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 to the low flow assessment undertaken for the proposed scheme.

1.1.2 Hydrological inputs are required for the Stage 3 DMRB assessment. 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 potentially at risk of being impacted by the proposed scheme.

1.1.3 A total of 23 watercourses and a number of waterbodies (including Loch Faskally and Loch Dunmore) have been identified as having the potential to be impacted by the proposed scheme and associated infrastructure. These water features range in size from small drainage ditches to large watercourses such as the River Tummel. 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

2.1 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 road 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 return periods).

2.1.2 For clarity, AEP refers to the chance that a flood of a particular size is experienced or exceeded during any year. In this report we use a probability value expressed as a percentage to quantify this. For example, the 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 that the reader recognises that a low probability doesn't preclude the event happening in the following year – it's exactly analogous to rolling a dice such that having rolled one 6 the next throw would also be a 6.

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 the 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.

2.2 Review of Previous Work

2.2.1 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); and
- DMRB Stage 2 Assessment: A9 Dualling – Pitlochry to Killiecrankie: Environmental Statement, Appendix A9.1 – Surface Water Hydrology (Jacobs, 2016).

2.2.2 A review of any Potential Vulnerable Areas[1] (PVA) within the study 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.

2.3 Regional Hydrological Considerations

2.3.1 The existing A9 forming the focus of this work 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.

2.3.2 Orographic uplift of the rainfall 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 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.

2.3.3 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.

2.3.4 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.

2.4 Climate Change

2.4.1 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%[2,3] 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.

2.4.2 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.

2.5 Baseline Assessment

2.5.1 To undertake this assessment all watercourses, waterbodies and springs that could potentially be impacted by the A9 dualling programme (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.

2.5.2 The FEH CD-ROM v3 was used to derive catchment descriptors for all identified watercourses and waterbodies potentially impacted by the scheme. It should be noted that FEH CD-ROM is not ideal at picking up small catchments and that a review of the derived catchment parameters was required. 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 route 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 are 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).

2.5.3 A review of local data within the identified catchments and within the vicinity of the scheme was undertaken. Flow gauges present were assessed for suitability for providing relevant high quality data to the study area. This included assessment of gauge performance in terms of both high and low flows. Since the earlier production of the 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.

2.5.4 Details on the location of the proposed watercourse crossings by a culvert or by a bridge crossing were also noted, as design inflows are required at these locations for the hydraulic analyses of these culverts/bridges. 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 within the study area particularly where there is a known flood history or identified flood risk.

---

[2] The Highways Agency et al. (2009). HD45/09 DMRB, Volume 11, Section 3, Part 10, Road Drainage and the Water Environment, 2009. The Highways Agency, Scottish Executive, Welsh Assembly Government and The Department for Regional Development Northern Ireland.

[3] SEPA (2015). Technical Flood Risk Guidance for Stakeholders (Reference: SS-NFR-P-002)

2.6 Design Flows and Inflow Hydrographs

2.6.1 Peak flows are required for all watercourse crossing locations for the following 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 scheme 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.

2.6.2 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. The hydrological (flow) inputs to this study area are affected by processes across the whole of the River Tummel Drainage basin.) have small and ungauged catchments. Flow estimation for small[4], 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 (Pass of Birnam to Glen Garry)' 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 our assessment.

2.6.3 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.

Design Peak Flow Estimation – Small Ungauged Catchments

2.6.4 In the DMRB Stage 2 assessment the peak flows determined from the FEH statistical method 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 on the Stage 2 hydrology report, the methodology was revised during the Stage 3 assessments to select the larger of the two peak flow values from the FEH statistical and the FEH rainfall-runoff methods [basis of comparison being the 50% AEP (2-year) and 0.5% AEP (200-year) event peak flows].

2.6.5 The following paragraphs describe the two methodologies.

FEH Statistical Method

2.6.6 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' using a regionally derived QMED adjustment factor. Gauges in the general region of the Southern Section of the A9 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 route 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 $\text{QMED}_{\text{(observed)}}$ / $\text{QMED}_{\text{(catchment descriptors)}}$ values was used to derive the regional QMED adjustment factor of 1.237.

2.6.7 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). Three groups were identified

---

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

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.

2.6.8 The EA Document No. SC090031 (Faulkner et al, 2012)[5] states that the FEH statistical method should be used to derive flood estimates for catchments with area >0.5km^2. Where catchments areas are <0.5km^2, the document advocates areally scaling the estimate from a hydrologically similar catchment with and area of 0.5km^2. Accordingly, the peak flood estimates for all minor ungauged catchments with catchment areas <0.5km^2 were derived by scaling the flows from a hydrologically similar donor catchment with area >0.5km^2 in the vicinity of the subject site.

FEH Rainfall-Runoff model method

2.6.9 The design event application of the FEH rainfall-runoff model was used to derive peak flow for all catchments <25km^2, using the rainfall-runoff boundary unit in ISIS software package, based on the catchment descriptors derived from the FEH-CDROM.

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

2.6.11 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 when that flow was the higher.

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

2.6.12 The southern section of the scheme (Pass of 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 is not without its 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 (AMAX) series and 15-minute interval time series data but also their estimates of 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 earlier Stage 2 assessment was based on the hydrometric data received from SEPA in early 2015.

2.6.13 Scotland experienced extreme flooding during the winter of 2015/16. For this 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, and Table 2 presents the SEPA predicted annual exceedance probability flows for the stations on the rivers Tay, Tummel and Garry.

---

[5] Faulkner, D, Kjeldsen, T, Packman, J and Stewart, L (2012). Estimating flood peaks and hydrographs for small catchments: Phase 1, Environment Agency, Centre for Ecology and Hydrology, Department for Environment Food and Rural Affairs, SC090031.

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 flows were increased at Killiecrankie Station (e.g., the 0.5% AEP flow increased by approximately 19%) following the winter 2015/16 event, however the peak flows at other stations remained unchanged.

2.6.14 The SEPA AEP flow estimates at the gauging stations (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 more likely to result in better 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).

2.6.15 Results of the 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 = 65 years), Pitnacree (N= 65 years) 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 to 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.

2.6.16 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 minor watercourses, which were obtained using the methodology adopted for small ungauged catchment described above.

2.6.17 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 the River Tilt stations for the same event were used (shape allocated according to proximity of the small watercourse).

2.7 Low Flow Estimates

2.7.1 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 was used for deriving these flow estimates.

2.7.2 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.

Table 3: Gauging stations used to calculate low flows

Station Number	River Name	Station Name	Catchment Area (km²)	Q_{95} (m³/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

2.7.3 In general, to estimate Q_{95} flows for locations along 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 areal scaling to transpose Q_{95} values to the proposed outfall location.

2.7.4 For 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	Q_{95} (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 model (Model IV) are presented in Table 6.

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

Watercourse / Structure Reference	Grid Reference	Catchment Area (km²)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
57	295928, 756098	0.78	894	0.599	31.2	1.00	0.016
58	295862, 756177	0.13	894	0.599	31.2	1.00	0.056
59	295629, 756435	0.39	885	0.663	27.9	1.00	0.038
60	295517, 756528	0.29	888	0.663	28.0	1.00	0.062
61	295469, 756591	0.23	888	0.663	28.0	1.00	0.062

Watercourse / Structure Reference	Grid Reference	Catchment Area (km^2)	SAAR 1961 - 1990 (mm)	BFIHOST	SPRHOST (%)	FARL	URBEXT (2015)
63	294562, 756774	0.32	921	0.640	27.8	1.00	0.000
64	294329, 756976	2.32	962	0.606	29.3	0.983	0.001
65	293930, 757401	0.59	942	0.644	28.2	1.00	0.006
66	293525, 757489	0.63	942	0.644	28.2	1.00	0.001
67	293259, 757574	0.03	942	0.644	28.2	1.00	0.000
68	293195, 757587	0.70	969	0.615	29.3	1.00	0.000
69	292904, 757981	0.89	965	0.596	30.8	1.00	0.002
71	292726, 758841	0.24	897	0.598	30.7	1.00	0.003
72	292560, 758846	0.08	897	0.598	30.7	1.00	0.014
73	292141, 759139	0.10	897	0.598	30.7	1.00	0.000
74	292211, 759456	0.10	897	0.598	30.7	1.00	0.000
76	292166, 759666	1.04	897	0.598	30.7	1.00	0.001
77	291699, 760591	0.72	909	0.568	32.5	1.00	0.002
78	291590, 760905	1.16	904	0.521	36.3	1.00	0.000
191*	294884, 756455	1.02	921	0.640	27.8	1.00	0.000

* Only low flow estimates

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)
Tummel u/s A9 crossing	292794, 758600	1640	1492	0.416	48.16	0.766	0.000
WF 181	294600, 757500	10.8	995	0.471	37.67	0.959	0.004
WF 180	295000, 757400	13.1	978	0.455	37.09	1.00	0.002
Residual 1 (between two A9 crossings)	*	13.4	978	0.455	37.09	1.00	0.029
Residual 2 (d/s of d/s A9 crossing)	*	4.22	962	0.606	29.31	1.00	0.000
Tummel d/s modelling extent	296202, 755569	1685	1478	0.419	47.77	0.761	0.001

* 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

4.1 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 watercourses with catchment areas <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)	
57	0.78	0.55	1.83	0.35	1.22	Rainfall-Runoff
58	0.13	0.13	0.47	0.08	0.28	Rainfall-Runoff
59	0.39	0.27	0.92	0.16	0.55	Rainfall-Runoff
60	0.29	0.23	0.79	0.13	0.44	Rainfall-Runoff
61	0.23	0.19	0.66	0.11	0.37	Rainfall-Runoff
63	0.32	0.23	0.74	0.14	0.52	Rainfall-Runoff
64	2.32	1.21	3.98	0.91	3.31	Rainfall-Runoff
65	0.59	0.41	1.38	0.25	0.92	Rainfall-Runoff
66	0.63	0.43	1.42	0.27	0.96	Rainfall-Runoff
67	0.03	0.03	0.11	0.02	0.07	Rainfall-Runoff
68	0.70	0.51	1.69	0.34	1.24	Rainfall-Runoff
69	0.89	0.65	2.17	0.45	1.62	Rainfall-Runoff
71	0.24	0.22	0.75	0.13	0.46	Rainfall-Runoff
72	0.08	0.09	0.32	0.05	0.17	Rainfall-Runoff
73	0.10	0.11	0.36	0.06	0.22	Rainfall-Runoff
74	0.10	0.11	0.36	0.06	0.21	Rainfall-Runoff
76	1.04	0.77	2.51	0.44	1.59	Rainfall-Runoff
77	0.72	0.60	1.94	0.37	1.34	Rainfall-Runoff
78	1.16	1.03	3.32	0.64	2.31	Rainfall-Runoff

4.1.3 Diagrams 1 and 2 show that the flood estimates derived using the FEH rainfall-runoff method are generally higher than those derived using the statistical method for both 50% AEP and 0.5% AEP events. This result is consistent with that observed in the Project 5 catchments located downstream of the River Garry – River Bruar confluence, where the FEH rainfall – runoff method also generally produces higher peak flow estimates than the FEH statistical method.

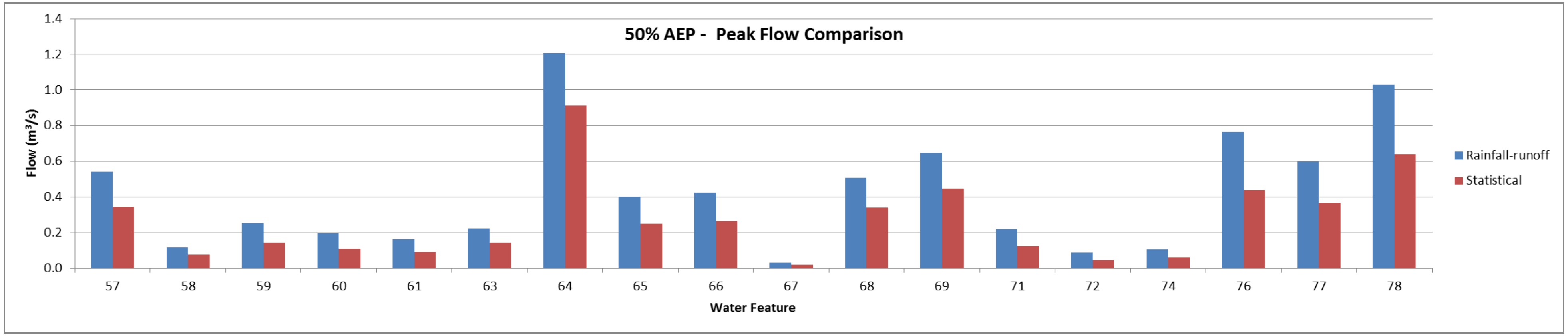


Diagram 1: Comparison of the 50% AEP (2-year) peak flow estimates from the FEH Rainfall-runoff and the FEH Statistical methods for catchments <25km^2

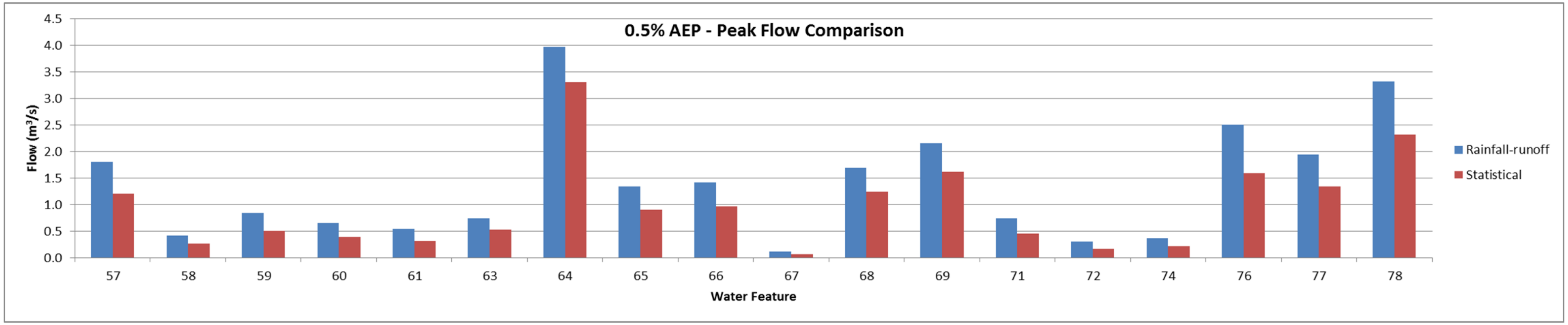


Diagram 2: Comparison of the 0.5% AEP (200-year) peak flow estimates from the FEH Rainfall-runoff and the FEH Statistical methods for catchments <25km^2

4.2 Final Design Peak Flow Estimates

4.2.1 As the peak flows produced by the FEH rainfall-runoff method were generally higher than those produced by the FEH statistical method, the flows produced by the FEH rainfall-runoff method have been adopted as the design peak flows for all small catchments (<25km²) in the P4 study area. Annex D provides a discourse on the adequacy of the estimates. For larger catchments (>25km²) the statistical method flows have been adopted.

4.2.2 The final design peak flow estimates are presented in Table 8. The 0.5% AEP (200-year) plus climate change estimate (referred to as 'plus CC') which includes 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-year) plus CC	0.1% AEP (1000-yr)
57	0.55	0.80	0.96	1.23	1.38	1.57	1.83	2.19	2.74
58	0.13	0.20	0.24	0.32	0.36	0.41	0.47	0.56	0.69
59	0.27	0.40	0.48	0.63	0.70	0.80	0.92	1.10	1.39
60	0.23	0.34	0.41	0.54	0.60	0.69	0.79	0.95	1.18
61	0.19	0.28	0.34	0.45	0.50	0.57	0.66	0.79	0.98
63	0.23	0.33	0.40	0.51	0.57	0.65	0.74	0.89	1.13
64	1.21	1.72	2.05	2.60	2.89	3.39	3.98	4.77	5.84
65	0.41	0.60	0.72	0.93	1.04	1.18	1.38	1.65	2.09
66	0.43	0.62	0.75	0.96	1.08	1.22	1.42	1.71	2.16
67	0.03	0.05	0.06	0.07	0.08	0.09	0.11	0.13	0.16
68	0.51	0.74	0.89	1.14	1.28	1.46	1.69	2.03	2.57
69	0.65	0.95	1.13	1.45	1.62	1.84	2.17	2.60	3.24
71	0.22	0.33	0.40	0.51	0.58	0.66	0.75	0.90	1.13
72	0.09	0.14	0.17	0.22	0.24	0.28	0.32	0.38	0.47
73	0.11	0.16	0.19	0.25	0.28	0.32	0.36	0.44	0.54
74	0.11	0.16	0.19	0.25	0.28	0.31	0.36	0.43	0.54
76	0.77	1.11	1.33	1.71	1.91	2.17	2.51	3.02	3.78
77	0.60	0.87	1.04	1.34	1.50	1.70	1.94	2.33	2.93
78	1.03	1.50	1.79	2.30	2.56	2.91	3.32	3.98	4.95

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

5.1 Design Peak Flows

5.1.1 The Southern Section of the A9 dualling scheme (Pass of Birnam to Glen Garry) consists of five numerical hydraulic models, including two models (Models V & V/VI) for the River Garry and its tributaries, one model (Model IV) for the River Tummel and its tributaries, one model (Model III) for the River Tay and the River Tummel and one model (Model II) for the River Tay and its tributaries (River Braan and Inchewan Burn).

5.1.2 The proposed scheme consists of one hydraulic model for the River Tummel and its tributaries (Diagram 3). The model requires design peak flow (target flow) estimation at various locations as described below:

- River Tummel – upstream of the U/S A9 Crossing (Clunie Underbridge)
- WF181 – Kinnaird Burn
- WF180 – Edradour Burn
- Unnamed minor watercourses WF 59, WF 60 & WF 61
- WF64 – Littleton of Fonab
- Residual catchment between the two A9 crossings
- Residual catchment downstream of the D/S A9 Crossing (Tummel Underbridge)
- The downstream model extent

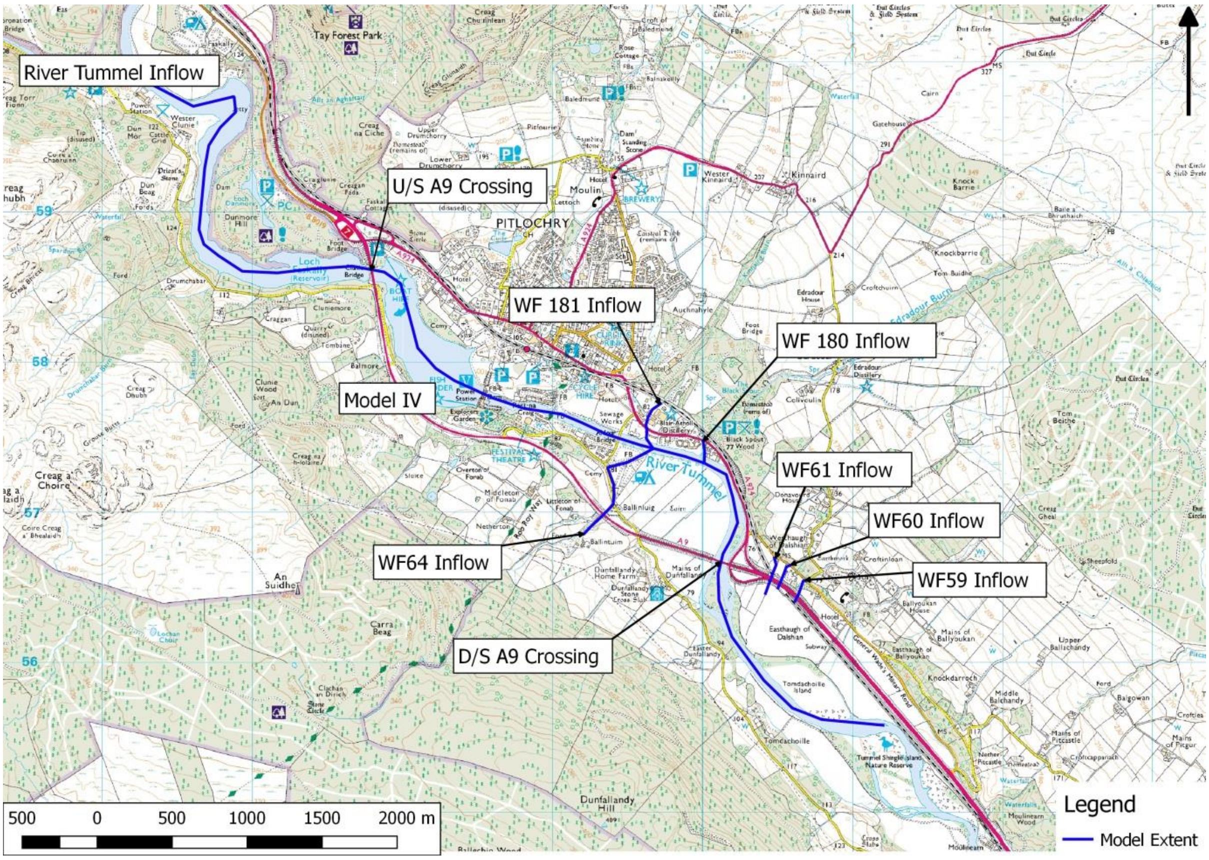


Diagram 3: Model Extents together with flow estimation locations.

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

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

Watercourse	AEP 50% (2-year)	AEP 3.33% (30-year)	AEP 1% (100-year)	AEP 0.5% (200-year)	AEP 0.5% (200-year) plus CC	AEP 0.1% (1000-year)
Tummel U/S A9 Crossing	571	1009	1228	1371	1645	1760
WF 181	6.15	12.8	16.8	19.4	23.3	27.6
WF 180	7.18	15.7	21.0	24.7	29.7	36.4
WF 59	0.27	0.63	0.80	0.92	1.10	1.39
WF 60	0.23	0.54	0.69	0.79	0.95	1.18
WF 61	0.19	0.45	0.57	0.66	0.79	0.98
WF 64	1.21	2.60	3.39	3.98	4.77	5.84
Residual 1 (between two A9 crossings)	7.57	16.5	22.1	26.1	31.3	38.4
Residual 2 (downstream of D/S A9 Crossing)	1.99	4.21	5.80	6.47	7.77	9.43
Tummel d/s modelling extent	561	990	1206	1346	1615	1728

5.2 Inflow Hydrographs

5.2.1 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 Tummel 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) event peak flow occurring in the main stem downstream.

The derivation of design inflow hydrographs for Model IV is described in the following paragraphs.

5.2.2 For Run 1, the model inflow for the River Tummel main stem is based on the peak flow in Table 9 and the hydrograph shape is derived from historic flood events at the Pitlochry gauging station. The January 1993 flood hydrograph shape was judged to be the most representative from a comparison of hydrograph shapes of the five largest historic flood events, and hence adopted for the shape of the River Tummel inflow. The target location in this model is set at the downstream modelling extent, where the theoretical critical storm duration for the River Tummel is 18 hours and 25 mins. As the critical storm durations for the other minor watercourses are shorter than that of the River Tummel, their catchment specific AEP flows (Table 9) were re-assessed (i.e. reduced) using scaling factors based on the ratio of the rainfall-runoff model design run using the catchment specific critical storm duration to that of an equivalent run in which an 18 hour 25 storm storm duration more suitable for the Tummel was used.

5.2.3 The hydrograph shape for deriving model inflow for the minor tributaries is based on the shape of 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 flow records (time series) are available. This is coupled with the slightly reduced peak flows (as described above) to provide the minor tributary inflow. 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 non-critical duration nature of the event on the small catchments.

5.2.4 The model routed flow at the downstream end of the model was reconciled with the target flow at that location (refer to the last row of Table 9) using a scaling factor determined from iterative runs in the hydraulic model. As the first modelled flow was only 3% larger than the target flow in Model IV, no scaling factor was considered necessary. This approach is marginally conservative but is not judged to impact the objective of the scheme.

5.2.5 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 Tummel), inflow hydrograph shapes for WFs 181, 180, 64, 61, 60, 59, Residual catchments 1 and 2 are based on the FEH rainfall-runoff model hydrograph for storm durations of 4.75hr, 5.75hr, 3.25hr, 1.5hr, 1.5hr, 1.7hr, 1.1hr, 1.9hr, 4.75hr and 3.25hr respectively. The flow in the River Tummel is QMED flow with its hydrograph shape based on the January 1993 event at Pitlochry; and its peak flow (QMED) occurring at the same time as that of the tributary peaks.

5.2.6 The inflow hydrographs for both runs for Model IV are presented in Diagrams 4 to 7.

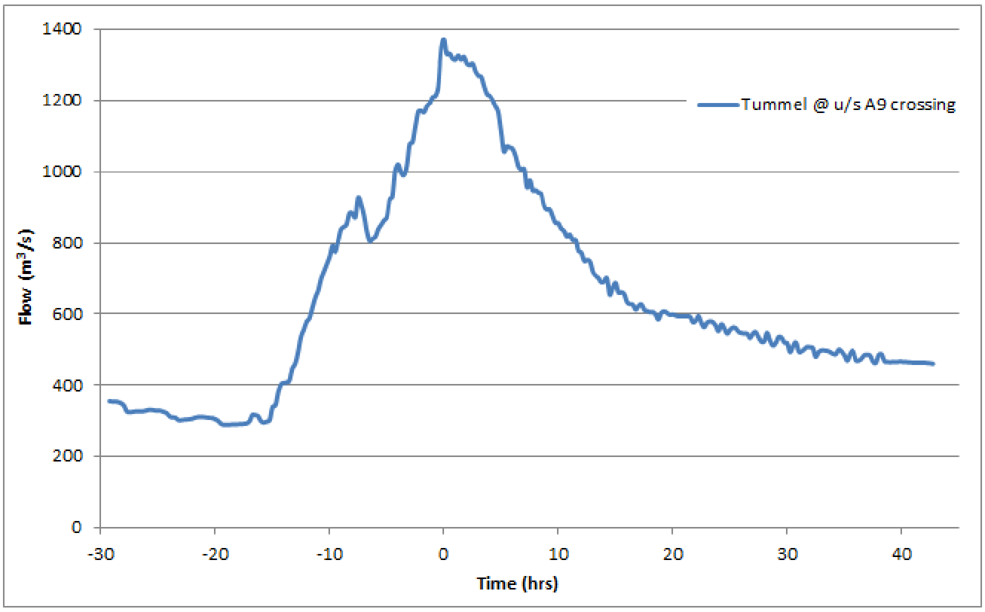


Diagram 4: Model IV 0.5% AEP (200-year) event inflow hydrograph in the River Tummel for Run 1

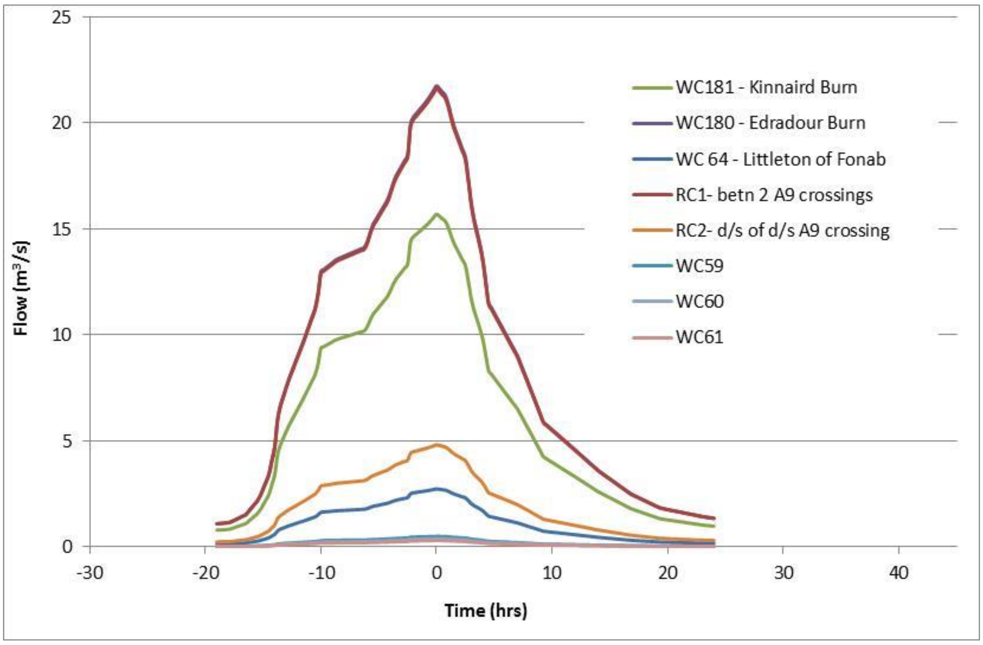


Diagram 5: Model IV 0.5% AEP (200-year) event inflow hydrographs in the tributaries for Run 1

*Inflow hydrographs of WC 180 and Residual Catchment 1 are overlapped; similarly, inflow hydrographs of WC 59, 60 and 61 are close to each other.

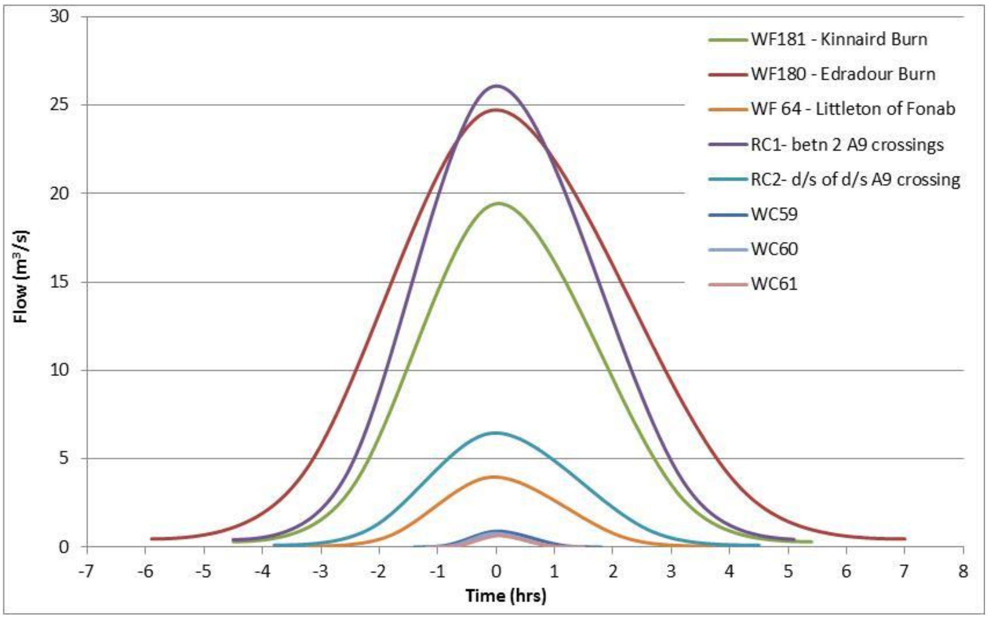


Diagram 6: Model IV 0.5% AEP(200-year) event inflow hydrographs in the tributaries for Run 2

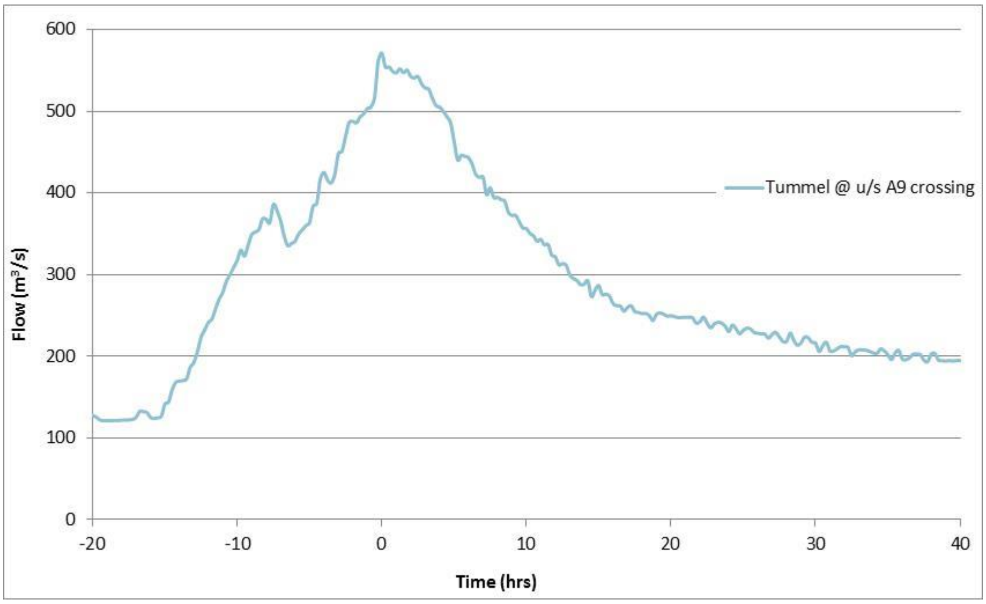


Diagram 7: Model IV inflow hydrographs for Run 2 (Tummel: 50% AEP (2-year) event)

(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 event on catchments of differing size will have a rarity that is less than that of the targeted tributary flood).

5.3 Hydrology for Hydraulic Model Calibration

5.3.1 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 with.

5.3.2 The Pitlochry gauging station is located within the modelled reach of Model IV; as such flood hydrographs of the historic events at this gauge can be used to calibrate the hydraulic model.

5.3.3 During this DMRB Stage 3 assessment, 15-minute interval flow data at the Pitlochry Station was obtained from SEPA for the winter 2015/16 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 modelling reach). Due to the lack of historic flood levels 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. Level and flow hydrographs for the December 2006 and January 2008 events were also supplied so that these could be used in a similar way within the calibration of the hydraulic model.

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 8 identifies the locations requiring low flow estimates and Table 10 presents the low flow estimates.

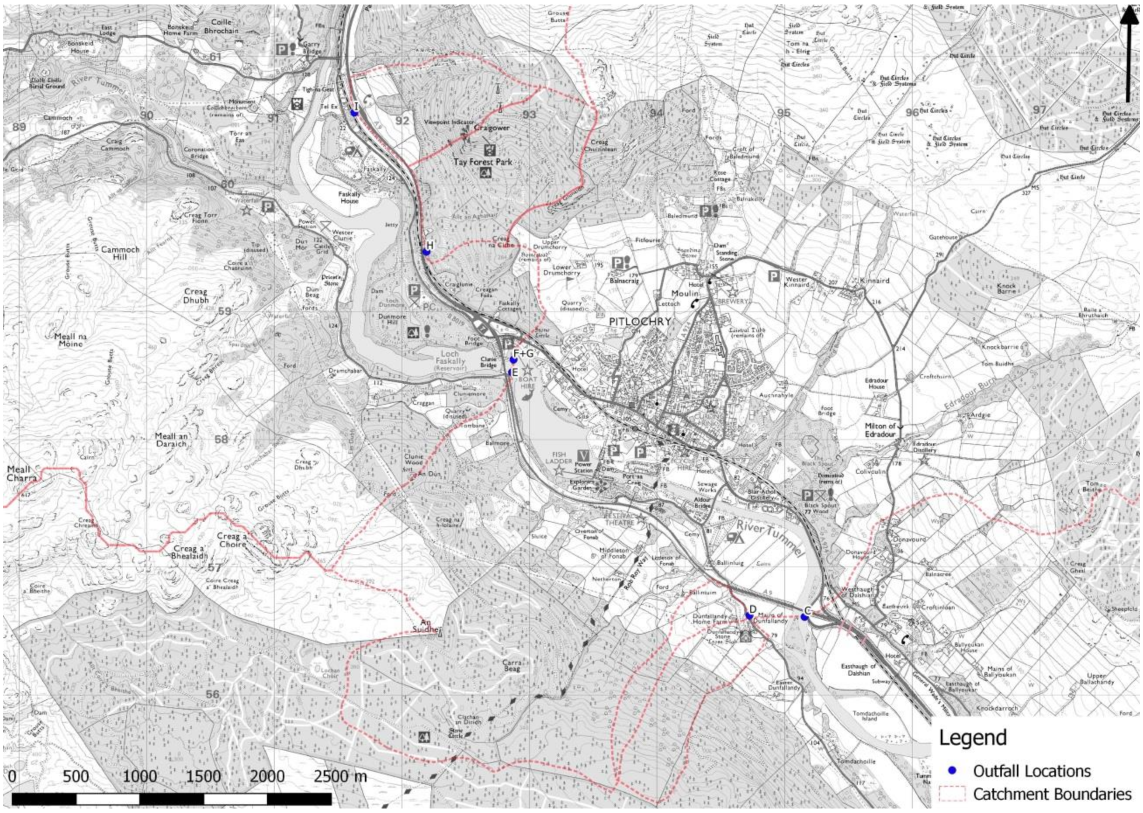


Diagram 8: Location of the proposed outfalls

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)
River Tummel (WF70)	C	295157, 756613	1680	19.81	75.0
WF191 (WF 63)	D	294724, 756624	1.02	0.003	0.015
Loch Faskally (WF75)	E	292864, 758530	1641	19.34	73.2
Loch Faskally (WF75)	F/G	292885, 758641	1641	19.34	73.2
WC74	H	292191, 759463	1.14	0.003	0.017
WC77	I	291631, 760569	0.75	0.002	0.011

7 Conclusions

7.1.1 This report has presented the assessment methods used to derive design peak flows, flood inflow hydrographs, and low flow estimates for watercourses within the proposed the scheme. Assessment methods have varied for catchments within this scheme study area 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 and therefore the results presented within this report should be considered with this in mind. 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<25km^2) were undertaken using both the FEH statistical and the 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>25km^2), 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. It should be noted that climate change is an area of current research and therefore 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 A9 dualling corridor. 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 flows within their simulations.
- Low flow estimates on the larger rivers are based upon local gauged data, where available, otherwise Low Flow Enterprise (LFE) estimates provided by CEH Wallingford (WHS, 2015) have been used to derive estimates.

8 References

Centre for Ecology and Hydrology (2008). Improving the FEH statistical procedures for flood frequency estimation. Science Report: SC050050. Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme.

Centre for Ecology and Hydrology (2009). Flood Estimate Handbook (FEH) CD ROM v3.

Centre for Ecology and Hydrology (2015). National River Flow Archive. Available at: http://nrfa.ceh.ac.uk/data/search

Environment Agency (2015). Flood estimation guidelines: Technical guidance 197_08, Version 5

(Issued 12/02/2015).

Faulkner, D, Kjeldsen, T, Packman, J and Stewart, L (2012). Estimating flood peaks and hydrographs for small catchments: Phase 1, Environment Agency, Centre for Ecology and Hydrology, Department for Environment Food and Rural Affairs, SC090031.

Institute of Hydrology (1999). Flood Estimation Handbook. Volumes 1 – 5.

Jacobs (2016). DMRB Stage 2 Assessment: A9 Dualling – Pitlochry to Killiecrankie: Environmental Statement, Appendix A9.1 – Surface Water Hydrology.

NERC (2008). UK Hydrometric Register, Centre for Hydrology & Ecology Wallingford, British Geological Survey

Scottish Environment Protection Agency (2015). Technical Flood Risk Guidance for Stakeholders Version 9.1, Reference: SS-NFR-P-002.

Scottish Environment Protection Agency (2015). SEPA Flood Maps. Available at: http://map.sepa.org.uk/floodmap/map.htm

The Highways Agency et al. (2009). HD45/09 DMRB, Volume 11, Section 3, Part 10, Road Drainage and the Water Environment, 2009. The Highways Agency, Scottish Executive, Welsh Assembly Government and The Department for Regional Development Northern Ireland.

Wallingford HydroSolutions Ltd (2009). WINFAP-FEH Version 3.0.003. Wallingford HydroSolutions Limited and NERC (CEH).

Wallingford HydroSolutions Ltd (2015). Flow estimates for six sites. WHS LowFlows Report 342/15, May 2015.

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[6]:

DPLBAR = $\text{AREA}^{0.548}$

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).

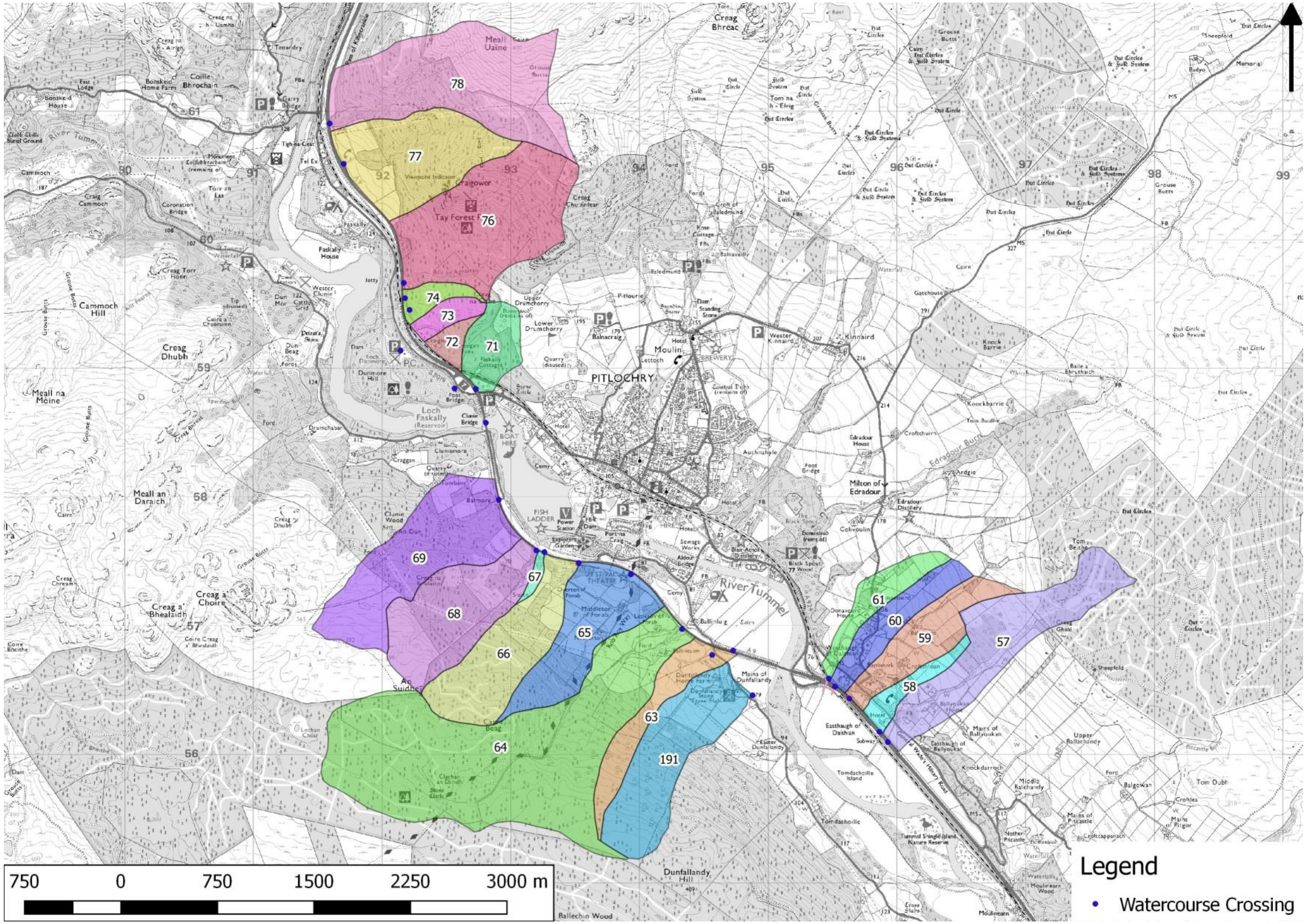
FPEXT

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.

---

[6] Bayliss, A (1999). Flood Estimation Handbook, Volume V, Catchment Descriptors, Institute of Hydrology.

Annex C: Catchment Boundary Map



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 7.7km^2
- Kirkton Burn @ Balquhidder (18018) – catchment area 6.9km^2

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

Diagram D.1 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.

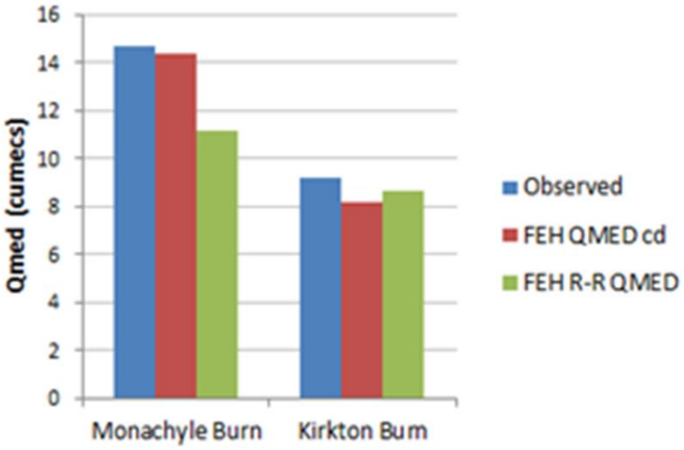


Diagram D.1: Comparison of QMED estimates from the FEH rainfall-runoff method and the FEH statistical method to the observed QMED values obtained from observed data in two small mountainous catchments in the Central Highlands

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[7] 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.

---

[7] Faulkner, D, Kjeldsen, T, Packman, J and Stewart, L (2012). Estimating flood peaks and hydrographs for small catchments: Phase 1, Environment Agency, Centre for Ecology and Hydrology, Department for Environment Food and Rural Affairs, SC090031

- 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 flows. A survey of all small gauged catchments in the NRFA Hydrometric Register[8] 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 scheme. 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.

---

[8] NERC (2008). UK Hydrometric Register, Centre for Hydrology & Ecology Wallingford, British Geological Survey