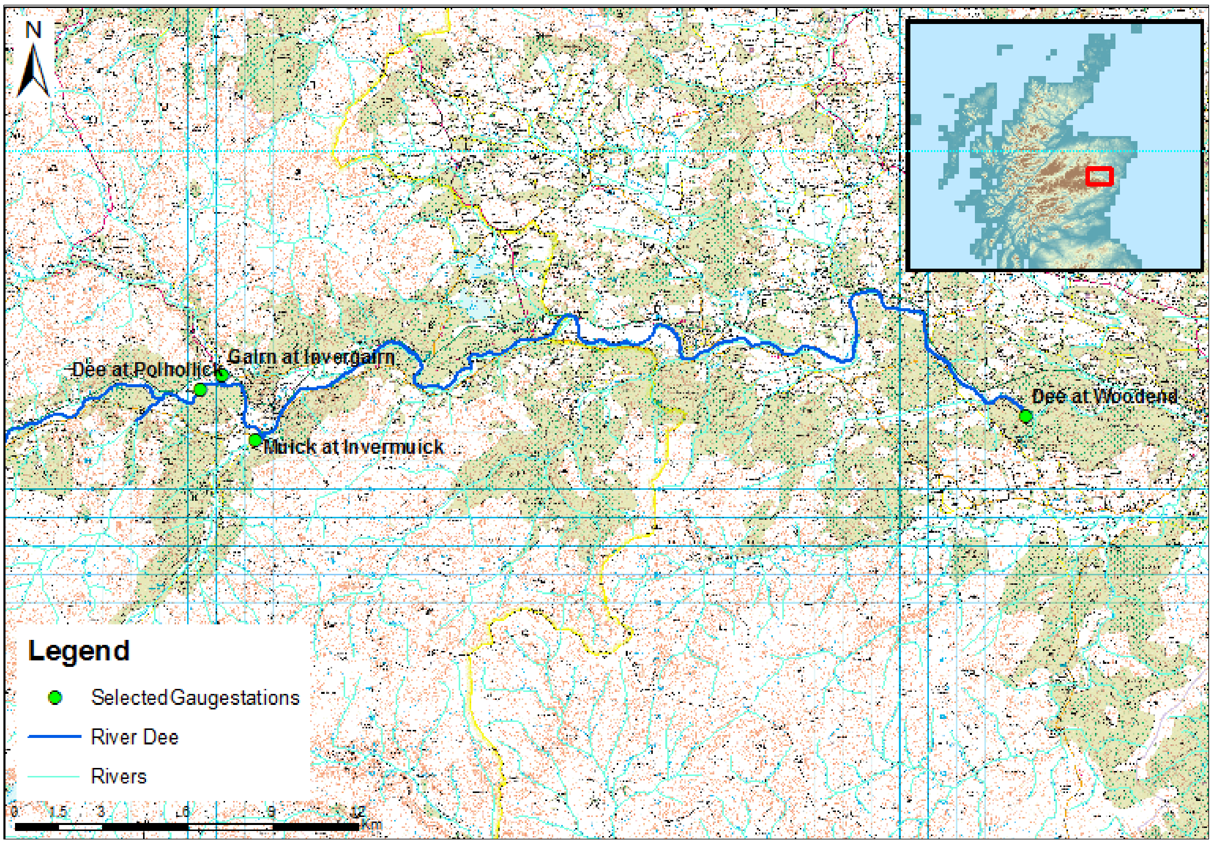


Figure 1.5 – Location of Gauging Stations

1.1.4 Historic Event Frequency

The first step in understanding the flood frequency conditions in relation to the three main rivers is the statistical analysis of the at site flood frequency behaviour recorded at the gauging stations. This analysis has been carried out in line with the procedures set out in FEH using the Annual Maxima (AMAX) series records described in Table 1.3. In addition to the three gauging stations located just upstream of Ballater, at site analysis was also undertaken on combined records just downstream of the confluence points of the Gairn and Muick Rivers. These records inherently capture the combined flood frequency conditions at the confluence points and the record combining all three can be considered to represent the cumulative flow arriving at Ballater. The records have been referred to as ‘synthetic gauging station’ records and the method for combining and adjusting the records is discussed further in 1.4.1.4.

1.1.4.1 The River Dee at Polhollick

The at site flood frequency curve for the gauging station Dee at Polhollick (12003) is presented in Figure 1.6. The Generalised Logistic distribution was selected as the distribution which provided the best fit to the data using L-Median technique.

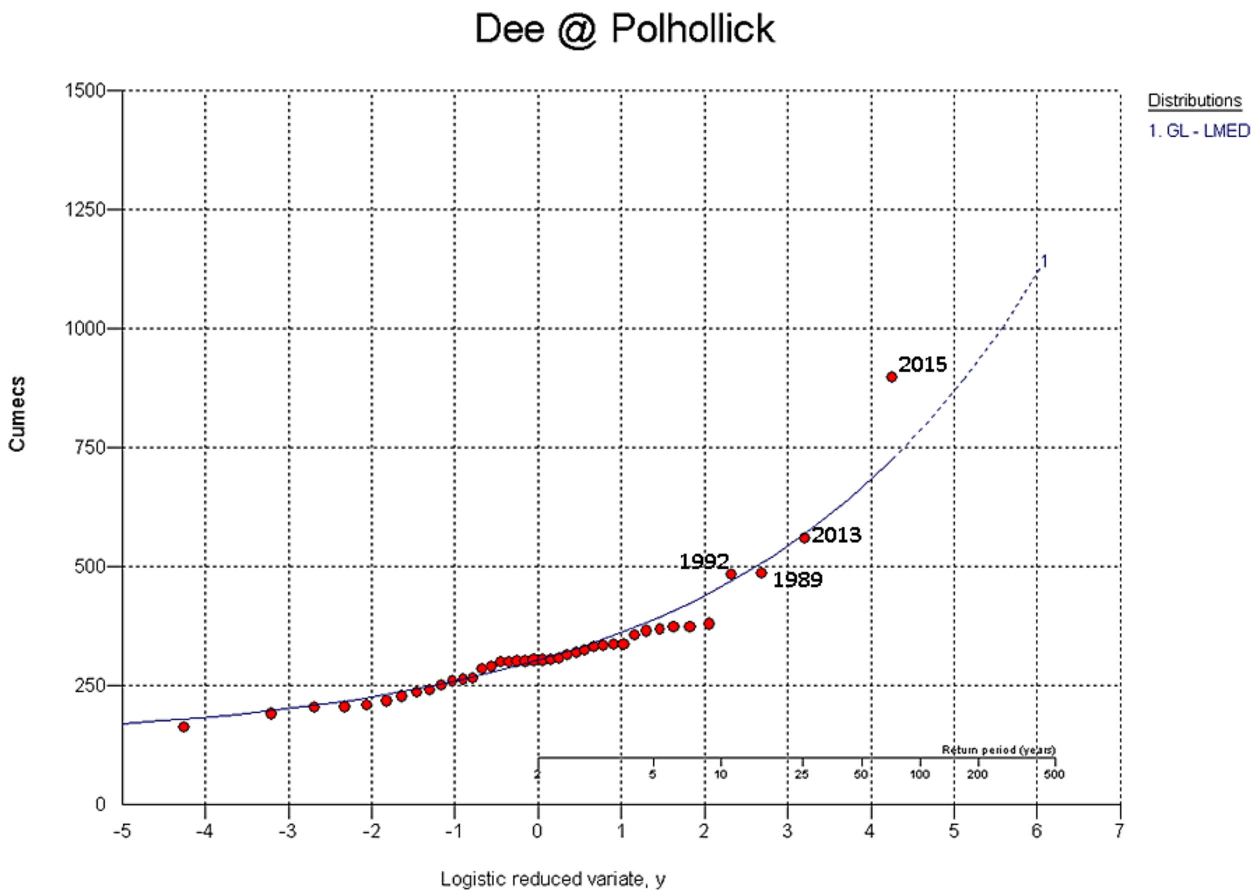


Figure 1.6 At site Flood Frequency curve for 12003

It can be seen from the flood frequency curve that the event of 2015 (Storm Frank), the largest within the record is much larger than any of the other previous events. The five largest events in the record are presented in Table 1.4 along with their estimated return periods.

Table 1.4 Five Highest recorded AMAX values for gauges 12003

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2015	30 Dec 2015	898.051	170.856*

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2013	11 Aug 2014	558.075	23.617
1989	05 Feb 1990	484.805	12.850
1992	17 Jan 1993	482.057	12.538
2014	14 Nov 2014	378.525	4.486

*Note: Estimated Return Period greater than record length – use with caution.

1.1.4.2 The River Muick

The at site flood frequency curve for the gauging station Muick at Invermuick (12005) is presented in Figure 1.7. The Generalised Logistic distribution was selected as the distribution which provided the best fit to the data using L-Median technique.

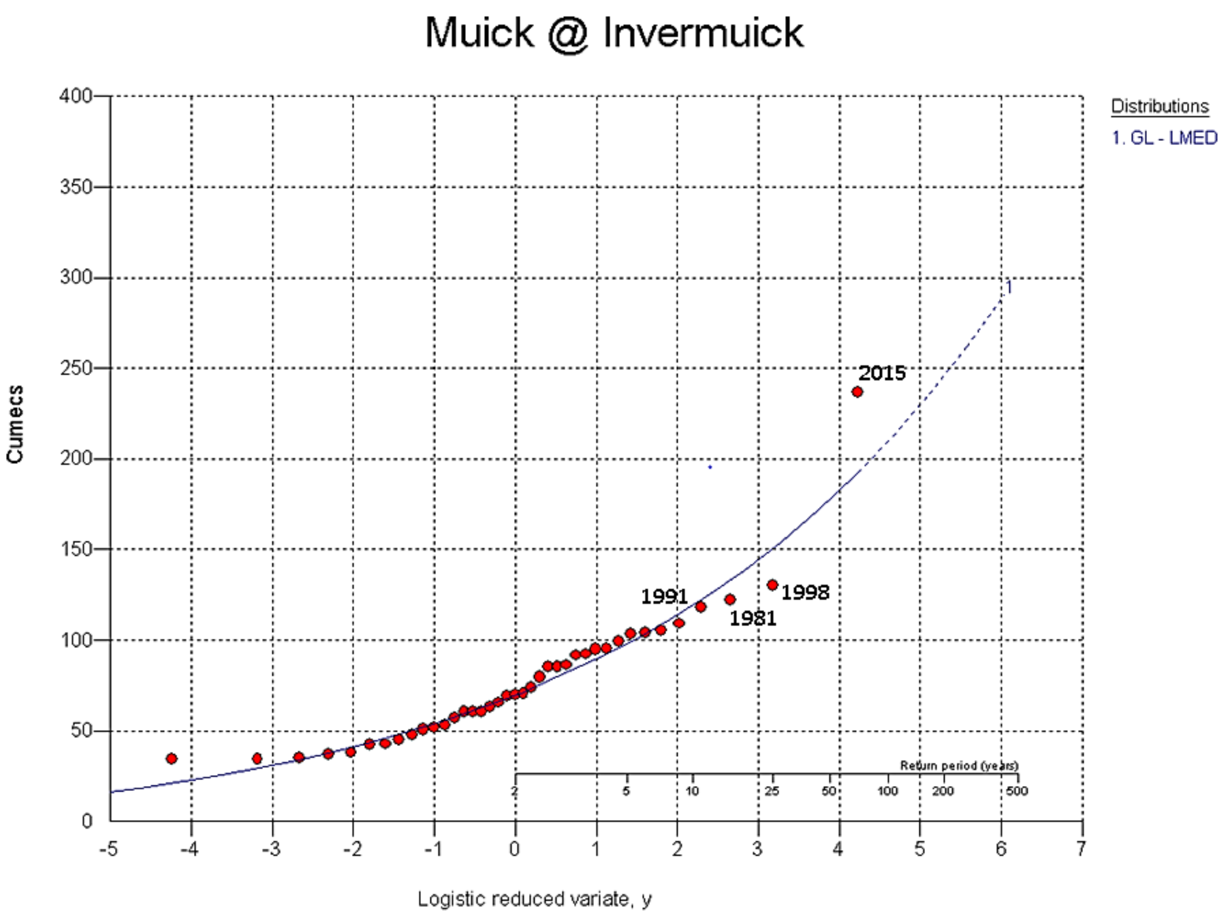


Figure 1.7 At site Flood Frequency curve for 12005

Again the event of 2015 (Storm Frank) is the largest within the record and is much larger than any of the other previous events. The five largest events in the record are presented in

Table 1.5 along with their estimated return periods.

Table 1.5 Five Highest recorded AMAX values for gauges 12005

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2015	30 Dec 2015	236.602	170.562*
1998	21 Sep 1999	130.128	13.927
1981	2 Oct 1981	122.322	10.959
1991	31 Oct 1991	118.016	9.568
1982	14 Nov 1982	109.146	7.181

*Note: Estimated Return Period greater than record length – use with caution.

1.1.4.3 The River Gairn

The at site flood frequency curve for the gauging station Gairn at Invergairn (12006) is presented in Figure 1.8. The Generalised Logistic distribution was selected as the distribution which provided the best fit to the data using L-Median technique.

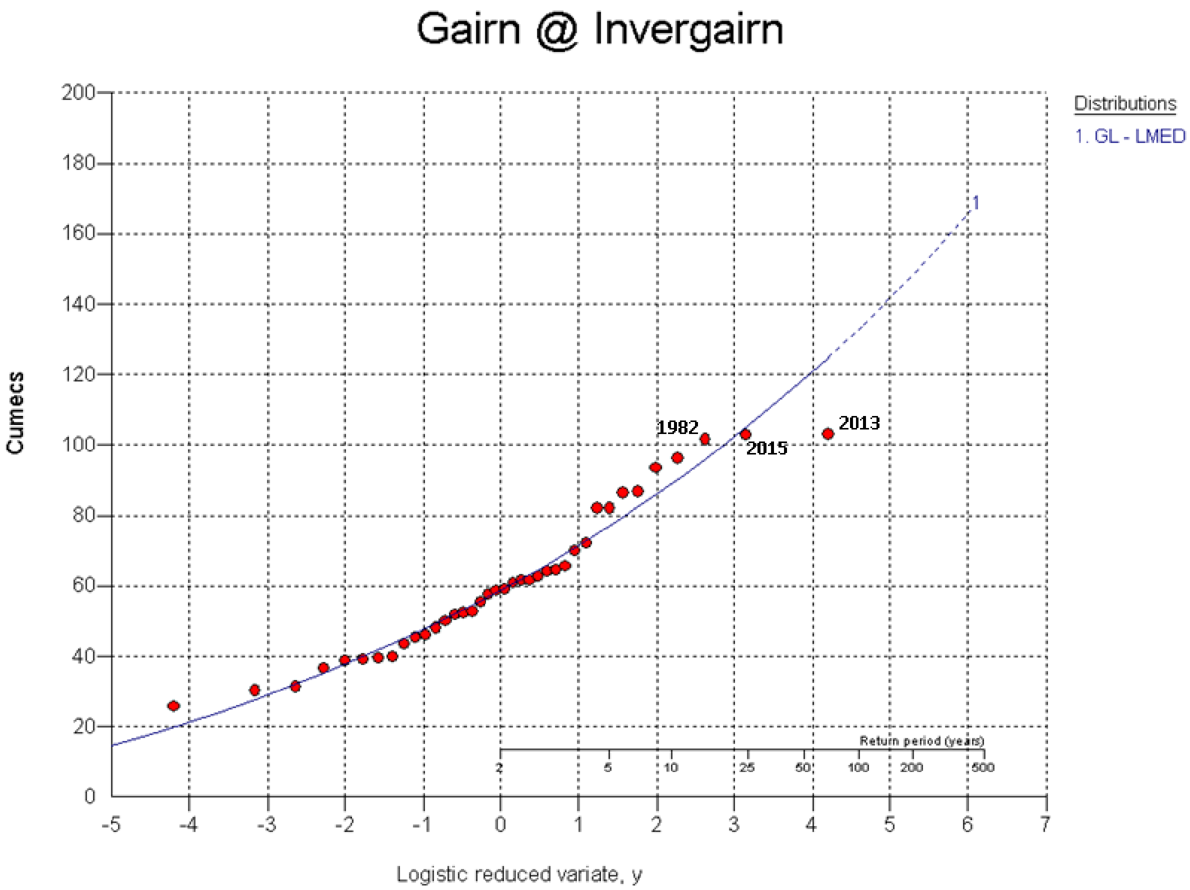


Figure 1.8 At site Flood Frequency curve for 12006

In the case of the Invergairn station the event during August 2014 (2013 hydrological year event) is the largest within the record although the recorded peak flow for the 2015 event is just marginally smaller. The five largest events in the record are presented in Table 1.6 along with their estimated return periods.

Table 1.6 Five Highest recorded AMAX values for gauges 12006

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2013	11 Aug 14	103.005	21.965

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2015	30 Dec 15	102.988	21.945
1982	13 Oct 82	101.505	20.233
1994	10 Sep 1995	96.119	15.000
1981	2 Oct 1981	93.417	12.880

1.1.4.4 Dee at Synthetic Gauge 01 (12003 +12006)

The at site flood frequency curve for the River Dee based on the combined gauging station records from Polhollick (12003) and Invergairn (12006) is presented in Figure 1.9. The Generalised Logistic distribution provided the best fit to the data using L-Median technique.

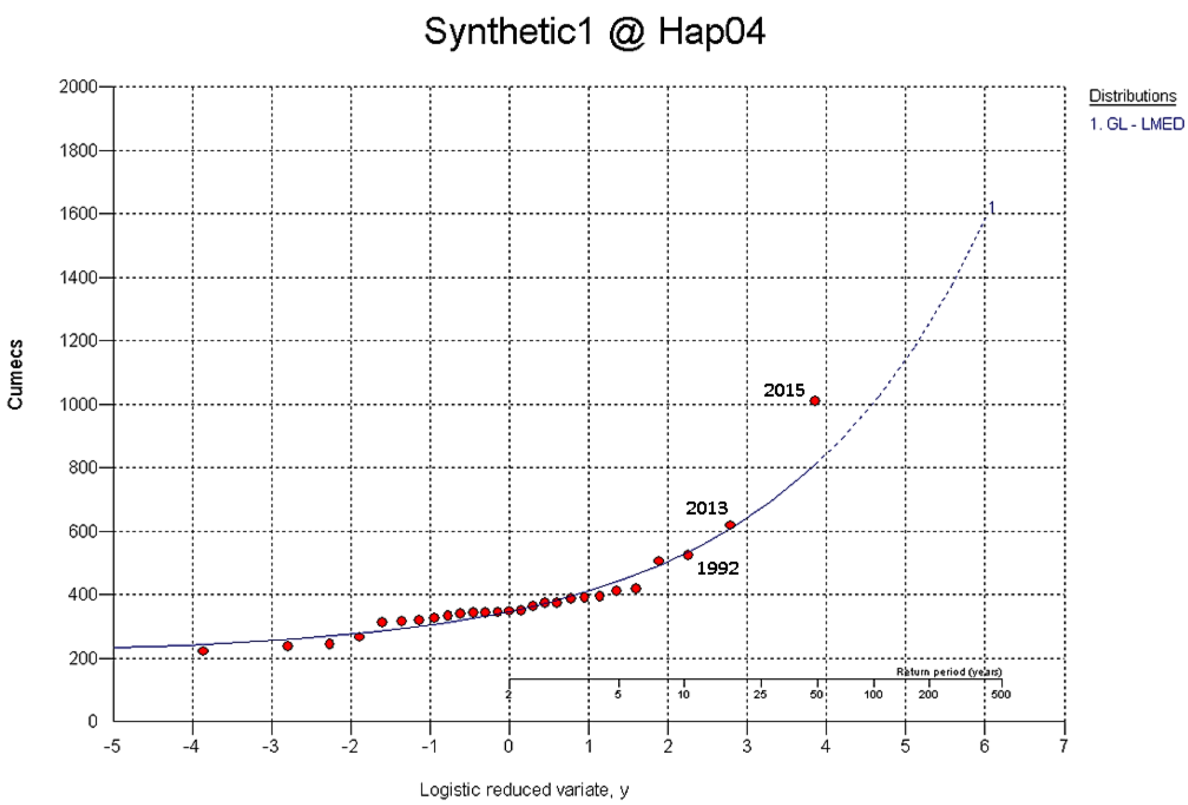


Figure 1.9 At site Flood Frequency curve for Synthetic gauge 01 (12003 +12006) Dee @ HAP_04.

The event of 2015 (Storm Frank) is the largest within the combined record just downstream of the Gairn confluence and again it is much larger than any of the other previous events. The five largest events in the record are presented in Table 1.7 along with their estimated return periods.

Table 1.7 Five Highest recorded AMAX values for Synthetic Gauge 01 (12003 + 12006)

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2015	30 Dec 15	1010.34	101.238*
2013	11 Aug 14	618.622	18.393
1992	17 Jan 93	524.718	9.787
1989	05 Feb 90	505.738	8.465
2010	16 Jan 11	417.366	3.938

*Note: Estimated Return Period greater than record length – use with caution.

1.1.4.5 Synthetic Gauge 02 (12003 +12006 + 12005)

The at site flood frequency curve for the Dee based on the combined gauging station records from Polhollick (12003), Invergairn (12006) and Invermuick (12005) is presented in Figure 1.10. The Generalised Logistic distribution provided the best fit to the data using the L-Median technique.

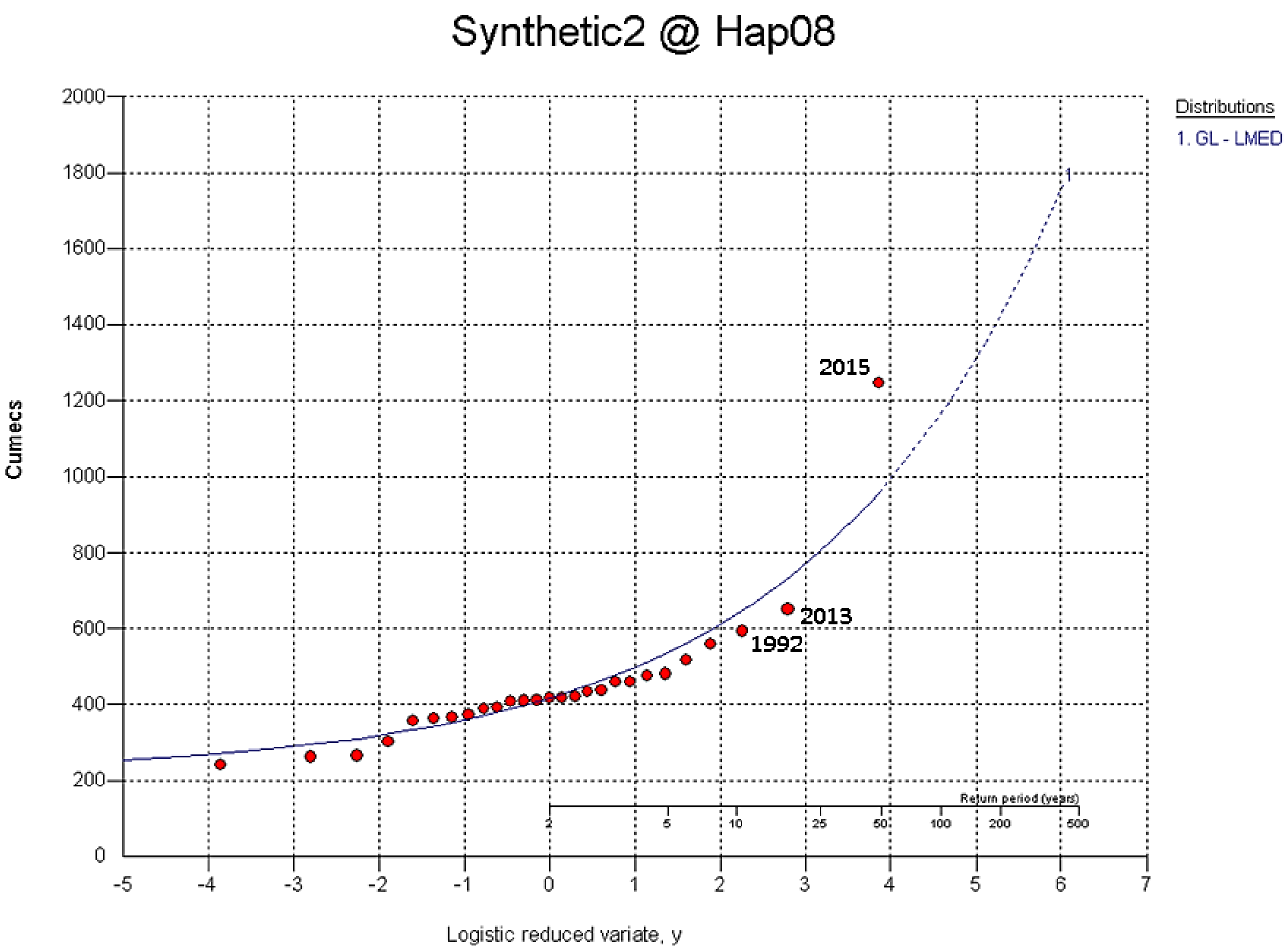


Figure 1.10 At site Flood Frequency curve for Synthetic gauge 02 (12003 +12006 + 12005) Dee @ HAP_08.

Again the event of 2015 (Storm Frank) is the largest within the record and is much larger than any of the other previous events. The five largest events in the record are presented in Table 1.8 along with their estimated return periods.

Table 1.8 Five Highest recorded AMAX values for Synthetic Gauge 01 (12003 + 12005 + 12006)

Hydrological Year	AMAX Date	Flow (m^3/s)	Return Period
2015	30 Dec 15	1246.942	125.863*
2013	11 Aug 14	650.544	10.901
1992	17 Jan 93	592.756	8.508
1989	05 Feb 90	559.988	5.979
1991	31 Oct 91	516.006	4.327

*Note: Estimated Return Period greater than record length – use with caution.

The combined gauging station records at synthetic gauging station 2 can be considered to represent the most accurate picture of the at site flood frequency behaviour at Ballater given that they consider the flows from all three rivers, adjusted for time and lateral catchment as discussed in 1.4.1.4.

The above estimated AMAX values have been derived from the concurrent flow data available for the Invergairn, Polhollick and Invermuick gauges (hydrological year 1989 to hydrological year 2015) and associated return periods have been generated in WINFAP. It should be noted however, that the flood frequency distribution at this location will be heavily affected by the record period used which may lead to inconsistencies in estimated return periods. For example, the 2015 event at the Polhollick gauge has been estimated as an almost 200yr event (using the entire record period available at that location). By using the same record period adopted for the synthetic gauge, the 2015 event frequency at the Polhollick gauge is increased to an estimated 1:91yr event. It is therefore likely that the return period observed at synthetic gauge HAP04 would be closer to a 1:200yr event if the record length was the same as at Polhollick.

1.2 DESIGN FLOW ESTIMATION

1.2.1 Methodology

The assessment of peak river flows and hydrographs follows the methodologies set out in the Flood Estimation Handbook (FEH) (Robson & Reed, 2008).

The following methodologies have been used in this study:

1. FEH Statistical method (single site and pooling group approaches) (Robson & Reed, 2008)
2. Revitalised Flood Hydrograph (ReFH2) (Kjeldsen, Stewart, Packman, Folwell, & Bayliss, 2005)

The ReFH1 model (published in 2005 as an update to the previous FEH rainfall runoff method) has recently been replaced by the ReFH2 which is now updated and calibrated for Scottish catchments. The FEH methods used in this assessment has been undertaken using the FEH CD-ROM (Centre for Ecology and Hydrology, 2009) and WINFAP VERSION 3 (Wallingford HydroSolutions Limited, 2009). Additionally the FEH13 Depth Duration Frequency (DDF) rainfall model has been downloaded from the FEH web service which supersedes the previous FEH99 DDF and been used in conjunction with.

It should be noted given the availability of high quality flood flow gauge records available on all the significant rivers affecting Ballater that statistical methods, anchored to the analysis of the records, is the preferred methodology for the derivation of peak flood flow estimates. However the ReFH2 method with the latest FEH 13 DDF rainfall model has been retained for comparison purposes and for the production of regularised flood hydrograph shapes which can then be scaled to the peak flow estimates. The ReFH2 based hydrographs have been adjusted based on a visual fit to ensure consistency with the observed hydrographs to ensure they are realistic and anchored in the gauged data.

Following modelling of the design inflows the hydrological analysis is reviewed to ensure that flows within the model at a number of intermediate/gauging station HAPs are consistent with the estimates from the hydrological analysis. This is presented in Section 4.3.3. ‘Comparison of hydrological flow estimates and modelled flows’

1.3 HYDROLOGIC ASSESSMENT POINTS AND CATCHMENTS

A detailed hydrological assessment was undertaken to determine the flood flow hydrographs and peak flows for the following watercourses:

- River Dee
- River Muick
- River Gairn

The analysis entailed reviewing all available existing hydrological data and employing FEH techniques to predict flood discharges. After determining the extents of the river survey, numerous Hydrologic Assessment Points (HAPs) were established at the most upstream and downstream extremities of the model, upstream and downstream of any tributaries, and on the tributaries just before their confluence with the main river channel. Intermediate HAPs were also created along the main channel (and at the gauges) and tributaries for generating lateral flow contributions and serve as check points along the modelled reaches to ensure that the hydraulic modelling is anchored to the hydrological analysis. It is acknowledged that HAPs 3 and 7 are just downstream of the gauging stations represented by HAPs 2 and 6 on the Gairn and Muick respectively however they have been retained to ensure the entire lateral catchment in both rivers is accounted for. The HAP locations are provided in Figure 1.11 along with catchment descriptors shown in Table 1.9.

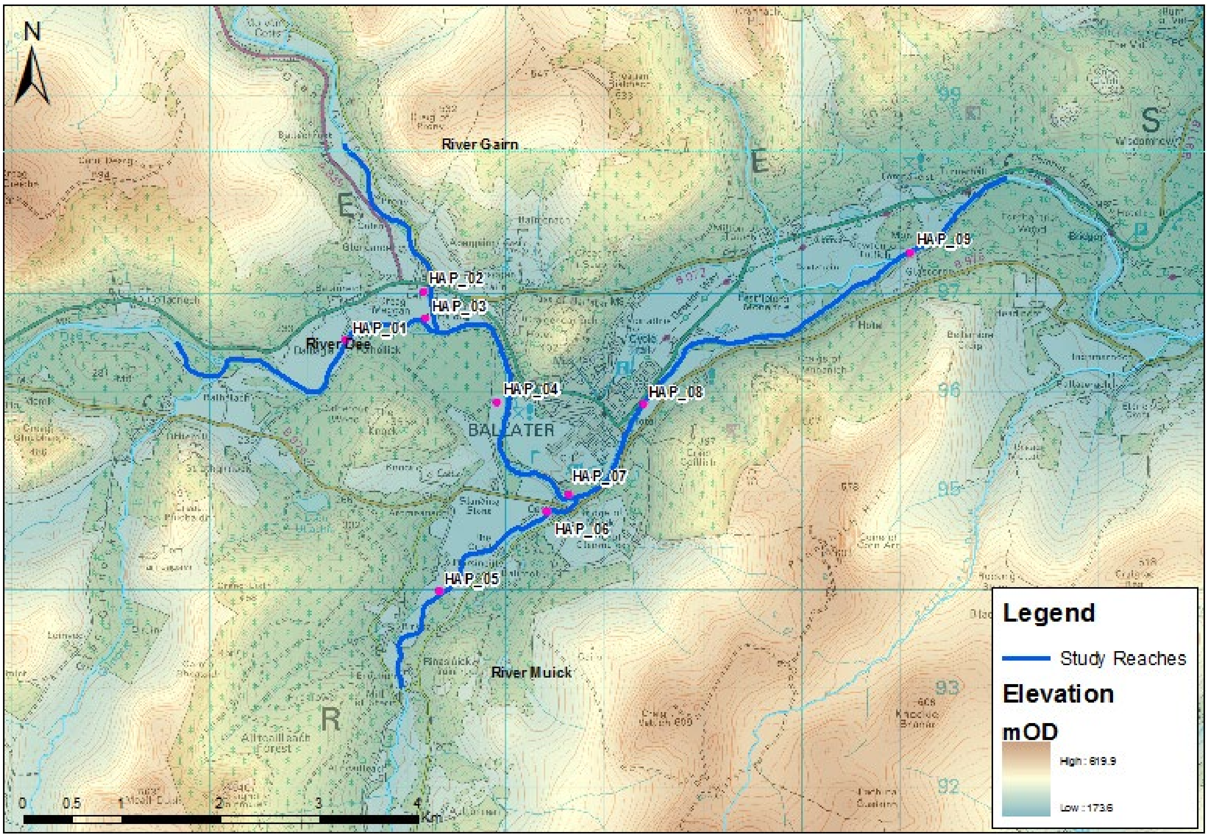


Figure 1.11 – HAP Locations

Table 1.9 – Catchment Descriptors for HAPs

HAP	AREA	SAAR	FARL	BFIHOST	URBEXT2000	SPRHOST
HAP_01	697.33	1231	0.986	0.459	0.0001	44.94
HAP_02	145.90	1048	0.997	0.452	0	42.66
HAP_03	145.94	1048	0.997	0.452	0	42.65
HAP_04	847.53	1198	0.988	0.459	0.0001	44.43
HAP_05	106.59	1253	0.893	0.509	0	43.37
HAP_06	109.39	1244	0.896	0.512	0.0001	43.00
HAP_07	113.97	1230	0.899	0.514	0.0001	42.61
HAP_08	966.68	1199	0.977	0.467	0.0005	44.09
HAP_09	995.73	1191	0.978	0.47	0.0005	43.77

Individual catchments were delineated for all HAPs whose areas were then compared to that given in the FEH. Delineating the catchments required the superimposition of multiple feature layers and raster's including 10k OS background mapping, rivers/streams feature classes, urban drainage networks and 1m DTM.

1.4 FEH SATISTICAL METHOD

The flow accumulating from the various sub catchments was calculated using the FEH statistical estimation procedures. This method can be used on any catchment that drains at least 0.5 km^2. The FEH aims to provide clear guidance to practitioners concerned with flood frequency estimation. Much of the relevant information, including catchment descriptors and depiction of catchment boundaries by digital terrain model, is provided in digital format. The procedure introduces and is based on a number of fundamental concepts including the return period (T), index flood (QMED) and the flood (regional) frequency curve. These concepts are defined as follows:

Return Period (T): a measure of the rarity of a flood (or reoccurrence interval). The return period represents the statistical average interval between years containing floods of a particular magnitude.

Index Flood (QMED): a reference flood that can be relatively reliably estimated from gauged data; the index flood adopted in the FEH is the median annual flood QMED; this is the median of the annual maximum (AMAX) flow series.

Flood Frequency Curve: relates flood magnitude to flood rarity (generally return period). The curve can be fitted to recorded data for a range of statistical distributions; however the Generalised Logistic distribution is most often used in the UK.

There are two main types of flood data series used in the FEH. These series are the annual maximum series and peak-over threshold (POT) data. Both series are usually analysed in terms of the hydrological year which runs from 1st October to 31st September in the UK.

In most situations, flood records for a single location are too short to allow reliable estimation for long return-period floods. If a pooled approach is used then more flood data becomes available to use in the analysis. This compensates for the lack of a long record at the subject site, by pooling flood data from several similar sites to obtain more reliable estimates of long return-period floods.

1.4.1 QMED Estimation at Gauged Locations

Hydrometric data received from SEPA on the River Dee, River Muick and River Gairn was used to update the AMAX series available from the NRFA website. The following section discusses each of the gauges considered for generating a robust estimation of QMED.

1.4.1.1 Dee at Polhollick (Station No. 12003)

The Polhollick gauge is located on the River Dee and is upstream of Ballater with an area of 697.33km^2. This gauge is included in the Hi-Flows dataset and is a suitable candidate for estimating QMED as the site has a cableway and is gauged and rated with confidence above QMED.

RPS acquired raw Q15 flow data and AMAX series from SEPA for this gauge. A comparison of the raw data and AMAX obtained confirmed the AMAX series to be consistent with the Q15 data. The Polhollick gauge provides 37 consecutive years of annual maxima records spanning the hydrological years 1976 – 2015 (Figure 1.12) and the QMED at this gauge is calculated as 302.6 m^3/s.

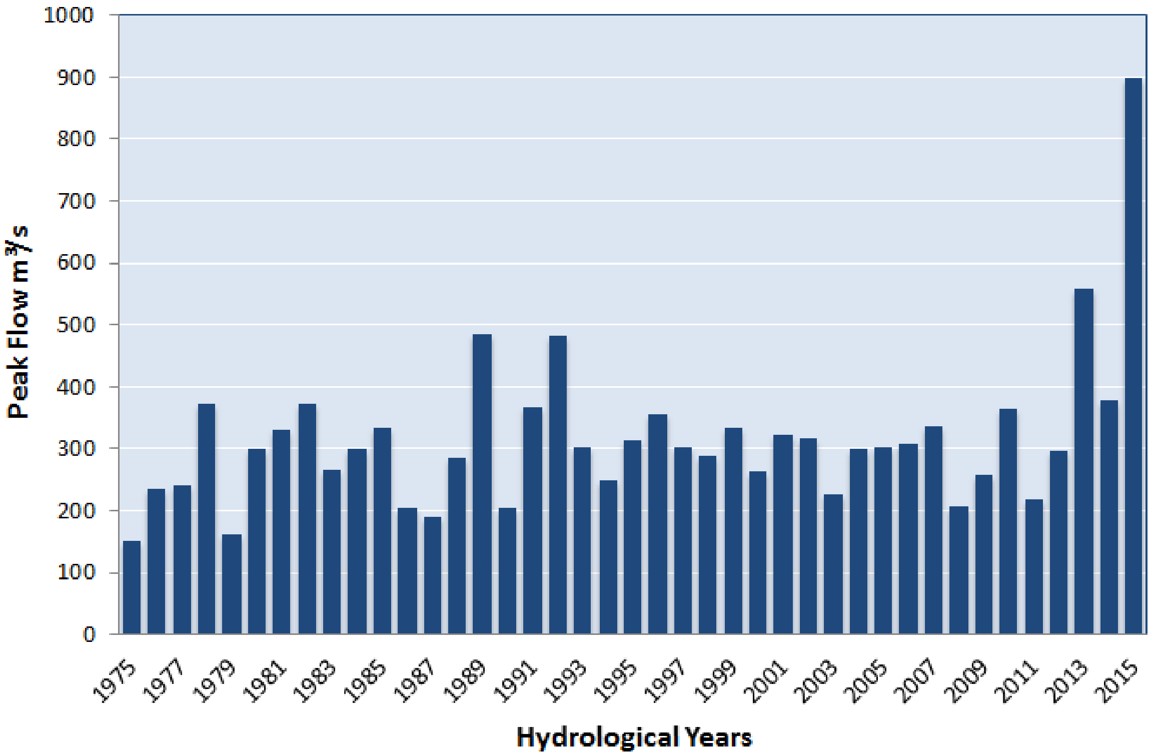


Figure 1.12 – Polhollick AMAX

The AMAX data provided above gives a clear representation of AMAX1, AMAX2 and AMAX3 occurring in the hydrological years 2015, 2013 and 1989 respectively. This gauge is a suitable candidate for QMED estimation and FEH based pooling. Ratings are derived from the current meter gauging's up to 2.3m (1.31 QMED) and a simple extrapolation beyond.

1.4.1.2 Muick @ Invermuick (Station No. 12005)

The Invermuick gauge is located upstream of the study area on the River Muick tributary with an area of 109.4km^2. The gauge has 36 years of recorded AMAX when updated with data (up to hydrological year 2015) provided by SEPA. The observed QMED at this gauge is calculated as 69.8 m^3/s for the entire period of record.

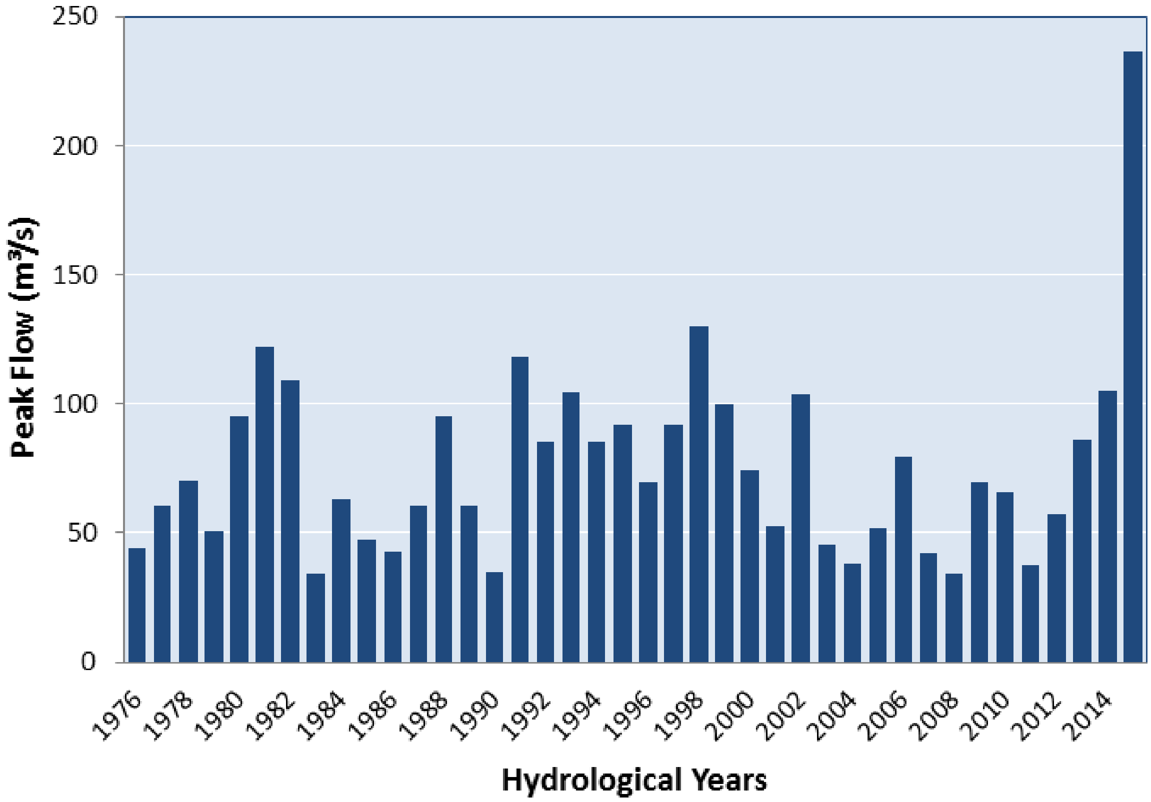


Figure 1.13 – Invermuick AMAX

As discussed previously, by far the largest event on record is that which occurred in December 2015. This gauge is a suitable for QMED estimation and FEH based pooling however it is worth noting that the largest event on record is far beyond largest spot gauging however a review of the rating through the hydraulic model did not indicate that the rating is inaccurate at extreme flood flows. Ratings are derived from the current gaugings of up to 1.7m (about QMED) and a simple extrapolation beyond.

1.4.1.3 Gairn @ Invergairn (Station No. 12006)

The Invergairn gauge is located upstream of the study area on the River Gairn tributary with an area of 146km^2.The Invergairn AMAX series has been updated with data (up to hydrological year 2015) provided by SEPA resulting in a total record period of 38 years. The observed QMED at this gauge is calculated as 58.8 m^3/s.

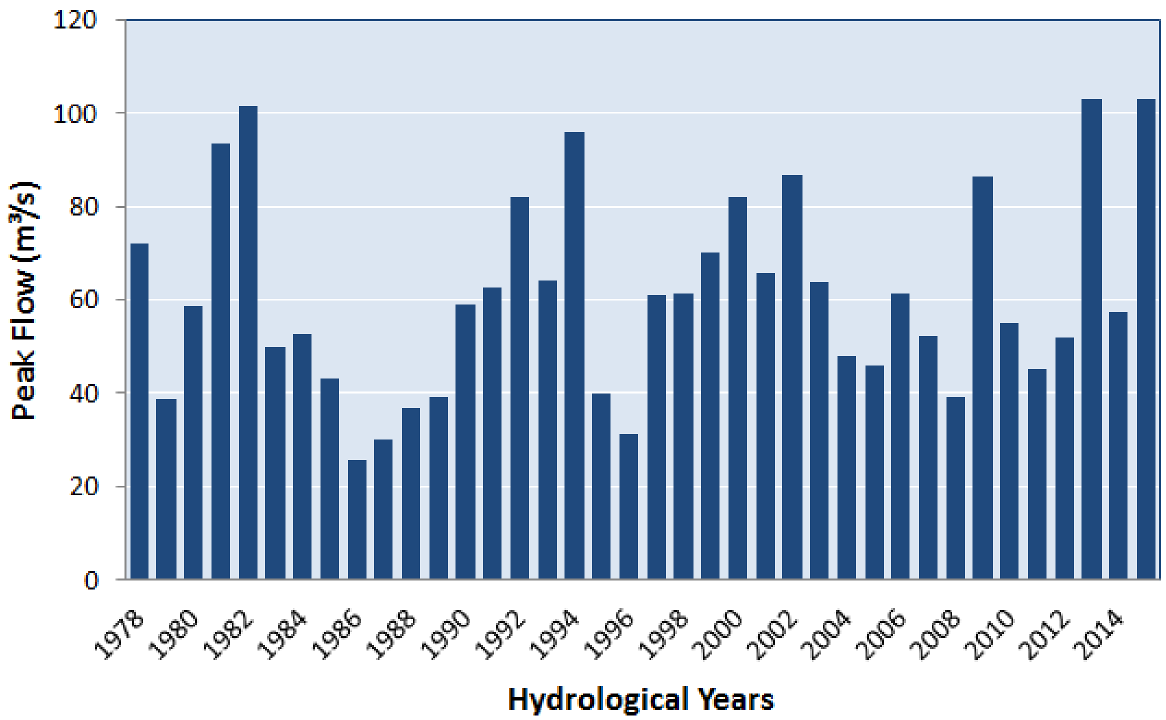


Figure 1.14 – Invergairn AMAX

The AMAX data provided above suggests a number of recorded flood events around the 100 cumec mark. In order from largest these are the events from the hydrological years 2013, 3015, 1982 and 1994. This gauge is a suitable candidate for QMED estimation and FEH based pooling. Ratings are derived from the current gaugings of up to 2.3m (1.31 QMED) and a simple extrapolation beyond.

1.4.1.4 Synthetic Gauging stations

'Synthetic' combined gauged records have been created to represent the combined records of the gauges upstream to HAP_04 and HAP_08. The 15min data for 12003 and 12006 have been merged together and then used to create a synthetic AMAX for HAP_04. This synthetic AMAX enables WINFAP to essentially treat HAP_04 as ‘gauged’ as it classifies the site to have observed data. This same process was also completed for HAP_08 by including the data from station 12005 also .

The flows recorded at 12005 reach HAP_08 53.3 minutes before the flows from 12003 and 12006 assuming a typical travelling speed of the peak flood hydrograph of 1m/s. To account for this, the 15min data series for 12003 and 12006 were delayed by an hour (four timesteps) before being merged with 12005 to create the synthetic AMAX series.

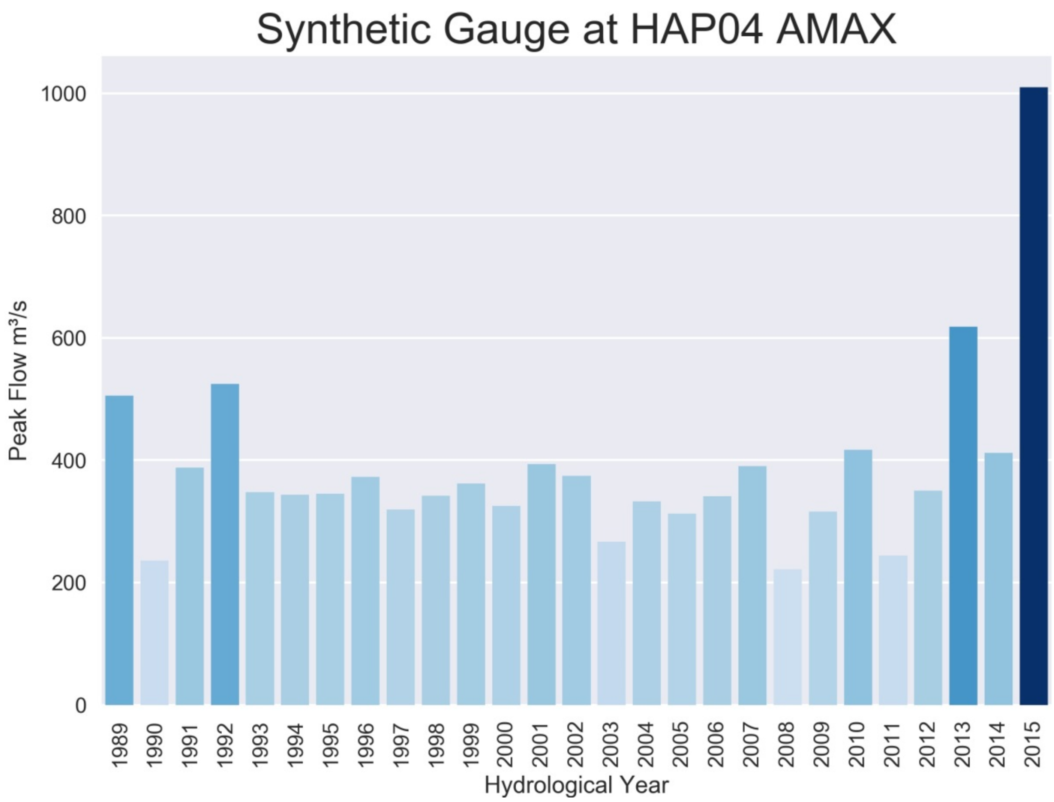


Figure 1.15 Synthetic Gauge 1 (12003 + 12006)

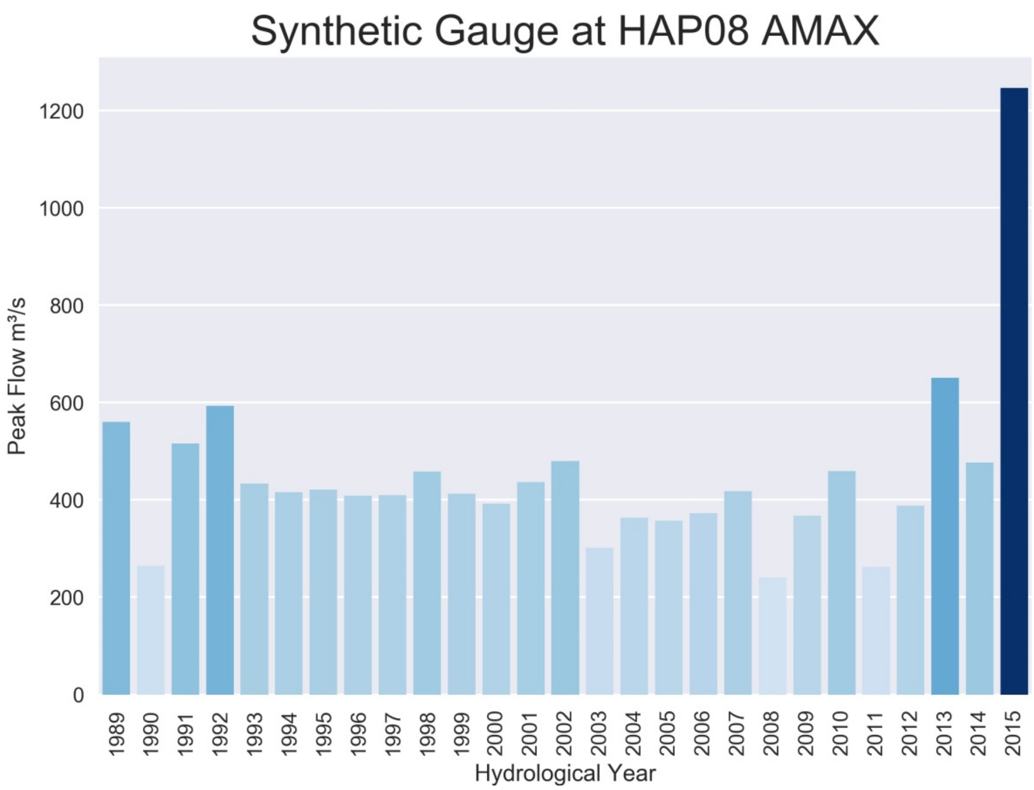


Figure 1.16 Synthetic Gauge 2 (12003 +12005 + 12006)

All HAPs are now essentially treated as gauged and considered appropriate for the derivation of both single site and enhanced single site flood frequency curves as the basis for design flow estimation. The QMEDs estimated at HAP04 and HAP08 synthetic gauges are 347.979m^3/s and 415.684m^3/s respectively.

1.4.2 QMED Estimation at Ungauged Locations

Six out of the nine HAPs established within the study area are classified by FEH WINFAP as 'ungauged catchments' as there is no gauging station at that specific point to record observed data – even though they fall within the gauged catchments of stations 12003, 12005 and 12006. Of these six HAPs two are located just downstream of confluence points for which the synthetic gauging station records discussed previously can be used to treat these locations as essentially 'gauged'. This leaves four HAPs which are initially treated as 'ungauged' however it should be noted that the estimation of QMED at these locations will be brought in line with the gauged observed values by application of the donor site adjustment applied from the 'gauged' locations just upstream/downstream.

The initial estimation of QMED at these 'ungauged' locations follows the improved methodologies set out in the FEH which is based on the following catchment descriptors: catchment size (AREA), typical wetness (SAAR), soils (BFIHOST) and the effects of lakes and reservoirs (FARL). The equation used for estimating the QMED is given below. This equation was developed in 2007 by CEH Wallingford, using higher quality records from the Hiflows-UK dataset.

$$Q_{med} = 8.3062 AREA^{0.8510} 0.1536^{\frac{1000}{SAAR}} FARL^{3.4451} 0.0460^{BFIHOST^2}$$

The initial estimate using this equation is known as $QMED_{rural,}$ as it only considers the runoff generated from the catchment in its 'as rural' condition. The FEH provides guidelines on converting a QMED rural estimation into a QMED urban estimate, taking into account the increased runoff generated by an increased area of impervious surfaces.

1.4.2.1 QMED Urban adjustment

Current FEH guidelines recommend applying an urban adjustment to the QMED estimate if the $URBEXT_{2000}$ catchment descriptor exceeds 0.03. Urbanisation modifies the natural flood response and therefore QMED and the growth curve should be adjusted for urbanisation in accordance with FEH guidelines. However all of the HAP sub-catchments are either totally rural or only slightly urbanised (max URBEXT = 0.0006), with no sub-catchments that would be considered 'urban'.

It is assumed, that any increased runoff generated by urban areas is embodied in the QMED estimates at the gauges. With this in mind and in the interest of maintaining spatial consistency, adjustments to QMED accounting for urbanisation are not required; rather a more appropriate method of improving QMED estimates is through the use of similar gauged catchments as donor sites.

1.4.3 Data Transfer

The index flood (QMED) at each HAP was initially estimated using FEH catchment descriptors and the equation defined in Section 1.4.2. To improve the accuracy of these estimates the FEH suggests the employment of data transfer from catchments judged to be hydrologically similar to the target site but for which annual maximum flood data are available. In essence data transfer tries to account for the proportional error in QMED estimated from catchment descriptors. Since the ungauged locations lie just downstream or just upstream of a reliable gauge, a direct transfer method has been employed. The performance of the data transfer method can be improved by selecting donor sites which are located in the same catchment as the target site. Each of the three main catchments within the study area has a gauging station located within the study reaches at Polhollick (12003), Invermuick (12005) and Invergairn (12006) which can be considered potential donor sites. Furthermore each of these sites has been identified as having a reliable rating such that they are suitable as donor sites for adjustment of QMED. All three gauges have been chosen as the primary donors for all catchments associated with the water course the gauge is located on. Downstream of the confluence points the total catchment is considered robustly represented by the QMED from the relevant synthetic observed records by combining 12003 + 12006 downstream of the Gairn confluence and 12003 + 12005 + 12006 downstream of the Muick confluence.

1.4.3.1 Multi-site adjustment procedure

In the FEH a multi-site adjustment procedure employs two or more donors and treats each donor site separately. The final QMED estimate is obtained as a weighted average of the individually transferred estimates and FEH recommends that the average be taken by geometrical weighting.

A multi-site adjustment procedure was not under taken for the HAPs in the modelled watercourse reaches as there is a gauging station located at, upstream or downstream of each HAP in question which is the obvious choice for donor adjustment. It could be considered that the HAPs located downstream of confluence points (HAPs 04, 08 and 09) on the Dee could benefit from a multi-site adjustment procedure which accounts in some way for the influence of the Muick and the Gairn. However it is considered that the Dee is the dominant catchment. This decision may be reviewed subject to hydraulic model calibration.

1.4.4 Final FEH statistical QMED estimates

The FEH data transfer procedure resulted in the all catchments in the study receiving an upward adjustment (see Figure 1.17)

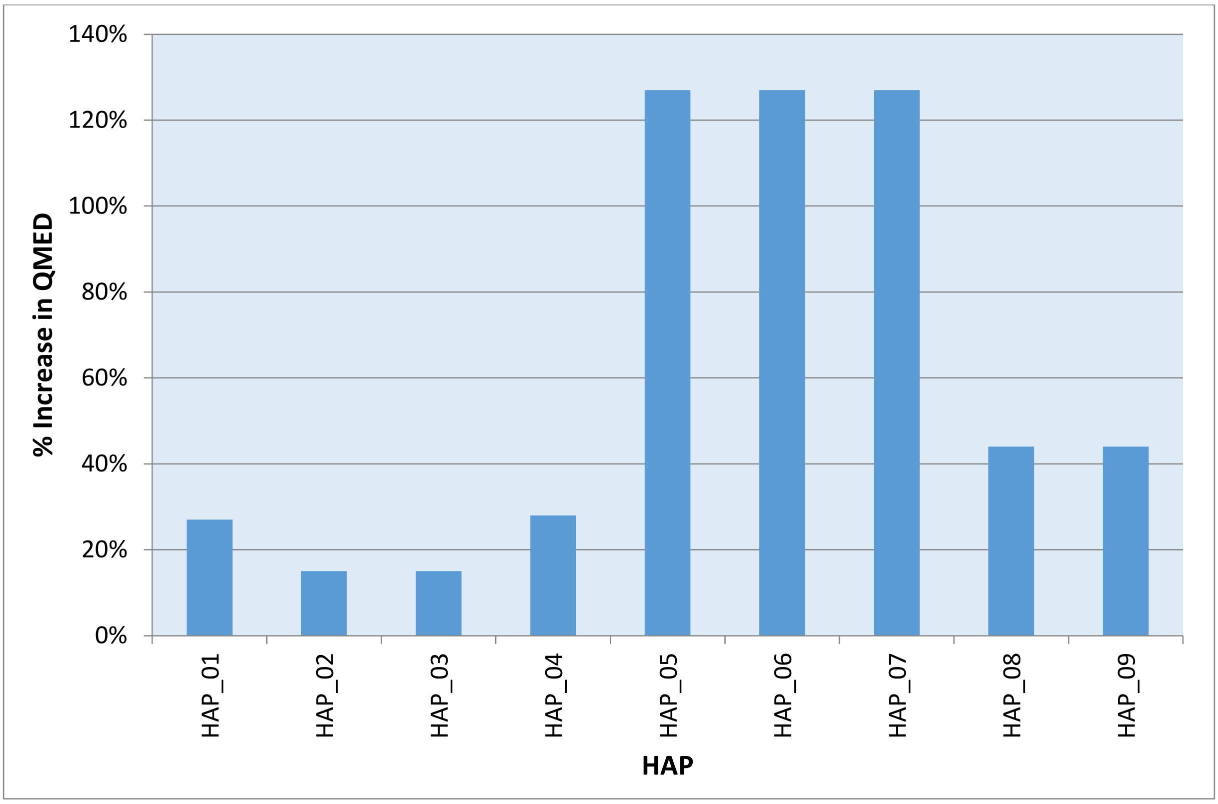


Figure 1.17 – QMED % adjustments

The minimum upward adjustment is 16% (HAPs 02 & 03) and the maximum is 128% (HAPs 06, 07 and 08). These QMED estimates are considered to be robust in that they are anchored to the observed QMED values at multiple gauging stations, with reliable observed QMED values located within the study reaches. Table 1.10 provides the QMED estimates at all HAPs in the Ballater study area.

Table 1.10 – Final QMED estimates

HAP	QMED	Donor Site Adjustment	AdjFac
HAP_01	**302.60**	Observed QMED at Dee @ Polhollick (12003) from 1976 -2015.	1.27
HAP_02	**58.80**	Observed QMED at Gairn @ Invergairn (12006) from 1978 -2015.	1.16
HAP_03	**58.84**	QMED estimated by catchment descriptors then adjusted by Gairn @ Invergairn (12006) from 1978 -2015	1.16

HAP	QMED	Donor Site Adjustment	AdjFac
HAP_04	**347.98**	'Observed' QMED at Synthetic gauge (12003 + 12006) from 1989 -2015.	1.29
HAP_05	**68.86**	QMED estimated by catchment descriptors then adjusted by Muick at Invermuick (12005) from 1976 -2015.	2.28
HAP_06	**69.79**	Observed QMED at Muick @ Invermuick (12005) from 1976 -2015.	2.28
HAP_07	**71.39**	QMED estimated by catchment descriptors then adjusted by Muick at Invermuick (12005) from 1976 -2015.	2.28
HAP_08	**411.61**	'Observed' QMED at Synthetic gauge (12003 + 12005 + 12006) from 1989 - 2015.	1.46
HAP_09	**419.53**	QMED estimated by catchment descriptors then adjusted by 'Observed' QMED at Synthetic gauge (12003 + 12005 + 12006) from 1989 -2015.	1.46

1.4.4.1 Comparison of QMED Adjustment with Dee at Woodend

The downstream extent of the modelled reaches represent a total catchment area of 996km^2 and an adjustment has been applied based on the synthetic gauging station 2 (HAP_08) representing an area of 967km^2. This adjustment considers a combined gauging station record of 27 AMAX years (1989 – 2015) as this is total of concurrently available Q15 data at all three gauging stations for which continuous flow data could be combined. The resulting adjustment factor is 1.46. The gauging station at Woodend represents a long term, flood flow record on the River Dee downstream of Ballater. The gauge is located approximately 33km downstream of the modelled extents and represents a catchment area of 1370km^2. Estimation of the QMEDrural based on catchment descriptors at Woodend results in a value of 339 m^3/s. The observed QMED value at Woodend for the entire record period from 1929 (87 AMAX years) is 437 m^3/s resulting in an adjustment factor of 1.29. When only the period of record concurrent with the synthetic gauging station 2 record is considered from 1989 – 2015 the resulting observed QMED is 465 m^3/s equating to an adjustment factor of 1.37. It is considered that the synthetic gauging station based record is the most appropriate basis for adjustment at HAPs 08 and 09 given that this record represents a combined catchment area much closer to the HAPs at which it has been applied; HAP_08 which is at the location of the synthetic gauging and at HAP_09. Furthermore it is considered that the shorter but more recent record is likely to be more representative of the current catchment conditions and the 27 years of record is sufficiently statistically robust in terms of observed QMED. In light of these considerations the adjustment factor derived from the gauging station at Woodend for the latter record period is considered to provide good validation of the adjustment factor derived from the synthetic gauging station.

1.4.5 Flood Frequency Curve Derivation

For ungauged catchments, the FEH statistical method provides a robust procedure for deriving the design flood for any return period by factoring the QMED value. The technique involves pooling a number of gauged sites throughout the UK based on their Hydrological Similarity (also referred to as Similarity Distance Measure - SDM). The hydrological similarity is based on similarity of catchment area (AREA), annual average rainfall (SAAR), presence of lakes and reservoirs (FARL) and flood plain extents (FPEXT). The sites included in the pooling analysis are predominately rural, resulting in an 'as-rural' growth curve for the site of interest. FEH provides guidance on using urban adjustments to the growth curves in order to reflect the effect of urbanisation on a catchment in terms of its flood frequency. An urban adjustment to the growth curves has not been applied across the study HAPs as the catchments are considered almost totally rural.

1.4.5.1 Pooling Group Development

The approach to pooling is to use the WINFAP 'Enhanced Single Site' procedure which is a joint method combining both the at site flood frequency curves from each of the gauged records weighted within a pooling group of hydrologically similar sites such that the at-site record is given additional weighting compared to the other gauging stations. Note that for return periods up to 10 years the at site flood frequency curve is preferred as the method for deriving growth factors for design flow estimation in the Flood Estimation Handbook (FEH Volume 3 Chapter8). This is because the at site relationship is considered to have sufficient statistical confidence up to 0.5 times the number of AMAX years available in the at site record. Pooling groups were developed for the three gauging stations on the study reaches as well as the two synthetic gauges created at HAP_04 and HAP_08. Using the most up to date AMAX data from WINFAP (v5) files download from the NRFA website and subsequent AMAX years added from SEPA data for the gauging stations, WINFAP-FEH (version 3.0) software generates flood growth curves which can be then be factored by the QMED to obtain the flood frequency curve.

All stations that WINFAP highlighted as being not suitable for QMED estimation or pooling were automatically excluded from the pooling groups. The groups were then further reviewed and adapted pooling groups were formed based on hydrological similarity. Additionally, the FEH guidelines recommend a pooling group of at least 500 years of gauged data which was conserved throughout all pooling groups. Table 1.11 provides a breakdown of the number of years removed or added (corresponding to sites removed or added) for each of the pooling groups.

Table 1.11 – Original/modified pooling group

HAP	Original Total Years	Removed	Added	Total Years in Group
HAP_01	644	3	0	500
HAP_02	612	7	3	505
HAP_04	644	2	0	543
HAP_06	648	5	0	478
HAP_08	621	2	0	519

All pooling groups were assessed for homogeneity which indicates how hydrologically similar the pooling group is to the catchment. A 'goodness-of- fit' test was undertaken to identify the best fitting distribution. The GLO distribution was chosen as on average it produced slightly higher growth factors which resulted in more conservative flows and as such is consistent with a precautionary approach to scheme design. It is also the distribution recommended for UK flood data as discussed in the FEH (Volume 3,, Section 15.3). Therefore in the interest of maintaining spatial consistency throughout the study, this method was applied to all the subject catchments. Details of initial and adopted (modified) pooling groups are provided in Appendix B. Table 1.12 provides a summary of the heterogeneity measures (H2) and 'goodness-of-fit' for each of the pooling groups across three selected distributions (GLO, GEV, PTIII corresponding to the Generalised Logistic, Generalised Extreme Value and Pearson Type III respectively).

Table 1.12 – Pooling group heterogeneity measures and distributions

HAP	H2	GLO	GEV	PT III	Best Fit
HAP_01	-1.460	-0.967	-2.247	-2.822	GLO
HAP_02	1.808	2.109	-0.025	-0.452	GEV
HAP_04	-1.680	-0.468	-1.878	-2.474	GLO
HAP_06	0.066	1.221	-0.660	-1.033	GEV
HAP_08	-0.790	0.918	-0.861	-1.470	GEV

There is a split in the best performance between the GEV and the GLO distribution across the pooling groups. In terms of goodness of the heterogeneity measure there is very little to choose between the two distributions. However a review of the growth factors for each distribution indicated slightly higher growth factors on average for GLO distribution. In the interests of spatial consistency the GLO is taken forward as the preferred flood frequency distribution across the modelled reaches.

1.4.5.2 Growth Curves

As discussed the FEH recommend Single Site Analysis alone is insufficient unless the site record is more than twice the target return period. Enhanced single site analysis is recommended where there is limited data at the subject site but the record is not long enough to allow a robust single site analysis. The gauges at Polhollick (HAP_01), Invergairn (HAP_02), Invermuick (HAP_06) and the synthetic gauges (HAP_04 and HAP_08) are all eligible for Enhanced Single Site analysis; however as the three actual gauges have over thirty years of observed data each, they are also suitable for Single Site analysis and the growth factors from years 1-10 may be used with confidence for each gauge in combination with the growth factors derived from the Enhanced Single Site Analysis for events greater than a 20 year return period.

1.4.5.3 Single Site vs Enhanced Single Site

Initially the approach described in 1.4.5.2 was applied and the design flows reviewed against the historic event data. The growth curve generated using the enhanced single site analysis undertaken at the Polhollick gauge can be seen in Figure 1.18. The enhanced single site curve results in a flatter flood frequency than that for the single site curve alone. This is due to the effect of the pooled sites included within the ESS method. Using this flatter enhanced single site flood frequency curve the December 2015 event is estimated to have had a return period of greater than 200 years.

The result of this if taken forward for design flood flow estimation is that the design flows for the 200 year return period event would be slightly less than that which was observed during December 2015. Following completion of the rating review it could not be determined that the recorded maximum flow values observed in 2015 were unreliable. This presents problems in terms of the design development of a scheme based on this hydrological analysis in that it would result in a design standard less than an event that has recently occurred. It must be considered that the flood frequency curve derived from a single site analysis may be a more accurate reflection of the true flood frequency behaviour in line with a pre-cautionary approach to scheme design.

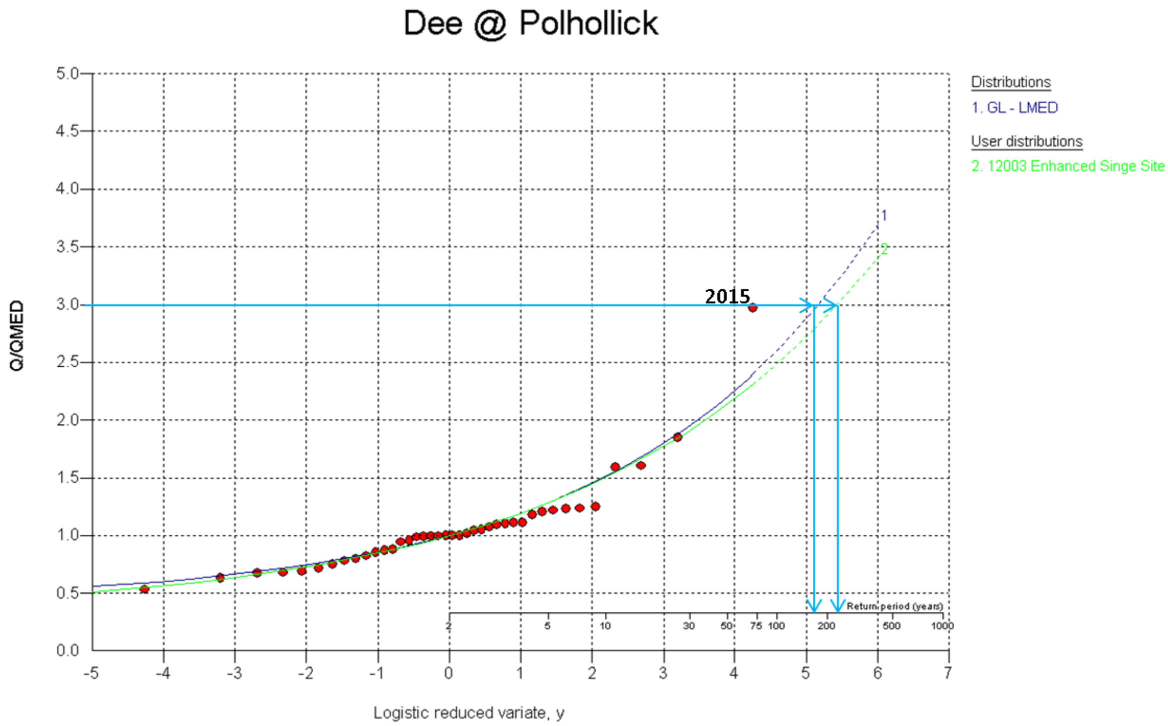


Figure 1.18 - Dee @ Polhollick Gauge (12003) Enhanced Single Site Analysis

Similarly, the Invermuick gauge, the synthetic gauge at HAP04 and the synthetic gauge at HAP08 have also underwent a growth curve flattening when subject to an enhanced single site analysis (i.e. the growth curve is influenced by data from pooling from hydrologically similar sites) whereas the growth curve factors at the Invergairn gauge have been increased. The divergence of growth factors is particularly noticeable beyond the 1:30yr estimated flood event. A comparison of the single site versus the enhanced single site growth factors is presented in Table 1.13 below.

Table 1.13 - Single Site vs Enhanced Growth Factors

	Polhollick		Invermuick		Invergairn		HAP04		HAP08	
T	SS	ESS	SS	ESS	SS	ESS	SS	ESS	SS	ESS
2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.28	1.29	1.41	1.38	1.31	1.33	1.27	1.30	1.29	1.26
10	1.51	1.50	1.71	1.66	1.51	1.56	1.52	1.52	1.53	1.46
30	1.95	1.91	2.26	2.14	1.85	1.97	2.03	1.95	2.03	1.84
50	2.20	2.14	2.55	2.40	2.02	2.18	2.35	2.18	2.32	2.04
75	2.43	2.33	2.80	2.62	2.16	2.36	2.65	2.39	2.59	2.23
100	2.60	2.49	3.00	2.78	2.26	2.49	2.89	2.55	2.81	2.37
200	3.09	2.90	3.52	3.22	2.53	2.85	3.60	2.99	3.43	2.76
500	3.90	3.57	4.33	3.91	2.91	3.39	4.87	3.70	4.50	3.39
1000	4.67	4.19	5.07	4.51	3.23	3.87	6.18	4.35	5.57	3.98

1.4.5.4 Adopted Growth Curves

Following discussion between RPS and SEPA it was decided to change the basis of the design flow growth curve from using the enhanced single site growth curve to the single site derived growth curves at the three gauging stations. It is acknowledged that this deviates from the recommendations detailed in FEH Volume 3, Chapter 8 but it is considered justified for the following reasons:

1. Following completion of the rating review it was found that there is no evidence to suggest the peak flows recorded for the 2015 event are inaccurate.
2. There is evidence of floods of a similar scale having occurred pre-dating the gauging station records.
3. The risk of using the less statistically robust at site growth curve; that it could lead to design events which are unrealistic resulting in the over design of flood schemes, is not valid as the resulting design 200 year event would be only slightly larger than the largest observed historic event (2015).

HAP04 and HAP08 AMAX series have been synthesised and while they are based on observed data upstream, their reliability remains highly untested and uncertain, particularly for high return periods. Consequently, RPS have employed the enhanced single site growth curves for these locations as the single site growth curves are particularly steep and may not be reflective off the River Dee catchment responses downstream of the River Gairn and River Muick.

1.4.5.5 Flood Frequency Curves

Following the review of the growth curves, the estimated QMED values are factored by the chosen growth factors given in Table 1.13 (single site at the gauges and enhanced single site at the synthetic gauges) to produce the flood frequency curves (FFC). The ungauged locations on the River Muick have inherited the growth curve derived at the Invermuick gauge and the most downstream ungauged location on the River Dee (HAP09) has inherited the growth curve derived at the synthetic gauge (HAP08).

1.4.5.5.1 Finalised FEH Statistical Peak Flow Estimates

Error! Reference source not found. below provides a breakdown of the estimated peak flows (in cumecs) using the FEH statistical methods described above for each HAP using the chosen flood frequency curves.

Table 1.14 – FEH Statistical Peak Design Flow Estimates

HAP	2yr	5yr	10yr	30yr	50yr	75yr	100yr	200yr	500yr	1000yr	30yr + CC	200yr + CC
HAP_01	302.6	388.5	457.5	590.1	665.7	733.8	786.8	934.1	1179.2	1412.6	708.1	1121.0
HAP_02	58.8	82.8	100.6	132.6	149.8	164.8	176.2	206.8	254.9	298.2	159.1	248.2
HAP_03	58.8	82.8	100.7	132.7	149.9	164.9	176.3	206.9	255.0	298.4	159.2	248.3
HAP_04	348.0	451.0	530.3	677.9	759.3	831.7	887.7	1039.8	1285.8	1513.4	813.4	1247.7
HAP_05	68.9	97.0	117.8	155.3	175.4	192.9	206.4	242.2	298.4	349.2	186.3	290.6
HAP_06	69.8	98.3	119.4	157.4	177.8	195.6	209.2	245.5	302.5	353.9	188.9	294.5
HAP_07	71.4	100.5	122.1	161.0	181.8	200.0	213.9	251.1	309.4	362.0	193.2	301.3
HAP_08	415.7	523.8	607.3	762.8	849.2	926.1	985.2	1146.9	1408.8	1652.3	915.3	1376.3
HAP_09	419.5	528.6	612.9	769.8	857.1	934.7	994.3	1157.5	1421.8	1667.7	923.8	1389.0

1.4.5.5.2 Reconciliation of Flood Frequency Conditions across the Modelled Watercourses

It is accepted that the critical storm event and flood frequency conditions may vary across the modelled reaches, particularly between the flashier River Gairn and the River Dee. For the purposes of modelling practicalities the design flow estimation seeks to achieve design event conditions in all of the modelled watercourses within each design event simulation, despite the fact that in reality this may not occur in each catchment during a particular event. This is resolved through the consideration of the intermediate and check flow HAPs which are anchored to the observed flow data through the consideration of the synthetic at site records derived for the locations just downstream of the confluences (i.e. HAP_04 and HAP_08). The sum of model inflows at these locations is checked to ensure they do not significantly exceed the design event moving down through the modelled catchment. Where this has occurred the lateral inflows have been adjusted where possible to ensure the design conditions are achieved at each HAP. It can be seen from Table 1.15 that the sum of the design inflow hydrographs at QMED (2 year return period) are well matched to the estimated target check flows at each of the main check flow HAPs along the Dee.

Table 1.15 – Comparison of Estimated QMED Inflows against Sum of Model Inflows

HAP	QMED Estimated	QMED Sum of Inflows	Difference
HAP_04	347.98	352.77	1.4%
HAP_08	415.68	417.79	0.5%
HAP_09	419.53	437.95	4.4%

Table 1.16 outlines the comparison of the estimated Q200 design flows at each of the HAPs along the River Dee against the sum of the design inflows to be entered into the model. The sum of the inflows is largely dictated by the three major inflows based on the single site analyses at Polhollick, Invergairn and Invermuick and as such there is little scope to significantly affect the sum of the inflows at HAPs 04, 08 and 09 through adjustment of the lateral inflows.

Table 1.16 – Comparison of Estimated Q200 Inflows against Sum of Model Inflows

HAP	Q200 Estimated (Enhanced Single Site)	Q200 Sum of Inflows	Difference	Q200 Estimated (SS)	Q200 Sum of Inflows	Difference
HAP_04	1039.8	1110.0	+6.8%	1252.0	1110.0	-11.3%
HAP_08	1146.9	1336.7	+16.6%	1425.0	1336.7	-6.2%
HAP_09	1157.5	1392.3	+20.3%	1438.2	1392.3	-3.2%

It can be seen that the sum of the inflows at HAP04 is 7% greater than the design check flow estimated using the enhanced single site analysis. However at HAP08 and 09 the difference rises to approximately 17% and 20% greater respectively. This is due to the difference in growth curve behaviour between the single site curves used to derive the inflows, which tend to be relatively steep, and the enhanced single site (pooled) curves used to estimate the design check flows at HAPs 04, 08 and 09. For comparison the single site Q200 growth factor used at Polhollick is 3.09 while the Q200 ESS growth factor applied at HAP04 is 2.99 and 2.76 at HAPs 08 and 09. A comparison with single site derived check flows is also provided in Table 1.16 and it can be seen that this time the sum of the inflows is lower than the check flow estimates. This is because the single site derived check flows are generated by much steeper growth curves, reflective of the synthesised records at HAPs 04 and 08 where the 2015 event has a big effect on the curve within the 27 years of combined AMAX data. For comparison the single site Q200 growth factors are 3.59 and 3.43 at HAPs 04 and 08 compared to 3.09 at Polhollick.

In summary it appears that neither set of growth curves for the synthesised record HAPs 04 and 08 fits well to the generated sum of inflows at all of the Dee check flow HAPs. It is not considered that this is cause for adjustment of the inflows but rather an indication that the true growth curve behaviour lies somewhere in between the single site and enhanced single site curves at HAPs 04 and 08. In other words it is accepted that the sum of the inflows dictated by the single site flood frequency at the three gauge sites upstream is allowed to dictate the combined flows in the Dee at Ballater. The sum of the inflows may not be fully reflective of the modelled flows which will be generated at these HAPs due to the effects of hydraulic attenuation and hydrograph travel time. A review of the model shows that these effects only account for a small proportion of the difference.

Full details of the checks on the design inflows for modelling can be found in Appendix A.

1.5 FEH REVITALISED FLOOD HYDROGRAPH (REFH2) RAINFALL RUNOFF

This assessment has also considered the FEH Revitalised Flood Hydrograph (ReFH2) rainfall runoff based methodology with the FEH13 Depth Duration Frequency (DDF) rainfall model which has been downloaded from the FEH web service, as an alternative for estimating peak flows. This method differs from the statistical approach in that it is a deterministic model and aims to represent the main hydrological processes which occur at a catchment scale. The ReFH2 rainfall-runoff method can also be used to create a flood hydrograph matching the peak flows estimated using the statistical method (if the peak flows from the statistical method are preferred).

1.5.1 Storm Duration and Season

The ReFH2 software initially provides a recommended storm duration based on catchment descriptors. However an iterative process is undertaken, whereby the storm duration is modified until the largest peak flow is achieved, and therefore the 'critical storm duration' achieved. This was assessed at the most downstream point in the hydrological analysis (HAP_09). The chosen storm season is 'winter' which is the default recommended in the FEH for predominately rural catchments.

The recommended storm duration in the ReFH2 model was 9.5 hours, but an iterative process revealed the critical storm duration to be 35.5 hours. The critical storm duration was also assessed on the River Muick (HAP_07 – 23.5hrs) and the River Gairn (HAP_03 – 10 hours). Subsequently, 35.5 hours was applied to all the catchments along the modelled reaches in an effort to achieve spatial consistency for the event driving the flows to be generated at each HAP. It is acknowledged that this approach may not result in the maximum peak flows at each HAP as can be generated in the ReFH2 model but it is considered appropriate in the interests of achieving spatial consistency in the modelled flood events which are assumed to be generated by the same rainfall event.

1.5.2 ReFH2 Peak Flow Estimates

The peak flow estimates for all return periods simulated in the ReFH2 model are presented in Table 1.17 below:

	Peak Flow (m^3/s) for the given return period									
HAP	2yr	5yr	10yr	30yr	50yr	75yr	100yr	200yr	500yr	1000yr
HAP_01	288.20	359.42	409.67	489.11	526.99	558.30	580.86	634.81	708.13	784.63
HAP_02	61.88	77.48	88.78	107.11	115.94	123.21	128.45	140.93	157.38	173.59
HAP_03	56.91	76.83	91.32	114.86	126.46	135.91	142.72	159.62	183.15	201.73
HAP_04	305.24	398.25	467.28	583.46	641.34	689.34	724.46	811.74	934.71	1031.63
HAP_05	47.53	61.19	71.60	89.74	99.09	106.97	112.74	127.27	147.88	164.38
HAP_06	50.50	64.04	73.83	89.79	97.57	104.07	108.82	120.76	137.77	155.53
HAP_07	48.29	62.41	72.97	91.55	101.14	109.13	115.01	129.98	168.03	168.03
HAP_08	340.89	444.02	520.76	651.10	716.44	770.41	809.74	907.58	1154.24	1154.24
HAP_09	340.83	444.62	521.14	652.17	716.97	770.78	810.16	908.14	1046.37	1155.71

Table 1.17 ReFH2 Peak Flow estimates

The hydrographs produced by the ReFH2 model can be represented as semi-dimensionless. This shape represents the response of the catchment and may be used for scaling to match FEH statistical peak flow estimates (i.e. if the statistical method is chosen as the preferred peak flow estimation method) and later used for input to the computational model. Additionally, the hydrograph shapes will be compared with the observed flow data obtained from SEPA at all the gauges for a number of selected flood events.

1.5.3 Flood Event Analysis

1.5.3.1 Selected Events

Multiple flood events have been extracted from the Q15 flow data supplied by SEPA at each of the gauges. This data may be used to inform the time-to-peak of the design hydrographs and lateral inflows before input to the numerical model. Figure 1.19 shows six subplots corresponding to selected flood events between 1992 and 2015. These events have been selected as they represent the largest events for which Q15 concurrent continuous flow data was available.

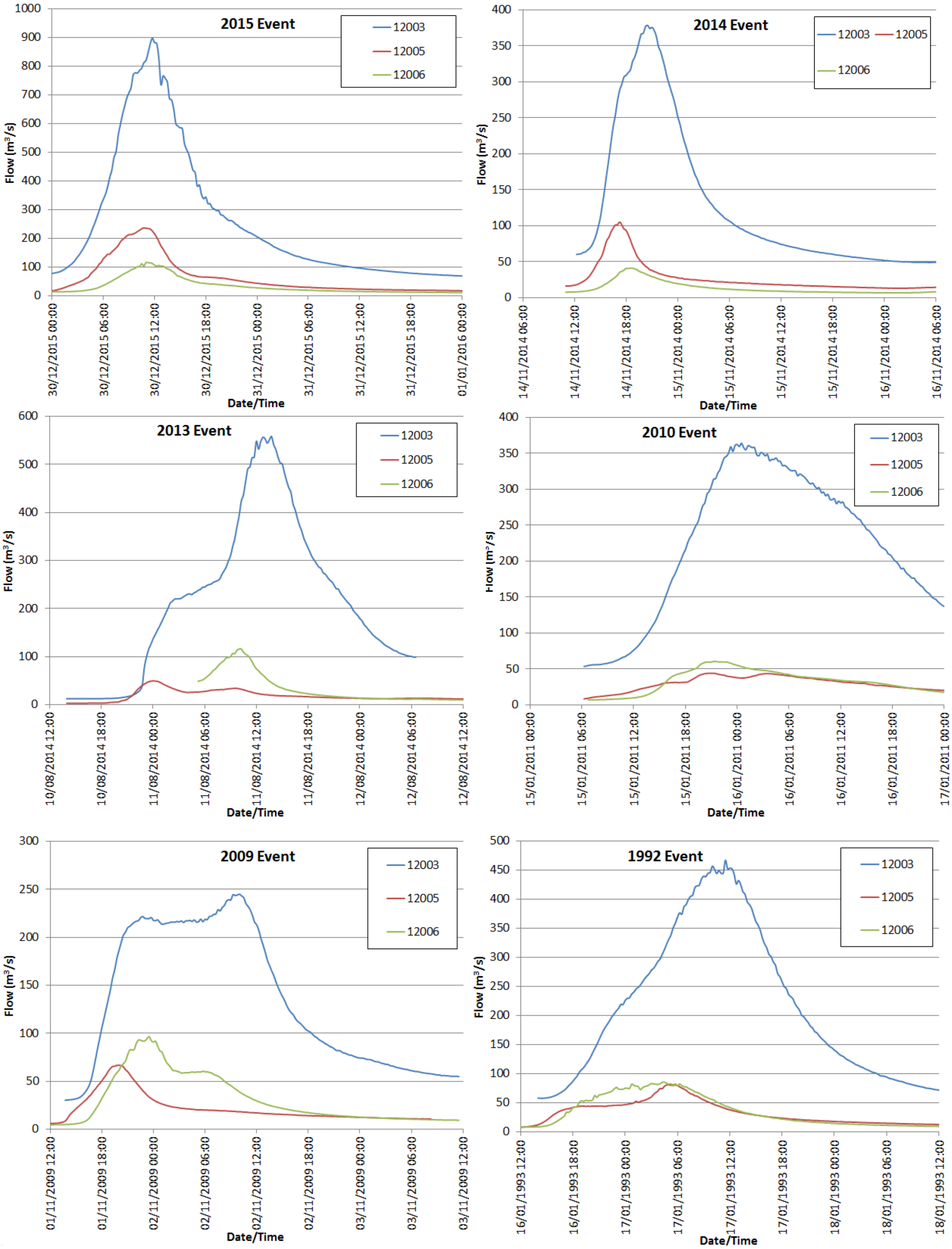


Figure 1.19 – Selected Flood Events

It can be seen from Figure 1.19 that the River Dee flood hydrographs are much larger and much wider (longer duration) than those for the Rivers Gairn and Muick. The gauging station at Invermuick peaks between 1 hour and 13.5 hours earlier for the six events. On average the peak flow is recorded 5 hours earlier at Invermuick than at Polhollick.

The gauging station at Invergairn peaks between 45 minutes and 9 hours 45 minutes earlier for the six events. On average the peak flow is recorded 4 hours earlier at Invergairn than at Polhollick.

Table 1.18 shows the hydrograph time to peak for the six largest flood events for which Q15 minute data is available at each of the gauging station locations.

Table 1.18 Time to Peak Hydrograph for Flood Events

Station	Hydrological Year	Time to Peak
12003	2015	11hours 45mins
	2014	7hours 45mins
	2013	18hours 30mins
	2010	16hours 30mins
	2009	20hour 30mins
	1992	18hours 45mins
12005	2015	12hours 15mins
	2014	5hours 45mins
	2013	16hours 45mins
	2010	14hours 30mins
	2009	7hours 45mins
	1992	6hours
12006	2015	9hours
	2014	6hours 45mins
	2013	5hours
	2010	14hours 30mins
	2009	11hours
	1992	15hours 15mins

Individual event hydrograph shapes were also compared against the design hydrographs. These were then compared with the design hydrographs output from the ReFH2 model to ensure accurate representation of catchment response is being achieved. Figure 1.20, Figure 1.21, Figure 1.22, Figure

1.23 and Figure 1.24 show the five largest flood events within the Q15 minute records at each of the three gauging stations but also at the two 'synthetic' gauging stations. Also shown is the design hydrograph shape at each location. A visual inspection of the hydrograph shapes shows that they are a good match to the historic events.

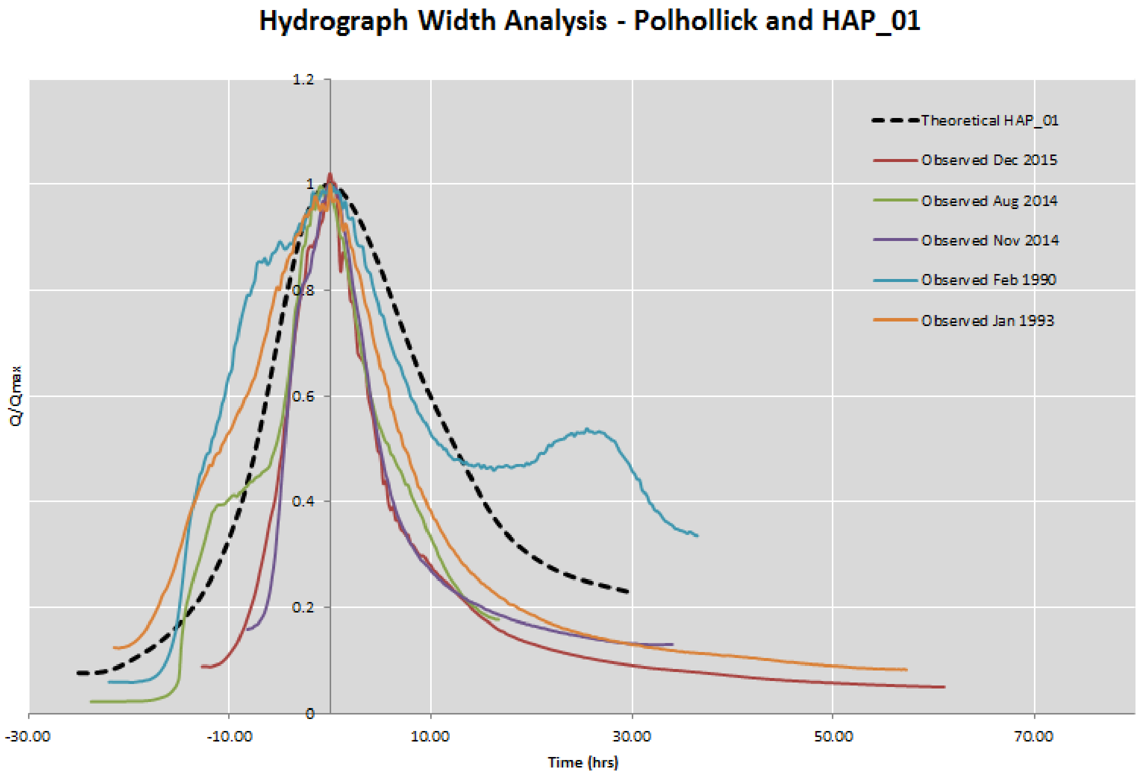


Figure 1.20 – Hydrograph shape comparison for the River Dee at Polhollick (ReFH2 Dashed Black Line)

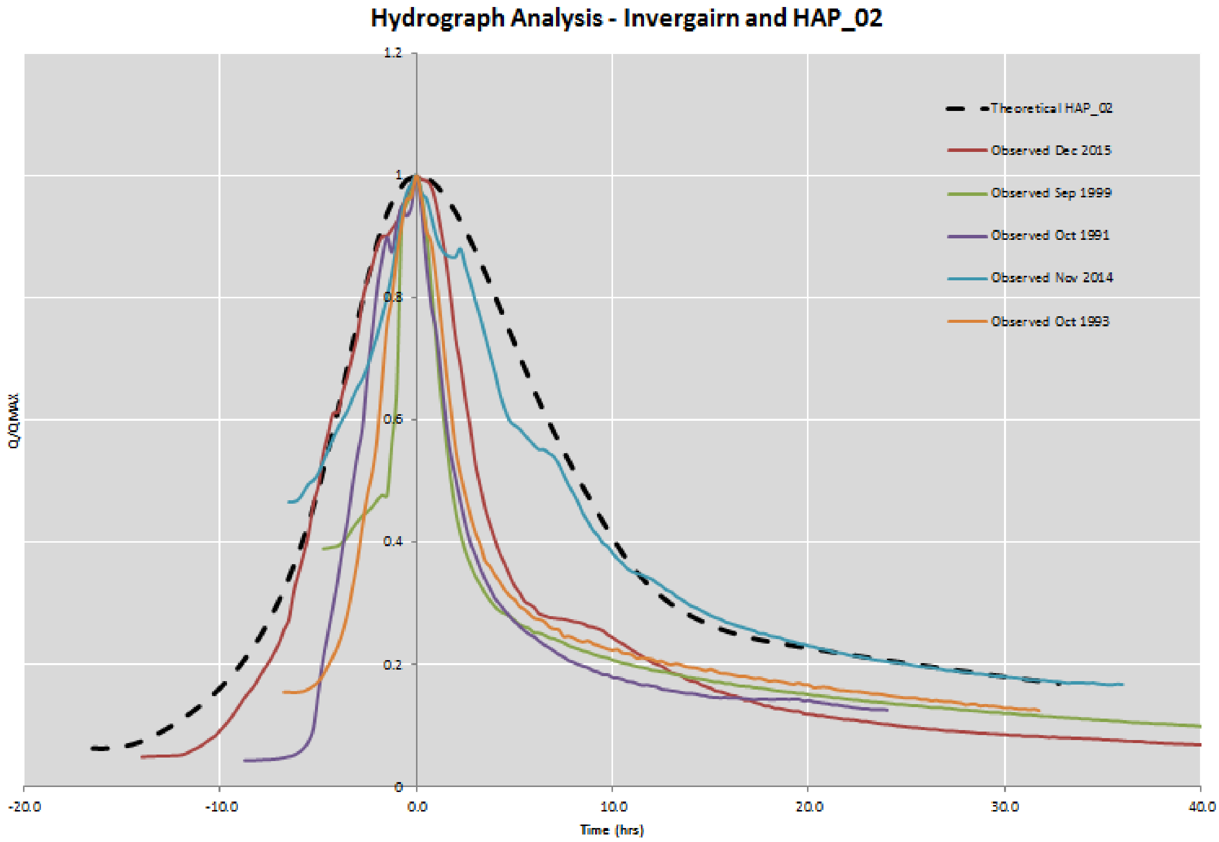


Figure 1.21 – Hydrograph shape comparison for the River Gairn at Invergairn (ReFH2 Dashed Black Line)

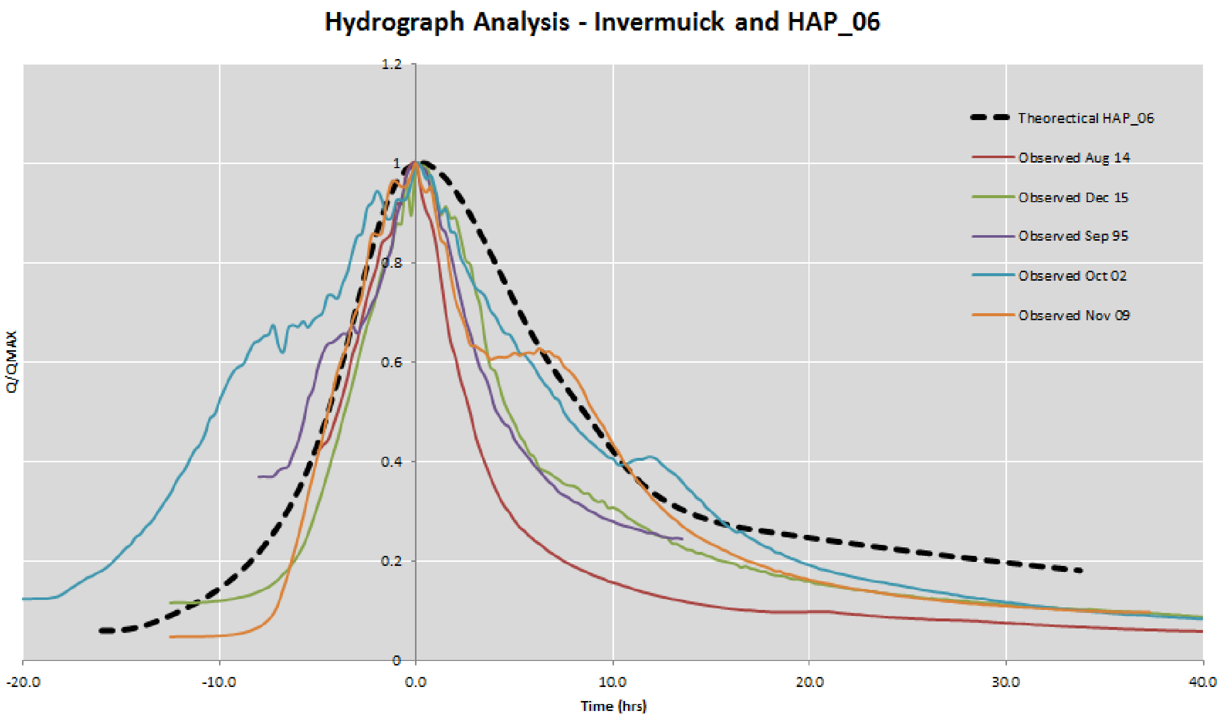


Figure 1.22 – Hydrograph shape comparison for the River Muick at Invermuick

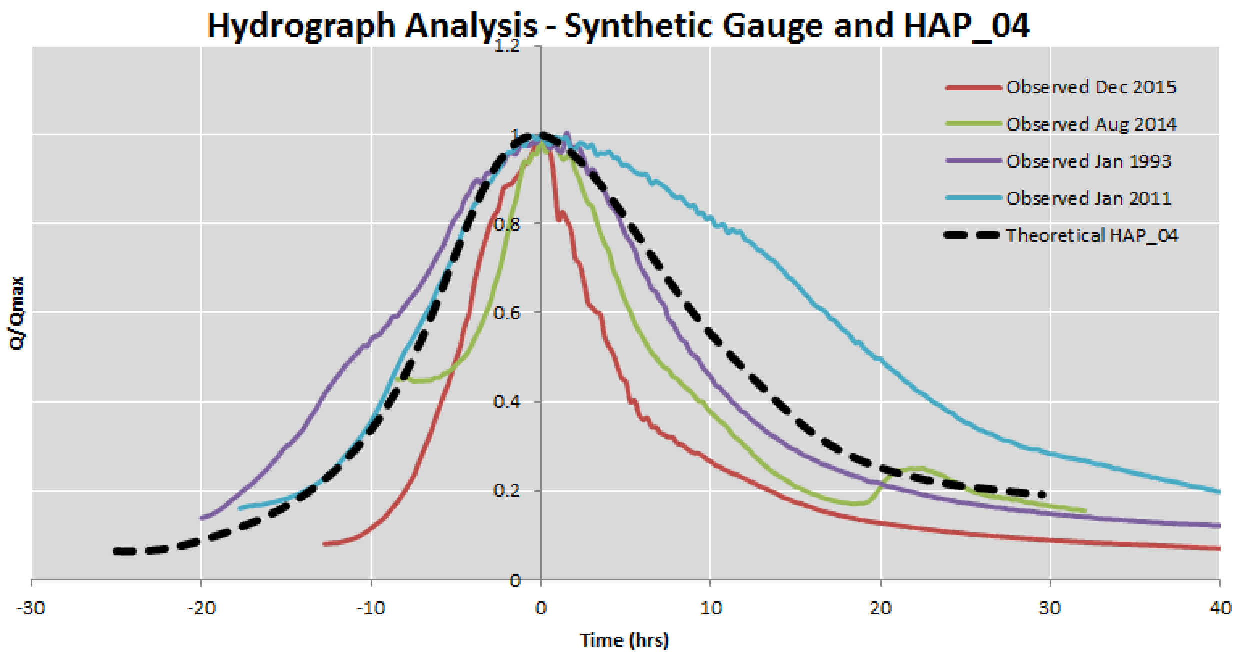


Figure 1.23 – Hydrograph shape comparison for the River Dee at Synthetic Gauge 01 (HAP_04)

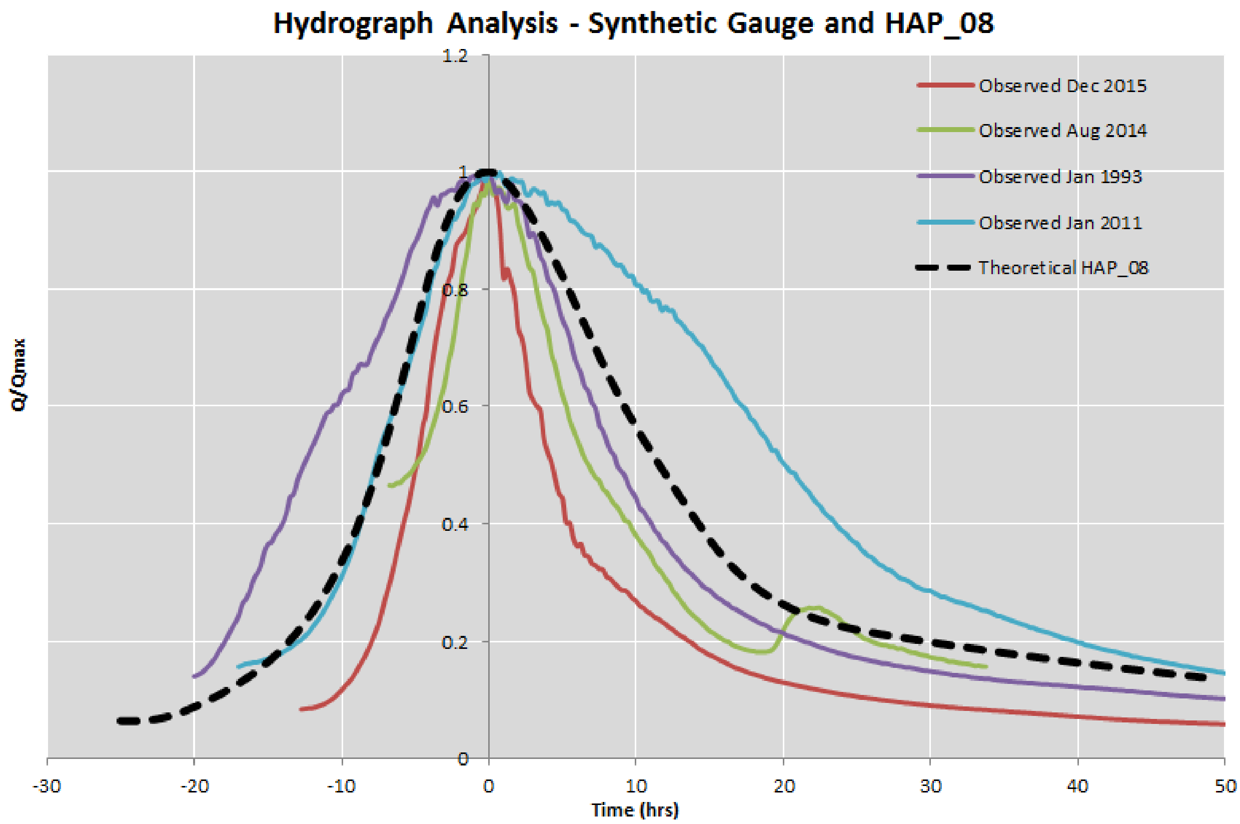


Figure 1.24 – Hydrograph shape comparison for the River Dee at Synthetic Gauge 02 (HAP_08)

To better understand the hydrograph shapes at the five HAPs for which there is data, full size historic event hydrographs have been compared against the five largest historic events within the continuous (Q15) flow records. In some cases the design hydrograph width tends to be as wide as the widest historic event and for that reasons they can be considered to be conservative but within the width limits of what has been observed. It is also notable that the December 2015 event (Storm Frank) does not appear to tie up with the equivalent design event hydrograph at the synthetic gauges in terms of peak flow. This is due to the discrepancy between the at site analysis from which the historic event return periods have been derived and the enhanced single site analysis (joint pooled) approach used to derive the design flows. As discussed in 1.4.5.5.2 it should be noted that the sum of the inflows at these HAPs (04 & 08) actually significantly exceeds the design hydrographs shown in Figure 1.28 and Figure 1.29.

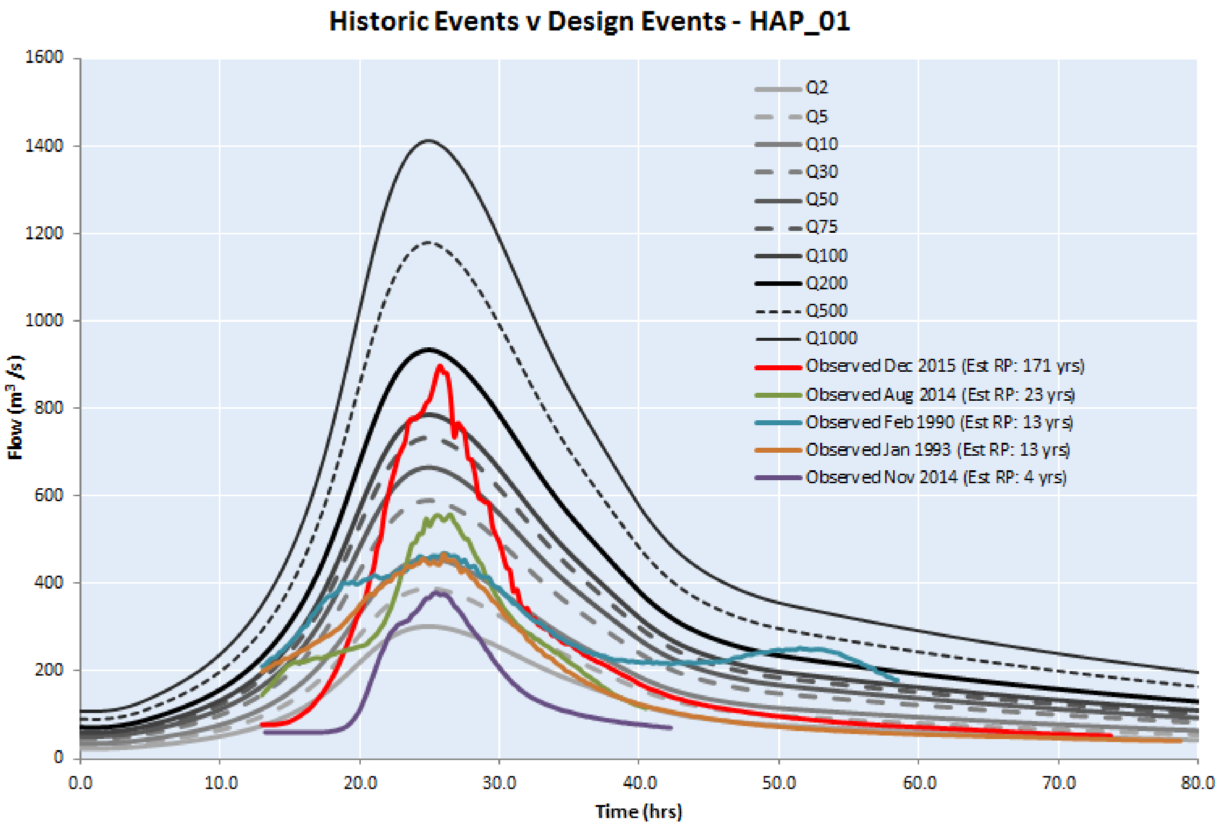


Figure 1.25 – Historic v Design Events at HAP01 on Dee

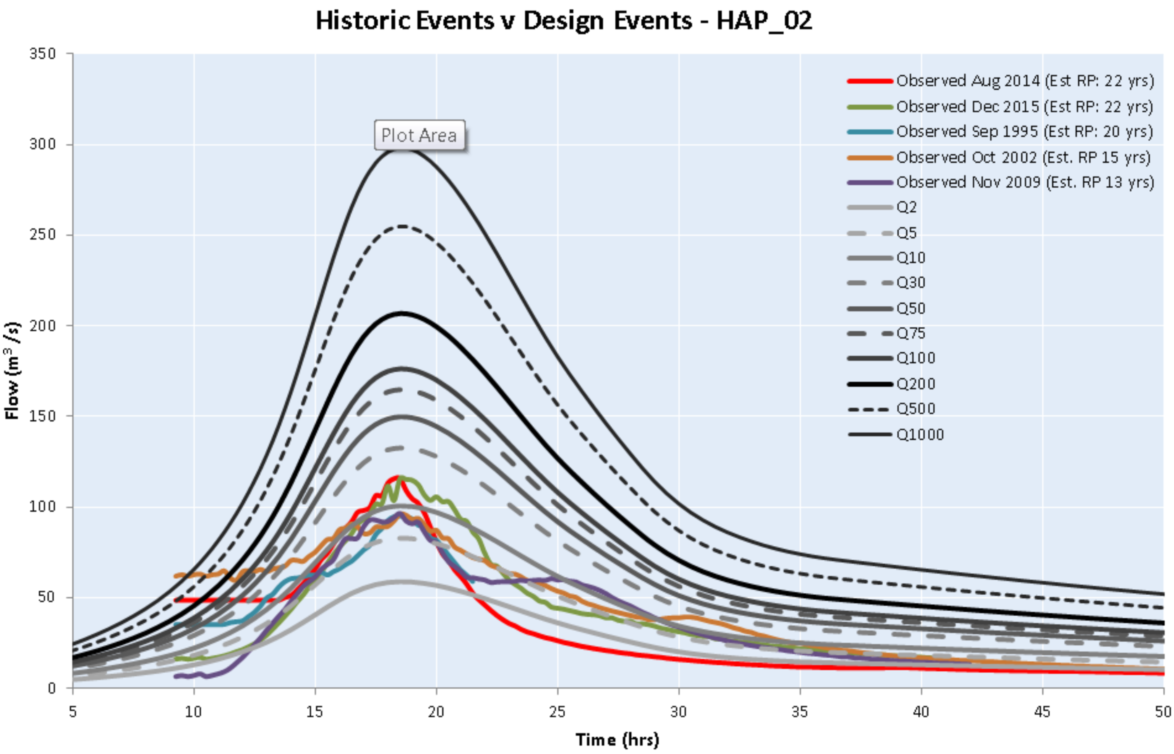


Figure 1.26 – Historic v Design Events at HAP02 on Gairn

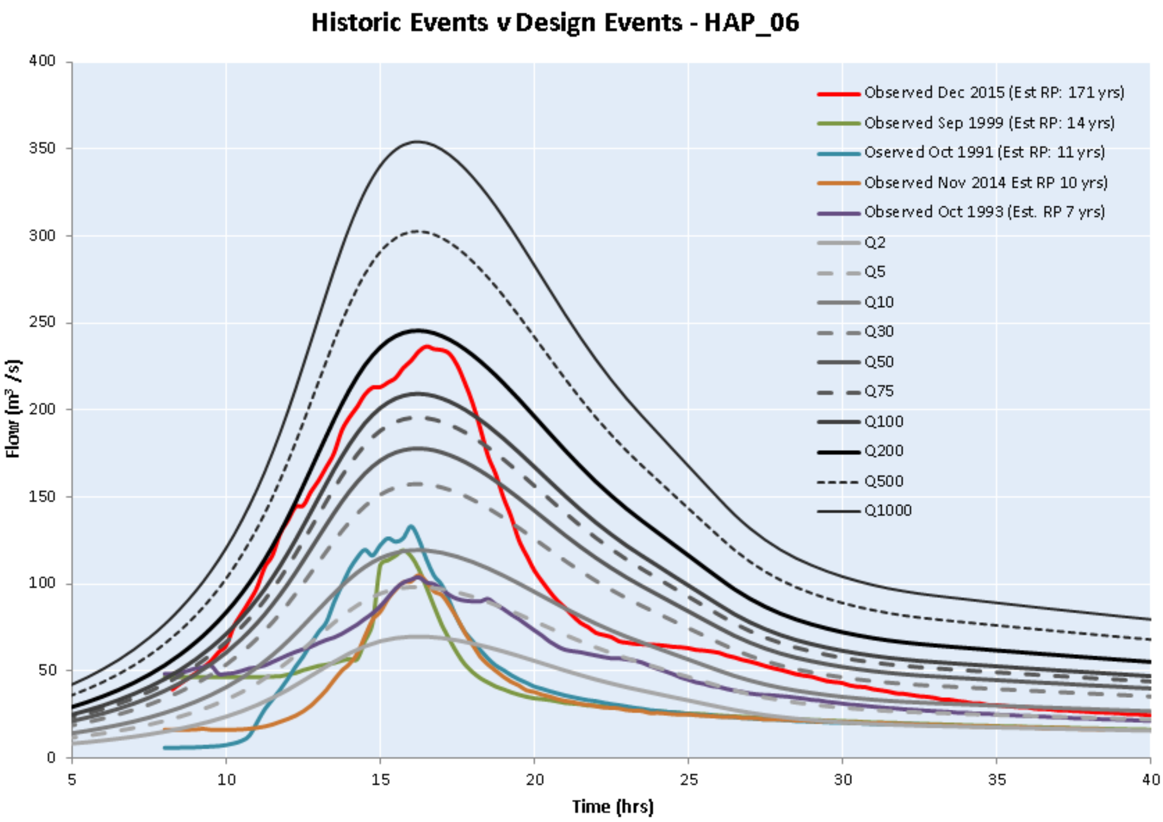


Figure 1.27 – Historic v Design Events at HAP06 on Muick

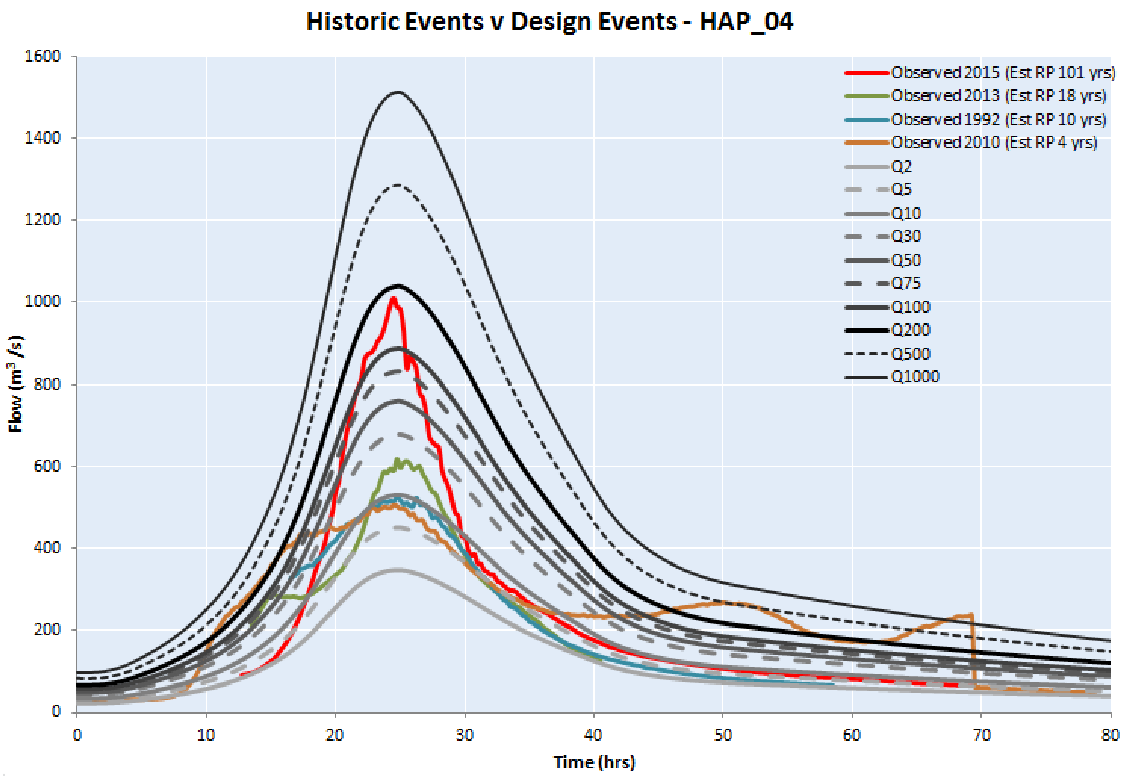


Figure 1.28 – Historic v Design Events at HAP04 on Dee

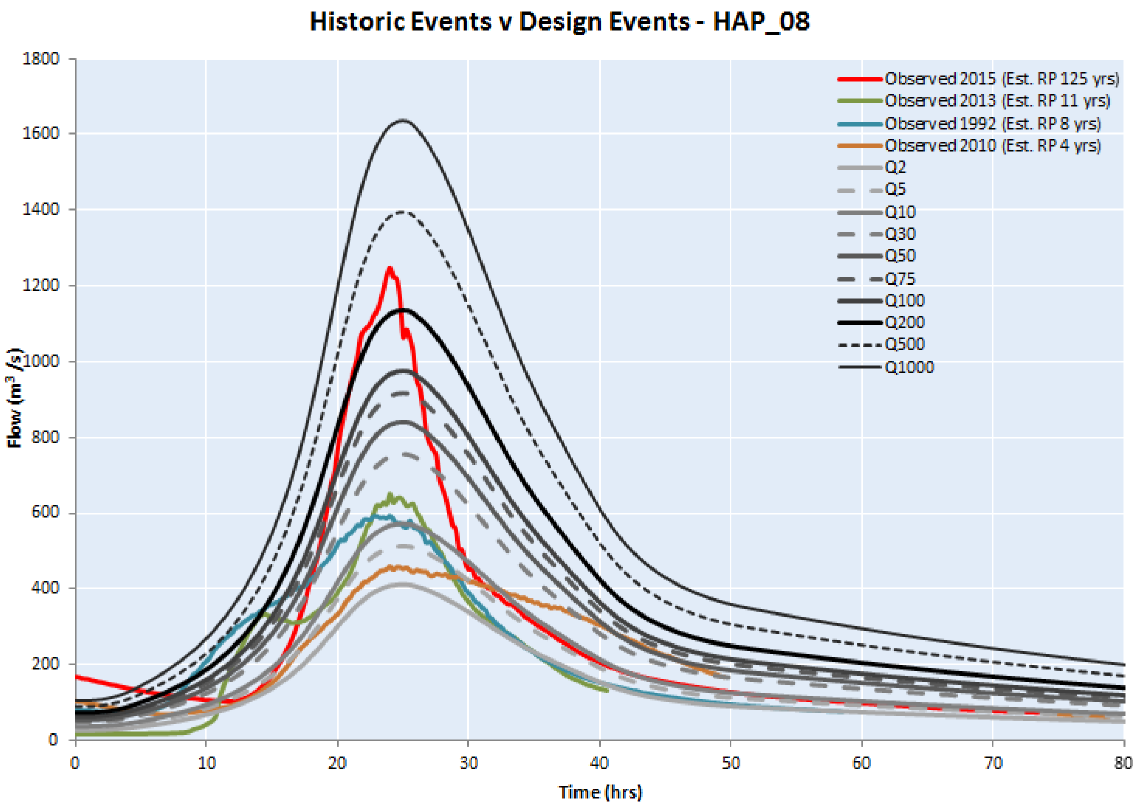


Figure 1.29 – Historic v Design Events at HAP08 on Dee

1.6 FLOOD ESTIMATION TECHNIQUE COMPARISON

Two methods of flood estimation were employed to provide design peak flow estimates in the Ballater area. The availability of high quality flood flow gauge records available on all the significant rivers affecting Ballater that statistical methods, anchored to the analysis of the records, is the preferred methodology for the derivation of peak flood flow estimates. However the ReFH2 method with the latest FEH 13 DDF rainfall model has been retained for comparison purposes. The FEH statistical method produces higher peak flows consistently across all HAPs. The dimensionless ReFH2 based design flow hydrographs have been scaled to match FEH statistical peak flows but these have been shown to be appropriate when considered against the observed hydrograph shape derived from the hydrometric data. Lateral inflows are calculated based on an area scaling of the downstream check flow hydrograph. Adjustment of the timings and peaks flows of these hydrographs have been made where necessary to ensure the sum of the inflows and hydrograph shape are reflective of the design estimate at the relevant HAP prior to modelling input. The calculated point inflows, check flows, lateral inflows are provided in Appendix A. Also included is a check on the sum of the inflows to a number of selected HAPs along the modelled reaches. This check ensures that sum of the inflows is sufficient to generate the check flow hydrograph in the model. Sums of inflows are designed to be slightly higher than the check flows as it is assumed that some hydraulic attenuation of flows will be evident in the model, particularly for larger events. Check flows that are generated in the model itself are reported and discussed following hydraulic modelling. Following these checks it was considered that the design flow estimation and model inflows are validated and no re-analysis was considered necessary.

1.7 CLIMATE CHANGE PROJECTIONS

UK Climate Projections (UKCP09) predict that future climate change may lead to warmer and drier summers, warmer and wetter winters with less snow, and more extreme temperature and rainfall events. This predicted increase in rainfall leads to predicted increases in river flows and increases in river flooding. In this assessment, RPS will consider the impact as a 20% increase of present day flow rates by the 2080s in line with SEPA guidance note 'Flood Modelling Guidance for Responsible Authorities (Version 1.1).

Note that the “present day” flow estimates presented above theoretically represent the period between the 1960s and present day as this assessment is based on data collected during this period.

The most targeted research into the effects of climate change on fluvial catchments in Scotland is summarised in the CEH document ‘An assessment of the vulnerability of Scotland’s river catchments and coasts to the impacts of climate change (Kay, Crooks, Davies and Reynard, 2011)’ which sets out changes in flood flows on a regional, probabilistic basis for varying time horizons and for various catchment response types. The hydrological modelling which underpins this analysis considered gauged catchments within the Dee catchment including the Polhollick station. For that reason the guidance can be considered well-grounded in relevant catchment data.

From the analysis a range of percentage uplifts on peak flows were derived for various emissions scenario likelihoods and for 2050 and 2080 time horizons for each River Basin Region in Scotland. For the 2050 time horizon in the North Eastern region flood peaks are expected to increase by between 2% - 21%. The central 50th percentile estimate is 12% and the 67th percentile estimate is 15%.

For the 2080 time horizon the North Eastern region flood peaks are expected to increase by between 2% and 33%. The central, 50th percentile estimate for a medium emissions scenario is 14%. The 67th percentile estimate for a high emissions scenario as used in SEPA’s fluvial hazard maps is 24%. In this context it is considered that 20% increase is appropriate for the 2080s for the North Eastern region within which the Dee is located. It is not as high as the 67th percentile high emissions uplifts used by SEPA but it is above the median estimate (14%).

APPENDIX A

Design Inflows

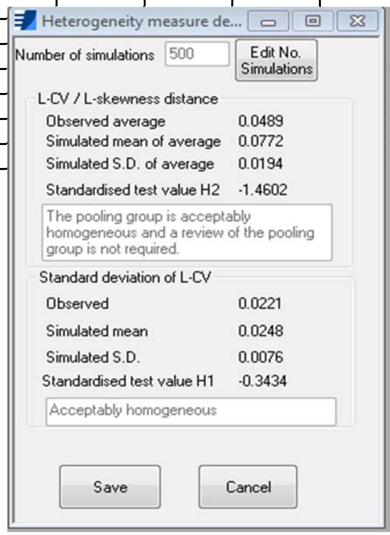
See attached spreadsheet

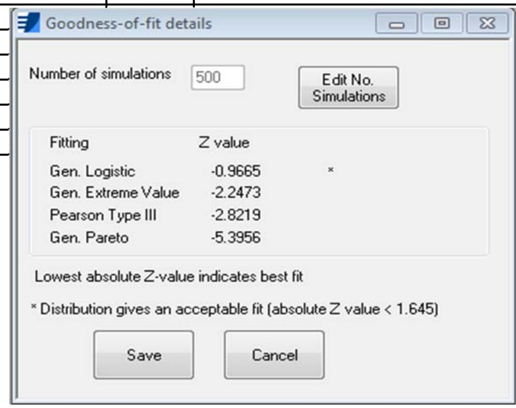
APPENDIX B

Final Pooling Groups

Pooling Group for 12003 (Dee @ Polhollick)

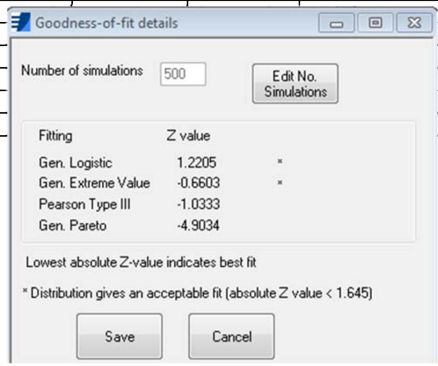
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	Removed	Comment
12003 (Dee @ Polhollick)	0	40	302.602	0.177	0.289	2.108	697.51	1231	0.038	0.986	0		
50002 (Torridge @ Torrington)	0.177	54	238.486	0.192	0.212	0.379	664.26	1184	0.05	0.996	0.004		
23004 (South Tyne @ Haydon Bridge)	0.183	56	452.241	0.138	0.175	0.724	749.9	1147	0.044	0.989	0.002		
45001 (Exe @ Thorverton)	0.207	59	176.51	0.178	0.266	0.382	608.16	1249	0.031	0.985	0.006		
21003 (Tweed @ Peebles)	0.218	56	177.465	0.194	0.269	0.133	698.12	1140	0.051	0.974	0.003		
50001 (Taw @ Umberleigh)	0.286	57	235.79	0.207	0.286	0.436	832.97	1153	0.037	0.997	0.004		
54028 (Vyrnwy @ Llanymynech)	0.294	45	264.242	0.167	0.185	1.048	779.14	1339	0.052	0.969	0.001		
84004 (Clyde @ Sills of Clyde)	0.32	51	196.355	0.174	0.214	0.113	742.27	1223	0.063	0.964	0.002		
28011 (Derwent @ Matlock Bath)	0.324	45	113.921	0.285	0.319	2.323	687.19	1114	0.03	0.947	0.015	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 28011 is suitabile for QMED estimation it is not suitable for pooling as flood water is not accounted for in the ratings as it is known to bypass the gauge. There for the rating can not be validated beyound QMED.
77001 (Esk @ Netherby)	0.34	42	636.51	0.136	0.162	0.883	848.74	1358	0.037	0.997	0.001	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 77001 is suitabile for QMED estimation it is not suitable for pooling. This is because there is only one gauging above QMED and that is from the earlier part of the record so the rating can not be validated beyond QMED.
76005 (Eden @ Temple Sowerby)	0.34	51	257.263	0.214	0.341	1.611	618.21	1142	0.06	0.998	0.004		
83006 (Ayr @ Mainholm)	0.349	31	248.945	0.157	0.217	2.089	579.04	1212	0.058	0.992	0.006		
7002 (Findhorn @ Forres)	0.35	57	342.573	0.23	0.252	0.773	781.78	1065	0.048	0.973	0	Yes	70002 has a low SAAR value of 1065 in comparison of the subject sites SAAR value of 1231.
Total		644											
Weighted means				0.18	0.25								
Finishing Total		500											
Finishing Weighted means		500		0.178	0.251								

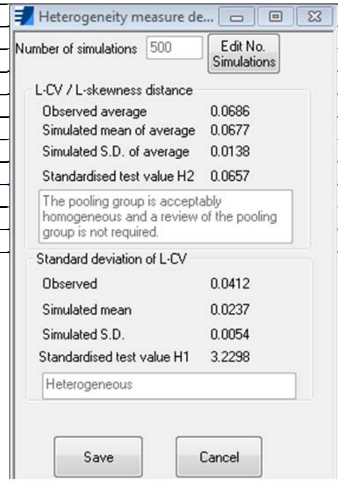




Pooling Group for 12005 (Muick @ Invermuick)

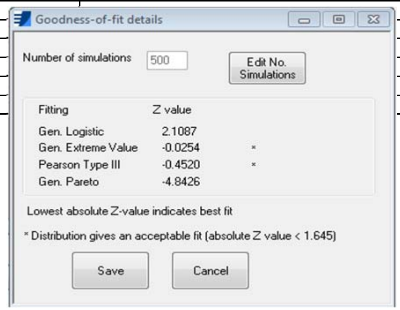
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	Removed	Comment
12005 (Muick @ Inve	0	39	69.789	0.249	0.219	0.789	109.39	1244	0.029	0.896	0		
8008 (Tromie @ Tron	0.378	54	50.652	0.242	0.185	1.059	131.61	1436	0.031	0.898	0		
6008 (Enrick @ Mill o	0.417	35	50.897	0.205	0.125	0.581	107.02	1290	0.047	0.839	0	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 6008 is suitible for QMED, it is not suitabile for pooling as it is out of bank at QMED. The AMAX is also not up to date as it only goes up to water year 2005 - 2006.
53025 (Mells @ Vallis	0.479	36	21.57	0.188	0.129	3.389	118.05	1056	0.045	0.943	0.02	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 53025 is suitible for QMED, it is not suitabile for pooling as it has too few high flow gaugings to validate the rating beyond QMED. The single gauging tha exists indicated that rating grossly under estimates flows.
203033 (Upper Bann	0.512	40	67.713	0.121	-0.018	2.626	101.64	1261	0.062	0.951	0.001		
17001 (Carron @ Hea	0.542	37	90.532	0.209	0.181	0.234	121.14	1519	0.04	0.843	0.013	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that 17001 is suitible for QMED although it does suggest using the data from 1988 onwards due to considerable uncertainity attached to the high flows up to 1988. Hiflow states the reason 17001 is unsuitabile for pooling is because it has no gaugings above QMED.
27088 (Calder @ Myt	0.546	26	84	0.194	0.228	1.042	146.87	1360	0.024	0.945	0.023		
72016 (Wyre @ Scort	0.563	19	79.331	0.164	0.069	0.807	87.99	1473	0.046	0.942	0	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that 72016 is suitible for QMED it is not suitable for pooling as there are no high flow gaugings. It does suggest that the modelled top end is probably suitable from 1996, but there is too much uncertainity in the embankment heights and floodplain flow before then.
96003 (Strathy @ Stra	0.573	21	50.021	0.192	0.236	1.09	120.87	1090	0.074	0.895	0		
45009 (Exe @ Pixton)	0.591	49	47.153	0.215	0.175	0.142	147.82	1375	0.017	0.95	0.001		
55025 (Llynfi @ Three	0.605	43	54.128	0.255	0.304	1.101	131.62	999	0.037	0.95	0.004	Yes	WINFAP highlighted this site as not suitable for pooling. An investigation of the site on Hiflows shows that 55025 is suitible for QMED it is not suitable for pooling as although all high flow records are in bank, the rating is unreliable above 1.5m where insufficient gaugings exist to verify stage - discharge relationship.
53004 (Chew @ Com	0.629	56	18.919	0.262	0.292	1.048	128.87	987	0.045	0.842	0.009		
28061 (Churnet @ Ba	0.645	40	27.456	0.227	0.227	0.194	136.34	976	0.053	0.927	0.029		
67005 (Ceiriog @ Bry	0.666	56	29.78	0.199	0.213	0.345	111.72	1198	0.023	1	0.001		
47008 (Thrushel @ Ti	0.677	46	41.001	0.213	0.25	0.563	112.72	1144	0.036	0.999	0.001		
47005 (Ottery @ Wer	0.699	51	64.06	0.148	0.113	0.992	121.66	1199	0.047	0.999	0.005		
Total		648											
Weighted means				0.235	0.189								
Finishing Total		478											
Finishing Weighted means		478		0.235	0.197								

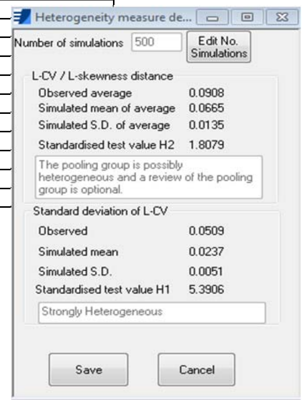




Pooling Group for 12006 (Gairn @ Invergairn)

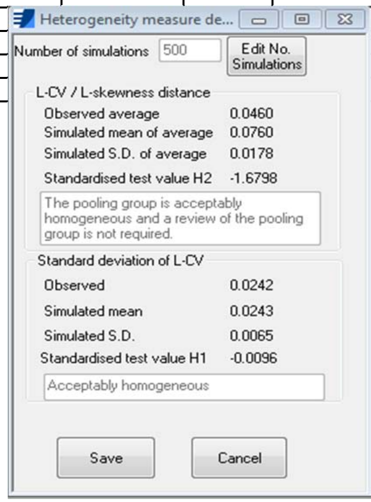
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	Removed	Comment
12006 (Gairn @ Invergairn)	0	38	58.802	0.2	0.126	0.12	145.91	1048	0.029	0.997	0		
28031 (Manifold @ Ilam)	0.1	45	66.58	0.185	0.361	1.065	148.15	1098	0.033	1	0.003	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation into Hiflows states that while 28031 is suitable for QMED it is not suitable for pooling as it has few high flow gaugings - the rating can not be validated beyond QMED and there is no information on the rationg above bankfull.
68018 (Dane @ Congleton Park)	0.204	61	41.679	0.172	0.419	2.155	142.57	1030	0.044	0.979	0.023	Yes	WINFAP flagged 68018 as being discordant. HiFlows indicates that data from 1950s - 1960s and 1980s is missing. The hydrometric description states that the crest is approx 2.9m above downstream channel, which is comparatively narrow, so extreme events (larger than recorded) might drown.
68006 (Dane @ Hulme Walfield)	0.257	30	53.477	0.238	0.151	1.206	151.42	1017	0.049	0.979	0.029	Yes	WINFAP highlighted this site as not suitable for pooling. HiFlows states that while 68006 is suitable for QMED it is not suitable for pooling as there is a few high flow gaugings and ratings can not be validated beyound QMED.
28023 (Wye @ Ashford)	0.259	51	16.37	0.205	0.315	1.332	152.28	1165	0.023	0.976	0.023		
21024 (Jed Water @ Jedburgh)	0.268	34	71.477	0.216	0.151	0.097	139.95	914	0.028	0.997	0.006		
55013 (Arrow @ Titley Mill)	0.281	47	27.617	0.194	0.168	0.105	125.9	962	0.038	0.999	0.005		
201007 (Burn Dennet @ Burndennet)	0.301	40	81.796	0.174	0.076	0.299	147.14	1186	0.046	0.994	0		
55025 (Llynfi @ Three Cocks)	0.352	43	54.128	0.255	0.304	0.178	131.62	999	0.037	0.95	0.004	Yes	WINFAP highlighted this site as not suitable for pooling. An investigation of the site on Hiflows shows that 55025 is suitable for QMED it is not suitable for pooling as although all high flow records are in bank, the rating is unreliable above 1.5m where insufficient gaugings exist to verify stage - discharge relationship.
9004 (Bogie @ Redcraig)	0.36	26	31.622	0.312	0.274	0.992	182.43	955	0.031	0.998	0.001		
19011 (North Esk @ Dalkeith Palace)	0.367	44	36.856	0.324	0.282	1.201	133.41	907	0.033	0.965	0.026		
23033 (Rede @ Otterburn)	0.371	15	143.113	0.153	-0.021	0.769	180.63	1024	0.03	0.963	0	Yes	WINFAP highlighted this site as not suitable for pooling.
23002 (Derwent @ Eddys Bridge)	0.372	11	48.41	0.171	0.032	0.467	118.11	943	0.02	0.996	0.001	Yes	Short record years.
27055 (Rye @ Broadway Foot)	0.398	37	41.433	0.371	0.582	3.396	131.3	882	0.015	0.998	0.001	Yes	WINFAP flagged 27055 as being discordant - this prompted an investigation into to the site. 27055 has a SAAR value of 882 and a PROPWET value of 0.340 in comparison to the subject site, which has a SAAR value of 1048 and a PROPWET value of 0.640.
203024 (Cusher @ Gamble's Bridge)	0.403	44	49.881	0.131	0.008	2.55	170.89	996	0.058	0.992	0.004		
47008 (Thrushel @ Tinhay)	0.405	46	41.001	0.213	0.25	0.068	112.72	1144	0.036	0.999	0.001		
9003 (Isla @ Grange)	0.431	56	50.356	0.239	0.159	0.479	179.98	900	0.04	0.994	0.005	Added	To increase record years.
12005 (Muick @ Invermuick)	0.823	39	69.789	0.249	0.219	0.113	109.39	1244	0.029	0.896	0	Added	To increase record years.
12003 (Dee @ Polhollick)	2.211	40	302.602	0.177	0.289	2.702	697.51	1231	0.038	0.986	0	Added	To increase record years.
Total		612											
Weighted means				0.206	0.225								
Finishing Total		505											
Finishing Weighted means				0.206	0.182								

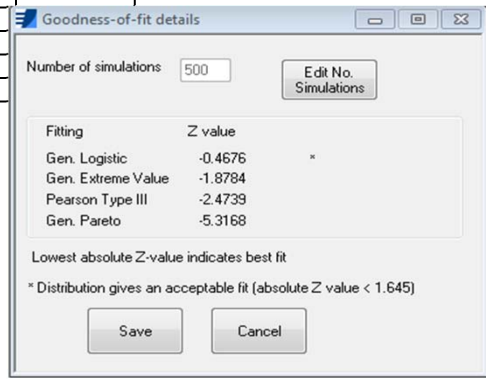




Pooling Group for Synthetic Gauge 01 (12003 + 12006)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	Removed	Comment
999200 (Dee @ Hapfour)	0	26	347.766	0.185	0.34	1.981	847.53	1198	0.037	0.988	0		
50001 (Taw @ Umberleigh)	0.096	57	235.79	0.207	0.286	0.876	832.97	1153	0.037	0.997	0.004		
47001 (Tamar @ Gunnislake)	0.145	59	265.1	0.182	0.265	0.83	920.22	1215	0.044	0.993	0.005		
23004 (South Tyne @ Haydon Bridge)	0.205	56	452.241	0.138	0.175	0.939	749.9	1147	0.044	0.989	0.002		
77001 (Esk @ Netherby)	0.246	42	636.51	0.136	0.162	1.036	848.74	1358	0.037	0.997	0.001	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 28011 is suitabile for QMED estimation it is not suitable for pooling as there is only one gauging above QMED and that is tn the early part of the record. Also, the rating can not be valiated beyond QMED.
12003 (Dee @ Polhollick)	0.278	40	302.602	0.177	0.289	0.64	697.51	1231	0.038	0.986	0		
56001 (Usk @ Chainbridge)	0.29	54	373.4	0.168	0.219	1.143	913.25	1367	0.044	0.98	0.006		
7002 (Findhorn @ Forres)	0.297	57	342.573	0.23	0.252	1.981	781.78	1065	0.048	0.973	0		
62001 (Teifi @ Glanteifi)	0.312	55	200.383	0.172	0.2	0.371	897.59	1379	0.049	0.995	0.005		
54028 (Vyrnwy @ Llanymynech)	0.319	45	264.242	0.167	0.185	0.79	779.14	1339	0.052	0.969	0.001		
21003 (Tweed @ Peebles)	0.336	56	177.465	0.194	0.269	0.207	698.12	1140	0.051	0.974	0.003		
84018 (Clyde @ Tulliford Mill)	0.339	38	247.738	0.17	0.222	0.117	938.36	1205	0.062	0.966	0.002		
25001 (Tees @ Broken Scar)	0.346	59	388.89	0.176	0.099	2.088	847.7	1122	0.053	0.945	0.004	Yes	The FARL for site 25001 is 0.945 in comparison to the FARL of subject site 0.988.
Total		644											
Weighted means				0.182	0.238								
Final Total		543											
Final Weighted means		543		0.183	0.254								





Pooling Group for Synthetic Gauge 02 (12003 + 12006 + 12005)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	Removed	Comment
999200 (Dee @ Hapeight)	0	23	419.139	0.158	0.51	3.202	966.83	1199	0.037	0.977	0.001	No	Subject site has remained in pooling group even though it is highlighted by WINFAP as discordant.
47001 (Tamar @ Gunnislake)	0.145	59	265.1	0.182	0.265	0.527	920.22	1215	0.044	0.993	0.005		
50001 (Taw @ Umberleigh)	0.255	57	235.79	0.207	0.286	1.569	832.97	1153	0.037	0.997	0.004		
56001 (Usk @ Chainbridge)	0.275	54	373.4	0.168	0.219	1.76	913.25	1367	0.044	0.98	0.006		
84018 (Clyde @ Tulliford Mill)	0.283	38	247.738	0.17	0.222	1.217	938.36	1205	0.062	0.966	0.002		
77001 (Esk @ Netherby)	0.325	42	636.51	0.136	0.162	1.091	848.74	1358	0.037	0.997	0.001	Yes	WINFAP highlighted this site as not suitable for pooling. Investigation of the site on Hiflows shows that while 28011 is suitabile for QMED estimation it is not suitable for pooling as there is only one gauging above QMED and that is tn the early part of the record. Also, the rating can not be valiated beyond QMED.
62001 (Teifi @ Glanteifi)	0.333	55	200.383	0.172	0.2	0.436	897.59	1379	0.049	0.995	0.005		
25001 (Tees @ Broken Scar)	0.346	59	388.89	0.176	0.099	0.878	847.7	1122	0.053	0.945	0.004		
84003 (Clyde @ Hazelbank)	0.355	51	274.929	0.144	0.25	0.485	1093.1	1165	0.065	0.97	0.004		
27007 (Ure @ Westwick Lock)	0.37	60	281.504	0.187	0.232	0.576	912.58	1120	0.067	0.981	0.008	Yes	The PROPWET for site 27007 is 0.410 in comparison to PROPWET of subject site which has a PROPWET value of 0.67.
23015 (North Tyne @ Barrasford)	0.373	22	422.68	0.152	0.183	0.265	1049.63	1013	0.049	0.989	0.001		
23004 (South Tyne @ Haydon Bridge)	0.38	56	452.241	0.138	0.175	0.831	749.9	1147	0.044	0.989	0.002		
67015 (Dee @ Manley Hall)	0.386	45	226	0.165	0.217	0.163	1008.74	1367	0.046	0.934	0.004		
Total		621											
Weighted means				0.162	0.249								
Final Total		519											
Final Weighted means		519		0.163	0.257