Appendix A13.2: Surface Water Hydrology

1 Introduction

1.1 This document provides detailed information on the hydrological analyses relevant to Appendix A13.1 (Flood Risk Assessment) and to the low flow assessment undertaken for the proposed A9/A96 Inshes to Smithton scheme (hereafter referred to as the proposed scheme).

1.2 Hydrological inputs are required for the Design Manual for Roads and Bridges (DMRB) Stage 3 assessment. This report specifically provides information on the methods and approach used to derive peak flows along with inflow hydrographs for the purpose of detailed hydraulic modelling of the Scretan Burn (SWF04) and Cairnlaw Burn (SWF08) along with their significant tributaries. This report also provides information on the methods used to estimate low flows in the watercourses where the road drainage outfalls are to be (this information is used in Appendix A13.3 (Sustainable Drainage Systems (SuDS) and Water Quality) in dilution calculations of the receiving watercourses). The design peak flow estimates, inflow hydrographs and low flow estimates are presented within this appendix for the watercourses potentially at risk of being impacted by the proposed scheme.

1.3 A total of 12 watercourses were identified as having the potential to be impacted by the proposed scheme and associated infrastructure. These watercourses are all relatively small (catchments areas ranging between 0.15km^2 to 12km^2) consisting of minor tributaries/drainage channels and small/medium watercourses. The catchment boundaries of these watercourses are shown in Annex B (Catchment Boundary Map), Diagram B1.

1.4 It should be noted that almost all the watercourses crossed by the proposed scheme would also be crossed by the A96 Inverness to Nairn (including Nairn Bypass) scheme; the previous studies referenced in paragraph 2.7 have been used to inform this assessment.

1.5 Refer to Annex A (Abbreviations) for a list of the abbreviations used in this appendix.

2 Approach and Methods

General Approach

2.1 Design peak flows, inflow flood hydrographs and low flow estimates are required for the DMRB Stage 3 assessment for watercourses/minor tributaries/drainage channels potentially impacted and/or crossed by the proposed scheme. The flood flow estimates (with appropriate allowance for climate change) 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). Low flow estimates 95-percentile flow (Q_{95}) and mean flow (Q_{mean}) are required for all outfall locations which are proposed to discharge to watercourses.

2.2 For clarity, AEP refers to the chance that a flood of a particular size is experienced or exceeded during any year. In this report a probability value expressed as a percentage is used 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 to note that a low probability does not preclude the event happening in the following year.

2.3 It should also be highlighted that return period is commonly used in 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% AEP. It refers to an on average spacing between floods of that size. A problem with this usage is that it can be mis-interpreted 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 the event will not re-occur for another 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 the return period might suggest.

2.4 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'.

2.5 Low flow estimates such as Q_{95} and Q_{mean} (the average long-term flow) are also required for road drainage outfall locations to assess the potential impacts of the outfalls on the receiving watercourses.

2.6 The hydrological methods and approaches used to derive this required information are presented in the sections below.

Review of Previous Study Reports

2.7 As part of the initial assessment for the proposed scheme the following reports were reviewed, and relevant information extracted:

- A96 Inverness to Nairn (including Nairn Bypass): DMRB Stage 2 Scheme Assessment Report (Jacobs 2014);
- A96 Dualling Inverness to Aberdeen Strategic Flood Risk Assessment (SFRA) (CH2M 2015a);
- A96 Dualling Inverness to Aberdeen Strategic Environmental Assessment, Tier 2 Environmental Report (CH2M 2015b);
- A96 Dualling Inverness to Aberdeen Preliminary Engineering Assessment (Jacobs 2015);
- A9/A96 Connections Study: Transport Appraisal Report (Jacobs 2016a);
- A96 Inverness to Nairn (Including Nairn Bypass) – DMRB Stage 3 Assessment Environmental Statement – Technical Appendices Flood Risk Assessment: Annex A13.2.G Hydrology Report (Jacobs 2016b); and
- A9/A96 Inshes to Smithton: DMRB Stage 2 Scheme Assessment Report (Jacobs 2017).

2.8 A review of any Potentially Vulnerable Areas (PVA) within the project area and any historic flooding/culvert sizing issues/flood prone areas was also undertaken. A PVA is an area which has been identified by the Scottish Environment Protection Agency (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. SEPA Flood Maps (2018) were also reviewed to look for locations/properties at potential flood risk in relation to the proposed scheme.

Climate Change

2.9 Climate change considerations are required to be included as part of this assessment for design flood events. At present the general approach to climate change is to increase design flows by 20% as per DMRB Volume 11, Section 3, Part 10, HD45/09: Road Drainage and the Water Environment (Highways Agency, Transport Scotland, Welsh Assembly Government and The Department for Regional Development Northern Ireland, 2009) and SEPA's Technical Flood Risk Guidance for Stakeholders (Reference: SS-NFR-P-002) (2019). This assessment follows standard practice and therefore an uplift factor of 20% has been applied to the design peak flow estimates.

2.10 No climate change adjustment factor has been applied to the low flow estimates.

3 Baseline Assessment

3.1 To undertake this assessment all watercourses, minor tributaries and drainage channels that could potentially be impacted by the proposed scheme were identified and a list of these features compiled. This was undertaken using a GIS basemap and layers showing the proposed scheme development footprint. The list of potentially impacted watercourses, minor tributaries and drainage channels formed the basis of the hydrological assessment. The Flood Estimation Handbook (FEH) CD-ROM v3 (Centre for Ecology & Hydrology 1999a) and latterly the FEH Web Service (Centre for Ecology & Hydrology 2019) were used to obtain catchment descriptors for all identified watercourses and water bodies potentially impacted. It should be noted that there are limitations to the FEH CD-ROM/FEH Web Service in identifying small catchments and a further review of the derived catchment parameters was required.

3.2 Catchment boundaries were checked on Ordnance Survey (OS) maps supplemented with 2m LiDAR derived contour data. For a small number of catchments alterations to the FEH catchment boundaries were required and the catchment parameters have been adjusted using FEH methodologies (refer to Annex C: Amendments to Catchment Descriptors). All watercourses had their catchment boundaries reviewed, particularly when the catchments contained potentially ambiguous flat areas or if a known artificial influence was present in the catchment. Some catchments within the route corridor were not picked up by the FEH CD-ROM/FEH Web Service due to the software imposing a minimum catchment area threshold of 0.5km². Where this was the case catchment descriptors have been applied (and adjusted by area) 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 cannot be areally scaled (e.g. DPLBAR, URBEXT and FARL).

3.3 A review of any available local flow and level hydrometric data within the region of the proposed scheme was undertaken as there are no hydrometric gauges on the watercourses in the immediate vicinity of the proposed scheme. This review included assessment of the suitability of the gauges to provide good quality data to inform the study.

3.4 A desk-based assessment of local flood histories was also undertaken using a combination of consultation with SEPA, The Highland Council and Scottish Water, third party reports of flooding incidents and local knowledge if readily available. A review of anthropogenic activity within the catchments was also undertaken and any notable impacts or activities to the watercourse channels or flows highlighted.

3.5 All road drainage outfall locations were identified for watercourse low flow estimates.

4 Design Peak Flows and Inflow Hydrographs

4.1 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). Watercourses identified for detailed hydraulic modelling require not only the design peak flow, but also the full inflow hydrograph.

4.2 All watercourses within the area of the proposed scheme have relatively small and ungauged catchments. Flow estimation for small, ungauged catchments is challenging and often open to greater uncertainty than for larger catchments, where more relevant gauged data is likely to be available to aid flow estimation.

Design Peak Flow Derivation

4.3 Peak flow was estimated at all new / extended culvert crossing locations using three methods: (1) FEH Statistical method, (2) FEH Rainfall-Runoff model, and (3) Revitalised Flood Hydrograph (ReFH2.2) model with FEH13 rainfall data. The assessment acknowledges that all three approaches have strengths and weaknesses. The design flows taken forward are those that come from the method that gives the highest flows for each watercourse.

4.4 The following paragraphs describe how the FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 methods were applied, together with how the inflow hydrograph shapes were derived.

<u>FEH Statistical Method</u>

4.5 For all the catchments the index flood (QMED) was initially derived from catchment descriptors. It should be noted that deriving QMED from catchments descriptors alone is subject to greater uncertainty than derivation using suitable local gauged data. Therefore, these initial QMED values were adjusted for all catchments using a regionally derived QMED adjustment factor similar to those derived for the A96 Inverness to Nairn (including Nairn Bypass) scheme. From the analysis of the five high flow rated gauges in Hydrometric Area 7[1] (National River Flow Archive, 2014) the ratio of station QMED (observed) / QMED (catchment descriptors) values were found to vary from 1.51 to 2.46 and the geometric mean of these to be 1.74. This regional QMED adjustment factor (1.74) was adopted for all catchments in the area of the proposed scheme.

4.6 To derive the AEP peak flows, the flood growth curve for each of the watercourses was adopted from the growth curve derived for the small ungauged watercourses considered in the A96 Inverness to Nairn (including Nairn Bypass) scheme. This growth curve was derived for where the Cairnlaw Burn (SWF08) crosses the A96 (at NH 82750 53850); the Cairnlaw Burn (SWF08) is also one of the modelled watercourses for the proposed scheme.

4.7 As part of the A96 Inverness to Nairn (including Nairn Bypass) scheme (Jacobs 2016b) sensitivity analysis was undertaken to assess the suitability of this growth curve for use for a variety of watercourses with differing catchment descriptors including FARL (Flood Attenuation due to Reservoirs and Lakes) values less than 1 and differing catchment areas. The outcome of that assessment was that the Cairnlaw Burn (SWF08) growth curve was assessed as similar to the other derived growth curves and therefore taken forward and used for all the small ungauged catchments across the A96 Inverness to Nairn (including Nairn Bypass) scheme.

4.8 As the Cairnlaw Burn (SWF08) is one of the small ungauged watercourses within the area of the proposed scheme and given it has been assessed as an appropriate donor for all the small ungauged watercourses within the study area this growth curve has been taken forward.

4.9 The Environment Agency Document No. SC090031 (Faulkner et al, 2012) indicates that the FEH Statistical method is appropriate for deriving flood estimates for catchments with areas > 0.5km^2. Where catchment areas are <0.5km^2 the document advocates scaling the estimate from a hydrologically similar catchment with an area above 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 an area > 0.5km^2 in the vicinity.

FEH Rainfall-Runoff Method

4.10 The FEH Rainfall-Runoff model (available in the Flood Modeller Pro software package) was used to derive inflow hydrographs for all watercourses.

4.11 It is noted here that if adequate flood event data is available this can improve the estimates of Tp (Time to peak) and SPR (Standard Percentage Runoff) which lead to improved design flood estimates. However, this requires hydrologically similar catchments that not only have adequate gauged flow data, but also a rain gauge that samples at an hourly (if not sub-hourly) time step and adequately samples the spatial variability of the rainfall event across the catchment. No such monitoring is available within the target catchments considered in this assessment and as such this approach could not be taken to refine the Tp and SPR estimates.

4.12 The critical storm duration for each catchment was calculated separately to provide catchment specific design estimates using the guidance provided in the Flood Estimation Handbook (FEH) Volume 4 (Centre for Ecology & Hydrology 1999b) and Environment Agency – Flood Estimation Guidelines Doc No. 197_08 (Environment Agency 2017).

ReFH2.2

4.13 The default application of ReFH2.2 was applied in order to derive design peak flow estimates at all new/extended culvert crossing locations.

[1] Hydrometric Areas are either integrated river catchments or may include several river catchments in close proximity to each other. Britain has been divided into 107 Hydrometric Areas. Hydrometric Area 7 is located in northern Scotland to the south of the Moray Firth. Available at https://nrfa.ceh.ac.uk/hydrometric-areas.

Modelled Watercourses - Hydrograph Shape Derivation and Peak Flow Reconciliation

4.14 The proposed scheme crosses the middle reaches and tributaries of the Cairnlaw Burn (SWF08) and the Scretan Burn (SWF04). These have been assessed as having the potential for being a flood risk, and both as having a degree of hydraulic complexity. They have therefore have been subject to detailed hydraulic modelling. Without a gauge to steer the selection of appropriate hydrograph shapes, the FEH Rainfall-Runoff based hydrograph shapes (as produced by the FEH R-R tool in the Flood Modeller software package) were used to provide the design inflows to be used in the hydraulic models (subject to scaling to the FEH Statistical peak flow estimates).

4.15 To assess the worst flooding condition at all storm durations, two hydraulic simulation runs were undertaken in the flood model: one for the longer storm duration for the entire catchment down to the A96 crossing, termed Run 1, and the other for shorter storm durations critical to the watercourses crossing the proposed scheme, termed here as Run 2. Further details on hydrograph shape derivation and flow reconciliation for the two model runs is provided below.

Hydraulic Simulation: Run 1

4.16 Run 1 aimed to provide understanding of a catchment-wide flood event with a focus on the design conditions on the watercourses where they cross the A96.

4.17 In deriving the model inflows for Run 1, the storm durations specific to each watercourse (where they cross the A96) were used. For the Cairnlaw Burn (SWF08) catchment at the A96 crossing, the critical storm duration was estimated to be 5.4hrs. For the Scretan Burn (SWF04) catchment at the A96 crossing, the critical storm duration was estimated to be 6.2hrs. The same storm duration was applied to all the sub-catchments represented in the model for that specific watercourse, i.e. all sub-catchments in the Scretan Burn (SWF04) receive the same 6.2hr design storm, and those in Cairnlaw Burn (SWF08) received the same 5.4hr storm duration.

4.18 Following the application of the design storm, the peak flow at the downstream target location was compared to the FEH Statistical peak flow estimate. Where they did not agree consideration was given to uniformly scaling the model inflows to gain agreement with the FEH Statistical peak flow estimates. The preferred target flows were predetermined by choosing the highest estimates from single catchment application of the FEH Statistical and FEH Rainfall-Runoff methods (as discussed in paragraph 4.3).

4.19 The approach is considered appropriate so long as the following complicating issues are not present: i) there is a significant volume of flood storage, or more unusually, ii) if water is transferred into or out of the catchment above the target location of interest. Where this situation arises, more reliance on the routing of design flood hydrographs needs to be considered that explicitly account for these complicating factors.

4.20 In the Run 1 representations, the models predicted that a relatively small amount of flood water is transferred from the Cairnlaw Burn catchment to the Scretan Burn catchment following the Highland Main Line Railway line from the 3.33% AEP (30-year) event. For the 0.5% AEP (200-year) event this amounts to a peak flow of 0.9m^3/sec. To account for this, the Scretan Burn (SWF04) target flow at the A96 crossing was increased by 0.9m^3/sec and the need for any scaling of inflows was considered on this basis.

4.21 For the Scretan Burn (SWF04) the 0.5% AEP (200-year) modelled flow agreed well with the target statistical flow (i.e. less than 3% difference). Similarly, no scaling was considered necessary for the Cairnlaw Burn (SWF08), where the target flow (without allowance for the small transfer of flow) matched the model flow without scaling. As such this may represent a slightly conservative (higher) flow for the Cairnlaw Burn (SWF08).

4.22 Once the modelled peak flows at the downstream locations of the Cairnlaw Burn (SWF08) and Scretan Burn (SWF04) were assessed as consistent with the FEH Statistical peak flows, Run 2 was undertaken to ensure design flows/hydrographs were appropriate at the proposed scheme culvert crossing locations.

Hydraulic Simulation: Run 2

4.23 Run 2 considers the design flows specific to each of the culvert crossing locations within the model extent which will be crossed by the proposed scheme (which changes the focus to upstream locations within the catchments). In this run the design storms appropriate for each of the proposed culvert locations were used.

4.24 The design duration for each location was obtained from the single catchment application of the FEH Rainfall-Runoff model. Where two culverts cross the same watercourse, in close proximity to each other, one duration was selected as appropriate for both. The following critical storm durations were used: 5.7hrs at culvert C01 and culvert C04 (both on Scretan Burn (SWF04)), 1.5hrs for culvert C02 and culvert C03 (both on Scretan Burn Tributary (SWF05)) and 3.9hrs for culvert C05 (on Beechwood Burn (SWF03)), culvert C06 and culvert C07 (both on Cairnlaw Burn (SWF08)). Three model runs were therefore performed, one for each storm duration i.e. Run 2a (5.7hrs), 2b (3.9hrs) and 2c (1.5hrs).

4.25 Initially the reconciliation between model and target flows at each of the upstream culverts was to follow the procedure outlined above for Run 1. i.e. the inflows to the hydraulic model would be scaled such that the hydraulic model flow at each of the culverts would match the target flow at the culvert. However, given that some flow was predicted by the model to be re-routed (e.g. bypassing culverts C01 and C04) reconciliation to a flow calculated on the assumption that all of the flow would reach the target location was considered inappropriate. Consequently, the inflows to the hydraulic model were scaled in line with the ratio of the FEH Statistical Method to that of the estimate gained from a single lumped catchment FEH Rainfall-Runoff application directly to the culvert. The adjusted inflows were then routed through the hydraulic model (allowing for re-routing of flood waters where necessary) to finally determine the flow reaching the target culvert location.

4.26 The scaling factors used were derived by averaging the ratio between the FEH Statistical peaks and FEH Rainfall-Runoff peaks at the culverts for the 50%, 3.33% and 0.5% AEP (2, 30 and 200-year return period) events. The scaling factors adopted for inflows were as follows; culverts C01 and C04 as 1.39, culverts C02 and C03 as 1 (no scaling as FEH Rainfall-Runoff peaks were larger than those from the FEH Statistical approach), culvert C05 as 1.19 and culverts C06 and C07 as 1.07.

4.27 The two model runs (Run 1 and Run 2) allowed appropriate design peak flows and flood extents to be represented not only at the downstream model extent (at the A96) but also at the proposed scheme. The approach also includes representation of the functioning of the floodplain and hence how this may be impacted by the proposed scheme.

5 Low Flow Estimates

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

5.2 The Low Flows Enterprise (LFE) data purchased for the A96 Inverness to Nairn (including Nairn Bypass) scheme was assessed as suitable to be used to estimate the flows on the proposed scheme. The LFE flows are tabulated in Table 1 (reproduced from Table 3 of the A96 Inverness to Nairn (including Nairn Bypass), DMRB Stage 3: Environmental Statement, Appendix A13.2G: Hydrology Report, Jacobs 2016b). Areal scaling was then applied to what was judged to be the most hydrologically similar LFE site to transpose the estimate to the target site. The assessment of hydrologically similarity was based on the likeness of key catchment descriptors (in particular BFIHOST, though catchment AREA, SPRHOST, FARL, and URBEXT were also considered) between the target and donor site.

Table 1: LFE Estimates (reproduced from Table 3 of A96 Inverness to Nairn (Including Nairn Bypass), DMRB Stage 3: Environmental Statement, Appendix A13.2.G: Hydrology Report Jacobs 2016b)

Site	Catchment Area (km^2)	Easting	Northing	Q_{95} (m^3/s)	Q_{mean} (m^3/s)
1	3.08	292276	856494	0.003	0.023
2	4.39	276933	850754	0.008	0.041
3	5.85	285231	854279	0.009	0.045
4	1.45	288982	854525	0.002	0.010

6 Baseline Hydrology

6.1 The catchment descriptors for each of the watercourses are presented in Table 2 (refer to Annex B (Catchment Boundary Map)) for the location of the catchments and watercourses, and to Diagram 3 for the location of the numbered culverts). Catchment descriptors have also been included for the Run 1 target locations on the Scretan Burn (SWF04) and Cairnlaw Burn (SWF08). Manual adjustment of catchment descriptor values was required for some watercourses and are discussed in further detail in Annex C (Amendments to Catchment Descriptors).

6.2 Catchment descriptors have not been included for culvert C10 (on Beechwood Burn (SWF03)) as this culvert appears to be the old path of the Inshes Burn (SWF02) which is now diverted to the north-west of this location flowing up the western edge of the existing A9 before being culverted under the carriageway just south of the Raigmore Interchange. This old watercourse / drainage channel is believed to have minimal flow / only convey road drainage in the vicinity of culvert C10. The existing headwall will be maintained for this culvert and therefore no further assessment is required.

Table 2: Target Site Catchment Descriptors

Watercourse / Culvert	SWF Reference	Catchment Area (km^2)	SAAR (mm)	BFI-HOST	SPR-HOST (%)	FARL	URBEXT (2000)
Beechwood Burn Culvert C05	SWF03-1	1.18	760	0.58*	29.61	1	0.024
Beechwood Burn Culvert C09	SWF03-2	0.66	760	0.58*	29.61	1	0.038
Scretan Burn Culvert C01	SWF04-1	3.23	800	0.529	36.97	1	0.041
Scretan Burn Culvert C04	SWF04-2	3.38	800	0.529	36.97	1	0.039
Scretan Burn Culvert C08	SWF04-3	3.37	800	0.529	36.97	1	0.039
Scretan Burn on A96** (Run 1)	SWF04-4	7.20	771	0.647	32.52	1	0.037
Scretan Burn Tributary Culvert C02	SWF05-1	0.15	788***	0.566***	34.1***	1	0.129
Scretan Burn Tributary Culvert C03	SWF05-2	0.19	788***	0.566***	34.1***	1	0.102
Cairnlaw Burn on A96 (Run 1)	SWF08-1	5.19	772	0.606	32.4	0.972	0.073
Cairnlaw Burn Culvert C06	SWF08-2	1.91	788	0.566	34.1	0.994	0.052
Cairnlaw Burn Culvert C07	SWF08-3	2.21	781	0.584	33.1	0.994	0.045

* Inshes Burn (SWF02) at Inshes Overbridge BFIHOST value adopted

** Catchment descriptors calculated using FEH methodologies as FEH catchment picked up incorrectly by FEH CD-ROM/Web Service.

*** Catchment descriptors borrowed from Cairnlaw Burn (SWF08) at culvert C06 as catchment could not be picked up correctly by FEH CD-ROM/Web Service

7 Design Peak Flow Estimates

Comparison of Methods

7.1 The design peak flow estimates based on the FEH Statistical method are presented below in Table 3. The 0.5% AEP (200-year) estimate is also given including a +20% allowance for climate change (+CC).

Table 3: Peak Flow Estimates – FEH Statistical Method (m^3/s)

Watercourse / Structure Reference	AEP 50% (2-yr)	AEP 20% (5-yr)	AEP 10% (10-yr)	AEP 3.3% (30-yr)	AEP 2% (50-yr)	AEP 1% (100-yr)	AEP 0.5% (200-yr)	AEP 0.5% + CC	AEP 0.1% (1000-yr)
Beechwood Burn (SWF03-1) Culvert C05	0.52	0.73	0.90	1.19	1.35	1.60	1.90	2.28	2.80
Beechwood Burn (SWF03-2) Culvert C09	0.33	0.46	0.56	0.75	0.85	1.00	1.19	1.42	1.75
Scretan Burn (SWF04-1) Culvert C01	1.70	2.39	2.91	3.86	4.38	5.20	6.15	7.39	9.09
Scretan Burn (SWF04-2) Culvert C04	1.76	2.47	3.02	4.01	4.55	5.39	6.38	7.66	9.42
Scretan Burn (SWF04-3) Culvert C08	1.76	2.46	3.00	3.99	4.53	5.37	6.36	7.63	9.38
Scretan Burn (SWF04-4) at A96 (SB target QT_ Run 1)	2.03	2.85	3.47	4.61	5.24	6.21	7.35	8.82	10.85
Scretan Burn Tributary (SWF05-1) Culvert C02	0.08*	0.12	0.14	0.19	0.21	0.25	0.30	0.36	0.44
Scretan Burn Tributary (SWF05-2) Culvert C03	0.10*	0.14	0.17	0.23	0.26	0.31	0.36	0.44	0.54
Cairnlaw Burn (SWF08-1) (CB target QT_Run 1)	1.75	2.46	3.00	3.99	4.53	5.37	6.35	7.62	9.38
Cairnlaw Burn (SWF08-2) Culvert C06	0.93	1.31	1.60	2.12	2.41	2.85	3.38	4.05	4.98
Cairnlaw Burn (SWF08-3) Culvert C07	0.96	1.35	1.64	2.18	2.48	2.94	3.47	4.17	5.13

area scaled as catchment area less than 0.5km^2

7.2 Table 4 presents the FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 model peak flow estimates for the 50% and 0.5% AEP events for the watercourses (culvert locations only). Diagrams 1 and 2 compare the FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 estimates of the 50% and 0.5% AEP event peak flows at the culvert locations.

Table 4: FEH Statistical, FEH Rainfall-Runoff, and ReFH2.2 Peak Flow Estimates (m^3/s)

Structure / Watercourse reference	Catchment area (km^2)	AEP 50%			AEP 0.5%		
		FEH Statistical	FEH R-R	ReFH2.2	FEH Statistical	FEH R-R	ReFH2.2
Beechwood Burn (SWF03-1) Culvert C05	1.18	0.52	0.44	0.23	1.90	1.61	0.87
Beechwood Burn (SWF03-2) Culvert C09	0.66	0.33	0.29	0.14	1.19	1.05	0.53
Scretan Burn (SWF04-1) Culvert C01	3.23	1.70	1.25	0.72	6.15	4.31	2.48
Scretan Burn (SWF04-2) Culvert C04	3.38	1.76	1.30	0.75	6.38	4.47	2.60
Scretan Burn (SWF04-3) Culvert C08	3.37	1.76	1.29	0.74	6.36	4.45	2.58
Scretan Burn Tributary (SWF05-1) Culvert C02	0.15	0.08	0.13	0.05	0.30	0.51	0.25
Scretan Burn Tributary (SWF05-2) Culvert C03	0.19	0.10	0.15	0.06	0.36	0.57	0.30
Cairnlaw Burn (SWF08-2) Culvert C06	1.91	0.93	0.87	0.39	3.38	3.10	1.48
Cairnlaw Burn (SWF08-3) Culvert C07	2.21	0.96	0.92	0.41	3.47	3.27	1.53

7.3 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. The exception to this is for Tributary of Scretan Burn (SWF05) (culverts C02 and C03) where the FEH Rainfall-Runoff method produces higher design peak flows. This may be due to the watercourse / ditch having a very small catchment area (<0.2km^2) at the culvert crossings and therefore area scaling of a larger catchment's (>0.5km^2) FEH Statistical peak flow was required. ReFH2.2 for all culvert locations produces significantly lower peak flow estimates than either the FEH Statistical or FEH Rainfall-Runoff methods.

Diagram 1: Comparison of the 50% AEP (2-year) FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 Peak Flow Estimates for the Watercourses Crossed by the Proposed Scheme

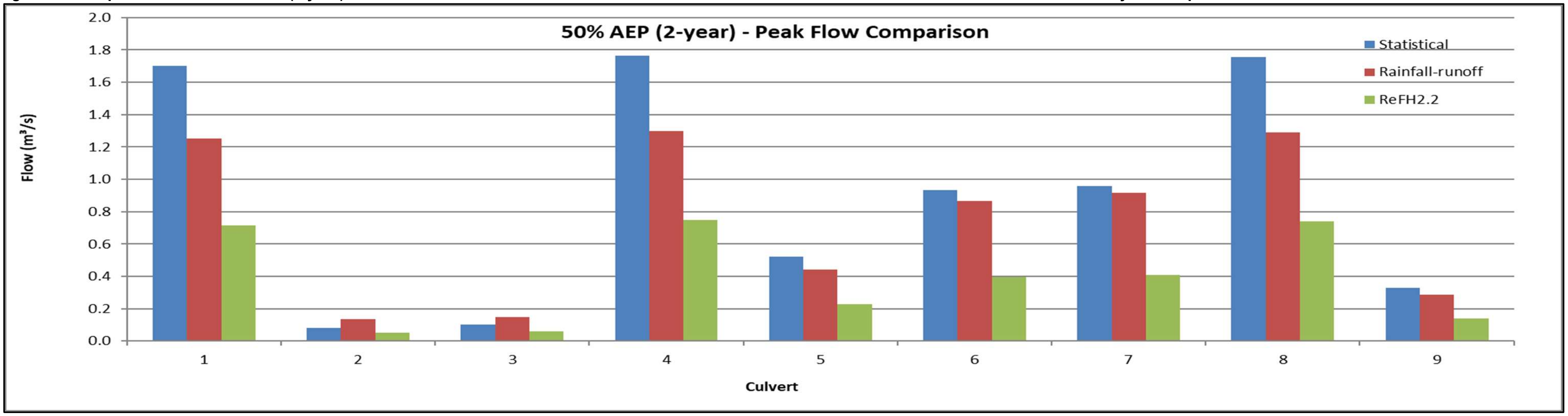
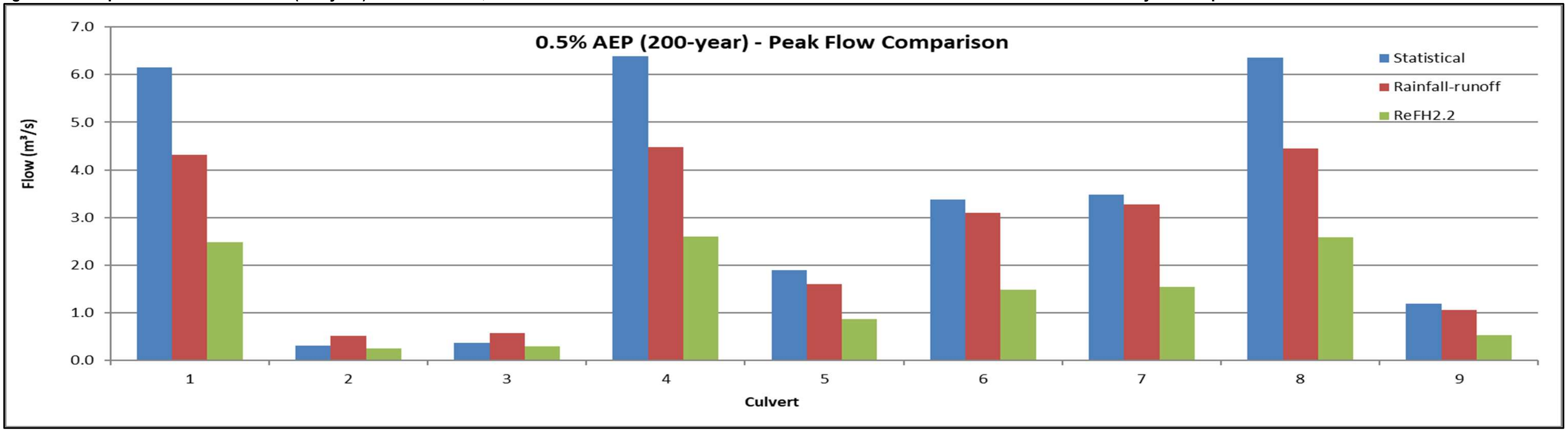


Diagram 2: Comparison of the 0.5% AEP (200-year) FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 Peak Flow Estimates for the Watercourses Crossed by the Proposed Scheme



Final Design Peak Flow Estimates

7.4 Given the FEH Statistical method generally produces higher peak flow estimates for the culvert crossing locations, the FEH Statistical peak flows were taken forward as the design peak flows for all watercourses apart from Tributary of Scretan Burn (SWF05) where the higher FEH Rainfall-Runoff flows were selected.

7.5 The final design peak flow estimates for the culvert locations are presented in Table 5. The 0.5% AEP (200-year) plus climate change event estimate (referred to as '+ CC'), which includes a 20% allowance for climate change, is also given.

7.6 It should be noted that the design peak flows presented in Table 5 do not include estimates of the flow transferred between Cairnlaw Burn catchment and Scretan Burn catchment which is simulated to occur from the 3.33% AEP (30-year) event. However, this transfer of flows is taken into consideration in the model.

Table 5: Final Design Peak Flow Estimates (m^3/s)

Structure / Watercourse Reference	AEP 50% (2-yr)	AEP 20% (5-yr)	AEP 10% (10-yr)	AEP 3.3% (30-yr)	AEP 2% (50-yr)	AEP 1% (100-yr)	AEP 0.5% (200-yr)	AEP 0.5% + CC	AEP 0.1% (1000-yr)
Beechwood Burn (SWF03-1) Culvert C05	0.52	0.73	0.90	1.19	1.35	1.60	1.90	2.28	2.80
Beechwood Burn (SWF03-2) Culvert C09	0.33	0.46	0.56	0.75	0.85	1.00	1.19	1.42	1.75
Scretan Burn (SWF04-1) Culvert C01	1.70	2.39	2.91	3.86	4.38	5.20	6.15	7.39	9.09
Scretan Burn (SWF04-2) Culvert C04	1.76	2.47	3.02	4.01	4.55	5.39	6.38	7.66	9.42
Scretan Burn (SWF04-3) Culvert C08	1.76	2.46	3.00	3.99	4.53	5.37	6.36	7.63	9.38
Scretan Burn (SWF04-4) (Run 1 target flow Scretan Burn)**	2.03	2.85	3.47	4.61	5.24	6.21	7.35	8.82	10.85
Scretan Burn Tributary (SWF05-1) Culvert C02*	0.13	0.20	0.25	0.33	0.37	0.43	0.51	0.61	0.79
Scretan Burn Tributary (SWF05-2) Culvert C03*	0.15	0.23	0.28	0.36	0.41	0.47	0.57	0.68	0.87
Cairnlaw Burn SWF08-1 (Run 1 target	1.75	2.46	3.00	3.99	4.53	5.37	6.35	7.62	9.38

Structure / Watercourse Reference	AEP 50% (2-yr)	AEP 20% (5-yr)	AEP 10% (10-yr)	AEP 3.3% (30-yr)	AEP 2% (50-yr)	AEP 1% (100-yr)	AEP 0.5% (200-yr)	AEP 0.5% + CC	AEP 0.1% (1000-yr)
flow Cairnlaw Burn)									
Cairnlaw Burn (SWF08-2) Culvert C06	0.93	1.31	1.60	2.12	2.41	2.85	3.38	4.05	4.99
Cairnlaw Burn (SWF08-3) Culvert C07	0.96	1.35	1.64	2.18	2.48	2.94	3.47	4.17	5.13

**Flows derived from FEH Rainfall-Runoff method*
***At downstream Scretan Burn (SWF04) at A96 (parameters calculated using FEH methods as FEH CD-ROM/Web Service have inconsistencies and don't identify catchment correctly). Used for Run 1.*

8 Inflow Hydrographs – Modelled Catchments

8.1 The proposed scheme required a numerical hydraulic model for the Cairnlaw Burn (SWF08) and Scretan Burn (SWF04). It is noted that the downstream reach of the Cairnlaw Burn (SWF08) was modelled during the DMRB Stage 3 assessment for the A96 Inverness to Nairn (including Nairn Bypass) scheme. This model was extended upstream on the Cairnlaw Burn (SWF08) (and associated tributaries) and the Scretan Burn (SWF04) (and associated tributaries) were added to the model.

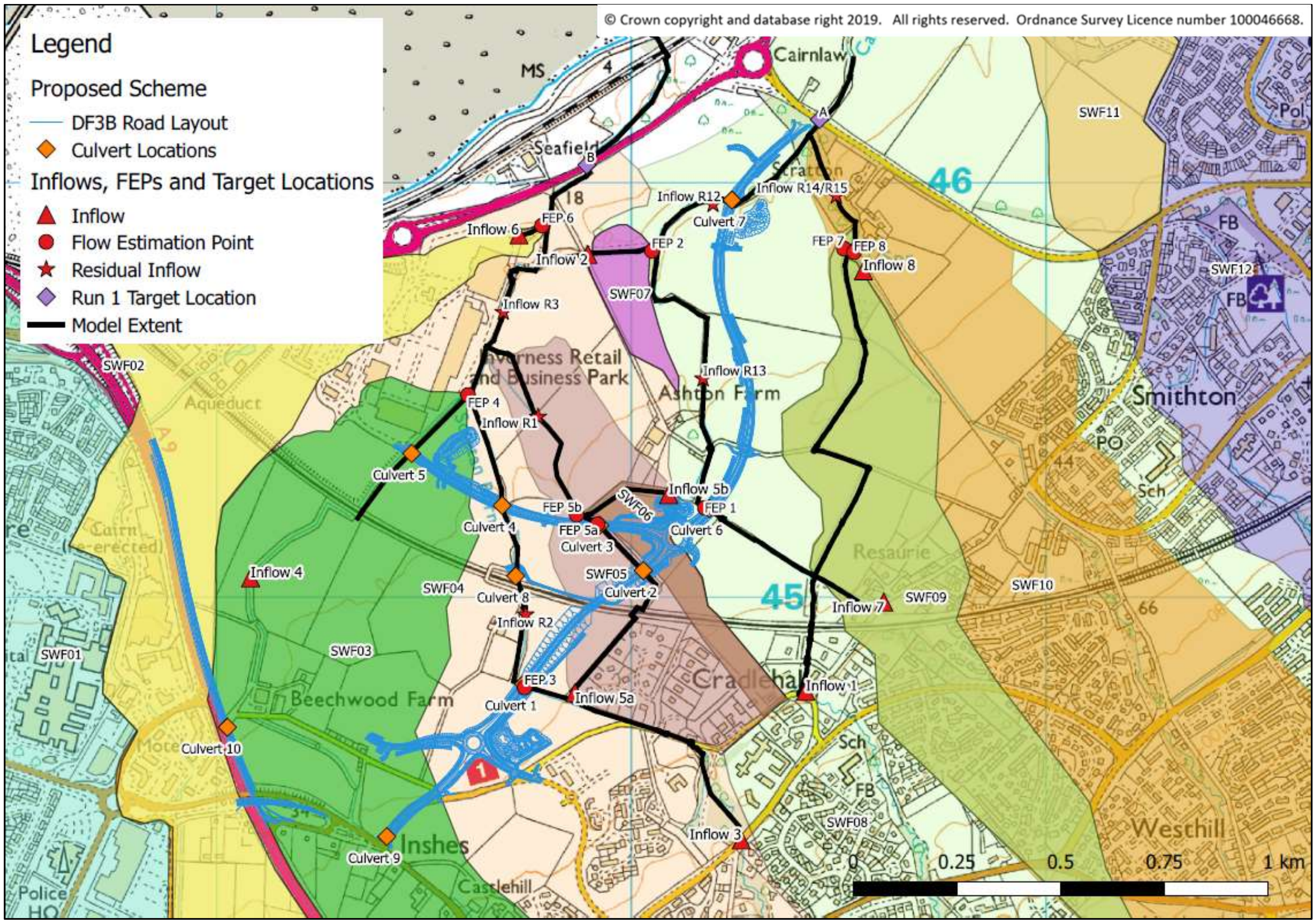
8.2 Two runs were undertaken for the hydraulic modelling to ensure the design peak flows were reconciled at both the downstream model extents (Run 1) but also to ensure design peak flows were appropriate at the proposed scheme watercourse crossing locations (Run 2). Different critical durations were used for these runs as described in Section 4.

8.3 The flow estimation points and inflow locations of the hydraulic model are the same for both Run 1 and Run 2 with the exception that Inflow 3 is split into Inflow 3a and Inflow 3b for the Run 2 simulations. This is due to a more accurate representation of this inflow being required for the Run 2 assessment to better represent the flood extents at culvert C01 (on Scretan Burn (SWF05)). A description of the Run 1 and Run 2 model flow estimation points, inflow locations, design inflows and hydrograph shapes are provided below.

Hydraulic Modelling: Run 1

8.4 The flow estimation points and inflow locations for Run 1 are shown in Diagram 3.

Diagram 3: Cairnlaw (SWF08) and Scretan Burn (SWF04) - Run 1 Flow Estimation Points and Inflow Locations



*Some watercourses are shown to flow in close proximity to each other in the model extent. This occurs for SWF08 / SWF09 (SWF08 is raised above SWF09) and SWF05/SWF04 (SWF05 is a ditch not directly connected to SWF04).

8.5 The final design peak flow estimates presented in Table 5 can be used in the model, with some adjustment. The model requires inflows at various locations for Run 1 as described below:

Cairnlaw Burn (SWF08) and Modelled Tributaries

8.6 Seven point/lateral flows have been applied to the model at the boundary of the 1D domain for the Cairnlaw Burn (SWF08) and its modelled tributaries, by sub-dividing the Cairnlaw Burn catchment up to the target location (Total catchment area = 5.19km^2) as following:

- Inflow 1: upstream extent of Cairnlaw Burn (culvert C06 inflow, AREA = 1.91km^2);
- Inflow 2: the left-hand side (SWF07) minor tributary (AREA = 0.04km^2));
- Residual inflow R12: lateral flow between Inflow 2 and downstream model extent (AREA = 0.16km^2);
- Residual inflow R13: lateral flow between railway and Inflow 2 tributary (AREA = 0.15km^2);
- Inflow 7: upstream extent of the modelled SWF09 watercourse (AREA = 0.44km^2);
- Inflow 8: upstream extent of the modelled SWF10 watercourse (AREA = 2.32km^2); and
- Residual inflow R14/15: residual catchment between SWF09/10 confluence and the downstream extent of SWF10 (AREA = 0.17km^2).

Scretan Burn (SWF04) and Modelled Tributaries

8.7 Eight point/lateral inflows have been applied to the model for the Scretan Burn (SWF04) and its modelled tributaries, by sub-dividing the Scretan Burn catchment (Total AREA = 7.2km^2) as following:

- Inflow 3: upstream extent of the Scretan Burn (culvert C01 inflow, AREA = 3.23km^2);
- Inflow 4: the SWF03 tributary (all area of SWF03-1, AREA = 1.20km^2);
- Inflow 5a: the upper reaches of SWF05 tributary (all area SWF05-3, AREA = 0.19km^2);
- Inflow 5b: the SWF06 tributary (AREA = 0.02km^2);
- Inflow 6: Inshes Burn (SWF02) (all area of SWF02-1, AREA = 1.9km^2);
- Residual inflow R1: residual catchment between Inflows 5a/b and confluence with Scretan Burn (AREA = 0.09km^2);
- Residual inflow R2: residual catchment between Inflow 3 and Inflow 4 (AREA = 0.19km^2); and
- Residual inflow R3: residual catchment between Inflow 4 and Scretan Burn model extent (AREA = 0.38km^2).

8.8 The model inflows for the following AEP events 50%, 3.33%, and 0.5% (equivalent to the 2, 30 and 200-year return periods) were used for the hydraulic simulation for Run 1; the peaks of the inflow hydrographs are presented in Table 6 for the Cairnlaw Burn (SWF08) and Scretan Burn (SWF04) and their modelled tributaries. The 0.5% AEP (200-year) event estimate is also presented including a 20% allowance for climate change.

Table 6: Run 1 Peak Flow Estimates (m³/s) for the Cairnlaw (SWF08) and Scretan Burn (SWF04) Model at the Inflow Locations

Watercourse	AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC
Cairnlaw Burn (SWF08) and Modelled Tributaries*				
Inflow 1 (Cairnlaw Burn (SWF08))	0.88	1.98	3.08	3.70
Inflow 2 (Un-named Drain (SWF07))	0.02	0.04	0.06	0.07
Inflow 7 (Indirect Tributary of Cairnlaw Burn (SWF09))	0.17	0.40	0.64	0.77
Inflow 8 (Tower Burn (SWF10))	0.89	2.01	3.16	3.79
R12 (lateral flow)	0.07	0.15	0.23	0.28
R13 (lateral flow)	0.06	0.14	0.21	0.26
R14/15 (lateral flow)	0.07	0.15	0.24	0.28
Target flow at SWF08-1	**1.75**	**3.99**	**6.35**	**7.62**
Modelled Flows SWF08-1	**2.08**	**4.39**	**6.35**	**7.31**
Scretan Burn (SWF04) and Modelled Tributaries*				
Inflow 3 (Scretan Burn (SWF04))	1.25	2.80	4.29	5.15
Inflow 4 (Beechwood Burn (SWF03))	0.45	1.03	1.61	1.94
Inflow 5a (Tributary of Scretan Burn (SWF05))	0.13	0.29	0.44	0.53
Inflow 5b (Indirect Tributary of Scretan Burn (SWF06))	0.01	0.02	0.04	0.04
Inflow 6 (Inshes Burn (SWF02))	0.54	1.24	1.97	2.37
R1 (lateral flow)	0.05	0.11	0.17	0.20
R2 (lateral flow)	0.07	0.16	0.25	0.30
R3 (lateral flow)	0.09	0.19	0.31	0.37
Target Flow from Statistical method (@SWF04-3)	**2.03**	**4.61**	**7.35**	**8.82**
Modelled Flows SWF04-3	**2.34**	**5.56**	**8.44**	**10.50**

**no scaling factors were assessed as being required to reconcile the modelled flows at the Run 1 target locations A and B (Cairnlaw Burn - SWF08-1 and Scretan Burn - SWF04-3) with the target flow from FEH Statistical method at these locations. This was due to the modelled flows at the downstream model extent of the Scretan Burn and Cairnlaw Burn being assessed as being acceptable when the simulated transfer of flood flows (simulated as occurring for the 30-year and rarer flood events) was taken into consideration between the two watercourses.*

8.9 The comparative size of the inflow hydrographs for the 0.5% AEP (200-year) event are presented in Diagrams 4a and 4b.

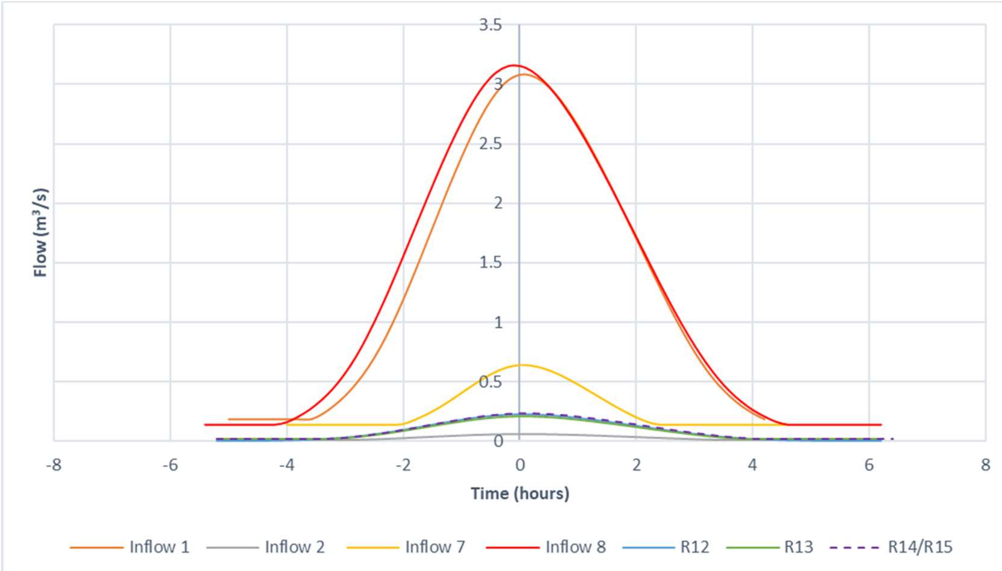


Diagram 4a: The 0.5% AEP (200-year) Event Inflow Hydrographs for the Cairnlaw Burn (SWF08) at Run 1

(*Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).*

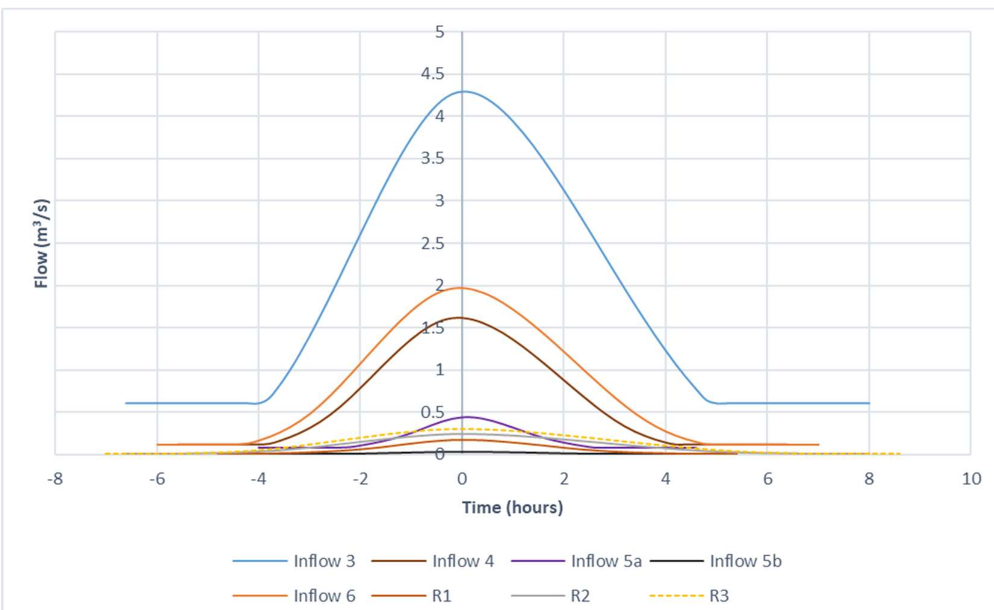


Diagram 4b: The Run 1 0.5% AEP (200-year) Event Inflow Hydrographs for the Scretan Burn (SWF04)

(*Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).*

Hydraulic Modelling: Run 2

8.10 The sub-catchment schematisation of the Cairnlaw Burn (SWF08) catchment for model inflows in Run 2 is the same to those described in Section 8.6 and shown in Diagram 3.

8.11 For the Scretan Burn (SWF04), the model schematisation is similar to that shown in Diagram 3 and described in Section 8.7 with the exception that the Inflow 3 in Run 1 is further sub-divided into two inflows (thus Scretan Burn will have a total of nine inflows in Run 2):

- Inflow 3a: upstream extent of the Scretan Burn (86% of the inflow catchment of culvert C01, AREA = 2.76km^2); and
- Inflow 3b: residual catchment between Inflow 3a and Scretan Burn culvert C01, AREA = 0.47km^2).

8.12 Run 2 involves:

- Run 2a: with a critical storm duration of 5.7hrs to assess the critical storm duration at culverts C01 and C04 (on Scretan Burn (SWF04));
- Run 2b: with a critical storm duration of 3.9hrs to assess the critical duration at culvert C05 (Beechwood Burn (SWF03)) and culverts C06 and C07 (on Cairnlaw Burn (SWF08)); and
- Run 2c: with a critical storm duration of 1.5hrs to assess the critical duration at culverts C02 and C03 (on Scretan Burn Tributary (SWF05)).

8.13 A scaling factor has also been applied to the Run 2 Flood Modeller IED files to reconcile the model peak flows to the target FEH Statistical design peak flows for all culvert crossing locations excluding Scretan Burn Tributary (SWF05) culverts C02 and C03. This is due to the FEH Statistical method being shown to be a more conservative estimate of design peak flows for all culvert crossing locations excluding SWF05 where the FEH Rainfall-Runoff method produces higher design peak flows. The scaling factor used for Run 2a was 1.39 and for Run 2c 1.13; no scaling factor was required for Run 2b.

8.14 Annex D (Design Peak Flow Estimates at the Inflow Locations) presents the peak flow estimates for the following AEP events 50%, 3.33%, and 0.5% (equivalent to the 2, 30 and 200-year design return periods) for each of the Run 2 simulations. The 0.5% AEP (200-year) event estimate is also presented including a 20% allowance for climate change.

8.15 The typical inflow hydrographs for Run 2a, 2b and 2c for the 0.5% AEP (200-year) event are presented in Annex E (Run 2: 0.5% AEP (200-year) Event Hydrographs).

9 Low Flow Estimates

9.1 Low flow estimates are required for road drainage outfall locations that require a water quality assessment in line with DMRB HD45/09 Method A. The low flow estimates for the outfall locations are presented in Diagram 5 and Table 7.

9.2 It should be noted that Outfall H has not been included in the low flows assessment as this outfall is proposed to discharge directly into the Inner Moray Firth Estuary.

Diagram 5: Proposed Outfall Locations

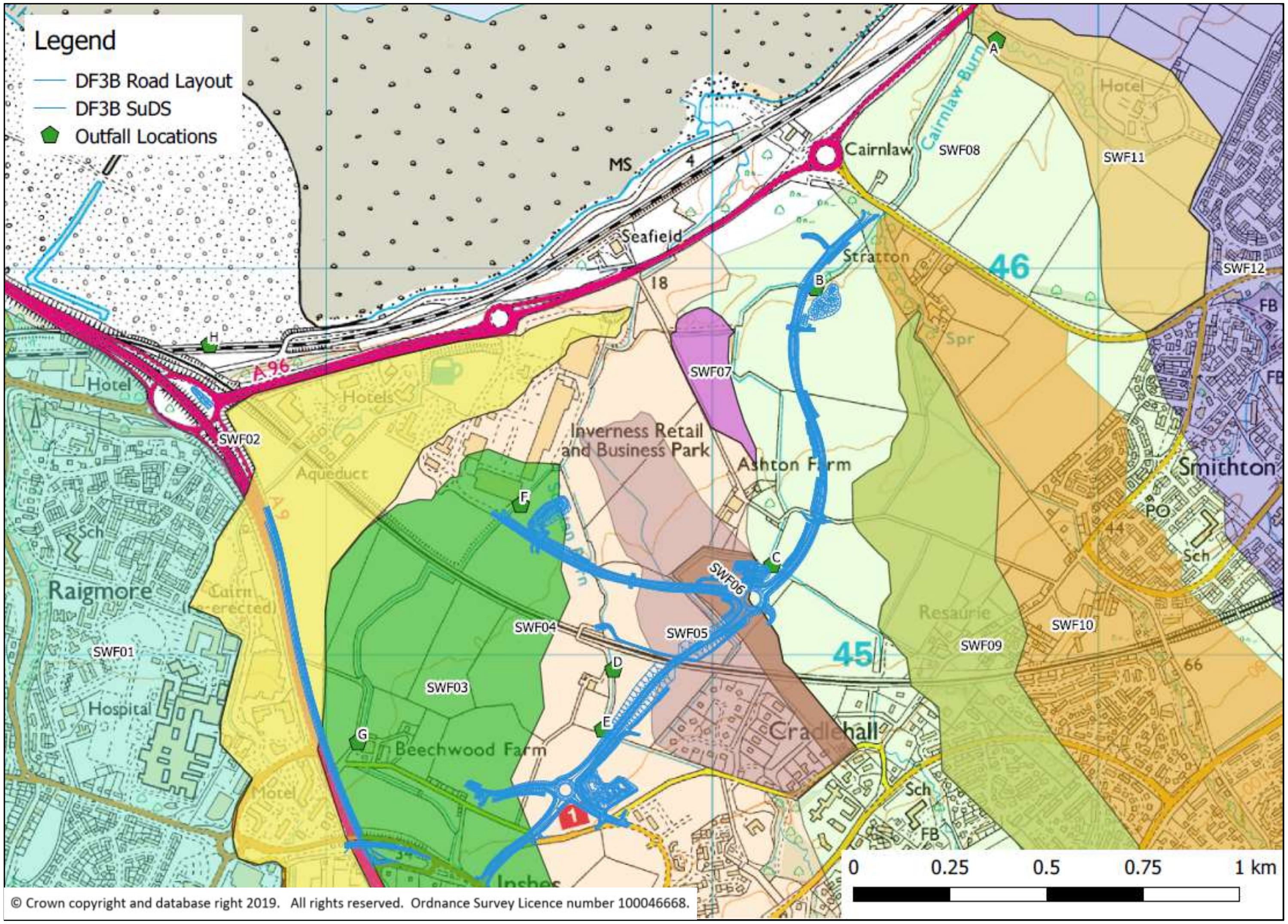


Table 7: Low Flow Estimates for the Outfall Locations

Watercourse	Outfall	Grid Reference (Easting, Northing)	Catchment Area (km²)	Q_{95} (l/s)	Mean Flow (l/s)
Cairnlaw Burn (SWF08)	A	270736, 846591	6.04	5.9	45.2
Cairnlaw Burn (SWF08)	B	270267, 845950	2.21	2.2	16.5
Cairnlaw Burn (SWF08)	C	270155, 845232	1.90	1.9	14.2
Scretan Burn (SWF04)	D	269743, 844944	3.32	3.2	24.8
Scretan Burn (SWF04)	E	269716, 844806	3.28	3.2	24.5
Beechwood Burn (SWF03)	F	269503, 845388	1.14	1.1	8.5
Beechwood Burn (SWF03)	G	269082, 844773	0.80	0.8	6.0

10 Conclusions

10.1 This report presents the assessment methods used to derive design peak flows, inflow flood hydrographs and low flows for watercourses within the proposed scheme. The assessments have been based on the best available information, methodologies and professional judgement; and hence the resulting flood and low flow estimates presented in the corresponding sections above are considered to be fit for purpose.

10.2 The following limitations should be noted when reviewing the findings from this report:

- Flow estimation is subject to some inevitable uncertainty. This is especially true of the flood estimates of ungauged small catchments where appreciable differences among the three methods exist for those catchments with high permeability.
- The peak flood estimates for the culvert crossing locations was undertaken using the FEH Statistical, FEH Rainfall-Runoff and ReFH2.2 methodologies. This enabled a comparison of three flow estimation methods. The FEH Statistical approach was favoured as it generally produced larger peaks in comparison to the other two methods. The exception to this was for Scretan Burn Tributary (SWF05) culverts C02 and C03 where the FEH Rainfall-Runoff method produced higher design peak flows, and hence the FEH Rainfall-Runoff method peaks were adopted for the design peaks (target flow) for these two culverts.
- A 20% climate change uplift factor has been applied to the 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 may be subject to change in the future based on the findings of evolving research.
- The Low Flow Enterprise (LFE) estimates provided by CEH Wallingford for the A96 Inverness to Nairn (including Nairn Bypass) scheme are considered to be fit for purpose and have been used to derive low flow estimates for all the watercourses.

11 References

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Annex A: Abbreviations

The abbreviations presented below are used within this appendix. These are mainly standard hydrological terms as presented in FEH Volume 5 (Bayliss 1999).

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 – Potentially Vulnerable Area (in reference to flood risk)

SAAR – 1961 – 90 standard-period average annual rainfall (mm)

SFRA – Strategic Flood Risk Assessment

SPR – Standard percentage runoff

SPRHOST – Standard percentage runoff derived using the hydrology of soil types classification (%)

Tp – Time to peak of unit hydrograph

Q_{95} – The percentage of flow exceeded 95% of the time

Q_{50} – The percentage of flow exceeded 50% of the time

Q_{mean} – Mean Flow

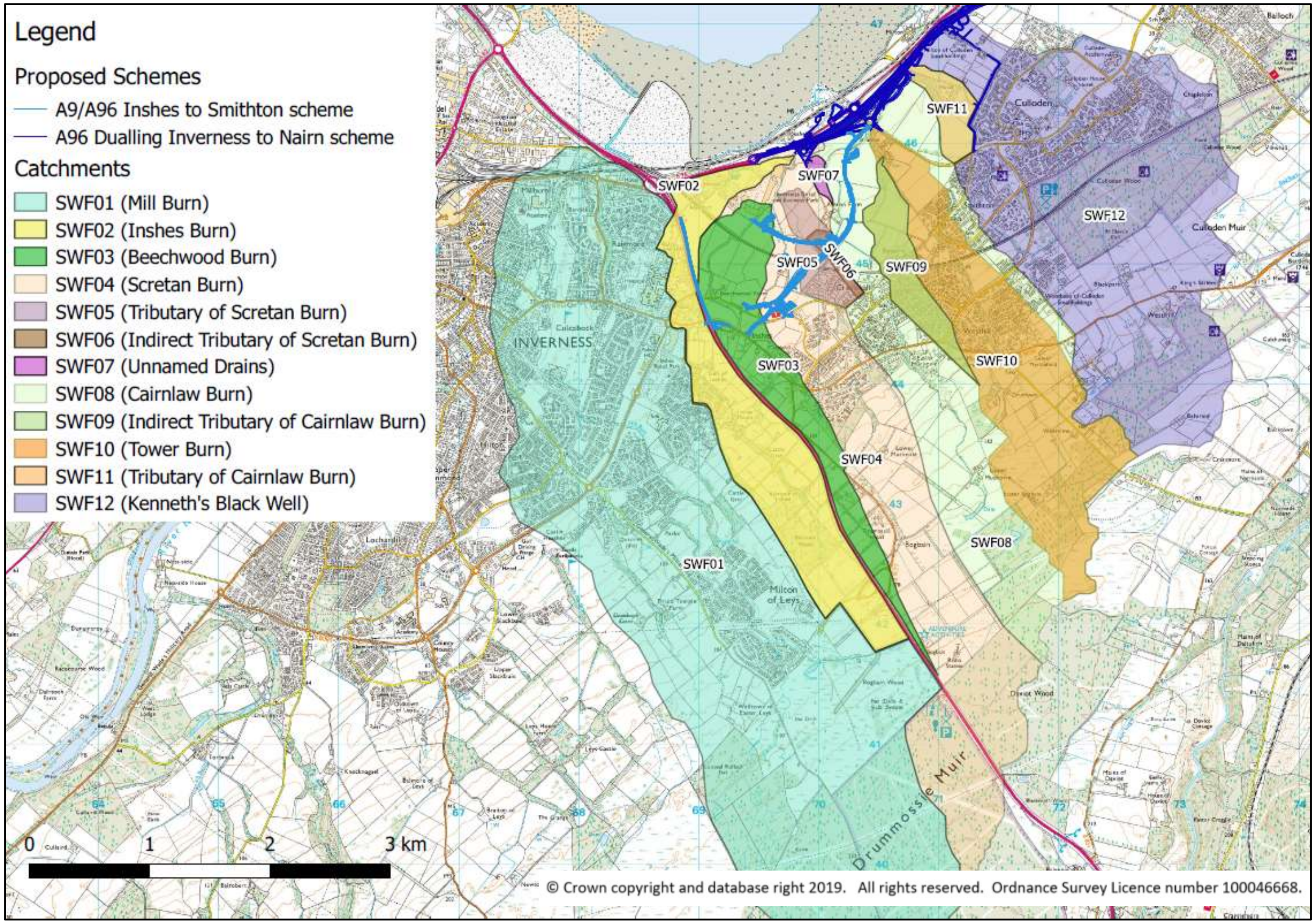
QMED – Median Annual Maximum Flood

URBEXT – FEH index of fractional urban extent

For amendments to catchment descriptors refer to Annex C (Amendments to Catchment Descriptors).

Annex B: Catchment Boundary Map

Diagram B1: Catchment Boundary Map



**For reference the Cairnlaw Burn (SWF08) catchment includes the Indirect Tributary of Cairnlaw Burn and Tower Burn (SWF09 and SWF10) catchments and ends at the current A96 culvert.*

Annex C: Amendments to Catchment Descriptors

To derive design peak flow estimates at each of the ungauged watercourses crossing the proposed scheme, FEH catchment descriptors are required.

For watercourses draining an area >0.5km², catchment descriptors are extracted directly from the FEH CD-ROM/FEH Web Service and provide a starting point for the analysis. For each individual catchment the following catchment descriptors have been checked, and where necessary manually adjusted following guidelines presented in the FEH Vol.5 (Bayliss 1999):

1) Catchment Area
2) DPLBAR
3) URBEXT
4) FARL
5) BFIHOST

Catchment Area – the catchment boundary for each watercourse (if available) was extracted from the FEH CD-ROM/FEH Web Service and 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;
- 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; and
- a check of the catchment boundary was also carried out using 2m LiDAR derived contour data where available.

For smaller watercourses (i.e. <0.5km²) not identified by the FEH CD-ROM/FEH Web Service, catchment areas have been delineated manually using 1: 25,000 scale OS mapping together with 2m LiDAR derived contour data and the boundary confirmed by a site walk over, if necessary.

DPLBAR – where catchment boundaries required modification, the mean drainage path length was re-calculated using equation 7.1 presented in Volume 5 of the FEH (Bayliss 1999).

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; catchment URBEXT was calculated manually from a 1:50,000 scale OS map and equation 6.2 presented in Volume 5 of the FEH and equation 5.4 presented in the Joint Defra/EA Technical Report 'URBEXT2000 – A new FEH catchment descriptor (Bayliss et al 2006).

FARL – For the watercourses having lochs and reservoir within their catchments, catchment FARL values are derived directly from the FEH CD-ROM/FEH Web Service. However, for those catchments not included within the FEH CD-ROM/FEH Web Service (i.e. those having a catchment area <0.5km²) or which have been identified incorrectly by the FEH CD-ROM/FEH Web Service, FARL is calculated manually following the methodology described within section 4.3 of the FEH Vol. 5.

BFIHOST - Values have been derived using the FEH CD-ROM/FEH Web Service for all catchments potentially impacted by the proposed scheme. BFIHOST values have been reviewed and some values adjusted as discrepancies were noted within the area of the proposed scheme (some catchments have notably higher BFIHOST values downstream than upstream). Where inconsistently high BFIHOST values were observed a review of soil types within the area was undertaken and donor site BFIHOST values were adopted if appropriate. This approach ensured that flows were not underestimated by the use of a high BFIHOST value.

Annex D: Run 2 Design Peak Flow Estimates at the Inflow Locations

Table D1: Run 2a* (storm duration = 5.7 hrs) Inflows Peaks (m^3/s) for the Cairnlaw Burn (SWF08) and Scretan Burn (SWF04) Sub-catchments

Watercourse	AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC
Cairnlaw Burn (SWF 08) Sub-catchments				
Inflow 1 (Cairnlaw Burn (SWF08))	0.887	2.008	3.116	3.740
Inflow 2 (Un-named Drain (SWF07))	0.017	0.038	0.060	0.073
Inflow 7 (Indirect Tributary of Cairnlaw Burn (SWF09))	0.171	0.399	0.644	0.773
Inflow 8 (Tower Burn (SWF 10))	0.900	2.043	3.201	3.842
R12 (lateral flow)	0.066	0.149	0.232	0.278
R13 (lateral flow)	0.061	0.138	0.215	0.258
R14/15 (lateral flow)	0.067	0.153	0.239	0.287
Scretan Burn (SWF 04) Sub-catchments				
Inflow 3a (84.5%) (Scretan Burn (SWF04))	1.486	3.330	5.122	6.148
Inflow 3b (Scretan Burn (SWF04))	0.251	0.563	0.871	1.043
Inflow 4 (Beechwood Burn (SWF 03))	0.456	1.043	1.645	1.974
Inflow 5a (Tributary of Scretan Burn (SWF 05))	0.130	0.298	0.462	0.554
Inflow 5b (Indirect Tributary of Scretan Burn (SWF 06))	0.011	0.025	0.038	0.046
Inflow 6 (Inshes Burn (SWF 02))	0.545	1.246	1.998	2.397
R1 (lateral flow)	0.049	0.112	0.174	0.209
R2 (lateral flow)	0.099	0.221	0.341	0.410
R3 (lateral flow)	0.085	0.191	0.306	0.365

*It should be highlighted that this run was undertaken to reconcile flow at Scretan Burn (SWF04) culverts C01 and C04 only.

Table D2: Run 2b* (SD=3.9 hrs) Model Inflows Peak (m^3/s) for the Cairnlaw Burn (SWF 08) and Scretan Burn (SWF 04) Sub-catchments

Watercourse	AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC
Cairnlaw Burn (SWF08) Sub-catchments				
Inflow 1 (Cairnlaw Burn (SWF08))	0.934	2.094	3.337	4.004
Inflow 2 (Un-named Drain (SWF07))	0.017	0.039	0.062	0.075
Inflow 7 (Indirect Tributary of Cairnlaw Burn (SWF09))	0.182	0.411	0.691	0.829
Inflow 8 (Tower Burn (SWF 10))	0.874	1.957	3.148	3.780
R12 (lateral flow)	0.069	0.154	0.246	0.295
R13 (lateral flow)	0.064	0.143	0.229	0.272
R14/15 (lateral flow)	0.065	0.146	0.235	0.282
Scretan Burn (SWF 04) Sub-catchments				
Inflow 3a (84.5%) (Scretan Burn (SWF04))	1.001	2.225	3.507	4.208
Inflow 3b (Scretan Burn (SWF04))	0.170	0.377	0.595	0.714
Inflow 4 (Beechwood Burn (SWF 03))	0.533	1.193	1.943	2.331
Inflow 5a (Tributary of Scretan Burn (SWF 05))	0.144	0.327	0.520	0.625
Inflow 5b (Indirect Tributary of Scretan Burn (SWF 06))	0.011	0.025	0.040	0.048
Inflow 6 (Inshes Burn (SWF 02))	0.523	1.162	1.927	2.313
R1 (lateral flow)	0.050	0.114	0.183	0.219
R2 (lateral flow)	0.067	0.148	0.234	0.279
R3 (lateral flow)	0.079	0.173	0.284	0.339

*It should be highlighted that this run was undertaken to reconcile flow at Beechwood Burn (SWF03) culvert C05 and Cairnlaw Burn culverts C06 and C07 only.

Table D3: Run 2c* (SD = 1.5hrs) Model Inflows Peak (m^3/s) for the Cairnlaw Burn (SWF 08) and Scretan Burn (SWF 04) Sub-catchments

Watercourse	AEP 50%	AEP 3.33%	AEP 0.5%	AEP 0.5% + CC
Cairnlaw Burn (SWF 08) Sub-catchments				
Inflow 1 (Cairnlaw Burn (SWF08))	0.710	1.689	2.608	3.129
Inflow 2 (Un-named Drain (SWF07))	0.013	0.031	0.048	0.059
Inflow 7 (Indirect Tributary of Cairnlaw Burn (SWF09))	0.170	0.409	0.648	0.777
Inflow 8 (Tower Burn (SWF10))	0.698	1.658	2.561	3.072
R12 (lateral flow)	0.051	0.122	0.188	0.229
R13 (lateral flow)	0.048	0.113	0.175	0.210
R14/15 (lateral flow)	0.052	0.124	0.191	0.230
Scretan Burn (SWF 04) Sub-catchments				
Inflow 3a (84.5%) (Scretan Burn (SWF04))	0.772	1.813	2.775	3.330
Inflow 3b (Scretan Burn (SWF04))	0.131	0.307	0.471	0.565
Inflow 4 (Beechwood Burn (SWF03))	0.363	0.861	1.340	1.608
Inflow 5a (Tributary of Scretan Burn (SWF05))	0.150	0.362	0.564	0.677
Inflow 5b (Indirect Tributary of Scretan Burn (SWF06))	0.010	0.023	0.036	0.043
Inflow 6 (Inshes Burn (SWF02))	0.414	0.972	1.516	1.820
R1 (lateral flow)	0.044	0.106	0.165	0.198
R2 (lateral flow)	0.051	0.121	0.185	0.224
R3 (lateral flow)	0.060	0.139	0.213	0.258

*It should be highlighted that this run was undertaken to reconcile flow at Scretan Burn Tributary (SWF05) culverts C02 and C03 only.

Annex E – Run 2: 0.5% AEP (200-year) Event Hydrographs

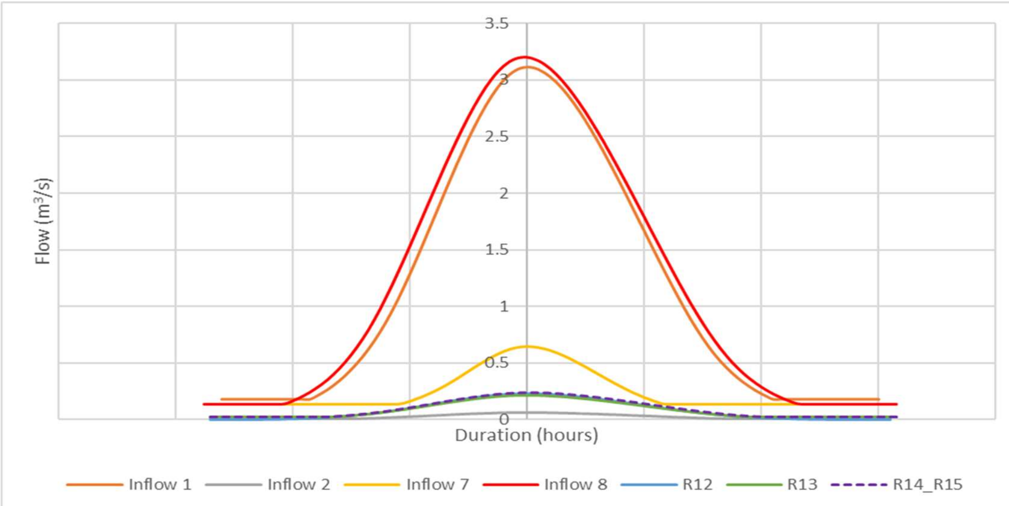


Diagram E1: Run 2a (Cairnlaw Burn (SWF 08)) - the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).

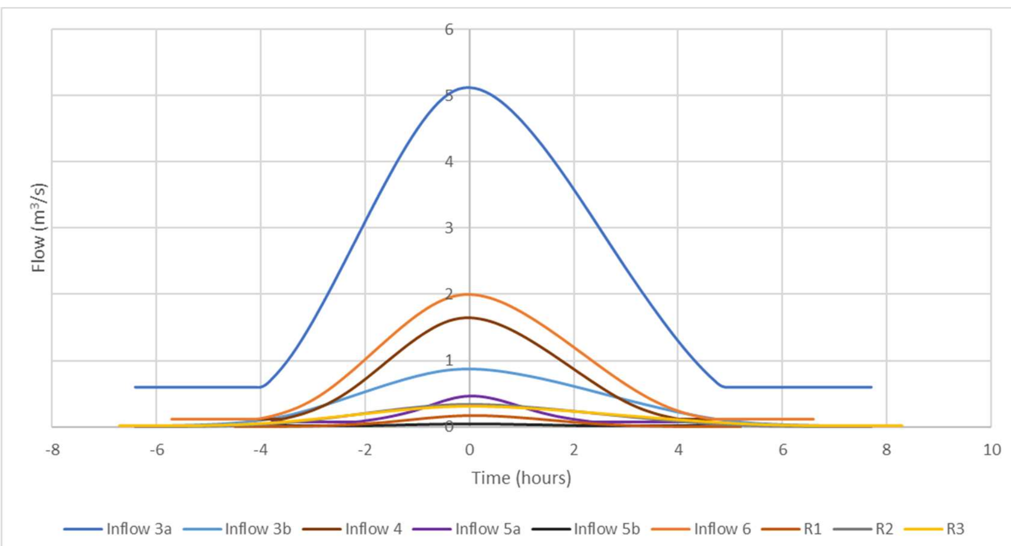


Diagram E2: Run 2a (Scretan Burn (SWF 04)) - the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).

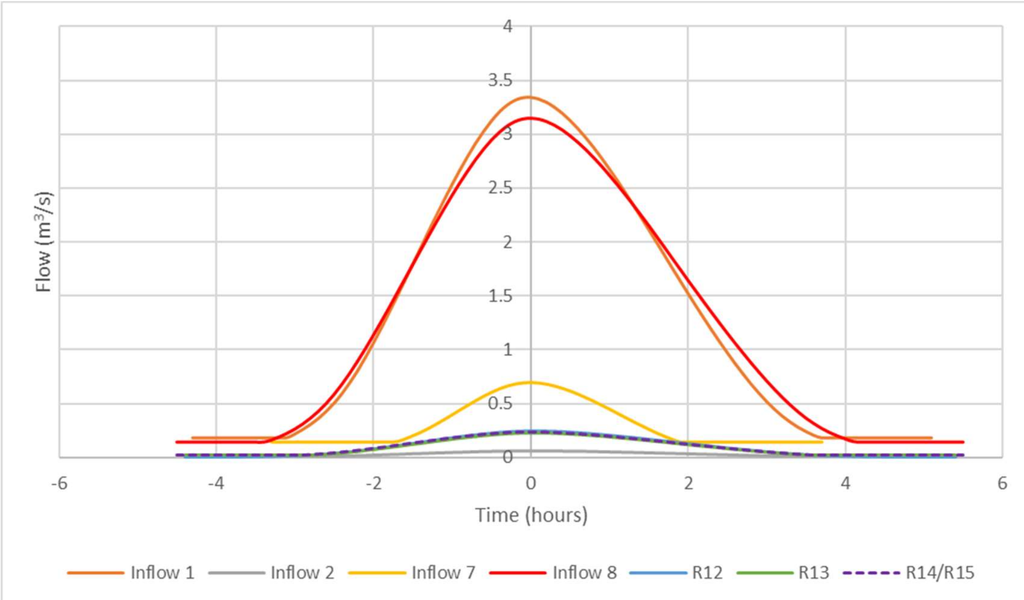


Diagram E3: Run 2b (Cairnlaw Burn (SWF 08)) – the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).

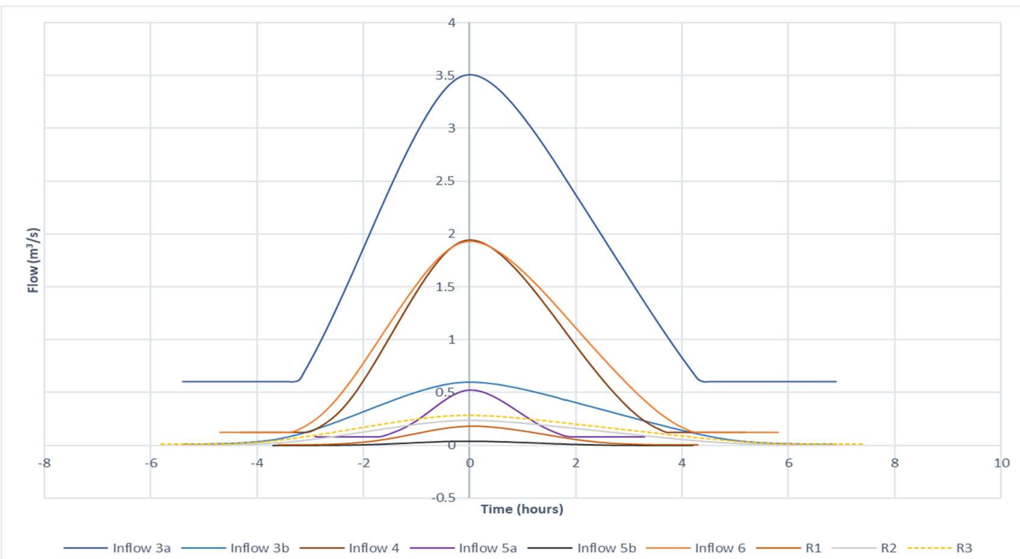


Diagram E4: Run 2b (Scretan Burn (SWF 04)) – the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).

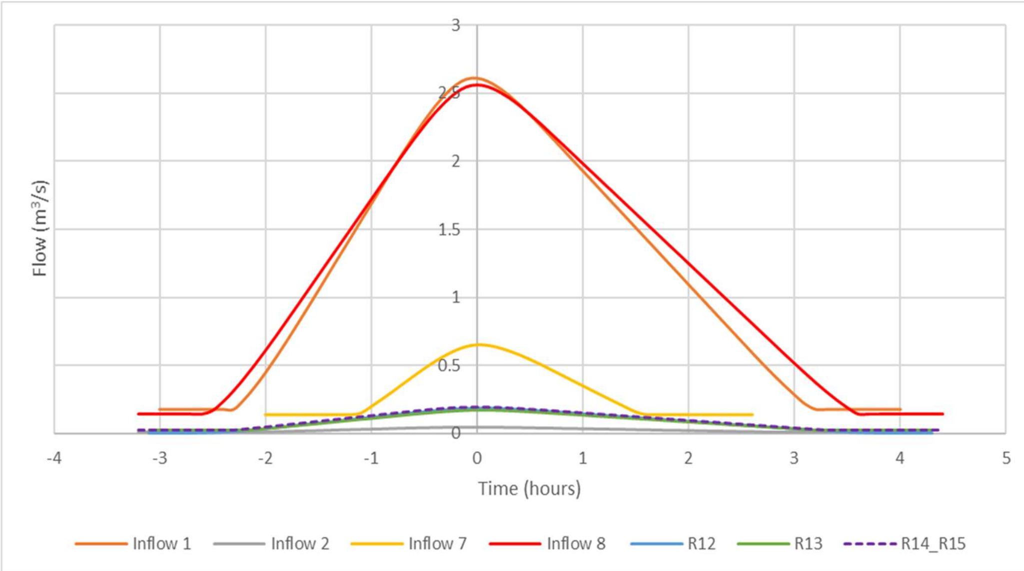


Diagram E5: Run 2c (Cairnlaw Burn (SWF 08)) - the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).

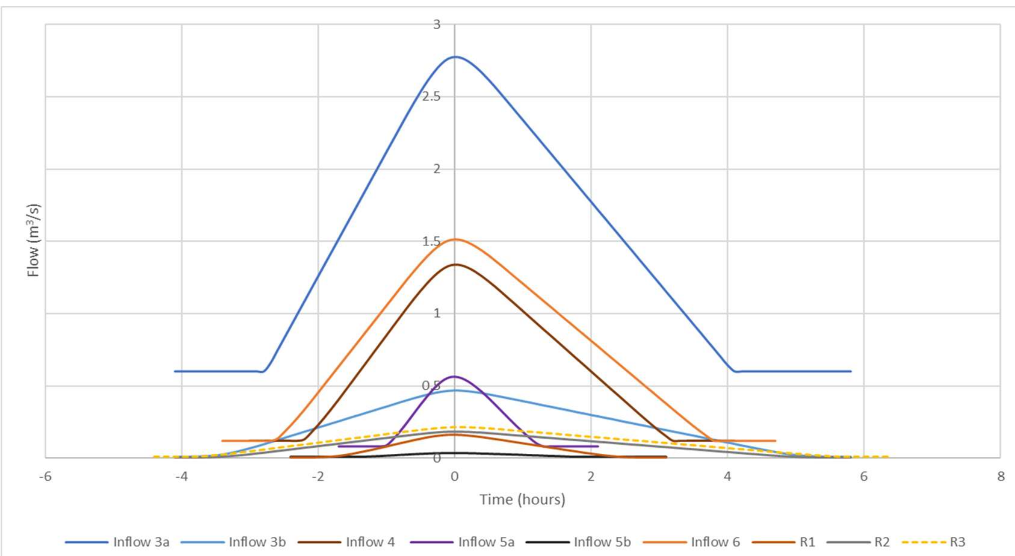


Diagram E6: Run 2c (Scretan Burn (SWF 04)) – the 0.5% AEP (200-year) Event Inflow Hydrographs

(Note: Although the peaks of all inflows are shown occurring at the same time to enable size comparison, the application of inflows in the model is based on their response to the rainfall event that is applied uniformly across the entire catchment).