Appendix A11.2: Surface Water Hydrology

1 Introduction

1.1.1 This appendix provides detailed information on the hydrological analyses relevant to Appendix A11.3 (Flood Risk Assessment (FRA)) and low flow assessment undertaken for the proposed scheme.

1.1.2 This report specifically provides information on the methods and approach used to derive design peak flow estimates for the culvert assessments of the smaller ungauged catchments. Design peak flows along with inflow hydrographs have also been derived for the purpose of hydraulic modelling of all modelled watercourses and significant tributaries that feed into the model extent. It also provides information on the methods used to derive low flow estimates at the road drainage outfall locations for dilution calculations of the receiving watercourses. The design peak flow estimates, inflow hydrographs and low flow estimates are presented within this report for the watercourses impacted by the proposed scheme.

1.1.3 A total of 89 watercourses have been identified within 500m of the proposed scheme. Seventy-three have the potential to be impacted by the proposed scheme and associated infrastructure. These watercourses range in size from small drainage ditches to large watercourses such as the River Bruar and the River Garry. Annex C of this report shows the catchment areas of the watercourses with the potential to be affected by the proposed scheme.

2 Approach and Methods

General Approach

2.1.1 Design peak flows, inflow flood hydrographs and low flow estimates are required for the Stage 3 DMRB Assessment for watercourses/water features that may potentially be impacted and/or crossed by the proposed scheme. Peak flows are required for all watercourse crossing locations for the following annual exceedance probability (AEP) events: 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% (equivalent to the 2, 5, 10, 30, 50, 100, 200 and 1000-year events).

2.1.2 For clarity Annual Exceedance Probability (AEP) refers to the chance that a flood of a particular size is experienced or exceeded during any year. In this report a probability value expressed as a percentage is used to quantify this. For example, a 50% AEP equates to a 1 in 2 chance of the flood being experienced or exceeded in a year. Similarly, the 0.5% AEP equates to a 1 in 200 chance of the flood being experienced or exceeded in a year. It is important to recognise that a low probability doesn't preclude the event happening in the following year.

2.1.3 It should also be highlighted that return period is commonly used within extreme event studies to refer to event rarity. The 2-year event is the same as the 50% AEP event, and the 200-year event is the same as the 0.5%. It refers to an on average spacing between floods of that size. A problem with this usage is that some wrongly interpret this as: once the event has occurred then it will not happen again for the period of the return period. For example, if a 200-year event was experienced it is a wrong interpretation to say that that event will not reoccur for 200 years. Every year there is a chance that a 200-year flood may happen, albeit a very small chance, and it is possible therefore for a really rare event to re-occur in quick succession, equally there could be a much larger gap between the recurrence of the event than return period might suggest.

2.1.4 For clarity, the notation used in this report, to describe for example the 0.5% AEP flood event, is '0.5% AEP (200-year) event'. Inflow hydrographs are further required for all watercourses identified for hydraulic modelling.

2.1.5 Low flow estimates such as Q_{95} flow and Qmean are also required for all road drainage outfall locations to assess the potential impacts of the proposed outfalls on the receiving watercourses. The hydrological methods and approaches used to derive this required information are presented in the sections below.

Review of Previous Work

2.1.6 As part of the initial assessment a review of previous reports for the A9 was undertaken. The following reports were reviewed and relevant information extracted:

- Transport Scotland (2013). A9 Dualling Programme, Strategic Environmental Assessment (SEA) Environmental Report;
- Transport Scotland (2014). A9 Dualling Programme, Environmental Report: Strategic Flood Risk Assessment;
- Transport Scotland (2014). A9 Dualling Programme Strategic Environmental Assessment (SEA) – Environmental Report Addendum;
- Transport Scotland (2014). A9 Dualling Programme Strategic Environmental Assessment (SEA) – Post Adoption SEA Statement;
- DMRB Stage 1 Assessment A9 Dualling: Preliminary Engineering Support Services (Jacobs, 2014);
- DMRB Stage 3 Assessment: A9 Dualling - Luncarty to Pass of Birnam Environmental Statement: Appendix A9.1 – Surface Water Hydrology (Jacobs, 2014);
- DMRB Stage 2 Assessment. A9 Dualling – Killiecrankie to Pittagowan: Environmental Statement, Appendix A9.1 – Surface Water Hydrology (Jacobs, 2015); and
- DMRB Stage 2 Assessment. A9 Dualling – Pitagowan to Glen Garry: Environmental Statement, Appendix A9.1 – Surface Water Hydrology (Jacobs, 2015).

2.1.7 A review of any Potential Vulnerable Areas (PVA[1]) within the surrounding area and any historic flooding / culvert sizing issues/flood prone areas was also undertaken. SEPA Flood Maps were also reviewed to look for locations/properties at risk from flooding along the route.

Regional Hydrological Considerations

2.1.8 The existing A9 runs through the southern portion of the Grampian Mountains. Hills and mountains formed from relatively impermeable geology form the landscape surrounding the road’s corridor and have a dominating influence on the hydrological characteristics of the streams and rivers. The steepness of the land coupled with the lack of permeability tends to promote fast responding watercourses.

2.1.9 Orographic uplift in the east is less than further west however the presence of snow within the catchments during the winter is of significance particularly snowmelt contribution to flood flows, an example of which would be the extreme January 1993 flood within the River Tay basin. However, the role of snow is more complicated than this since precipitation falling above the snowline\freezing line will be stored rather than contribute to storm event flood flows within the watercourses. These aspects make the estimation of design flood runoff particularly challenging (for example precipitation inputs to standard rainfall-runoff methods) and place extra emphasis on any gauged flow data within this upland region.

2.1.10 There is also notable attenuation and diversion of flows within a number of catchments in the area as a result of the development of hydropower (most notably the Tummel Valley hydropower scheme) and due to the numerous lochs/reservoirs (some of which are involved in the holding of water as part of the hydropower schemes). These aspects influence the downstream flow regime, including both floods and low flows. All these aspects need to be recognised when making hydrological estimates.

2.1.11 Further details are provided in Sections 2.6 to 2.7 as to how these issues have been catered for in the estimation of peak flows, inflow hydrographs and low flows for the catchments at potential to be impacted by the dualling.

[1] A PVA is an area which has been identified by SEPA as requiring further assessment due to the potential impact from flooding being assessed as being great enough to warrant further assessment /appraisal of Flood Risk Management actions.

Climate Change

2.1.12 Climate change considerations are required to be included as part of this assessment for design flood events. At present the general industry approach to climate change is to increase design flows by 20 (The Highways Agency et al. 2009, SEPA 2015) in order to take into consideration the potential increase in flood flows that may occur in future as a result of a warming climate. This assessment follows standard practice and therefore an uplift factor of 20% has been applied to the design peak flow estimates.

2.1.13 No climate change uplift factor has been applied to the low flow estimates. An additional factor to be considered is that the low flows below the hydro schemes will in part to be controlled by the operational rules governing releases rather than the natural flow regime.

Baseline Assessment

2.1.14 To undertake this assessment all watercourses, waterbodies and springs that could potentially be impacted by the A9 dualling scheme (including the main carriageway and associated ancillary roads) were identified and a list of these features compiled. This was undertaken using a GIS base map and layers showing the current and proposed A9 development footprint. The list of watercourses, waterbodies and springs was then verified on site. This list of potentially impacted watercourses, waterbodies and springs formed the basis of the hydrological assessment.

2.1.15 The FEH CD-ROM v3 was used to derive catchment descriptors for all identified watercourses and waterbodies potentially impacted by the scheme. Catchment boundaries have been checked on Ordnance Survey maps and where required via site investigation. For a small number of catchments alterations to the FEH catchment were required and the catchment parameters have been adjusted using FEH methodologies (See Annex B). All catchments < 1km^2 had their catchment boundaries reviewed; catchments with areas between 1km^2 and 5km^2 had their areas reviewed when considered necessary (such as when the catchments contained ambiguous flat areas); and generally catchments > 5km^2 were only reviewed when a known artificial influence such as hydro-power was present in the catchment. Some catchments within the A9 corridor were not picked up by the FEH CD-ROM due to having very small catchment areas. Where this was the case catchment descriptors have been borrowed (and adjusted) from either an adjacent catchment considered to share similar features or by extending the selection point further downstream to pick up the nearest catchment from within the FEH dataset catchment (if judged suitable). Standard FEH methodologies were used for specific parameters that can’t be scaled based upon areal adjustment alone (e.g. DPLBAR, URBEXT and FARL).

2.1.16 A review of local data within the identified catchments and within the vicinity of the proposed scheme was undertaken. Flow gauges present were assessed, as outlined in Annex E, for suitability for providing relevant high quality data. This included assessment of gauge performance in terms of both high and low flows. Since the earlier production of the DMRB Stage 2 hydrology report extreme flooding has occurred within Scotland during the 2015/16 winter. This report incorporates this recent data. A desk based assessment of local flood histories was also undertaken using a combination of previous third party reports and local knowledge if readily available. A review of anthropogenic activity within the catchments was also undertaken and any notable impacts or activities highlighted.

2.1.17 Details on whether the proposed watercourse crossings were going to be a culvert or a bridge crossing were also noted. All road drainage outfall locations were also identified as low flow estimates are required at these locations for dilution calculations. Additionally, those watercourses requiring hydrological simulation within the detailed hydraulic (numerical) modelling were identified. Hydraulic modelling has been assessed as more appropriate for larger watercourses particularly where there is a known flood history or identified flood risk.

Design Flows and Inflow Hydrographs

2.1.18 Peak flows are required for all watercourse crossing locations for the following annual exceedance probability (AEP) events: 50%, 20%, 10%, 3.33%, 2%, 1%, 0.5% and 0.1% (equivalent to the 2, 5, 10, 30, 50, 100, 200 and 1000-year return periods). The level of detail required for design peak flow estimates within this project is generally based on the importance of the flow estimate and in particular whether the watercourse has been selected for detailed hydraulic modelling. Larger watercourses with known flood risk are more likely to require detailed numerical hydraulic modelling. Watercourses identified for detailed modelling require not only the peak flow but also the full inflow hydrographs.

2.1.19 The majority of watercourses within the study area (for surface water hydrology and flood risk, the study area was determined by the natural processes of watercourse and floodplain and the location of flood receptors, which can extend for some distance upstream and downstream) have small and ungauged catchments. Flow estimation for small[2] ungauged catchments is challenging and open to greater uncertainty than for larger catchments, where more relevant gauged data is likely to be available to aid design flow estimates. Where flow data is available it has been used to refine the hydrological assessment. It should be noted though that within or in close proximity to the southern section (Birnam to Glen Garry) of the A9 dualling programme there are a limited number of flow gauges which could be used. SEPA have also derived peak flow estimates for some of the larger watercourses located in this region as part of their Flood Map assessment. These flow estimates were supplied by SEPA and have been referred to in this assessment.

2.1.20 Due to slightly different methodologies being adopted for the estimation of design peak flow for smaller and larger catchments this section has been split into two sub-sections.

<u>Design Peak Flow Estimation – Small Ungauged Catchments</u>

2.1.21 In the DMRB Stage 2 assessment the FEH statistical method based peak flows were adopted for design purposes, although the FEH rainfall-runoff model method was also used to derive the 50% AEP (2-year) and 0.5% AEP (200-year) event peak flows for comparison purposes. Following SEPA's advice, the methodology was revised during the DMRB Stage 3 assessment to adopt the larger of the two peak flow values derived from FEH statistical and FEH rainfall-runoff methods [basis of comparison being the 50% AEP (2-year) and 0.5% AEP (200-year) event peak flows].

2.1.22 The following paragraphs describe the two methodologies involved.

FEH Statistical Method

2.1.23 In the FEH statistical method, the index flood (QMED) was initially derived from catchment descriptors for each target site. It should be noted that deriving QMED from catchment descriptors alone is subject to greater uncertainty than derivation using suitable local gauged data. Flow estimation is improved by the use of local flow data; however, for these small catchments no direct flow gauging was available. These initial QMED values were however adjusted for all catchments in the southern section of the A9 dualling programme using a regionally derived QMED adjustment factor. Gauges in the general region of the southern section were analysed and high flow rated stations with catchment areas less than 300km^2 short listed. Stations with artificial influences in the catchment judged likely to influence the flood regime (such as large scale hydropower) were removed. Some flow stations not appearing in the Peak Flow dataset (previously referred to as Hiflows-UK) were also considered in the vicinity of the proposed scheme and assessed for suitability for QMED estimation. From this assessment four non Peak Flow stations were assessed as being suitable for inclusion in the regional QMED adjustment along with 23 Peak Flows stations. All 27 stations were assessed as natural catchments. The geomean of the ratios of station $QMED_{(observed)}$ / $QMED_{(catchment\ descriptors)}$ values was used to derive the regional QMED adjustment factor of 1.237.

2.1.24 To derive flood growth curves for each site, the target watercourses were grouped into hydrologically similar groups based on the similarity of the following catchment descriptors: AREA, FARL, SAAR and FPEXT (the same attributes as used in the current FEH pooling approach). Seven groups were identified based on the above catchment descriptors. FEH pooling group analysis was then undertaken on one representative target catchment from each group. The estimated growth curve was then applied to the QMED values within each group allowing the derivation of the required design peak flows.

[2] Catchments with areas <25km^2 are considered to be small catchments in this assessment.

2.1.25 The EA Document No. SC090031 (Faulkner et al, 2012) states that the FEH statistical method should be used to derive flood estimates for catchments with areas > 0.5km². Where catchment areas are <0.5km² the document advocates scaling the estimate from a hydrologically similar catchment with an area of 0.5km². Accordingly, the peak flood estimates for all minor ungauged catchments with catchment areas <0.5km² were derived by scaling the flows from a hydrologically similar donor catchment with an area > 0.5km² in the vicinity.

FEH Rainfall-Runoff model method

2.1.26 The design event application of the FEH rainfall-runoff model was used to derive peak flows for all catchments <25km², using the ISIS boundary unit, based on the catchment descriptors derived from the FEH CD-ROM. It is noted here that if adequate flood event data is available this can improve the estimates of Tp and SPR which lead to improve design flood estimates. This requires hydrologically similar catchments that not only have adequate gauged flow data but also an operating rain gauge network that samples at an hourly (if not sub-hourly) time step; and the network also adequately sample the spatial variability of the rainfall event across the catchment. This can be particularly challenging in mountainous catchments where orographic effects lead to steep rainfall gradients, and where snow may add an additional dimension of complexity. However, no such monitored catchments and rainfall network are available locally to undertake this.

2.1.27 The critical storm duration for each catchment was calculated separately to provide catchment specific design estimates using the guidance provided in Science Report: SC050050 and EA – Flood Estimation Guidelines Doc No. 197_08.

2.1.28 When hydrograph shapes for minor watercourses were required (for example in the culvert flood risk assessments) these were obtained directly from the FEH rainfall-runoff model when this method provided the higher peak flow, or by linearly scaling the rainfall-runoff hydrograph to agree with the FEH Statistical peak flow where that flow was the higher.

Design Peak Flow Estimation and Inflow Hydrographs – Large/Modelled Catchments

2.1.29 The southern section (Birnam to Glen Garry) crosses four large watercourses, namely the rivers Tay, Tummel, Garry and Braan. Estimation of design peak flows for these large watercourses has limitations and uncertainties. Flow in the rivers Tummel and Garry is controlled in part by hydropower generation, which adds complexity into the peak flow estimation. In order to avoid inconsistencies in peak flow estimation, SEPA was requested to provide not only the most up-to-date annual maximum series and 15-minute interval time series data but also their estimates of annual exceedance probability (AEP) flows at the gauge locations on these rivers. Additionally, the same was also requested for the River Tilt that joins the River Garry at Blair Atholl (though not crossed by the A9). The DMRB Stage 2 hydrological assessment was based on the hydrometric data received from SEPA in early 2015.

2.1.30 Scotland experienced extreme flooding during the winter of 2015/16. For the DMRB Stage 3 assessment the flow data from that period was obtained from SEPA and has been incorporated in the assessment. Table 1 lists the data received from SEPA during the DMRB Stage 2 and Stage 3 assessments, and Table 2 presents SEPA's predicted annual exceedance probability flows for the stations on the rivers Tay, Tummel and Garry.

Table 1: Hydrometric Data received from SEPA

Station Number	River Name	Station Name	AEP flows	AMAX	15min time series
15003	Tay	Caputh	✓	✓	✓
15007	Tay	Pitnacree	✓	✓	✓
15012	Tummel	Pitlochry	✓	✓	✓
15023	Braan	Hermitage		✓	✓
15034	Garry	Killiecrankie	✓	✓	✓
15039	Tilt	Marble Lodge		✓	✓

Table 2: AEP flow estimates provided by SEPA

Station Number	River Name	Station Name	Length of AMAX, N (years)	Peak flow (m^3/s)				
				50% AEP (2-year)	3.3% AEP (30-year)	1% AEP (100-year)	0.5% AEP (200-year)	0.1% AEP (1000-year)
15003	Tay	Caputh	65 (1952 – 2015)	838	1575	2017	2328	3265
15007	Tay	Pitnacree	65 (1952 – 2015)	351	686	896	1048	1516
15012	Tummel	Pitlochry	44 (1972 – 2015)	552	975	1187	1325	1701
15034	Garry	Killiecrankie	26 (1990-2015)	405*	679*	852*	976*	1361*

*The SEPA provided AEP event flows were increased at Killiecrankie Station (e.g., the 0.5% AEP (200-year) event flow increased by approximately 19%) following the winter 2015/16 event, however the flows at other stations remained unchanged.

2.1.31 The SEPA AEP flow estimates at the gauging stations (refer to Table 2) were checked using both single site flood frequency analysis involving the AMAX data at the corresponding gauges and FEH pooling group methods. Due to the complex nature of the catchments in this region (they have the potential to be impacted by snow and snow melt and flood flows are likely to be influenced by the presence of the hydropower schemes) single site analysis was judged as likely to result in more accurate peak flow estimates than those that could be derived using FEH pooling group analysis (assuming a suitable length of record is available for the single site analysis).

2.1.32 Results of our analysis indicate that the SEPA provided peak flows at Caputh, Pitnacree, Pitlochry and Killiecrankie gauges are based on single site flood frequency analyses. While the length of AMAX data at Caputh (N = 65years), Pitnacree (N= 65years) and Pitlochry (N = 44 years) are considered to be beneficially long for the purposes of single site analysis, the AMAX at Killiecrankie (N = 26 years) is much shorter raising concerns regarding the robustness of the single site analysis for the estimation of rarer events such as the 0.5% AEP (200-year) event. However, it is noted that the resulting flood growth curve for Killiecrankie is similar with those for the other stations giving some comfort that its use for estimating the rarer events will not be inconsistent with other parts of the wider catchment.

2.1.33 The hydraulic models required inflows at locations other than the gauging stations on the major watercourses. The design peak flows at those locations were estimated as follows: estimate the index flood (QMED) using catchment descriptors extracted from FEH CD-ROM; revise the QMED estimate using the adjustment factor borrowed from the nearby gauging station; and estimate the AEP peak flows by applying the single site growth curve from the nearest appropriate gauging station. The numerical modelling also required peak flows in some ungauged watercourses, which were obtained using the methodology adopted for small ungauged catchment described above.

2.1.34 Inflow hydrographs were required for the hydraulic modelling of the main stem. A representative (design) hydrograph shape was selected from a comparison of the five largest flood events on record. To model the inflows from the smaller ungauged catchments the shape of the equivalent hydrographs as recorded at the River Braan or River Tilt stations for the same event were used (shape allocated according to proximity of the small watercourse).

Low Flow Estimates

2.1.35 Low flow estimates such as 95-percentile flow (Q_{95}) and mean flow (Qmean) are required for all outfall locations for the Stage 3 DMRB assessment. These low flow estimates are required to support water quality, ecological and geomorphological assessments on the receiving watercourses. The following methodology has been used for deriving low flow estimates.

2.1.36 Where an adequate flow gauge exists the low flow values are based directly on the gauge record. The flow gauges considered are given in Table 3.

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Table 3: Gauging stations used to calculate low flows

Station Number	River Name	Station Name	Catchment Area (km^2)	Q_{95} (m^3/s)
15003	Tay	Caputh	3210	35.6
15007	Tay	Pitnacree	1149	12.5
15012	Tummel	Pitlochry	1670	19.7
15023	Braan	Hermitage	210	0.56
15034	Garry	Killiecrankie	745	3.06
15039	Tilt	Marble Lodge	165	1.28

2.1.37 To estimate Q_{95} flows for the major watercourses within the study area (viz: River Tay, River Tummel, River Garry and River Braan) - SEPA gauging stations were used together with catchment area scaling to transpose Q_{95} values to the proposed outfall location.

2.1.38 For the smaller ungauged watercourses, Q_{95} flows were estimated based on Low Flows Enterprise (LFE) data. Six LFE datasets judged to be representative of the range of small catchments requiring estimates were used in this process. Table 4 presents the LFE estimates used for this analysis. Areal scaling of the LFE Q_{95} flows was used to estimate Q_{95} flows at the target locations using a donor catchment principal based on hydrological similarity (similarity criteria used – BFIHOST).

Table 4: LFE calculation locations

Location	Area (km2)	Easting	Northing	Q95 (m3/s)
Inchewan Burn	5.6	303018	741731	0.025
Kindallachan Burn	18.8	299400	749841	0.092
Allt Bhaic (WF115)	10.7	284543	765604	0.036
Allt a' Chrombaidh (WF142)	10.8	278925	766592	0.042
Unnamed Watercourse (WF151)	0.2	277250	768350	0.0005
Allt Anndeir (WF158)	61.6	275536	769635	0.350

3 Baseline Hydrology

3.1.1 The catchment descriptors derived from the FEH CD-ROM v3 for each of the watercourses that could potentially be impacted by the proposed scheme are presented in Table 5. The catchment descriptors for the inflow catchments feeding into the detailed hydraulic models (Model V and V/VI) are presented in Table 6.

Table 5: Target site FEH catchment descriptors – small ungauged catchments

Watercourse/ Structure Reference	Grid Reference	Catchment Area (km^2)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
79	291839, 761870	0.25	1001	0.446	39.9	1.00	0.00
80	291864, 761933	0.07	1001	0.446	39.9	1.00	0.00
81	291877, 761976	0.11	1001	0.446	39.9	1.00	0.00
82	291914, 762132	0.12	1001	0.446	39.9	1.00	0.00
83	291908, 762247	0.03	1001	0.446	39.9	1.00	0.00
84	291901, 762498	3.64	1001	0.446	39.9	1.00	0.00
85	291890, 762688	0.08	964	0.484	39.3	1.00	0.00
86	291861, 762711	0.01	964	0.484	39.3	1.00	0.00
87	291722, 762870	1.27	964	0.484	39.3	1.00	0.00
89*	291558, 763104	39.5	1124	0.476	37.9	0.988	0.00
90	291444, 763246	0.05	964	0.484	39.3	1.00	0.00
91	291206, 763429	0.25	964	0.484	39.3	1.00	0.00
92	290979, 763527	0.41	964	0.484	39.3	1.00	0.00

Watercourse/ Structure Reference	Grid Reference	Catchment Area (km^2)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
93	290766, 763659	0.04	964	0.484	39.3	1.00	0.00
95	290752, 763764	0.10	987	0.542	28.9	1.00	0.00
96	290464, 763805	0.27	987	0.542	28.9	1.00	0.00
97	290097, 764034	0.48	987	0.542	28.9	0.994	0.00
98	290016, 764065	7.43	987	0.542	28.9	0.897	0.00
99	289079, 764229	0.86	985	0.721	13.5	1.00	0.00
101	288383, 764321	0.78	985	0.721	13.5	1.00	0.00
102	287288, 764736	0.54	985	0.721	13.5	1.00	0.00
103	287074, 764858	0.74	985	0.721	13.5	0.934	0.00
104	286942, 764928	0.07	985	0.721	13.5	1.00	0.00
105	286919, 764953	0.06	985	0.721	13.5	1.00	0.00
106	286698, 765063	0.21	985	0.721	13.5	1.00	0.00
107	286523, 765151	0.27	985	0.721	13.5	1.00	0.00
108	286122, 765234	0.16	987	0.469	35.8	1.00	0.00
109	285962, 765237	0.13	987	0.469	35.8	1.00	0.00
110	285574, 765241	0.09	987	0.469	35.8	1.00	0.00
111	285438, 765245	0.28	987	0.469	35.8	1.00	0.00
112	285188, 765241	0.22	987	0.469	35.8	1.00	0.00
113	285023, 765270	0.26	987	0.469	35.8	1.00	0.00
114	284927, 765300	0.19	987	0.469	35.8	1.00	0.00
115	284531, 765611	11.1	987	0.469	35.8	0.924	0.00
116	284222, 765724	0.30	987	0.469	35.8	1.00	0.00
117	283776, 765579	0.74	987	0.469	35.8	1.00	0.00
118	283596, 765540	0.06	987	0.469	35.8	1.00	0.00
119	283482, 765495	0.28	987	0.469	35.8	1.00	0.00
120	283218, 765479	0.32	987	0.469	35.8	1.00	0.00
121	283081, 765501	0.43	987	0.469	35.8	1.00	0.00
122	282932, 765610	0.10	987	0.469	35.8	1.00	0.00
124	282064, 765862	0.03	1053	0.396	46.4	1.00	0.00
125	281975, 765837	0.13	1053	0.396	46.4	1.00	0.00
126	281825, 765792	0.14	1053	0.396	46.4	1.00	0.00
127	281661, 765781	0.42	1053	0.396	46.4	1.00	0.00
128	281256, 765788	0.14	1053	0.396	46.4	1.00	0.00
129	281032, 765825	0.15	1053	0.396	46.4	1.00	0.00
131	280638, 765877	0.09	1053	0.396	46.4	1.00	0.00
132	280517, 765808	0.04	1053	0.396	46.4	1.00	0.00
134	280426, 765915	0.66	1053	0.396	46.4	1.00	0.00
136	280301, 765926	0.31	1053	0.396	46.4	1.00	0.00
137	280156, 765970	0.20	1053	0.396	46.4	1.00	0.00
139	279711, 766089	0.34	1053	0.396	46.4	1.00	0.00
140	279426, 766211	0.54	1053	0.396	46.4	1.00	0.00
141	279183, 766362	0.55	1053	0.396	46.4	1.00	0.00
142	278945, 766589	10.8	1128	0.392	51.6	0.998	0.00
143	278849, 766684	0.22	1053	0.396	46.4	1.00	0.00
144	278568, 766911	0.26	1053	0.396	46.4	1.00	0.00
145	278347, 767085	0.59	1053	0.396	46.4	1.00	0.00
146	278272, 767196	0.04	1053	0.396	46.4	1.00	0.00

Watercourse/ Structure Reference	Grid Reference	Catchment Area (km^2)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
147	278103, 767276	0.15	1053	0.396	46.4	1.00	0.00
148	277931, 767407	0.10	1053	0.396	46.4	1.00	0.00
149	277848, 767478	1.47	1080	0.385	47.8	1.00	0.00
150	277444, 767837	0.31	1053	0.396	46.4	1.00	0.00
151	277213, 768355	0.28	1053	0.396	46.4	1.00	0.00
152	277107, 768644	0.04	1053	0.396	46.4	1.00	0.00
153	277060, 768766	0.20	1053	0.396	46.4	1.00	0.00
88 (167)	276946, 768889	3.33	1155	0.358	50.0	1.00	0.00
154	276662, 769074	0.43	1161	0.456	35.7	1.00	0.00
155	276381, 769212	0.13	1161	0.456	35.7	1.00	0.00
156	276089, 769411	0.56	1161	0.456	35.7	1.00	0.00
157	275841, 769481	0.12	1161	0.456	35.7	1.00	0.00
158*	275511, 769610	61.4	1340	0.445	56.5	1.00	0.00
159	274463, 769810	0.47	1161	0.456	35.7	1.00	0.00
160	274840, 769734	0.28	1161	0.456	35.7	1.00	0.00
161	274732, 769767	0.27	1161	0.456	35.7	1.00	0.00
162	274681, 769790	0.22	1161	0.456	35.7	1.00	0.00
163	273805, 770055	0.16	1161	0.456	35.7	1.00	0.00
164	273483, 770254	8.80	1272	0.289	51.8	1.00	0.00
165	273082, 770331	1.53	1220	0.347	45.3	1.00	0.00

*Watercourses 89 and 158 have catchment area>25km^2

Table 6: FEH catchment descriptors for those catchments feeding into the detailed hydraulic model together with the descriptors for the full catchment down to the model's downstream extent

Watercourse / Structure Reference	Grid Reference	Catchment Area (km^2)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
Model V/VI							
Garry u/s of Garry/Bruar confluence	282650, 765850	380	1460	0.396	51.7	0.923	0.00
Bruar u/s of Garry/Bruar confluence	282450, 765900	71.0	1396	0.429	51.9	0.981	0.00
Residual catchments – Model V/VI	*	11.4	987	0.469	35.8	0.924	0.00
Garry @ downstream extent of Model V/VI	286450, 765350	473	1427	0.429	50.8	0.953	0.00
Model V							
Garry u/s of A9 crossing near Blair Atholl	289100, 764250	733	1367	0.427	49.6	0.953	0.00
Residual catchment Model V	*	11.0	987	0.542	28.9	0.897	0.00
Garry d/s extent of Model V	290150, 763500	744	1362	0.429	49.31	0.953	0.00

*A residual catchment doesn't have a single point of inflow as it represents the runoff from the land immediately adjacent to the river that does not fall within one of the large discrete catchments.

4 Flood Peak Flow Estimates – Small Ungauged Catchments

Comparison of Methods

4.1.1 As described in Section 2.6, peak flow estimation for all small ungauged catchments was undertaken using both the FEH rainfall-runoff model and the FEH statistical methodologies. The estimated peak flows for the 50% AEP (2-year) and 0.5% AEP (200-year) events for all catchments <25km^2 were compared so that the conservatively high estimate could be adopted for flood risk assessment purposes.

4.1.2 Table 7 presents the FEH rainfall-runoff model and the FEH statistical method derived peak flow estimates for all watercourses with catchment areas <25km^2.

Table 7: Peak flow estimates – FEH rainfall-runoff and FEH statistical methodologies (m^3/s)

Watercourse/ Structure Reference	Catchment Area (km^2)	FEH Rainfall-runoff		FEH Statistical		Adopted method
		50% AEP (2-year)	0.5% AEP (200-yr)	50% AEP (2-year)	0.5% AEP (200-yr)	
79	0.25	0.36	1.21	0.23	0.82	Rainfall - runoff
80	0.07	0.12	0.38	0.07	0.24	Rainfall - runoff
81	0.11	0.16	0.55	0.11	0.37	Rainfall - runoff
82	0.12	0.17	0.59	0.11	0.39	Rainfall - runoff
83	0.03	0.05	0.17	0.02	0.09	Rainfall - runoff
84	3.64	2.91	9.26	2.57	8.96	Rainfall - runoff
85	0.08	0.12	0.40	0.07	0.23	Rainfall - runoff
86	0.01	0.02	0.07	0.01	0.03	Rainfall - runoff
87	1.27	1.16	3.69	0.87	3.04	Rainfall - runoff
90	0.05	0.08	0.26	0.04	0.14	Rainfall - runoff
91	0.25	0.30	0.98	0.20	0.70	Rainfall - runoff
92	0.41	0.46	1.51	0.33	1.14	Rainfall - runoff
93	0.04	0.06	0.22	0.04	0.12	Rainfall - runoff
95	0.10	0.09	0.30	0.07	0.24	Rainfall - runoff
96	0.27	0.21	0.68	0.18	0.64	Rainfall - runoff
97	0.48	0.33	1.11	0.33	1.15	Statistical
98	7.43	3.06	9.85	2.36	6.57	Statistical*
99	0.86	0.29	0.96	0.27	0.88	Rainfall - runoff
101	0.78	0.26	0.84	0.25	0.81	Rainfall - runoff
102	0.54	0.19	0.63	0.18	0.60	Rainfall - runoff
103	0.74	0.24	0.79	0.19	0.49	Rainfall - runoff
104	0.07	0.04	0.12	0.02	0.08	Rainfall - runoff
105	0.06	0.03	0.11	0.02	0.06	Rainfall - runoff
106	0.21	0.09	0.29	0.07	0.24	Rainfall - runoff
107	0.27	0.11	0.37	0.09	0.30	Rainfall - runoff
108	0.16	0.16	0.55	0.14	0.50	Rainfall - runoff
109	0.13	0.14	0.49	0.11	0.38	Rainfall - runoff
110	0.09	0.10	0.35	0.08	0.27	Rainfall - runoff
111	0.28	0.26	0.88	0.25	0.85	Rainfall - runoff
112	0.22	0.22	0.74	0.19	0.65	Rainfall - runoff
113	0.26	0.25	0.83	0.23	0.78	Rainfall - runoff
114	0.19	0.19	0.66	0.17	0.58	Rainfall - runoff
115	11.1	5.08	16.2	4.62	12.0	Statistical*
116	0.30	0.28	0.93	0.26	0.91	Rainfall - runoff
117	0.74	0.58	1.95	0.60	2.10	Statistical

Watercourse/ Structure Reference	Catchment Area (km²)	FEH Rainfall-runoff		FEH Statistical		Adopted method
		50% AEP (2-year)	0.5% AEP (200-yr)	50% AEP (2-year)	0.5% AEP (200-yr)	
118	0.06	0.07	0.26	0.06	0.19	Rainfall - runoff
119	0.28	0.26	0.89	0.24	0.83	Rainfall - runoff
120	0.32	0.30	1.00	0.28	0.98	Rainfall - runoff
121	0.43	0.37	1.26	0.38	1.31	Statistical
122	0.10	0.11	0.36	0.11	0.39	Statistical
124	0.03	0.05	0.17	0.05	0.17	Statistical
125	0.13	0.12	0.39	0.15	0.55	Statistical
126	0.14	0.19	0.63	0.19	0.67	Statistical
127	0.42	0.41	1.36	0.49	1.77	Statistical
128	0.14	0.19	0.64	0.19	0.68	Statistical
129	0.15	0.19	0.66	0.19	0.70	Statistical
131	0.09	0.14	0.47	0.14	0.50	Statistical
132	0.04	0.07	0.24	0.07	0.25	Statistical
134	0.66	0.53	1.72	0.75	2.73	Statistical
136	0.31	0.38	1.28	0.38	1.38	Statistical
137	0.20	0.26	0.89	0.26	0.96	Statistical
139	0.34	0.39	1.33	0.39	1.43	Statistical
140	0.54	0.59	1.97	0.64	2.30	Statistical
141	0.55	0.60	1.99	0.64	2.34	Statistical
142	10.8	7.40	23.3	9.16	33.2	Statistical
143	0.22	0.28	0.95	0.28	1.02	Statistical
144	0.26	0.30	1.01	0.31	1.11	Statistical
145	0.59	0.55	1.83	0.68	2.48	Statistical
146	0.04	0.07	0.25	0.07	0.26	Statistical
147	0.15	0.19	0.66	0.19	0.70	Statistical
148	0.10	0.15	0.52	0.15	0.54	Statistical
149	1.47	1.28	4.18	1.59	5.77	Statistical
150	0.31	0.38	1.26	0.38	1.36	Statistical
151	0.28	0.29	0.96	0.33	1.18	Statistical
152	0.04	0.07	0.24	0.07	0.25	Statistical
153	0.20	0.26	0.89	0.26	0.95	Statistical
88 (167)	3.33	2.76	8.95	3.80	13.8	Statistical
154	0.43	0.37	1.25	0.52	1.88	Statistical
155	0.13	0.13	0.45	0.15	0.56	Statistical
156	0.56	0.44	1.48	0.66	2.41	Statistical
157	0.12	0.13	0.44	0.15	0.53	Statistical
159	0.47	0.4	1.36	0.56	1.92	Statistical
160	0.28	0.26	0.89	0.34	1.16	Statistical
161	0.27	0.25	0.85	0.32	1.09	Statistical
162	0.22	0.16	0.53	0.26	0.89	Statistical
163	0.16	0.16	0.55	0.19	0.64	Statistical
164	8.80	6.77	22.0	11.6	39.6	Statistical
165	1.53	1.33	4.46	2.20	7.50	Statistical

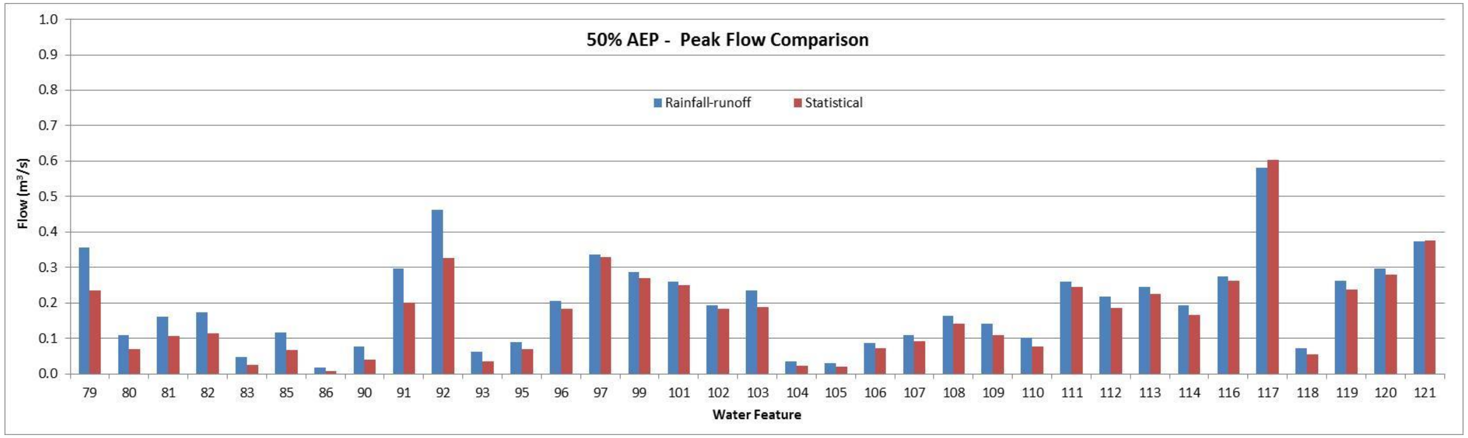
* For Watercourse 98 (FARL = 0.897) & Watercourse 115 (FARL = 0.927) – statistical method was adopted since the rainfall-runoff method does not account for the attenuating influence of the waterbody.

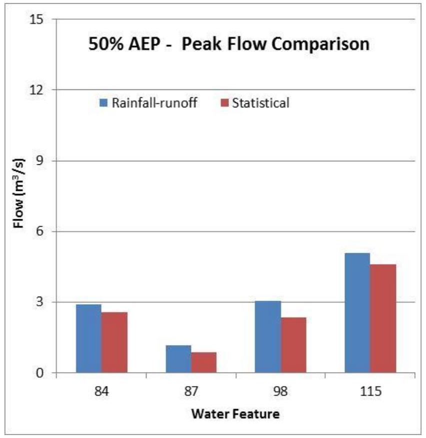
4.1.3 Diagrams 1 and 2 show that the flood estimates derived using the FEH statistical method are generally higher than those derived using the FEH rainfall-runoff method for the catchments located upstream of the River Garry - River Bruar confluence (SWF121 to 165). However, for the catchments located on the lower reach, downstream of the confluence (SWF 79 to 120), the flood estimates derived using the FEH statistical method are generally lower than the corresponding flood estimates using the FEH rainfall-runoff method.

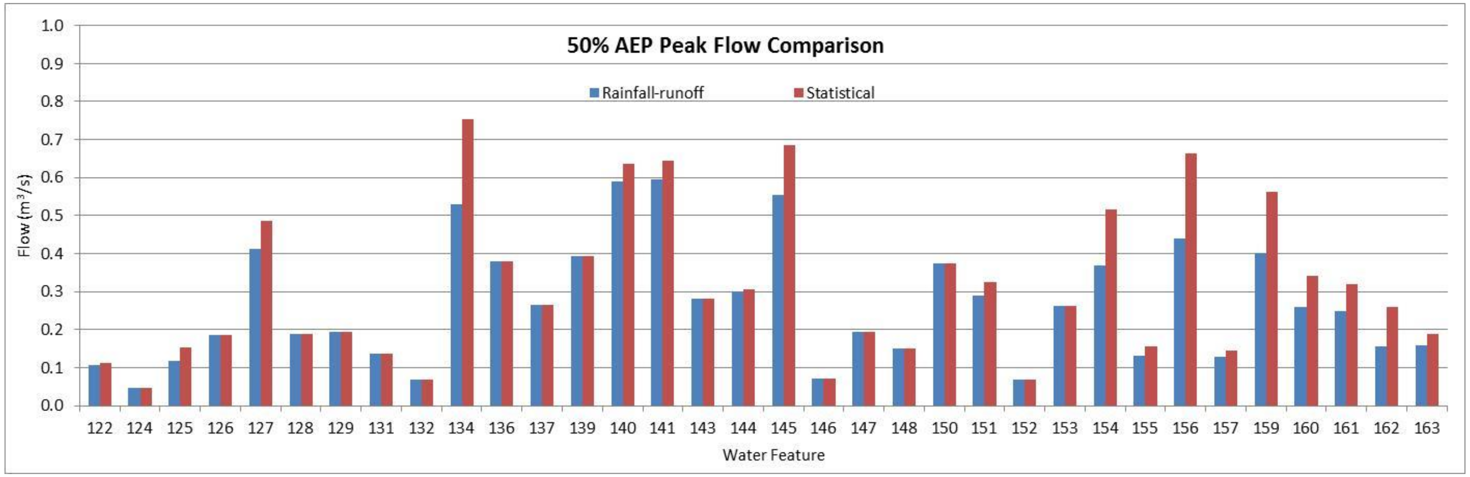
4.1.4 The catchment descriptors of the watercourses show slightly higher rainfall statistics in the upper reaches than in the lower reaches. Similarly, the lower catchments have slightly higher BFIHOST values (slightly lower SPRHOST values) than those in the upper reaches, suggesting that these catchments are generally more permeable than those in the upper reaches.

4.1.5 Table 7 also shows that for two catchments (Watercourse 98 (FARL = 0.897) and Watercourse 115 (FARL = 0.924)) the rainfall-runoff method produces higher flow than the statistical method. However, for the design flow purpose, the flow estimated by the statistical method is adopted because the FEH statistical method makes some allowance for the attenuating effects of the open-water bodies in both the estimation of QMED and also in the targeted pooling group procedure used for these catchments; whereas the FEH rainfall-runoff method does not consider attenuation (to do this would require a much more detailed flood routing to also be undertaken). A simple sensitivity check with the statistical method for these catchments, with FARL = 1, produces flows close to that from rainfall-runoff method.

Diagram 1: Comparison of 50% AEP (2-year) event peak flow estimates from the FEH rainfall-runoff and the FEH statistical method for catchments <25km²







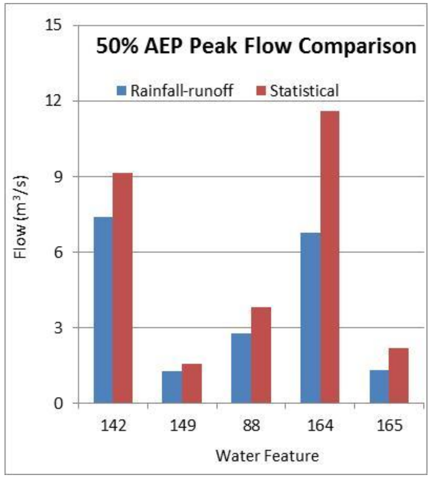
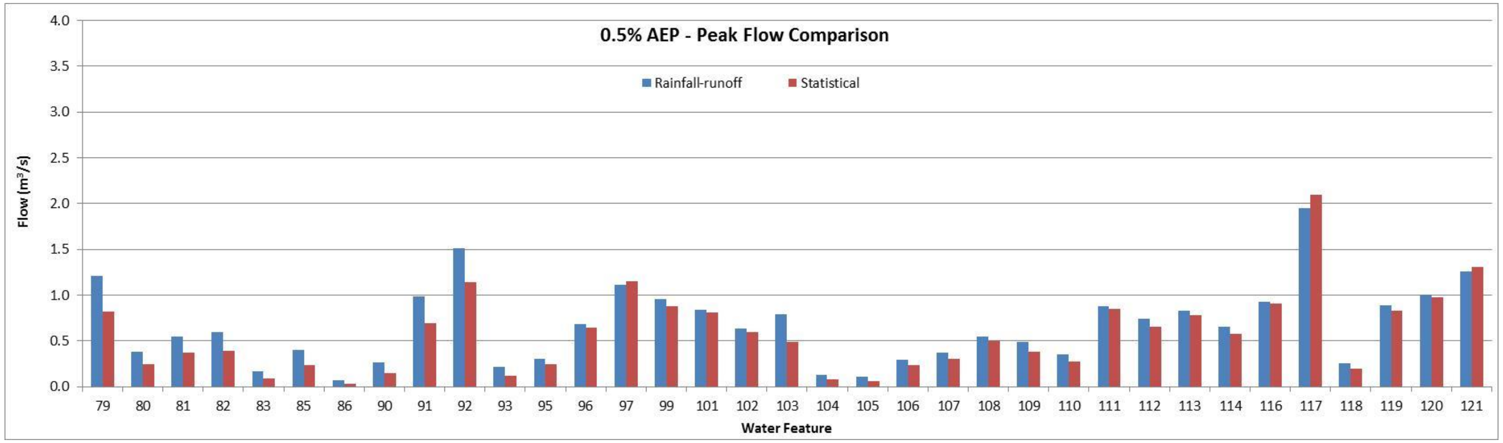
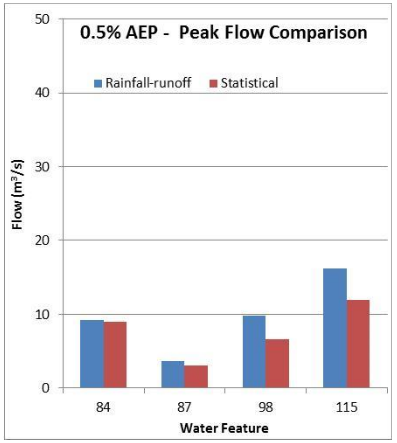
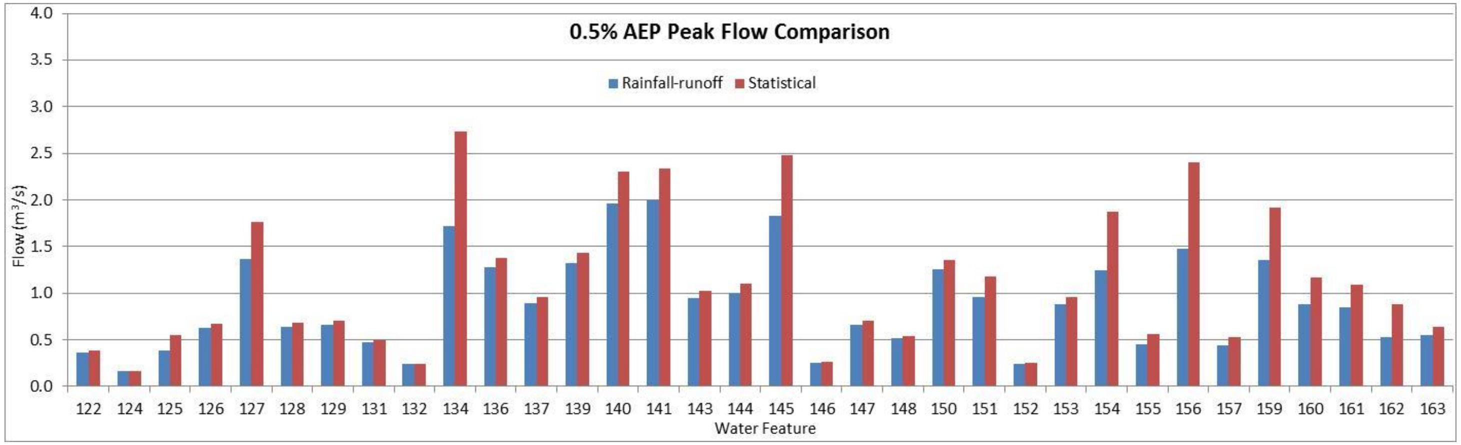
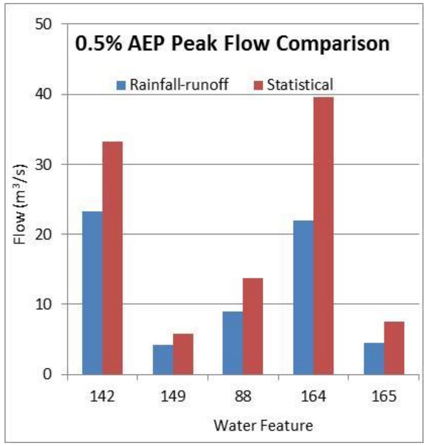


Diagram 2: Comparison of 0.5% AEP (200-year) event peak flow estimates from the FEH rainfall-runoff and the FEH statistical method for catchments <25km²









Final Design Peak Flow Estimates

4.1.6 Of the two methods investigated the higher peak flows produced by using either the FEH statistical method or the FEH rainfall-runoff method have been adopted as the design peak flow for the small catchments (<25km^2) in this study. Annex D provides a discourse on the adequacy of the estimates. For larger catchments (>25km^2) the statistical method flows have been adopted.

4.1.7 The final design peak flow estimates are presented in Table 8. The 0.5% AEP (200-year) plus climate change event estimate (referred to as 'plus CC') which includes a 20% allowance for climate change is also given.

Table 8: Final design peak flow estimates for the small ungauged catchments (m^3/s)

Watercourse/ Structure Reference	50% AEP (2-yr)	20% AEP (5-yr)	10% AEP (10-yr)	3.33% AEP (30-yr)	2% AEP (50-yr)	1% AEP (100-yr)	0.5% AEP (200-yr)	0.5% AEP (200-yr) plus CC	0.1% AEP (1000-yr)
79	0.36	0.53	0.64	0.83	0.93	1.06	1.21	1.45	1.75
80	0.11	0.16	0.20	0.26	0.29	0.33	0.38	0.45	0.54
81	0.16	0.24	0.29	0.37	0.42	0.48	0.55	0.66	0.79
82	0.17	0.26	0.31	0.40	0.45	0.52	0.59	0.71	0.86
83	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.20	0.24
84	2.91	4.16	4.94	6.30	7.01	7.92	9.26	11.1	13.4
85	0.12	0.17	0.21	0.27	0.30	0.35	0.40	0.48	0.57
86	0.02	0.03	0.03	0.05	0.05	0.06	0.07	0.08	0.10
87	1.16	1.67	2.00	2.56	2.86	3.24	3.69	4.42	5.46
89	21.2	27.9	32.6	40.8	45.0	51.3	58.3	70.0	78.3
90	0.08	0.11	0.14	0.18	0.20	0.23	0.26	0.31	0.38
91	0.30	0.44	0.52	0.68	0.76	0.86	0.98	1.18	1.44
92	0.46	0.67	0.81	1.04	1.17	1.33	1.51	1.82	2.22
93	0.06	0.09	0.11	0.15	0.16	0.19	0.22	0.26	0.31
95	0.09	0.13	0.16	0.21	0.23	0.26	0.30	0.36	0.46
96	0.21	0.30	0.36	0.47	0.53	0.60	0.68	0.82	1.04
97	0.33	0.45	0.54	0.72	0.82	0.97	1.15	1.38	1.71
98	2.36	3.19	3.75	4.68	5.14	5.82	6.57	7.88	8.58
99	0.29	0.41	0.49	0.63	0.71	0.81	0.96	1.15	1.59
101	0.26	0.38	0.45	0.58	0.65	0.74	0.84	1.01	1.44
102	0.19	0.28	0.33	0.43	0.48	0.55	0.63	0.76	1.08
103	0.24	0.34	0.41	0.52	0.58	0.66	0.79	0.95	1.31
104	0.04	0.05	0.06	0.08	0.09	0.11	0.12	0.15	0.20
105	0.03	0.05	0.06	0.07	0.08	0.10	0.11	0.13	0.18
106	0.09	0.13	0.15	0.20	0.22	0.25	0.29	0.35	0.48
107	0.11	0.16	0.19	0.25	0.28	0.32	0.37	0.44	0.62
108	0.16	0.24	0.29	0.38	0.42	0.48	0.55	0.66	0.84
109	0.14	0.21	0.25	0.33	0.37	0.42	0.49	0.58	0.73
110	0.10	0.15	0.18	0.24	0.26	0.30	0.35	0.42	0.52
111	0.26	0.38	0.46	0.60	0.67	0.76	0.88	1.06	1.32
112	0.22	0.32	0.39	0.50	0.57	0.64	0.74	0.88	1.12
113	0.25	0.36	0.43	0.56	0.63	0.72	0.83	0.99	1.25
114	0.19	0.29	0.35	0.45	0.50	0.57	0.66	0.79	1.00
115	4.62	6.13	7.14	8.77	9.57	10.7	12.0	14.4	15.3
116	0.28	0.40	0.49	0.63	0.70	0.80	0.93	1.11	1.40
117	0.60	0.82	0.99	1.31	1.49	1.77	2.10	2.52	3.12

Watercourse/ Structure Reference	50% AEP (2-yr)	20% AEP (5-yr)	10% AEP (10-yr)	3.33% AEP (30-yr)	2% AEP (50-yr)	1% AEP (100-yr)	0.5% AEP (200-yr)	0.5% AEP (200-yr) plus CC	0.1% AEP (1000-yr)
118	0.07	0.11	0.13	0.17	0.20	0.22	0.26	0.31	0.39
119	0.26	0.39	0.46	0.60	0.67	0.77	0.89	1.06	1.33
120	0.30	0.44	0.52	0.68	0.76	0.86	1.00	1.20	1.50
121	0.38	0.52	0.62	0.82	0.93	1.11	1.31	1.57	1.95
122	0.11	0.15	0.18	0.24	0.28	0.33	0.39	0.47	0.58
124	0.05	0.06	0.08	0.09	0.12	0.14	0.17	0.20	0.26
125	0.15	0.21	0.26	0.31	0.39	0.46	0.55	0.67	0.84
126	0.19	0.26	0.31	0.37	0.47	0.56	0.67	0.81	1.02
127	0.49	0.67	0.82	0.98	1.24	1.48	1.77	2.12	2.67
128	0.19	0.26	0.31	0.38	0.48	0.57	0.68	0.82	1.03
129	0.19	0.27	0.32	0.39	0.49	0.59	0.70	0.84	1.07
131	0.14	0.19	0.23	0.28	0.35	0.42	0.50	0.60	0.76
132	0.07	0.09	0.11	0.14	0.17	0.21	0.25	0.30	0.37
134	0.75	1.04	1.26	1.51	1.92	2.29	2.73	3.28	4.13
136	0.38	0.52	0.64	0.76	0.97	1.15	1.38	1.65	2.09
137	0.26	0.36	0.44	0.53	0.67	0.80	0.96	1.15	1.45
139	0.39	0.54	0.66	0.79	1.00	1.20	1.43	1.71	2.16
140	0.64	0.88	1.06	1.28	1.62	1.93	2.30	2.76	3.49
141	0.64	0.89	1.08	1.30	1.64	1.96	2.34	2.80	3.54
142	9.16	12.6	15.3	18.4	23.3	27.8	33.2	39.9	50.3
143	0.28	0.39	0.47	0.57	0.72	0.86	1.02	1.23	1.55
144	0.31	0.42	0.51	0.61	0.78	0.93	1.11	1.33	1.68
145	0.68	0.94	1.15	1.38	1.74	2.08	2.48	2.98	3.76
146	0.07	0.10	0.12	0.14	0.18	0.22	0.26	0.31	0.40
147	0.19	0.27	0.32	0.39	0.49	0.59	0.70	0.84	1.07
148	0.15	0.21	0.25	0.30	0.38	0.46	0.54	0.65	0.82
149	1.59	2.19	2.66	3.20	4.05	4.83	5.77	6.92	8.73
150	0.38	0.52	0.63	0.75	0.95	1.14	1.36	1.63	2.06
151	0.33	0.45	0.55	0.65	0.83	0.99	1.18	1.42	1.79
152	0.07	0.10	0.12	0.14	0.18	0.21	0.25	0.30	0.38
153	0.26	0.36	0.44	0.53	0.67	0.80	0.95	1.14	1.44
88 (167)	3.80	5.25	6.37	7.65	9.68	11.6	13.8	16.6	20.9
154	0.52	0.71	0.87	1.04	1.32	1.57	1.88	2.25	2.84
155	0.15	0.21	0.26	0.31	0.39	0.47	0.56	0.67	0.85
156	0.66	0.91	1.11	1.33	1.69	2.01	2.41	2.89	3.64
157	0.15	0.20	0.24	0.29	0.37	0.44	0.53	0.63	0.80
158	45.9	58.8	67.8	82.8	90.5	102	114	137	149
159	0.56	0.77	0.92	1.21	1.37	1.62	1.92	2.30	2.84
160	0.34	0.46	0.56	0.73	0.83	0.98	1.16	1.40	1.72
161	0.32	0.44	0.53	0.69	0.78	0.92	1.09	1.31	1.62
162	0.26	0.35	0.43	0.56	0.63	0.75	0.89	1.06	1.31
163	0.19	0.26	0.31	0.40	0.46	0.54	0.64	0.77	0.95
164	11.6	15.8	19.0	25.0	28.3	33.5	39.6	47.5	58.6
165	2.20	3.00	3.61	4.74	5.36	6.34	7.50	9.00	11.1

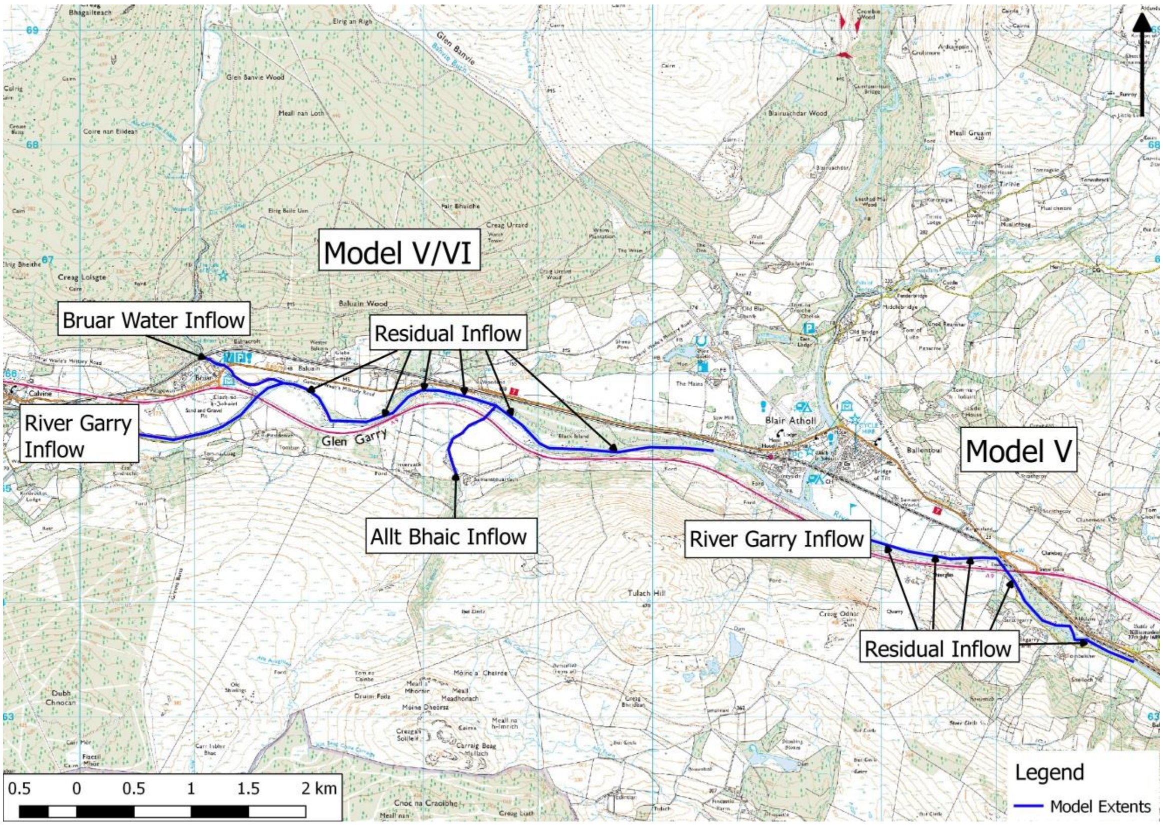
5 Flood Peak Flow and Inflow Hydrographs – Large / Modelled Catchments

Design Peak Flows

5.1.1 The proposed scheme consists of two hydraulic models for the River Garry and its tributaries (see Diagram 3). These two models require design peak flow (target flow) estimation at various locations as described below:

- Model V/VI (River Garry @ River Bruar confluence):
  - River Garry at the Garry / Bruar confluence,
  - River Bruar at the Garry / Bruar confluence,
  - WF 115 – Allt Bhaic,
  - Residual catchment between Garry/Bruar confluence and d/s end of the model; and
  - River Garry at the downstream extent of Model V/VI.
- Model V (River Garry @ Blair Atholl):
  - River Garry at the A9 crossing near Blair Atholl,
  - Residual catchment between A9 crossing and Killiecrankie; and
  - River Garry at the downstream extent of Model V (i.e., at the Killiecrankie gauging station).

Diagram 3: Model Extents together with flow estimation locations



5.1.2 The design peak flow estimates for the following AEP events 50%, 3.33%, 1%, 0.5% and 0.1% (2, 30, 100, 200 and 1000-year) at variation locations along the modelled reaches are presented in Table 9. The 0.5% AEP (200-year) plus climate change estimate is also presented. The peak flow estimates presented are the catchment specific AEP flows corresponding to the catchment specific critical storm duration.

Table 9: Design peak (target) flow estimates (River Garry and tributaries) (m^3/s)

Watercourse	50% AEP (2-yr)	3.3% AEP (30-yr)	1% AEP (100-yr)	0.5% AEP (200-yr)	0.5% AEP (200-yr) plus CC	0.1% AEP (1000-yr)
Model V/VI						
Garry u/s of Garry / Bruar confluence	194	334	412	433	519	621
Bruar u/s of Garry / Bruar confluence	49.3	84.8	105	110	132	158
WC 115 – Allt Bhaic	4.61	8.76	10.7	12.0	14.4	15.3
Residual catchments	4.71	8.94	11.0	12.2	14.7	15.6
Garry @ downstream extent of the model	227	391	482	545	654	727
Model V						
Garry u/s of A9 crossing	404	677	850	974	1169	1358
Residual catchments – Model V	3.29	6.51	8.10	9.14	11.0	11.9
Garry @ downstream extent of the model*	405	679	852	976	1171	1361

*Peak flows at the d/s extent of Model V are the same as those provided by SEPA at Killiecrankie gauging station

Inflow Hydrographs

5.1.3 The inflow hydrographs to be applied to the hydraulic model are generally derived for two simulation scenarios, namely,

- Run 1 – to determine the 0.5% AEP (200-year) event flood risk along the River Garry main stem, with the tributary inflows adjusted to be consistent with the main stem storm duration.
- Run 2 – to determine the 0.5% AEP (200-year) event flood risk along the tributaries, with their inflows consistent with their own critical storm durations coupled with the 50% AEP (2-year) peak flow occurring in the main stem downstream.

5.1.4 The derivation of design inflow hydrographs for the above two models is described in the following sub-sections.

Model V/VI

5.1.5 For Run 1, model inflows for the River Garry main stem is based on the peak flow in Table 9 and hydrograph shape derived from historic flood events at the Killiecrankie gauging station. The January 1993 event was found to the most representative from a comparison of hydrograph shapes of the five largest historic flood events, and hence adopted for the River Garry inflows. The target location in this model is set at the downstream modelling extent, at which the theoretical critical storm duration for the River Garry is 12.75-hour. As the critical storm durations for the River Bruar, Allt Bhaic and the residual catchments are shorter than that of the River Garry at the target location, their catchment specific AEP flows (Table 9) were modified (i.e., reduced) using a scaling factor. The scaling factor is based on the ratio of the rainfall-runoff model design run to that of an equivalent run in which a 12.75-hour storm duration for the Garry.

5.1.6 The hydrograph shape for deriving model inflow for the River Bruar and other tributaries is based on the January 1993 event hydrograph shape for the River Tilt (@Marble Lodge station), which is the only smaller catchment in the area for which historic flood records (time series) are available. This approach aims to keep the shape and timing of the various catchment inputs consistent with the January 1993 event, and provides for a slight allowance for the fact that the estimated design flows on the large catchment don't occur as a result of the same event on a smaller tributary catchment.

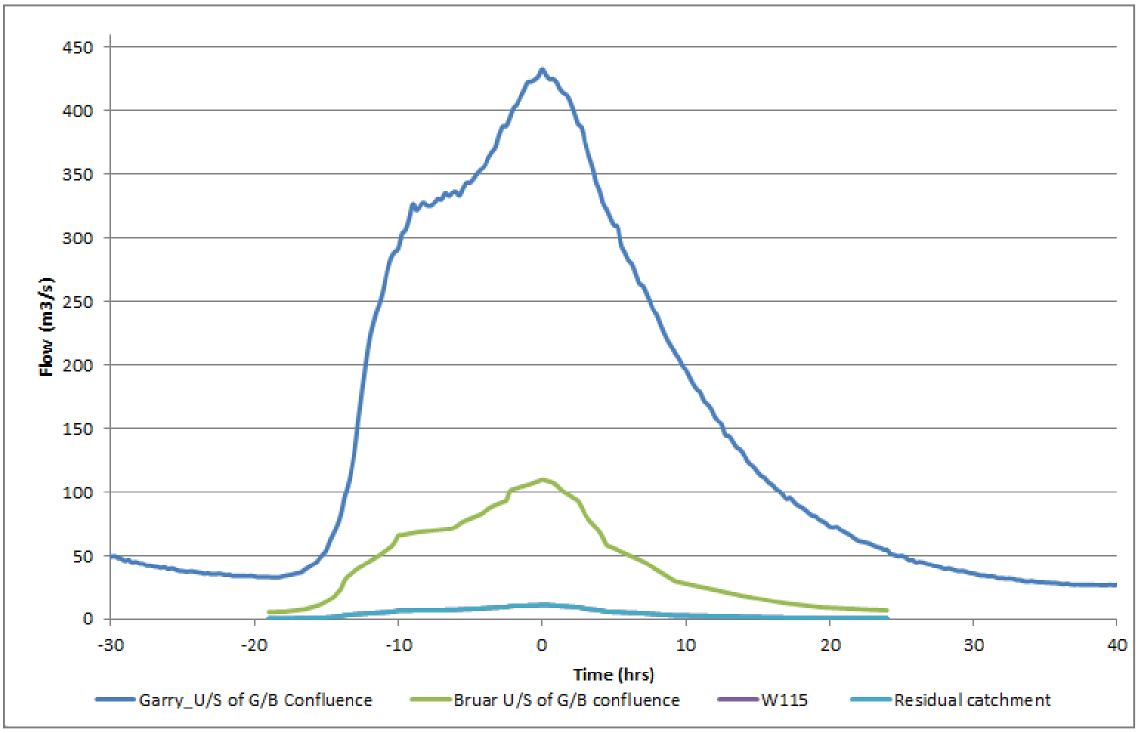
5.1.7 The routed flow at the downstream end of the model was reconciled with the target flow at that location (refer to the row 7 of Table 9) using a scaling factor determined from iterative runs in the hydraulic model. For Model V/VI, this was the case without requiring any scaling of inflow hydrographs, for the 0.5% AEP (200-yr) and 0.5% AEP (200-year) plus climate change events. However, a slight scaling factor of 0.95 was required to reconcile the model routed flow with the target flow at 50% AEP (2-year) and 3.33%

AEP (30-year) events. In this way the river model was made consistent with the statistical estimate of the River Garry design flow at the downstream boundary.

5.1.8 For the Run 2 scenario (where the focus is upon the design conditions of the tributary as opposed to the main stem of the River Garry), inflow hydrograph shapes for WF115 and for the residual catchment are based on the FEH rainfall-runoff model hydrograph shape obtained from their own critical storm durations (which in both cases is about 5.75-hr). The flow in the River Garry and Bruar are QMED flows with their hydrograph shape based on the 1993 event at Killiecrankie and Marble Lodge stations respectively, and their peak flow (QMED) occurring at the same time as that of the tributary peaks.

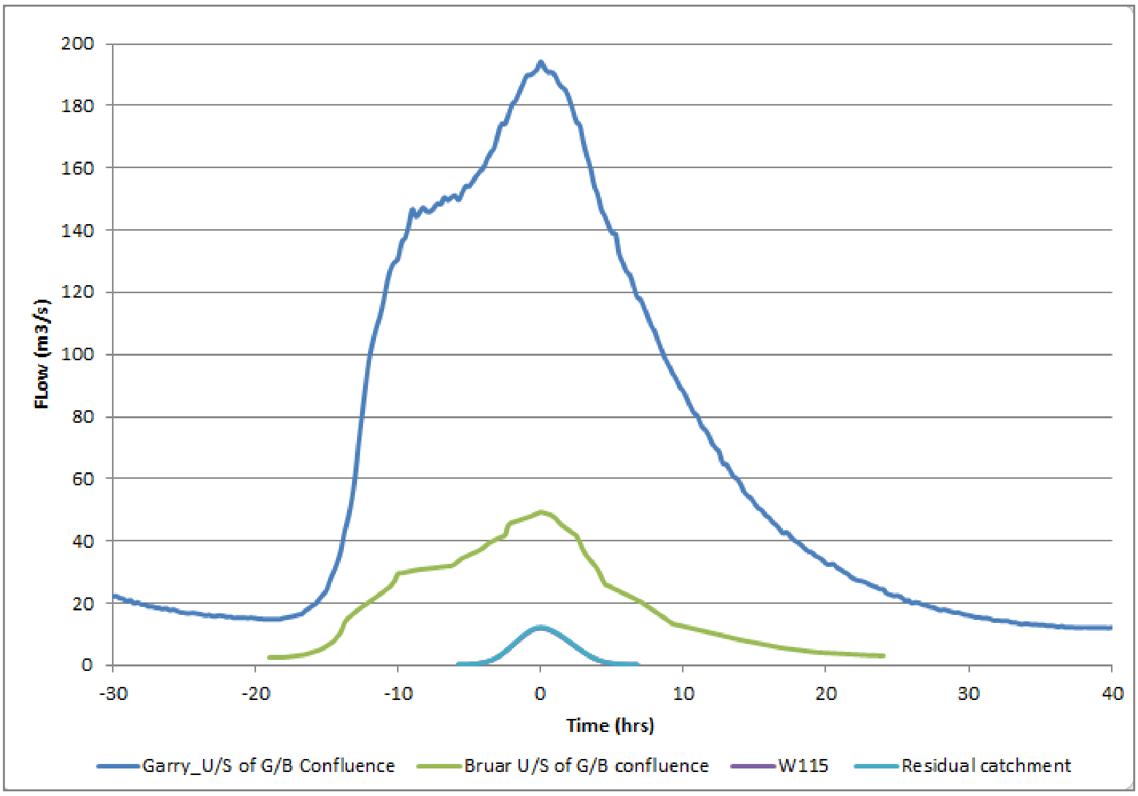
5.1.9 The inflow hydrographs for both runs for Model V/VI are presented in Diagrams 4 and 5.

Diagram 4: Model V/VI 0.5% AEP (200-year) event inflow hydrographs for Run 1



(Note: SWF115 hydrograph plots underneath the residual catchment hydrograph)

Diagram 5: Model V/VI 0.5% AEP (200-year) event inflow hydrographs for Run 2



(Note: this arrangement is focused on the design conditions along the tributaries and not the main stem. The flows in the main stem are simply to provide a credible downstream boundary which given the concepts behind what constitutes a design flood event on catchments of differing size will have a rarity that is less than that of the targeted tributary flood).
(Note: SWF115 hydrograph plots underneath the residual catchment hydrograph)

Model V

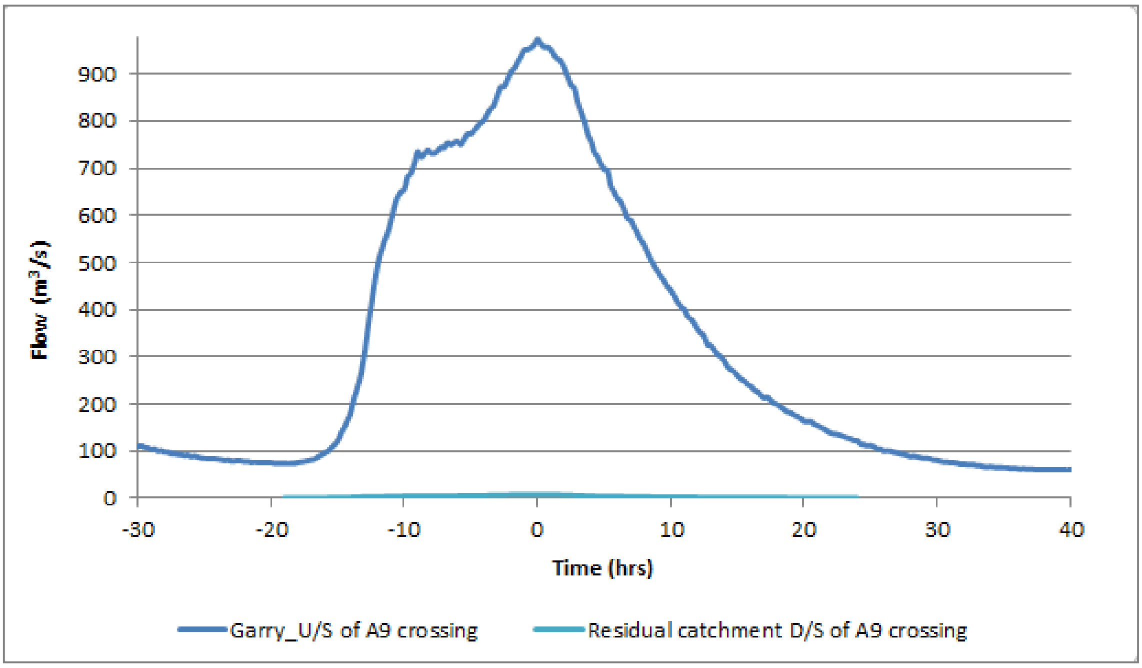
5.1.10 For Run 1, model inflows for the River Garry main stem is based on the peak flows as shown in Table 9 and the hydrograph shape is the same as that for Model V/VI, i.e., based on the January 1993 flood event as recorded at the Killiecrankie gauging station. The target location of the Model V is also set at the downstream modelling extent, at which the theoretical critical storm duration of the River Garry is 12.75-hours. As the critical storm duration of the residual catchment is shorter than that of the River Garry at the target location, the catchment specific return period flow of the residual catchment was reassessed (i.e., reduced) using a scaling factor derived using the same procedure to that described above for Model V/VI. The hydrograph shape for deriving the model inflow for the residual catchment is again based on the 1993 historic flood event hydrograph shape for the River Tilt @ Marble Lodge station, which is the only smaller catchment in the area for which historic flood records (time series) are available. This approach attempts to keep the shape and timing of the various catchment inputs consistent with the January 1993 event and recognises and makes a slight allowance for the fact that the estimated design flows on the large catchment don’t occur as a result of the same event on a smaller tributary catchment.

5.1.11 As the model routed flow at the downstream end of the model was almost equal to the targeted flow at that location (refer to the last row of Table 9), no scaling of inflow hydrograph was required.

5.1.12 No Run 2 was required for this model.

5.1.13 The inflow hydrographs for Model V are presented in Diagram 6.

Diagram 6: Model V 0.5% AEP (200-year) event inflow hydrographs for Run 1



Hydrology for Hydraulic Model Calibration

5.1.14 Calibration of a hydraulic model requires accurate recorded flood flows with which to run the model and observed level data from the event to compare the model predicted water levels to.

5.1.15 There are no hydrometric stations within or close to the Model V/VI modelled extent. Therefore, calibration of this model was not possible.

5.1.16 The Killiecrankie gauging station is located at the downstream end of Model V. For the DMRB Stage 3 assessment, 15-minute interval flow data at the Killicrankie Station was obtained from SEPA for the winter 2015/2016 period. (Water level data at the station during the November/December 2015 event was downloaded by Jacobs during the actual flooding events). No other flood wrack marks were available from the winter 2015/16 event (or indeed for any other historic events along the modelled reach). Due to the lack of historic flood level at locations other than the gauging station, a full calibration of this model is not possible, except for comparing the simulated water level for the December 2015 event with that recorded at the gauging station.

6 Low Flow Estimates

6.1.1 Low flow estimates are required for all road drainage outfall locations. It is important that the low flow estimates (in particular Q_{95}) are reasonably accurate for dilution calculations.

6.1.2 Diagram 7 identifies the locations requiring low flow estimates and Table 10 presents the low flow estimates.

Diagram 7: Location of the proposed outfalls

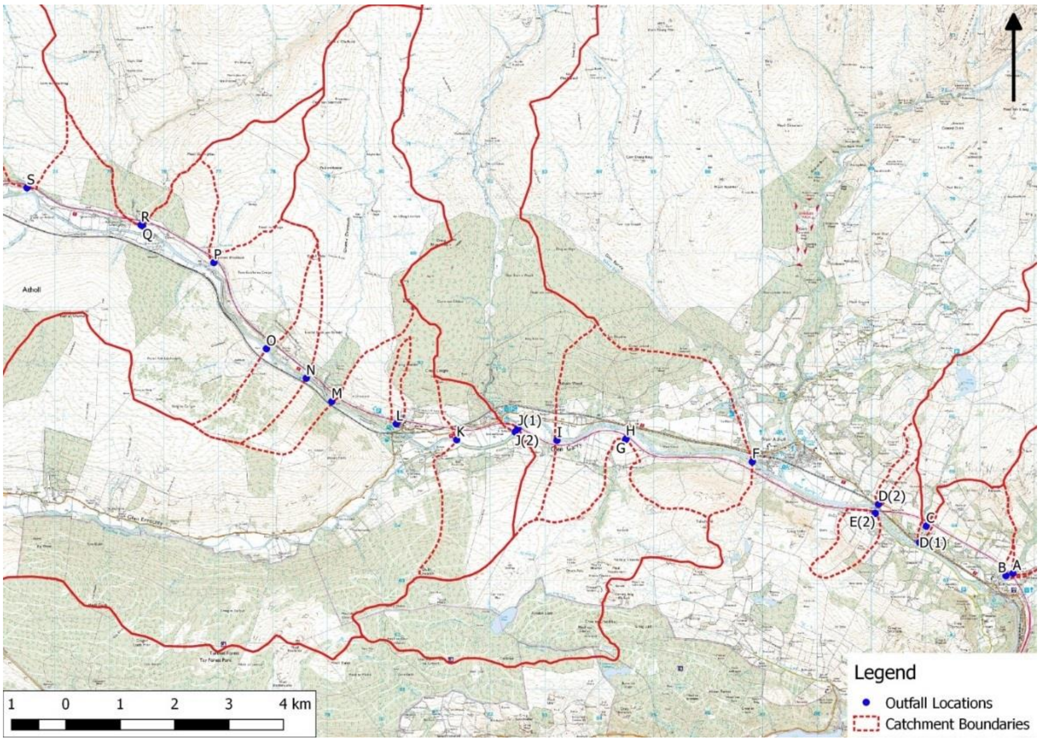


Table 10: Low flow estimates for the outfall locations

Watercourse	Outfall	Grid Reference	Catchment Area (km^2)	Q_{95} (m^3/s)	Mean Flow (m^3/s)
Allt Girnaig (WF89)	A	291606, 763128	39.5	0.153	0.80
Allt Girnaig (WF89)	B	291478, 763084	39.6	0.154	0.81
Allt Chluain (WF98)	C	290014, 763995	7.4	0.025	0.13
Allt Chluain (WF98)	D(1)	289890, 763694	7.5	0.025	0.13
WF178	D(2)	289135, 764396	0.4	0.001	0.01
WF99	E(1)	289076, 764227	0.9	0.003	0.02
WF99	E(2)	289076, 764227	0.9	0.003	0.02
River Garry (WF100)	F	286816, 765175	474.1	1.055	5.53
Allt Bhaic (WF115)	G	284484, 765579	11.1	0.037	0.19
Allt Bhaic (WF115)	H	284494, 765595	11.1	0.037	0.19
River Garry (WF100)	I	283225, 765565	453.7	0.992	5.20
River Garry (WF100)	J(1)	282506, 765784	380.1	0.941	4.93
River Garry (WF100)	J(2)	282455, 765720	380.1	0.941	4.93
River Garry (WF100)	K	281380, 765578	375.6	0.927	4.86
WF136	L	280271, 765869	0.3	0.001	0.00
River Garry (WF100)	M	279083, 766277	280.7	0.791	4.14
River Garry (WF100)	N	278616, 766706	267.9	0.752	3.94
River Garry (WF100)	O	277884, 767246	265.3	0.744	3.90
Allt Crom Bhruthaich (WF88/167)	P	276918, 768827	3.4	0.013	0.07
Allt Anndeir (WF158)	Q	275608, 769500	61.7	0.140	0.73
Allt Anndeir (WF158)	R	275579, 769515	61.7	0.140	0.73
Allt Geallaidh (WF164)	S	273482, 770199	8.8	0.020	0.11

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7 Conclusions

7.1.1 This appendix presents the assessment methods used to derive design peak flows, inflow hydrographs and low flow estimates for watercourses that may be affected by the proposed scheme. Assessment methods have varied for catchments based on a variety of factors such as catchment size, flood risk and the availability of gauged data. Larger watercourses which are identified for detailed numerical hydraulic modelling have undergone a more detailed assessment than small ungauged watercourses.

7.1.2 The following limitations and comments should be noted when reviewing the findings from this report:

- Flow estimation is subject to some inevitable uncertainty. The design flow estimates / inflow hydrographs / low flow estimates presented within this report have been derived using standard methods and adjusted when appropriate.
- The peak flood estimates for the small watercourses (AREA<25km2) were undertaken using both the FEH statistical and FEH rainfall-runoff methodologies. This enabled a conservative peak flow to be selected for each watercourse by using the approach that resulted in the higher value. For larger catchments (AREA>25km2) the design flows are based solely on the statistical methods.
- A 20% climate change uplift factor has been applied to the resultant design peak flow estimates based on current standard practice. This uplift factor could be subject to change in the future based on the findings of evolving research.
- SEPA have provided design peak flow estimates for the gauging stations within the A9corridor. SEPA have not identified the exact flow derivation methods used. Their values have been checked using standard methods and have been accepted by this study. These flows have been used within the detailed hydraulic models to set the design flood flows within their simulations.
- Low flow estimates on the larger rivers are based upon local gauged data, where available, otherwise LFE estimates provided by CEH Wallingford have been used to derive estimates. If the flow of any catchment is diverted for hydropower generation (e.g., River Garry), this has been taken into consideration by reviewing the catchment area at the diversion location and the compensatory flows (if any).

8 References

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Annex A: Abbreviations

Abbreviations used in this report are presented in Table 11.

Table 11: Abbreviations

Abbreviations	Details
ALTBAR	Mean catchment altitude (m above sea level)
AREA	Catchment drainage area (km^2)
AEP	Annual exceedance probability
BFIHOST	Base flow index derived using the hydrology of soil types classification
DPLBAR	Index describing catchment size and drainage path configuration (km)
DPSBAR	Index of catchment steepness (m / km)
FARL	Index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
LDP	Longest drainage path (km)
LFE	Low Flows Enterprise
NRFA	National Rivers Flow Archive
PVA	Potential Vulnerable Area (in reference to flood risk)
$SAAR_{1961-90}$	Standard average annual rainfall for the 30-year period 1961 to 1990 (mm)
SFRA	Strategic Flood Risk Assessment
SPRHOST	Standard percentage runoff derived using the hydrology of soil types classification (%)
Q_{95}	The flow equalled or exceeded for 95% of the time
Q_{50}	The flow equalled or exceeded for 50% of the time
Qmean	Long-term mean flow
QMED	Median Annual Maximum Flood [also referred to as the 50% AEP (2-year) event]
URBEXT	FEH index of fractional urban extent

Annex B: Amendments to Catchment Descriptors

To derive peak flow estimates at each of the watercourses crossing the A9 carriageway, FEH catchment descriptors are required.

For watercourses draining an area >0.5km², catchment descriptors are extracted directly from the FEH CD-ROM and provide a starting point for the analysis. For each individual catchment lying within the study area (for surface water hydrology and flood risk, the study area was determined by the natural processes of watercourse and floodplain and the location of flood receptors, which can extend for some distance upstream and downstream), the following catchment descriptors have been checked and where necessary, have been manually updated following guidelines presented in the FEH Vol.V:

- Catchment Area
- DPLBAR
- DPSBAR
- URBEXT
- FARL
- FPEXT

Catchment Area

The catchment boundary for each watercourse (if available) was extracted from the FEH CD-ROM as a raster image and imported into a GIS package where it was georeferenced. The resulting output at each of the watercourse crossings was checked for accuracy within a GIS application by:

- Plotting and comparing the location of the FEH derived catchment outflow against the supplied structure grid reference; and
- Comparison of the FEH derived catchment area against the surface water drainage network as interpreted from a 1:25,000 scale OS map and as observed on site.

For watercourses too small (i.e. <0.5km²) to be picked up by the FEH CD-ROM software, catchment areas have been delineated manually using 1:25,000 scale OS mapping and the boundary confirmed by a site walk over, if necessary.

DPLBAR

The mean drainage path length was estimated by using the following FEH formulae (Bayliss, 1999): $DPLBAR = AREA^{0.548}$

DPSBAR

For the majority of catchments DPSBAR (mean drainage path slope) was borrowed from a donor catchment which was included in the FEH CD-ROM software. Where a user defined DPSBAR was required, this was calculated by using a simple gradient calculation. The length of the mean drainage path was measured within a GIS application and maximum and minimum catchment altitude estimated from 1:25,000 scale OS mapping.

URBEXT

The majority of catchments within the study area are rural in nature and as such have an URBEXT value of zero or very close to zero. Where a catchment is located within a particularly urban area and the catchment is too small to be included within the FEH software, the URBEXT was calculated manually. Using OS master map data, surface areas of all buildings and hardstanding (roads etc.) were calculated. This area was then divided by the total catchment area of the watercourse to produce an estimate of URBEXT.

FARL

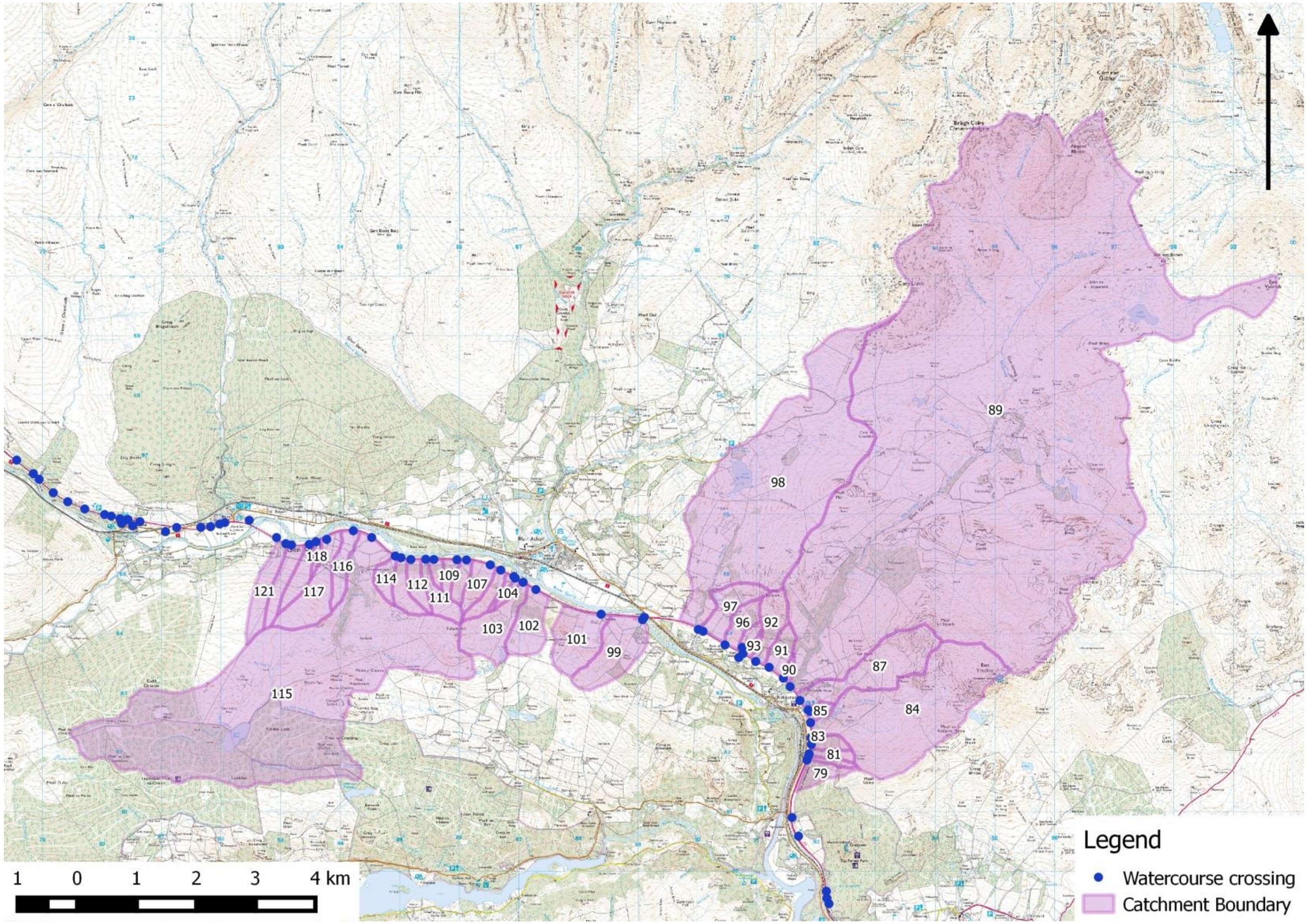
For the larger watercourses, the FEH software was used to get estimates of FARL. However, for small catchments not included within FEH, FARL was calculated manually. This was achieved by measuring the surface area of any waterbodies (excluding watercourses) within the catchment. The following equation was then used to determine the FARL for the catchment:

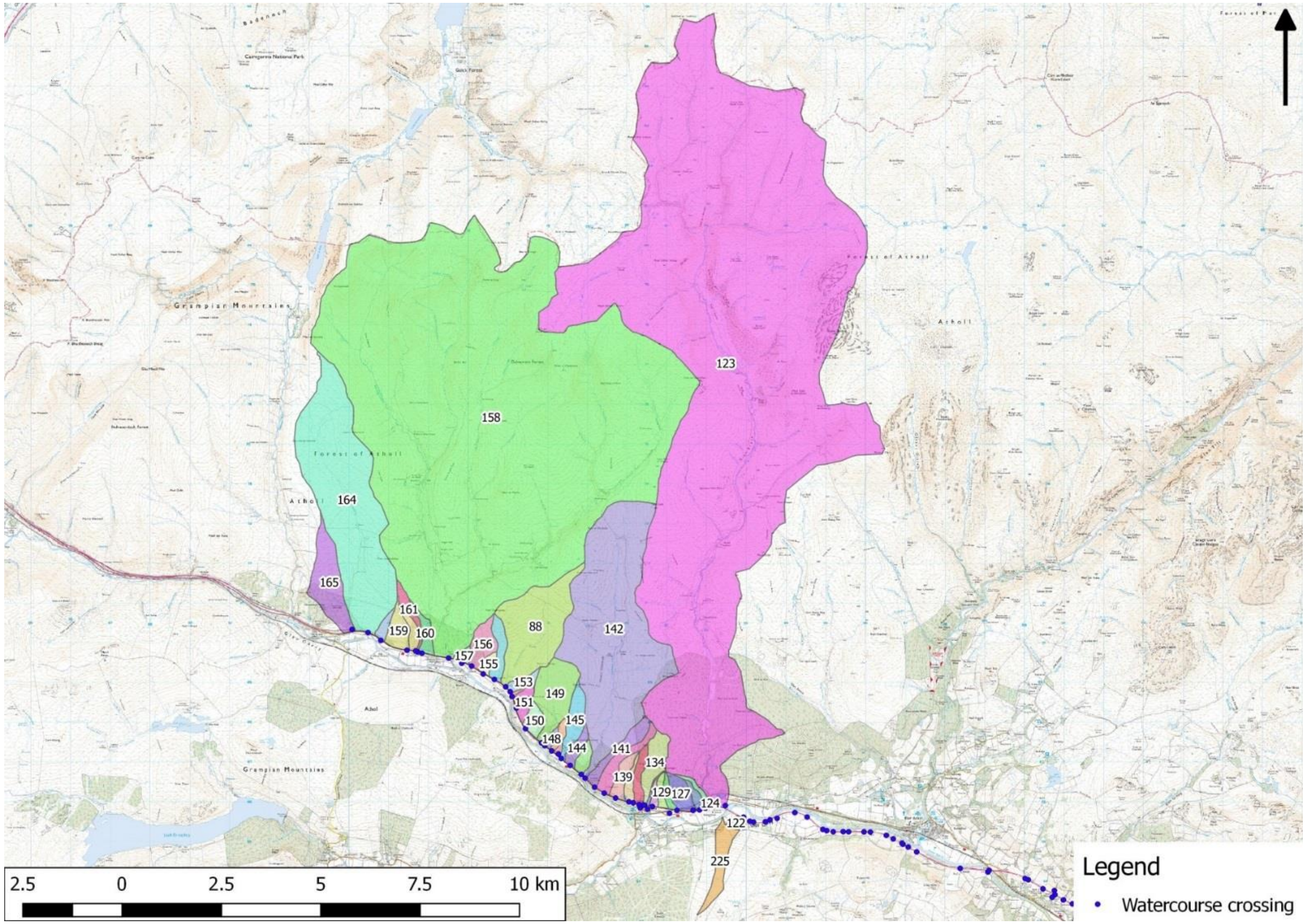
FARL = 1-(Waterbody surface area/catchment area).

FPEXT

The floodplain extent for most catchments was borrowed from a donor catchment (generally in close proximity to the target site) and a subjective judgement was applied upon its suitability, based on the information available on the 1:25,000 map.

Annex C: Catchment Boundary Maps (small watercourses crossed by the road)




123
158
164
165
161
159
160
156
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88
142
153
149
151
150
145
148
144
141
139
134
129
127
124
122
225
2.5
0
2.5
5
7.5
10 km
Legend
Watercourse crossing

Annex D: Adequacy of small catchment estimates

A check on the suitability of the two methods for application to small upland catchments in the Central Highlands was undertaken on two gauged catchments at Balquhidder. These gauges were installed by the Institute of Hydrology for hydrological research and were calibrated to operate over the full range of flows.

- Monachyle Burn @ Balquhidder (18017) – catchment area 7.7km2
- Kirkton Burn @ Balquhidder (18018) – catchment area 6.9km2

Both have small steep mountainous catchments not dissimilar to those along the A9 corridor. Being further west they do receive higher annual rainfall totals. Both receive appreciable amounts of winter precipitation in the form of snow.

Diagram 8 plots the performance of the FEH rainfall-runoff model and the FEH QMED equation (without donor adjustment) in comparison to the observed QMED values of the two gauges. The FEH QMED equation underestimates the QMED flows by on average 7% whilst the FEH rainfall-runoff method underestimates the QMED flows by on average 19%. It should be noted though that the FEH rainfall-runoff method does have a closer fit to the observed data for the Kirkton Burn than the FEH QMED equation but overall performance is skewed by poor performance of the FEH rainfall-runoff method for the Monachyle Burn which significantly underestimates the QMED.

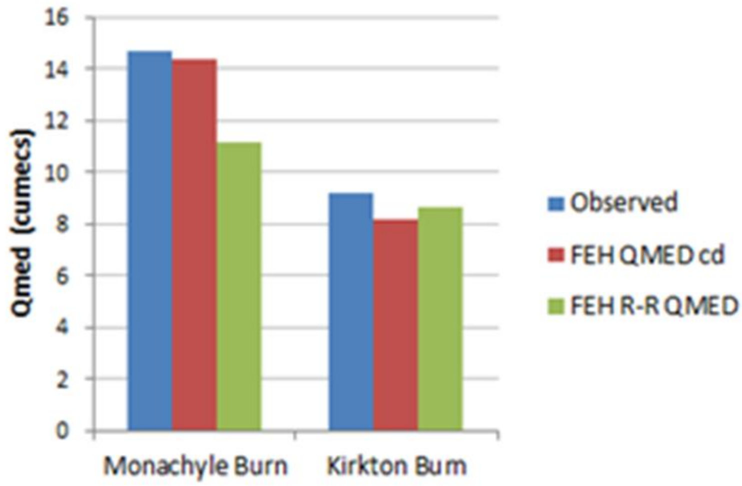

Diagram 8: Comparison of QMED estimates from the FEH Rainfall-runoff method and the FEH Statistical method to the observed QMED values obtained from observed data in two small mountainous catchments in the Central Highlands.

Selecting the higher of the two estimates corresponds well with the observed, though in the small catchment flow estimates given in chapter 4 it should be noted that the statistical estimates were additionally subject to a QMED adjustment uplift factor of 1.237.

The following points are noted concerning the derivation methods:

- The recent Environment Agency study (Faulkner et. al, 2012) undertaken by CEH Wallingford and JBA on flood estimation in small catchments across the UK concluded that “the FEH statistical method and the Revitalised Flood Hydrograph (ReFH) event-based method both outperform the older methods” in the estimation of floods in small catchments.
- Long-term rainfall measurement (either daily or sub-daily) in the region of interest is particularly sparse leading to questions regarding the robustness of the depth-duration-frequency statistics used in the rainfall-runoff method.
- The mountainous region is prone to snow which adds a significant layer of seasonal complexity to the consideration of design flood flows. A survey of all small gauged catchments in the NRFA

Hydrometric Register (NERC, 2008) within what was the SEPA East boundary in the proximity of the Highland area shows that the highest recorded flood flows at each gauge occur almost exclusively between October and March indicating a strong winter dominance to the flood regime. Snow events affect storm event runoff in several ways: i) snowmelt can add more water to the flood, ii) precipitation falling above the snow\freezing line is effectively stored and held within that portion of the catchment and doesn't contribute to the flood waters. It is clear that the application of the rainfall-runoff method does not take this into account. It is also problematic for the statistical approach in that the available pool of hydro-climatically similar catchments is limited. However, the use of a regional donor adjustment factor to the index flood (QMED) should help to include the influence of wintery conditions in the analysis.

- Both methods are severely hampered by the lack of available monitoring in small mountainous catchments typical of that through which the A9 passes. Models are developed and calibrated based upon available datasets. For the FEH rainfall-runoff model these datasets (for the small mountainous catchments with the particular hydro-climatic conditions) will not have been available for model development; compounded by the fact that the development undertaken in the late 1960s and early 1970s does not benefit from the addition years of record now available. Similarly, the FEH empirical equation for estimating QMED will not have been influenced by much data from the small mountainous catchments with the particular hydro-climatic conditions of relevance to this project. A distinct weakness, but one that has been attempted to be addressed via the use of a regional donor based adjustment to the estimate. Pooling hydrologically similar catchments will be hampered by the lack of similar catchments to choose from – weakening the robustness of the flood growth curve. Equally though the understanding of the design precipitation for inclusion in the rainfall-runoff model is hampered by the lack of long-term rain gauges in the area and the influence of snow.

Based on SEPA's comments/suggestions on the earlier Stage 2 Hydrology Report it was decided to adopt the more conservative value of the two methods.

Annex E: Review of the high/low flow performance of the gauges

Gauges were assessed as to their suitability for high flow and low flow performance based on the following method.

High flow performance

- All gauges used for flood work were first checked on the Peak Flows website for suitability for QMED and Pooling. The guidance given there is based upon detailed reviews of the high flow performance of the gauges.
- All gauges in Hydrometric Area 15 used to steer the development of a QMED adjustment factor for the small catchments were classed as suitable for QMED in the Peak Flows dataset.
- Of the gauges used for deriving peak flows in the larger watercourses, the Caputh (15003) and Pitnacree (15007) gauges on the Tay are identified as suitable for pooling in the Peak Flows dataset.
- Not all of the gauges used were included in the Peak Flows dataset. This can result from the shortness of record when collection was originally undertaken for the FEH (i.e. insufficient data at the time to warrant inclusion), the catchment was considered atypical and not deemed appropriate for inclusion in a dataset designed for pooling, or that the high flow performance was considered poor by the gauging authority
- For these gauges' flood data was sourced for the assessment from SEPA who provided their own return period flows together with the station annual maximum flood series that they used to calculate them. These were considered as acceptable by SEPA, and checks upon the return period estimates using the data were made to ensure consistency.

Low flow performance

For the quality of low flow estimation of the gauges three checks were made as to their suitability:

- Had the gauge been accepted within the Scottish Low Flows Enterprise dataset. To achieve this, they must have passed quality checks and be classified as natural. (15023 & 15039 are included in LFE – the others won't have been considered due to the presence of hydropower within the catchments).
- The quality score given in the IH Report "108 Low Flow Estimation in the United Kingdom". (15003, 15007, 15012, 15023 all have the high quality "A" grade – indicating accurate low flow measurement. 15034 & 15039 were not listed).
- The gauge's Sensitivity Index. All gauges used have SI values <20%. This is the threshold set within IH Report 108 for accurate flow measurement. (Refer to both: NERC, 2008. UK Hydrometric Register; IH, 1992. Low flow estimation in the United Kingdom).