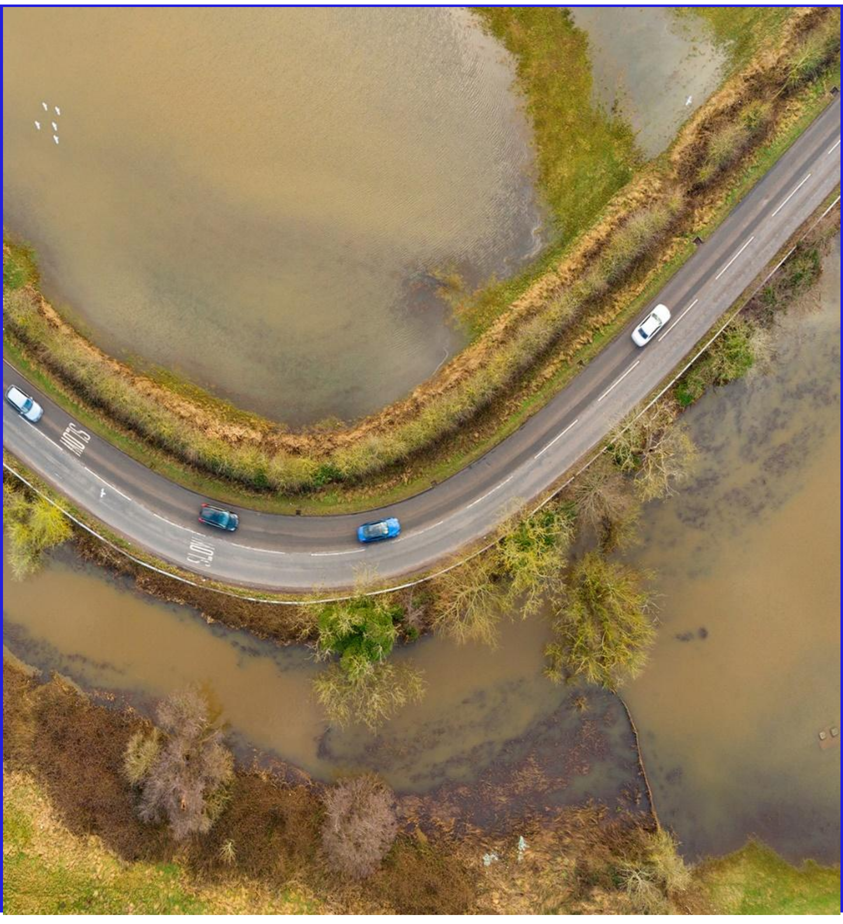
Cambushinnie Haul Track: Appendix A Hydrology Report

Document no: B2468300_DOC_007
Version: P01

Scottish and Southern Electricity Networks
LT520

Cambushinnie Haul Track
8 November 2024



Cambushinnie Haul Track: Appendix A Hydrology Report

Client name:	Scottish and Southern Electricity Networks		
Project name:	Cambushinnie Haul Track		
Client reference:	LT520	**Project no:**	B2468300
Document no:	B2468300_DOC_007	**Project manager:**	Alan Blair
Version:	P01	**Prepared by:**	James Walker
Date:	8 November 2024	**File name:**	B2468300_DOC_007 Rev.P01 Cambushinnie Haul Track Appendix A Hydrology Report

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
P01	08/11/2024	First issue	JJW	KB	KB	AB

Distribution of copies

Revision	Issue approved	Date issued	Issued to	Comments

Jacobs U.K. Limited

95 Bothwell Street
Glasgow, Scotland G2 7HX
United Kingdom

T +44 (0)141 243 8000
F +44 (0)141 226 3109
www.jacobs.com

Contents

Appendices

Tables

Figures

Acronyms and abbreviations

AEP	Annual Exceedance Probability
AMAX	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST19	Base Flow Index derived using the HOST soil classification, revised in 2019
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
GEV	Generalised Extreme Value
GLO	Generalised Logistic
HOST	Hydrology of Soil Types
IF	Impervious Fraction
IRF	Impervious Runoff Factor
LF	Low flow statistics (flow duration curve)
NRFA	National River Flow Archive
PMF	Probable Maximum Flood
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
Tp	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP	Windows Frequency Analysis Package (software that can be used for FEH statistical method)

1. Summary of Assessment

Catchment location	The focus of this study is the catchment of the River Allan located close to the village of Braco in Perth and Kinross.
Purpose of study and complexity **e.g. for scope just include whether it is simple, routine, moderate, difficult, very difficult**	Jacobs UK Limited (Jacobs) has been commissioned by Scottish & Southern Electricity Networks PLC (SSEN) to prepare a flood risk assessment (FRA) to support the proposed haul track. A hydraulic model of the River Allan and five tributaries is required to inform the FRA and design of the project. The purpose of this study is to estimate both peak flows and hydrographs for input into the hydraulic model. This document details the hydrological analysis including methodology, key deliverables, and assumptions. This report forms an appendix to the Cambushinnie Haul Track FRA. The study involves deriving peak flows and hydrographs at seven flood estimation points (FEPs), namely, two on the Allan Water and one for the Kier Burn, Knaik River, Feddal Burn, Millstone Burn and an unnamed tributary. Additional sub catchment flows are required for two residual catchment areas. Standard Flood Estimation Handbook (FEH) hydrological methods will be applied to derive the peak flow and model inflow hydrographs. Additional task such as derivation of hydrograph shape from historic flood events at the Allan Water gauge, lag analysis involving rainfall and flow data, and critical storm duration optimisation were also considered. The study was therefore judged to be of moderate complexity.
Key catchment features **e.g. permeable, urban, pumped, mined, reservoirs**	Refer to Section 2.2.
Flooding mechanisms **e.g. fluvial, surface water, groundwater**	Flooding is judged to result from fluvial (river water) which includes a combination of peak flows and flood volumes that exceed channel capacity, resulting in overbank flooding and/or exceed the conveyance capacity of hydraulic structures.
Gauged / ungauged **State if there are flow or level gauges and a very brief indication of quality if there are**	There are two gauging stations along the River Allan: ▪ The station at Kinbuck (18001) is the closest to the area of interest at approximately 7.5km downstream of the proposed study area. ▪ The station at Bridge of Allan (18005) is a further 5km downstream of station 18001. Both stations are classified by the National River Flow Archive (NRFA) as suitable for QMED estimation but not pooling group analysis.
Final choice of method	The FEH statistical (pooling group) method was selected to estimate peak flows for all watercourses. QMED was estimated using the catchment descriptor equation and adjusted using the station at Kinbuck (18001) for donor adjustment. The 'ungauged pooled' method was used to derive a growth curve at three flood estimation points. Hydrographs were generated using ReFH2 with two approaches taken to applying model inflows: ▪ Run 1 – A distributive approach in which ReFH2 hydrographs were generated for each watercourse set to the critical duration of the Allan

	Water (23.5-hours). A flow reconciliation exercise will be undertaken such that flows match those estimated using the FEH statistical method at the downstream boundary of the model. ▪ Run 2 – Lumped approach in which ReFH2 hydrographs were generated using the storm duration relevant to each catchment and scaled to the target FEH statistical peak flow estimate. Lag analysis was undertaken on the river gauge at Kinbuck (18001) to derive an adjustment factor for the time to peak within ReFH2. The final hydrograph shape was compared to that derived using the Archers method and found to have a close similarity. Both approaches will be tested within the hydraulic model and the most conservative in terms of flood risk will be progressed.
Key limitations / uncertainties in results	Key limitations and uncertainties of the presented flood estimation peaks presented in this document include: ▪ No available local gauged data was available for the tributary watercourses. Although peak flow rated gauges are available 7.5 km downstream of Allan Water modelling extent, the AMAX data is not suitable for single site / enhance single site analysis. ▪ Lag analysis uses the nearest available rain gauge; however this may not be representative of the catchment. ▪ Hydrological calibration was found to be unfeasible as the hydrometric gauge is located beyond modelling extent, and no suitable data is available in the vicinity of the study area to calibrate the model.

1.1 Key Flood Frequencies

The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period, as shown in Table 1-1.

Table 1-1 Annual exceedance probability (AEP) and related return period reference table

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.0133	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

2. Method Statement

2.1 Requirements for flood estimates

Overview:

Jacobs UK Limited (Jacobs) has been commissioned by Scottish & Southern Electricity Networks PLC (SSEN) to prepare a flood risk assessment (FRA) to support a proposed haul located to the south of the village of Braco (Cambushinnie), Perth and Kinross. The proposal forms part of the Beauly-Denny Second Circuit 400kV Upgrade Project which will aid the transfer of large-scale renewable energy generation from the north of Scotland to areas of demand. The proposed development crosses several watercourses and is partially within an area of high flood risk close to the confluence between the River Allan, the River Knaik and the Keir Burn. Detailed hydraulic modelling is required to assess the existing flood risk as well as to determine the impacts of the proposed development and inform the design.

The purpose of this hydrological study is to undertake a hydrological assessment of the River Allan and five tributaries including the River Knaik, the Keir, Feddal and Millstone Burns and an unnamed watercourse. The assessment will be used to derive inflows for input into the hydraulic model of the watercourses.

Peak flows and hydrographs are required for each modelled watercourse for the 50%, 3.3%, 2%, 1%, 0.5%, and 0.1% AEP events (equivalent to 2-year, 30-year, 50-year, 100-year, 200-year and 1000-year return periods).

The 0.5% AEP (1 in 200-year) flow including an allowance for future climate change (CC) will also be required. The CC allowance used for this study will be based on the most recent SEPA guidance (Issued November 2023)[1] for the Forth River Basin Region. A 56% uplift for CC will be applied to inflows for watercourses with catchments greater in area than 50km^2. For watercourses with catchments smaller than 30km^2 a 39% CC uplift will be applied on rainfall intensity using the ReFH2 rainfall-runoff model. For watercourses with catchments between 30 km^2 and 50km^2 both flow and rainfall CC allowances will be compared and the most conservative applied.

There is limited hydrometric data within the study area and information on past flooding is sparse. The River Allan is gauged at two locations, with the closest station (18001 - Allan Water at Kinbuck) approximately 7.5km downstream of the proposed model extent. Both stations are classified as suitable for QMED estimation but not pooling group analysis. There is one rainfall gauge (Braco Dandruff) within the River Allan catchment, for which 15-min rainfall data from 1990 is available. The available hydrometric data will be used for calculating time to peak (Tp) of the River Allan and also for the calibration/verification of the hydraulic model.

Project Scope:

This is a routine study to investigate the potential flood risk to and from a proposed development site. The study will involve the hydrological analysis of six watercourses with seven flood estimation points (FEP). Additional sub catchment flows are required for two residual areas.

The catchments are not unusual in terms of key characteristics such as geology and land-use however there is some attenuation due to reservoirs and lakes. The study is judged to be of moderate complexity and will be carried out in accordance with the latest UK flood estimation methodologies (LIT 11832, 2022[2] and SEPA Technical flood risk guidance for stakeholders, 2022[3]).

---

[1] SEPA (8 November 2023) Climate change allowances for flood risk assessment in land use planning. Version 4. LUPS-CC1.

[2] Environment Agency (2022). Flood Estimation Guidelines. LIT 11832.

[3] SEPA (Version 13 June 2022) Technical Flood Risk Guidance for Stakeholders - SEPA requirements for undertaking a Flood Risk Assessment -

The project scope includes:

- Catchment delineation (lumped catchment and sub-catchment for model inflow schematisation), review of catchment/sub-catchment boundaries as well as review of key catchment descriptors.
- Peak flow estimation for each flood estimation point (FEP) using the FEH statistical (pooling group analysis) method in WinFAP5 software package. For comparative purposes peak flows will also be estimated using the ReFH2.3 method. Peak flow estimates of rarer than 0.5% AEP (larger than 200-year return period) events will be derived using ReFH2.3 ratio method.
- Model inflows will be derived using a hybrid method, in which peak flows are adopted from Statistical method and hydrograph shape from ReFH2 method. The ReFH2 hydrograph will be derive as following:
  - Lag analysis using rainfall (Braco Dandruff) and river level data (18001 - Allan Water at Kinbuck) to derive an adjustment factor for the time to peak (Tp) parameter in ReFH2 to all AEPs.
  - An average hydrograph shape in Allan Water will be derived at the Kinbuck gauge from historic largest flooding events recorded at the gauge. This shape will be compared with the ReFH2 hydrograph shape derived for the lumped catchment at the downstream modelling extent.
  - Storm duration optimisation for the Allan Water and for the minor tributaries (River Knaik, Keir Burn and the unnamed tributary) for the 0.5% AEP event. This will involve estimating the hydrological critical duration within ReFH2 for each of the watercourses.
- Derivation of a full suite of return period model inflows for the critical storm duration of the Allan Water at downstream model extent (Run 1) and for the individual critical storm duration for the three tributary watercourses, namely, River Knaik, Kier Burn and Unnamed Tributary (Run 2). Two model runs (Run 1 – longer storm duration as that of Allan Water; and Run 2 – shorter storm duration as that of three individual tributary watercourses) are required as there is potential fluvial flood risk to the proposed development site from Allan Water as well as from tributary watercourses.

A review of past flooding and studies within the study area will also be undertaken to corroborate flow estimates and to inform the model calibration and verification stage of the project. This will include a review of studies undertaken by Halcrow Group Limited for the Greenloaning Flood Study in 2012.

During the hydraulic model build stage of the project further refinements may be made to the hydrological estimates. Sensitivity analysis will be undertaken to identify the critical storm duration for the 0.5% AEP event which provides the worst-case flood conditions within the area of interest.

Model flow reconciliation will also be undertaken at the downstream model extent on the Allan Water using iterative simulation within the hydraulic model in Run 1. During the model run for individual watercourse storm duration (Run 2), the model inflow hydrographs derived from ReFH2 will be scaled to the corresponding Statistical peaks, and hence no flow reconciliation is required. The results of the model flow reconciliation analysis will be detailed within the hydraulic modelling report.

2.2 The Catchment

Catchment Description:

The Allan Water rises from the Ochil Hills to the east of Blackford and flows south-westwards through Greenloaning, Kinbuck, Ashfield, Dunblane, and Bridge of Allan, before discharging into the River Forth near Stirling. The watercourse passes beneath the A822 between Braco and Greenloaning with the bridge located close to the confluences of the Allan Water, the Keir Burn and the River Knaik. The watercourse has a total catchment area of approximately 217km^2 at its confluence with the River Forth and approximately 127km^2 at the study area.

The Allan Water has several notable tributaries within the study area. The Keir Burn (also referred to as Bullie Burn) and River Knaik flow southwards adjacent to Braco and passing beneath Feddal Road at the Bridge of

Keir and the A822 at Ardoch Bridge. These discharging into the Allan Water on the northeastern and northwestern sides of the A822. A small unnamed watercourse and the Feddal Burn also discharge into the River Allan approximately 900m downstream of the A822. These watercourses are connected to a series of ponds or lakes to the west of Braco and flow southwards. The River Knaik has a catchment of 39.44km^2 whereas the Keir, Feddal and unnamed watercourse catchments are smaller at 12.54km^2, 3.82km^2 and 1.52km^2. The Milltone Burn drains the area to the south of Greenloaning and discharges into the River Allan approximately 300m to the west of the A822 bridge. This watercourse has a catchment area of approximately 5.5km^2 at its confluence with Allan Water.

The watercourses have all been heavily modified with channel straightening noted along the upper Allan Burn, Keir, Knaik and Millstone Burns. Most of the tributary watercourses were culverted as part of the A9 development and are crossed by several roads. The most recent SEPA flood maps show significant flood extents within the study area indicating a degree of interaction between the watercourses. An overview of the watercourse and flood extents can be seen in Figure 2-1.

The catchments are largely rural encompass agricultural farmland and woodland. The upper Allan Water catchment includes the village of Blackford, the River Knaik and Keir Burn encompass parts of the village of Braco and the Millstone Burn covers parts of Greenloaning. The catchments of all watercourses have an URBEXT2000 (revised) below 0.03 and are therefore classified as essentially rural.

The gradients of the catchments vary with the River Allan catchment upstream of the A822, as well as the River Knaik, Keir Burn, and Millstone Burns all having relatively high DPSbar (mean Drainage Path Slope) values ranging from 97.2 to 120 metres per Kilometre. The unnamed tributary watercourse and Feddal Burns have flatter gradients with DPSbar values of 35 to 58 metres per Kilometre.

The Allan Water catchment within the area of interest is predominantly underlain by Dunblane Sandstone of the Arbuthnott-Garvock Group which is described by the British Geological Survey (BGS) as medium- and coarse-grained sandstones, with subsidiary purple mudstones and rare pebbly sandstone beds. The bedrock is classified as a highly productive aquifer with fracture permeability the dominant form of aquifer flow. The Cromlix Mudstone Formation is also present within the centre of the River Allan Catchment underlying parts of the River Knaik and Keir Burn catchments. This is considered to have moderate groundwater productivity[4].

The bedrock formations are overlain by variable superficial deposits. Glacial till is prevalent within the upper catchment and glacial-fluvial and alluvial within the lower catchments. The heterogeneous till is considered to have no or poor groundwater potential. The glaciofluvial and alluvial sands and gravels typically form highly productive aquifers which may form locally important aquifers and likely have connectivity with nearby watercourses. The upper catchments of the River Knaik and Keir Burn are underlain by peat deposits which have no significant groundwater potential. These geological conditions are reflected in the BFIHOST19 value of 0.607 for the Allan Water catchment and the lower value of 0.433 and 0.318 for the River Knaik and Keir Burn catchments.

SPRHOST provides a measure of catchment responsiveness to rainfall in terms of the standard percentage of runoff. The catchment has a moderate SPRHOST of 33.84-53.96% which indicates that the catchment is likely to have a moderate responsiveness to rainfall. The watercourses have high to moderately permeability but are not classified as groundwater dominated (BFIHOST<0.66 and SPRHOST >20%).

Maps:

Figure 2-1 provides an overview of the watercourses and key structures. Figure 2-2 shows the catchment boundary of the River Allan defined on the FEH Online Service and the available hydrometric data.

[4] Baseline Scotland: the lower Devonian aquifer of Strathmore – CR/06/250N' (SEPA & BGS, 2006

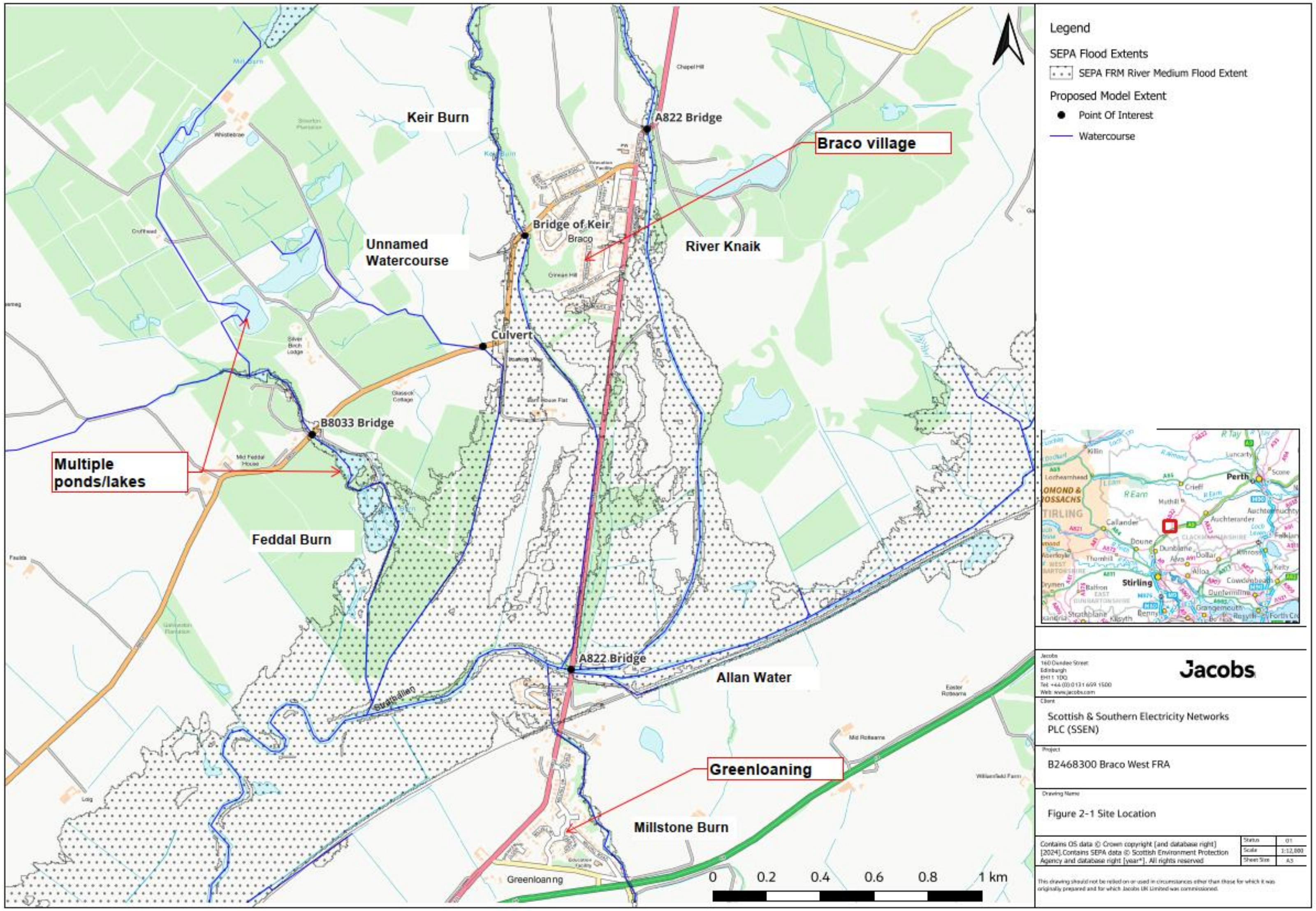


Figure 2-1 Overview of the key watercourses, hydraulic structures and SEPA flood extent

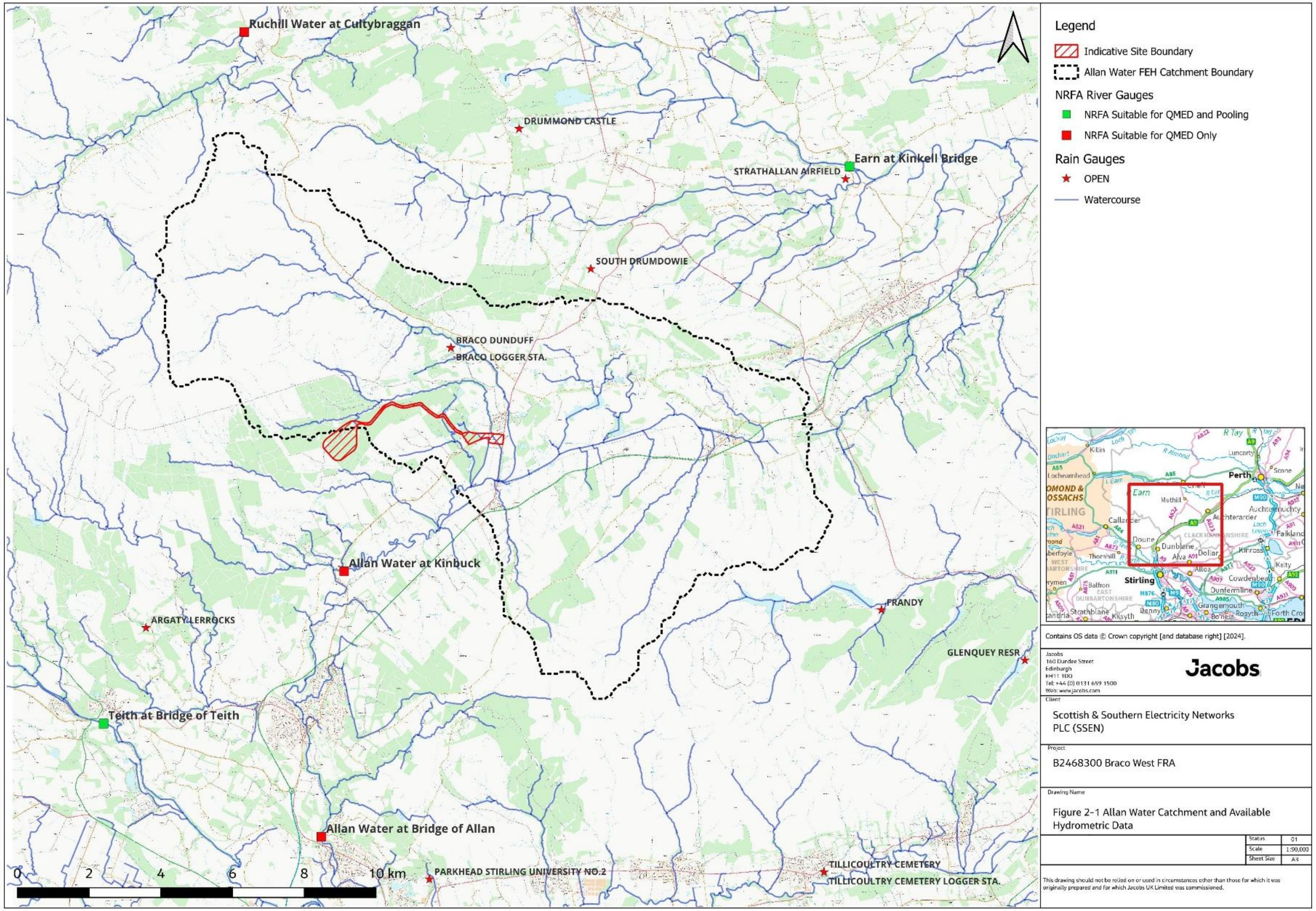


Figure 2-2 Overview of River Allan catchment and hydrometric data nearby

2.3 Hydrometric Data

Source of flood peak data:

NRFA peak flows dataset 12.1, released on 2nd November 2023. This contains data up to water year 2021-22.

Gauging stations (flow and level):

There are no river gauging stations directly within the study area and all tributary watercourses are ungauged (see Figure 2-2). The Kinbuck gauge (18001) is located on the River Allan approximately 7.5km downstream of the model extent. A second gauge is also located a further 9.5km downstream at Bridge of Allan (18005). Both are peak flow rated stations and are identified on the NRFA website as suitable for QMED estimation using the AMAX data but not for pooling analysis. The key properties at the two gauging stations can be seen in Table 2-1 and Table 2-2.

Table 2-1 Flow gauging stations along the River Allan

Water course	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level)	Start of record and end if station closed
Allan Water	Allan Water at Kinbuck	14890	18001	161	Velocity area	1992-present
	Allan Water at Bridge of Allan	14890	18005	210	Velocity-area	1996-Present

Table 2-2 Data available at each flow gauging station

Station name	Source	Data type	Start and end of flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Station and flow data quality summary
Allan Water at Kinbuck	NRFA	Flow, Stage, AMAX, POT	01/10/1992 - 01/10/2022	No	Yes	No	Not within project scope	NRFA Station Data for 18001 - Allan Water at Kinbuck (ceh.ac.uk)
Allan Water at Bridge of Allan	NRFA	Flow, Stage, AMAX, POT	01/10/1996 - 01/10/2022					NRFA Station Data for 18005 - Allan Water at Bridge of Allan (ceh.ac.uk)

The NRFA and SEPA API web service include AMAX series at the Allan Water at Kinbuck gauge dating back to 1992 however daily flow data is available going back to 1957 and gauging's to 1972. SEPA were consulted on the 08/07/2024 and the full annual max and monthly max series were provided. SEPA also clarified that Kinbuck was added to the Peak Flow dataset in 2020/21 after the optimal flood rating was applied through the digital stage record. The exercise was limited to the digital stage record from 1992. The mean daily flows from 1957 have been calculated through the years by manual processing of paper records but these have not yet been digitised and would require a full period rating review.

Updates or revisions to flood peak data:

No revisions or updates.

Data quality checks carried out:

Data quality for each of the gauges is included as part of the SEPA Time series data service (API). Data is categorised as Good, Suspect, Estimated or Unchecked.

Rating Equations:

Table 2-3 Summary of rating equations

Station name	Type of rating e.g., theoretical, empirical; degree of extrapolation	Rating review needed?	Comments and link to any rating reviews
Allan Water at Kinbuck	Rating fitted to check gauges. Extrapolation beyond QMED.	No, not within scope of project	-
Allan Water at Bridge of Allan	Rating fitted to check gauges. No extrapolation shown on rating curve.	No, not within scope of project	-

Rating reviews:

- *Allan Water at Kinbuck:*

The station was added to the peak flow dataset in August 2021, and it is assumed that the rating was reviewed as part of this process. The rating (shown in Figure 2-3) is described by the NRFA as stable and well defined throughout the full range. Four rating curves have been applied which show a close similarity. The station is gauged to QMED without extrapolation however there is only one check gauging above QMED (14/12/2011). There appears to be good fit between the observed check gauging and rating curves. As such, there would be a high degree of confidence in the QMED estimate.

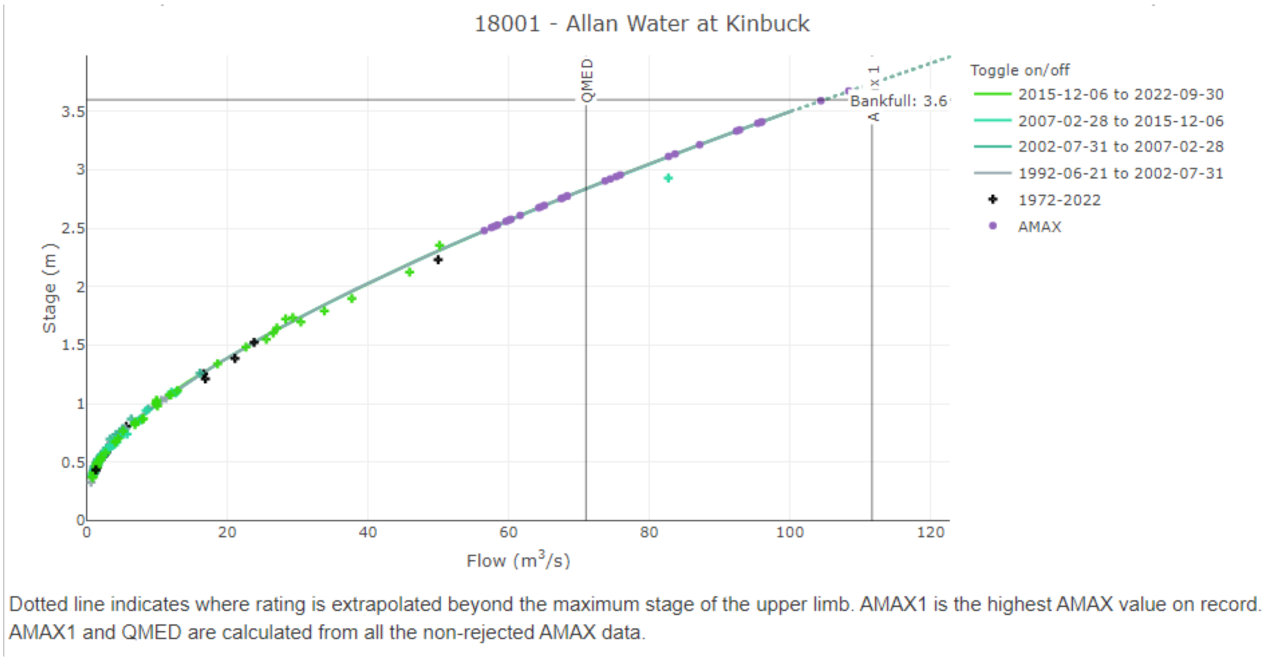


Figure 2-3 Peak flow rating information for the Kinbuck Gauge

- *Allan Water at Bridge of Allan:*

Full period of record peak flow data reviewed and released in August 2021 (WINFAP Files v10). The flood rating curves shown in Figure 2-4 appears stable however the station is not gauged to QMED, and more high flow gauging are required before it can be made suitable for pooling. The peak flow rating is based on data after 1995 due to the impact of a local development on channel geometry. The peak flow values at the Bridge of Allan Station are noted to be lower than at Kinbuck (18001) which is attributed to in-channel attenuation.

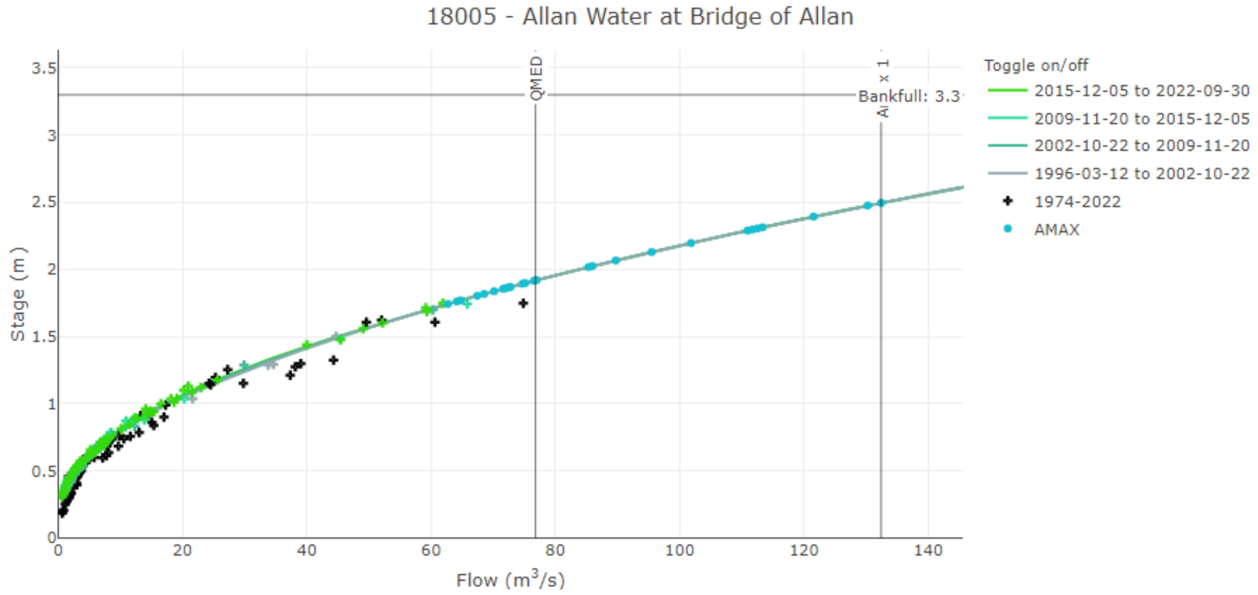


Figure 2-4 Peak flow rating information for the Bridge of Allan Gauge

Other data available and how it has been obtained:

Type of data	Data Relevant to this Study?	Data Available?	Source of Data	Comments
Check flow gaugings	No	No	-	A check of flow gauging is not within the scope of this work.
Historic flood data – give link to historic review if carried out.			Data request to PKC and SEPA. New reports on past flood events. Halcrow 2011 NFM study for the River Allan Council reports on the Greenloaning Flood Study.	SEPA confirmed in their reply (dated 01/05/2024) that the SEPA's Observed Flood Event database currently holds no records of flooding within the study area. PKC in their response (dated 05/04/2024) highlighted two notable flood events one in 2006 within Braco and a second in 2009 along the A822 between Braco and Greenloaning. These events affected both property and street levels, attributed to high groundwater levels and surface water accumulation. A significant flood event occurred on the 13th December 2006. The flood peak at the Kinbuck gauge suggesting flows in the region of 144m^3/s indicating a flood return period of approximately 1 in 50 years. Extensive flooding was observed on the 13th December 2006 along the Allan Water upstream of the gauge at Kinbuck and near the confluence with the River Knaik. Aerial photographs were taken the morning after the event by SEPA and are shown in Appendix A (Halcrow, 2011). Flooding occurred in the Allandale Crescent area of Greenloaning in August 2004 from the Millstone Burn. Flooding affected the Allanbank Inn as well as six houses. PKC engaged Mouchel to investigate the flooding and produce a flood study which was then progressed by Halcrow in 2009[5]. No further information could be found regarding the mechanism of flooding for this event.
Flow or river level data for events	Yes	Yes	SEPA Hydrology data explorer. Gauge locations included in Figure 2.8.	There are two river gauging stations along the River Allan recording flow and level data. Neither gauge is located within the study area however Kinbuck is in relatively close proximity downstream of the proposed model extent. The station is classified as suitable for QMED estimation but not for pooling analysis. The station AMAX flow data will be used for the process of QMED donor adjustment. Level gauge data will be used to identify high level events for lag analysis. Flow data (15-minute) will be used to generate an average flow hydrograph shape for the Allan Water as part of the model flow reconciliation process.

[5] PKC Environment Committee – 20 March 2013 GREENLOANING FLOOD MITIGATION SCHEME Report by Depute Director (Environment). Accessed [PERTH AND KINROSS COUNCIL (cmis.uk.com)]

Extra data for other sites in pooling groups				N/A
Rainfall data for events	Yes	Yes	DEFRA Hydrology data explorer. Rainfall gauge	15-minute rain gauge data was obtained through the SEPA time series data service (API) for the rain gauge Braco (Danduff – station number 15161) for the top 10 AMAX flood events. The station is located within the catchment of the Allan Water. Other gauges nearby (Drummond Castle, Argaty Lerrocks - 15162 and South Drumdowie - 36944) were reviewed but considered inappropriate due to either distance or lack of suitable data resolution.
Potential evaporation data	Yes	Yes	CEH CHESS database.	There is a requirement to verify hydraulic model performance against historic flood events and for this purpose, event rainfall is utilized within ReFH v2.3 to translate the event rainfall to a fluvial hydrograph. When simulating an observed event a daily antecedent rainfall series and mean daily potential evaporation rates are required. Potential evaporation data has been obtained from The CEH Climate hydrology and ecology research support system (CHESS).
Results from previous studies			Allan Water Natural Flood Management Techniques and Scoping Study (Halcrow, 2011). Greenloaning Flood Study (Halcrow, 2012)	Halcrow Group Ltd was commissioned by Stirling Council in 2009 to undertake a flood modelling and mapping study of the River Allan. No details could be found on the estimated peak flow. A hydrological assessment was undertaken by Halcrow Group Limited on Allan Water in 2011 as part of a natural flood management study. The study covered Allan Water as well as the River Knaik and Keir Burn. As part the study a catchment analysis of the median of annual maximum flow and time to peak was undertaken based on catchment descriptors. The results, shown in the table below, suggested that the River Knaik and Keir Burn are flashier than the Allan Water. Flood flows for the Keir Burn and Muckle Burn downstream were estimated to be larger than those on the Allan Water. ▪ Allan Water at the confluence with the River Knaik – QMED 18m^3/s (Tp = 5.2 hours) ▪ River Knaik – QMED of 42m^3/s (Tp 4.4 = hours) ▪ Keir – QMED 16m^3/s (Tp = 4.6 hours) ▪ Allan at Kinbuck – QMED 73m^3/s (Tp = 6.4 hours)

<table>
<tr><td></td><td></td><td></td><td></td><td>
A revised single site analysis was undertaken for the Kinbuck and Bridge of Allan gauges. The single site method was favoured as the pooled analysis produced a flatter growth curve. The final results are summarised below:
<table>
<tr><th>Flood Return Period</th><th>Allan Water at Kinbuck growth factor</th><th>Allan Water at Kinbuck peak flow (m³/s)</th></tr>
<tr><td>2</td><td>0.992</td><td>69</td></tr>
<tr><td>10</td><td>1.443</td><td>100</td></tr>
<tr><td>100</td><td>2.32</td><td>161</td></tr>
<tr><td>200</td><td>2.674</td><td>185</td></tr>
<tr><td>1000</td><td>3.720</td><td>257</td></tr>
</table>
Halcrow Group Limited were also commissioned by PKC to undertake an assessment of flooding as part of the Greenloaning Flood Study in 2012. The study involved hydraulic modelling and hydrological assessment of the River Allan and the Millstone Burn. Hydrological calculations were provided by PKC which indicated that peak flows for the River Allan (upstream of the confluence with the Millstone Burn) were calculated using the FEH statistical (pooling group) method with QMED estimated using 5 donor stations which included 18001 (Allan at Kinbuck,). For comparative purposes the FEH rainfall-runoff method was also applied, and the results are summarised below:
<table>
<tr><th>Flood Return Period</th><th>Allan Water – FEH Peak flow (m³/s)</th><th>FEH Rainfall-Runoff peak flow (m³/s)</th></tr>
<tr><td>2</td><td>42.9</td><td>-</td></tr>
<tr><td>10</td><td>63.5</td><td>-</td></tr>
<tr><td>100</td><td>94.2</td><td>163.42</td></tr>
<tr><td>200</td><td>105.1</td><td>186.72</td></tr>
<tr><td>1000</td><td>134.7</td><td>-</td></tr>
</table>
No details were provided on the method of hydrograph generation or flow estimates for the Millstone Burn.
</td></tr>
<tr><td>Other data /information</td><td>-</td><td>-</td><td>-</td><td>N/A</td></tr>
</table>

Rainfall Gauge data:

There is one suitable rainfall gauge located within the Allan Water catchment. The rain gauge at Braco (Dandruff) is shown on Figure 2-2. This includes 15-minute, hourly and daily rainfall data from 1990 to the present day, as shown in Figure 2-5. The data is of variable quality with significant periods of data classified as unchecked (imported from legacy dataset), suspect and missing. The station contains 15-minute rainfall for 7 of the top 10 AMAX events identified in the Kinbuck gauge. Figure 2-5 shows that the December 2006 flood event is well represented within the record and the data quality classified as good.

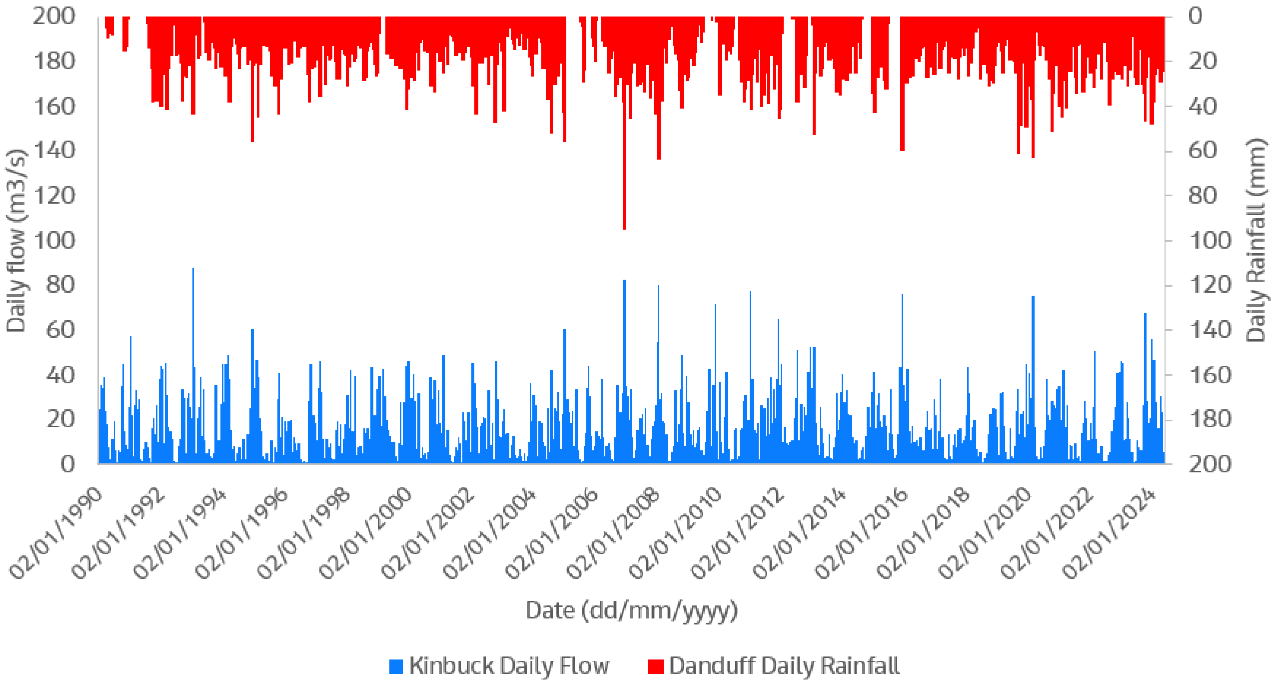


Figure 2-5 Comparison between 15-minute flow at Kinbuck and daily rainfall at Danduff Rain Gauge

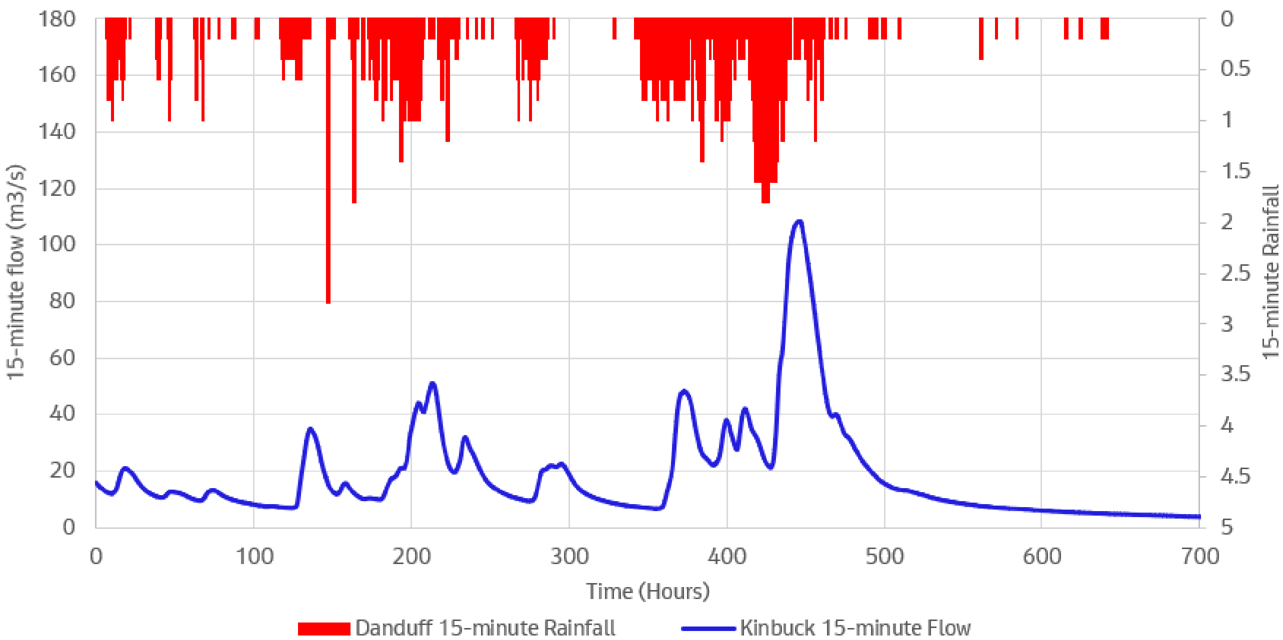


Figure 2-6 15-minute flow and 15-minute rainfall for the December 2006 flood event.

Other gauges located nearby including at Drummond Castle, Argaty Lerrocks and South Dumdowie are either no longer operational or do not include sufficient resolution data and were therefore discounted.

Conclusions of hydrometric data review:

A review of the hydrometric data has identified that there are no river gauges directly within the study area. The closest station is the Allan Water at Kinbuck (18001) which is approximately 7.5km downstream of the proposed model extent. A detailed rating review was outwith the scope of this assessment however quality checks indicated that the station is suitable to use as a donor for the estimation of QMED. The station is unsuitable for flood frequency analysis using either the single site, enhanced single site or pooling analysis.

The rain gauge Braco (Danduff) is the only gauge within the catchment or nearby which includes sub-daily 15-minute rainfall which may be used to improve calibration of the ReFH2.3 model through lag analysis.

Due to the lack of gauges within the study area and limited information on past flood events a detailed calibration of both the hydrological and hydraulic model will not be possible. Limited photographs are available for the flood event in 2006 and this is also well captured in the flow records at the Kinbuck (18001) gauge as well as the Braco (Danduff) rain gauge. These may be used for a high-level qualitative assessment of the hydraulic model performance.

2.4 Hydrological understanding of the catchment

Plots of flood peak data and interpretation:

Flood peak data from the NRFA flood peak dataset for the Allan Water at Kinbuck gauge (18001) can be seen in Figure 2-7. Maximum flow at this gauge was recorded in the water year 1992-1993 and reached 111.168 m^3/s, stage level of 3.744 m. The flood event in December 2006 is the second largest in the record with a peak flow of 108.365 m^3/s.

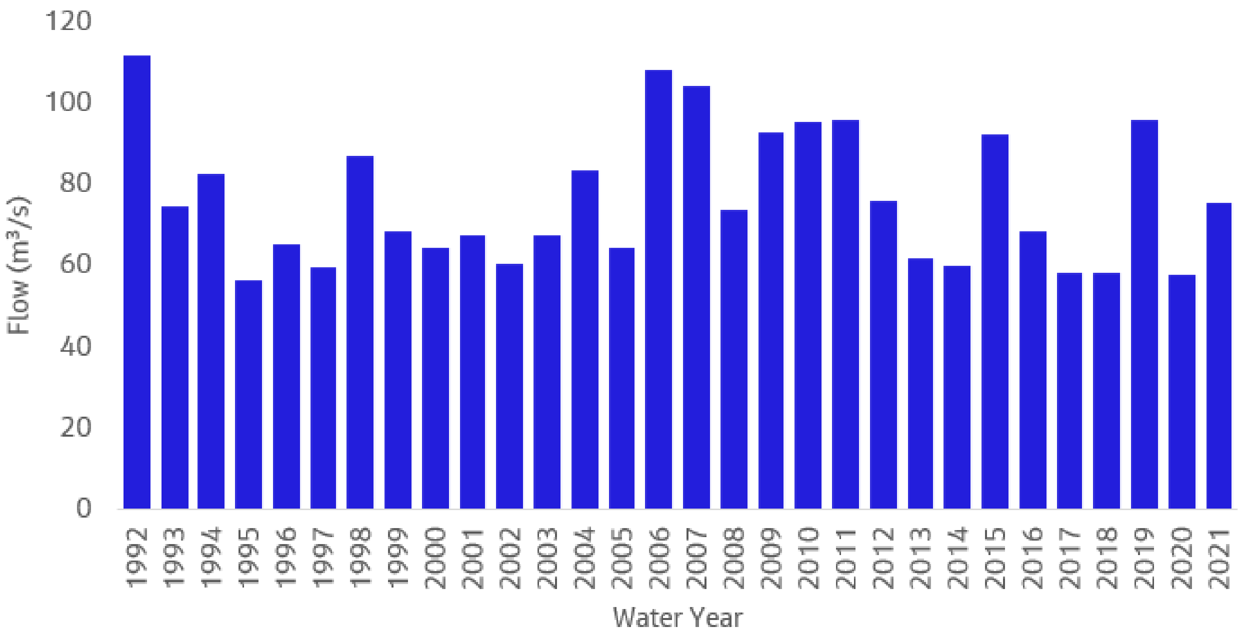


Figure 2-7 Annual Maximum (AMAX) series for Allan Water at Kinbuck gauge

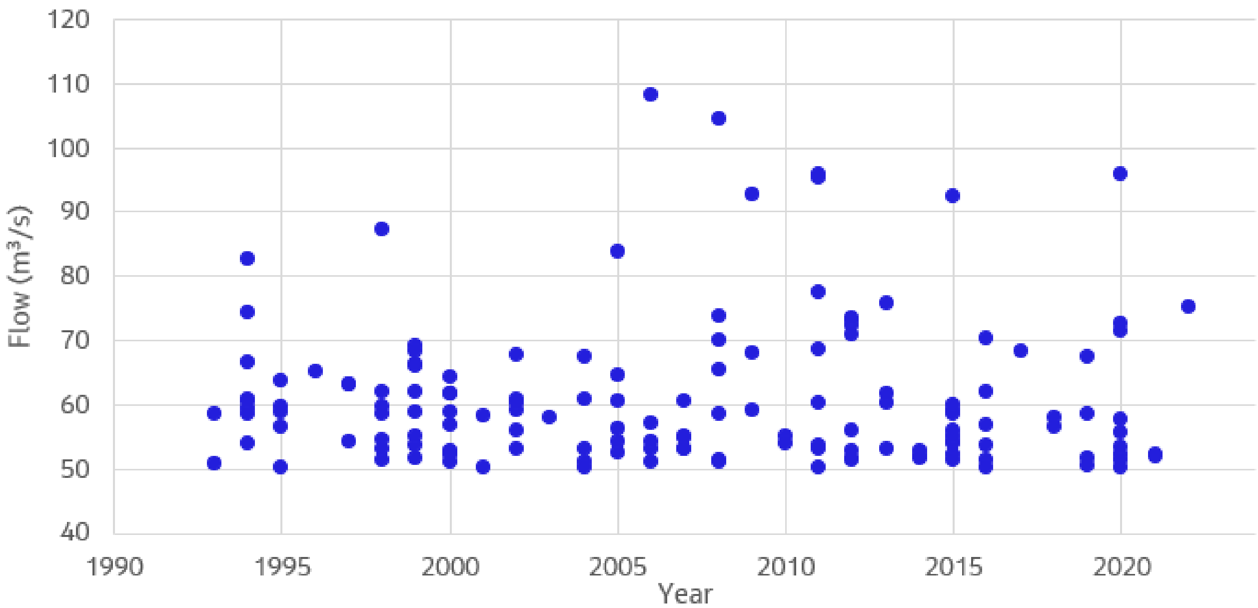


Figure 2-8 Peaks over Threshold (POT) series for Allan Water at Kinbuck gauge

Trends in the AMAX series at Allan Water at Kinbuck gauge (18001) were explored further for non-stationarity using the NRFA flow trends explorer[6]. Figure 2-9 shows that there is very minor decreasing trend in the data. The AMAX data at this station can therefore be assumed to be stationary and suitable for standard FEH methods, with no adjustment required. This means the flood in the study catchment also assumed to be from a stationary process, thus unaffected by non-stationarity.

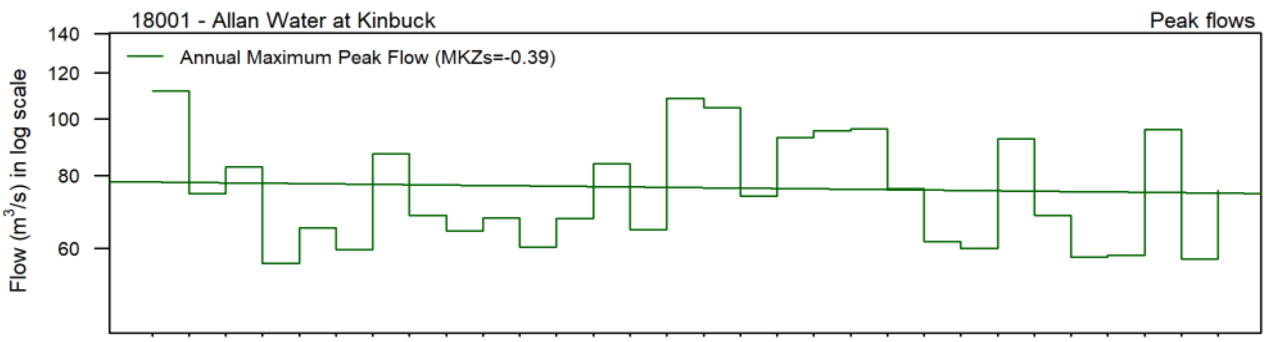


Figure 2-9 NRFA's trend analysis for peak flows at Kinbuck Guage

Conceptual model:

The site of interest is the location of the proposed haul track to the west of Braco in Perth and Kinross (Figure 2-2). The proposal crosses the unnamed watercourse and the Keir Burn and is close proximity to the confluence between the Allan Water and its tributaries. The key watercourses in the study area which will be modelled are the Allan water, Keir Burn, the River Knaik, Millstone Burn, Feddal Burn and an unnamed watercourse.

The likely cause of flooding in the study area was judged to be from peak flows in the watercourses. The SEPA flood mapping shows extensive flooding at the confluence between the River Allan and the Keir Burn close to the A822 bridge. This pattern of flooding is also shown on photographs taken after the major 2006 flood event

[6] NRFA Trends Explorer (ceh.ac.uk)

(Appendix A). Given the predicted extent of flooding within the area, likely interaction between watercourses and impact of hydraulic structures flood volume as well as the combination of flood peaks and timing may also be important influencing factors.

The catchment review indicated that the River Knaik and Keir Burn encompasses less permeable bedrock and superficial geology which is reflected in the higher SPRHOST compared to the other catchments. As such it is expected that these catchments will likely have a faster response to rainfall events and a higher peak flow compared to the upper River Allan catchment. This is supported by the finding of the previous Allan Water NFM study undertaken by Halcrow in 2011.

Unusual catchment features:

There are washlands, ponds and reservoirs located within the catchment which are likely to attenuate flood flows particularly for the unnamed tributary and Feddal Burn catchments.

The catchments are classified as essentially rural and negligible urban areas present within the catchments. None of the catchments are classified as groundwater dominated (BFIHOST<0.66 and SPRHOST >20%).

2.5 Initial choice of approach

Are FEH methods appropriate?

The Allan Water and its tributary catchments are not unusual in terms of catchment characteristics and are classified as essentially rural. The catchments are also not classified as groundwater dominated (BFIHOST<0.66 and SPRHOST >20%). Standard FEH methods are therefore appropriate for this study.

There are multiple ponds and lakes present within the catchments, most notably within the catchment of the unnamed watercourse and the upper Allan Water. FARL values are above 0.9 therefore both the FEH statistical and ReFH2 methods are still appropriate. The ponds may provide some flow attenuation therefore the FEH statistical method may be preferred over ReFH2 for the estimation of peak flows.

There are no gauges along the reach of Allan Water within the proposed extent of the hydraulic model. The station at Kinbuck (18001) is the closest to the study area and can be used to improve QMED estimation through donor transfer, calculation of catchment lag, and the estimation of hydrograph shape. The NRFA website indicates that the station is unsuitable for pooling analysis, although single site and enhanced site analysis will be undertaken to compare the flood growth curve of Allan Water.

Initial choice of method(s) and reasons:

The initial choice of method for all catchments is to use FEH statistical (pooling group) method to estimate peak flows. QMED will be estimated from the FEH regression equation using catchment descriptor equation at each FEP, and adjusted using donor transfer. The existing gauge along the Allan Water at Kinbuck (18001) will be used as a donor for the process of data transfer. The station is relatively close to the study area, is suitable for QMED estimation and will better account for local conditions. Alternative or additional gauging stations may also be considered to derive the Qmed adjustment factor.

QMED for residual catchment areas will be derived by area scaling of QMED from a suitable donor site.

Peak flow for rarer than 50% AEP (larger than QMED) events will be estimated using flood growth curve(s) derived from pooling group analyses of AMAX data of suitable gauges within WinFAP5. These will be reviewed based on key catchment parameters and station performance. The peak flow of rarer than 0.5% AEP (larger than 200-year) event will be derived using ReFH2 ratios.

The catchments vary in terms of area. For comparative purposes pooling groups will be derived for both the lumped Allan Water catchment at the downstream model extent as well as for the unnamed watercourse and for the Feddal Burn. The Feddal Burn has a catchment area less than 40km^2 hence the small catchment approach will be used following the recommendations set out in the latest Flood estimation guidance.

The ReFH2 method will be applied to provide a comparison with the FEH statistical method given the lack of suitable gauging data and historical flood information within the study area. Lag analysis will be undertaken for the Kinbuck gauge, located on Allan Water. This will account for the impact of the ponds located upstream. Time to peak will be adjusted in ReFH2 for all catchments.

How will hydrograph shapes be derived if needed?

Hydrographs will be generated using ReFH2 and scaled to the selected peak flow estimate. This will allow for a consistent approach across all catchments and allow for a critical duration analysis to be undertaken to account for the impact of flood volume as well as peak flows.

The catchment review and conceptual model identified that there is a potential interaction between the Allan Water and tributary watercourses hence combination of peak flows and timing may be an important consideration to flooding. To account for this storm duration optimisation will be undertaken. This will involve estimating the hydrological critical duration using an iterative process within ReFH2 for the Allan Water and the tributary watercourses. Two approaches will be applied to model inflows:

- Run 1 – A distributive approach in which ReFH2 hydrographs will be generated for each watercourse set to the critical duration of the Allan Water at the downstream model extent. The Areal reduction factor (ARF) and seasonal correction factors (SCF) will also be set to the values for the Allan Water catchment. A flow reconciliation exercise will be undertaken such that the model flows match with the target flows estimated using the FEH statistical method at the downstream model extent.
- Run 2 – Lumped approach in which ReFH2 hydrographs will be generated using the critical storm duration identified for each catchment independently and scaled to match the hydrograph peak with the corresponding watercourse target FEH statistical peak flow estimate.

Further critical duration analysis related sensitivity analysis will be undertaken as part of the hydraulic modelling stage of the project and will be outlined within the model report.

Will the catchment be split into sub-catchments? If so, how?

The catchments will be split into sub-catchments. Nine Flow Estimation Points (FEPs) are required due to the location of the site of interest in this study, which is situated in the vicinity of the confluence of the River Allan and several tributaries (refer to Table 3-1). These FEPs will include six lumped inflows to the hydraulic model. An additional FEP is also located at the downstream extent of the model along the Allan Water which will provide target lumped flow estimates for model flow reconciliation. Two sub-catchment inflows are also required for residual catchment areas. Details are provided in Section 2.4.

For the unnamed watercourse upstream of B8033 one lumped inflow will be calculated at FEP UNN_01 and then distributed at the five inflow locations using area weighting. Contributing areas will be estimated within QGIS using aerial and OS mapping.

Will Model Calibration and Verification be undertaken?

The data available in the vicinity of the study reaches of Allan Water is not sufficient to allow for the calibration or validation of a hydrologic model due to a lack of reliable flow records and historic flood information. Instead, a qualitative assessment will be undertaken as part of the hydraulic model build to compare the flood extents from simulated design events with proxy data (available photographs) for December 2006 flood. This will provide a broad indication of the scale of flooding and model performance. Further comparisons will be made to the flow estimates from previous studies.

Software to be used:

- FEH webservice for catchment descriptors:
- Peak Flow Dataset NRFA peak flows dataset 12.1, released on 2nd November 2023;
- Revitalised Flood Hydrograph (ReFH2.3) employing FEH22 rainfall; and
- WinFAP version 5.

3. Location where Flood Estimates are required.

Summary of subject sites

The hydrological assessment will be undertaken for the Allan water and its five tributary watercourses including the River Knaik, Keir Burn, Feddal Burn, Millstone Burn and the unnamed watercourse.

The FEPs identified are summarised in Table 3-1 and shown on Figure 3-1. The FEPs include six lumped catchments and two sub-catchments representing residual catchment areas. An additional lumped catchment is also located at the downstream extent of the model along the River Allan, the design (target) flow at which will be used for the model flow reconciliation. The site codes listed below are used in all subsequent tables in this hydrology report.

Table 3-1 Summary of hydrological estimation point

Site code	Type of estimate: lumped (L), sub-catchment (S), direct rainfall (D)	Watercourse	Site name /description	Easting	Northing	AREA on FEH Web Service (km^2)	Revised AREA (km^2)
ALLN_01	L	River Allan	River Allan upstream of A822 bridge.	283550	707850	63.225	63.008
ALLN_02	L		Reconciliation point at model downstream boundary	282400	707600	127.820	128.289
KNAK_01	L	River Knaik	Upstream of A822 bridge	283550	707900	39.440	40.111
KEIR_01	L	Keir Burn	Upstream of confluence with Allan Water.	283450	707950	12.543	11.875
MILL_01	L	Millstone Burn	Upstream of confluence with Allan Water.	283400	707850	5.360	5.627
FEDD_01	L	Feddal Burn	Upstream of confluence with Allan Water.	282750	707850	3.823	4.142
UNN_01	L	Unknown watercourse	Upstream of B8033.	283200	709050	1.118	1.132
UNN_02	S		Between Allan Water and B8033.	282800	707850	1.5225	0.339
RESD_01	S	Residual catchment	Residual catchment of Allan Water.	282400	707950	1.908	2.057

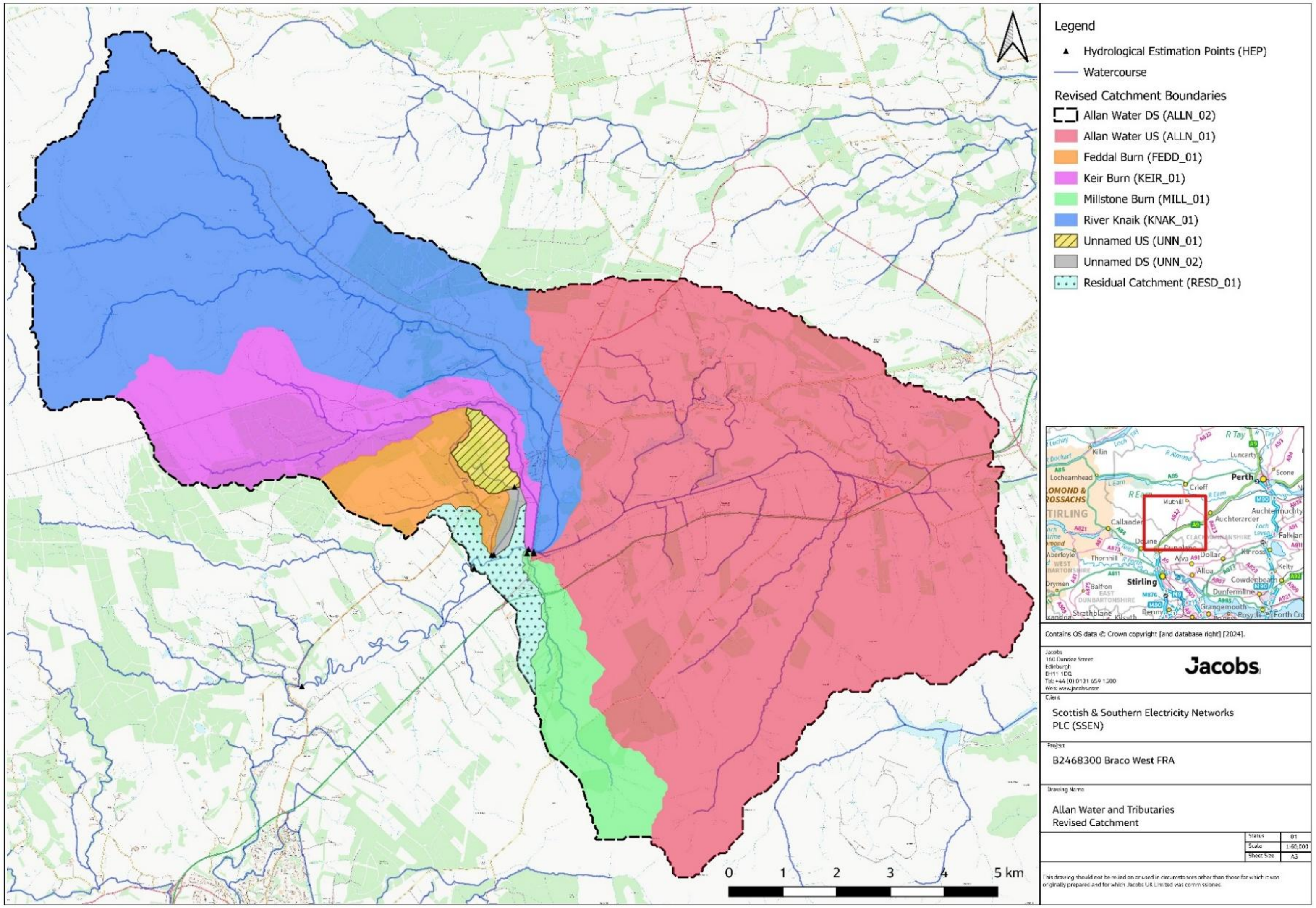


Figure 3-1 Allan Water and tributary revised Catchments.

A summary of the proposed model inflow locations and the corresponding FEPs can be seen in Table 3-2 and Figure 3-2. The lumped inflows are typically applied further upstream of the FEP at the upstream limit of each watercourse. Note that for the upper catchment of the unnamed watercourse the lumped flow estimate will be further distributed to five inflow locations using their corresponding sub-catchment areal weighting.

Table 3-2 Summary of inflow locations and corresponding flood estimation points

Watercourse	Inflow Location	Corresponding FEP	Type
Allan Water US	Full lumped catchment flows applied at inflow point 1.2km upstream of the A822 bridge between Braco and Greenloaning	ALLN_01	Point inflow
River Knaik	Full lumped catchment flows applied at inflow point 1.3km upstream of A822 bridge between Braco and Greenloaning	KNAK_01	Point inflow
Keir Water	Upstream of confluence with Allan Water. Full lumped catchment flows applied at inflow point approximately 450m upstream of Feddal Road bridge	KEIR_01	Point inflow
Unnamed Watercourse	Upstream of culvert beneath B8033. Flows will be distributed at five inflow points using aerial weighting.	UNN_01	Point inflow
	Residual catchment between the B8023 and confluence with the Allan Water. An areally scaled upstream inflow will be applied as lateral or point inflow.	UNN_2	Lateral inflow
Feddal Burn	Upstream of confluence with Allan Water. Applied at confluence with Allan Water.	FEDD_01	Lateral inflow
Milstone Burn	Inflow located approximately 600m upstream of the confluence with the Allan Water	MILL_01	Point inflow
Allan Water (Residual)	Residual catchment of Allan Water. Applied between the Feddal Burn and model downstream boundary.	RES_01	lateral inflow
Allan Water DS	No inflow.	ALLN_02	Flow reconciliation

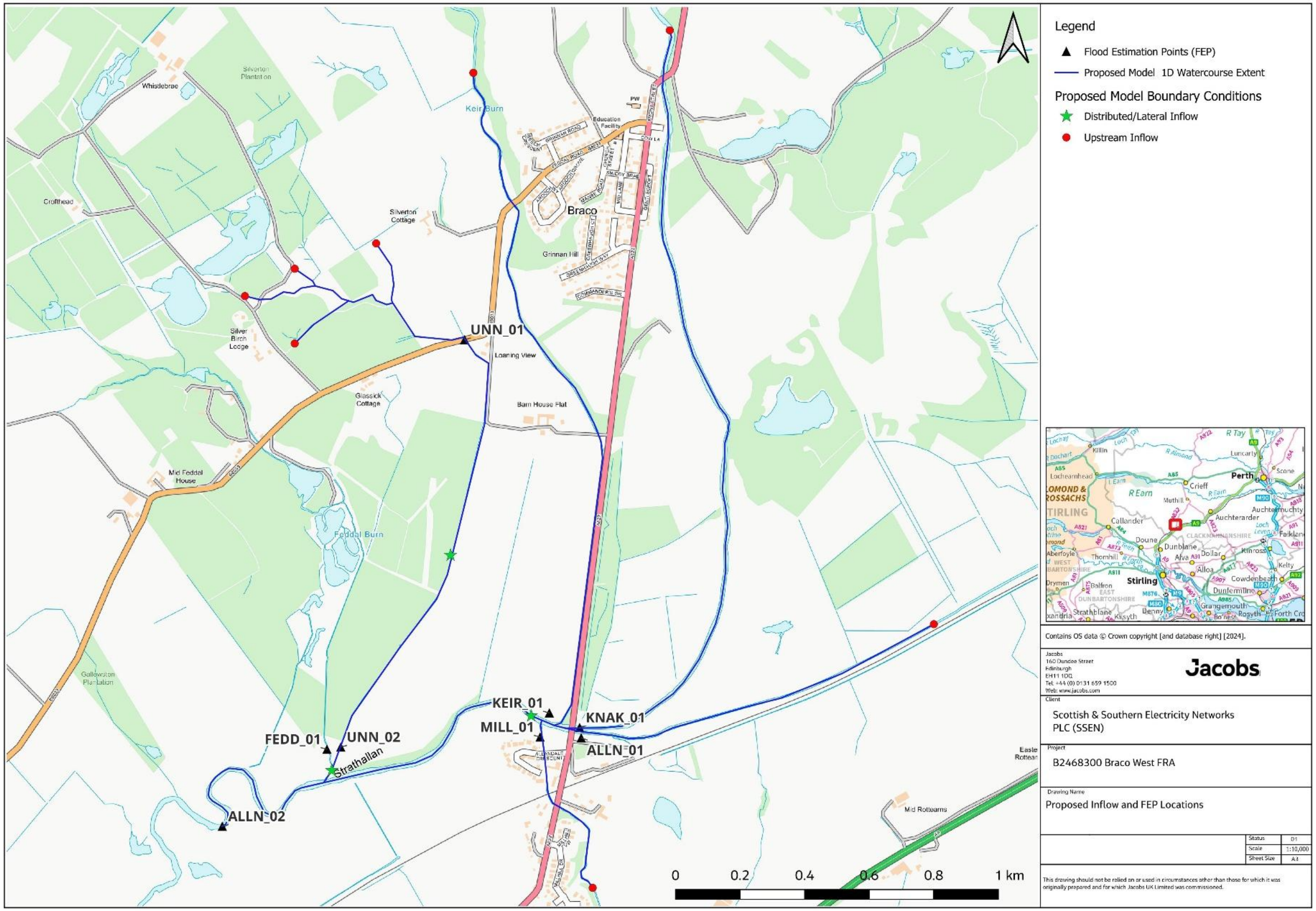


Figure 3-2 Proposed model schematisation showing inflow application locations.

Final catchment descriptors at each flood estimation location:

Table 3-3 outlines the final updated catchment descriptors for each FEP. Note that values which have been updated are highlighted in red.

Table 3-3 Updated catchment descriptors for the assessment

Site code	FARL	PROPWET	BFIHOST19	SPRHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000	FPEXT
ALLN_01	0.942	0.59	0.607	33.84	8.385	92.7	1280	0.001	0.002	0.075
ALLN_02	0.967	0.59	0.517	40.08	10.040	98.8	1401	0.001	0.002	0.068
KNAK_01	0.995	0.59	0.433	45.23	10.959	120.1	1608	0.001	0.001	0.054
KEIR_01	0.998	0.59	0.318	53.96	7.339	84.7	1475	0.001	0.001	0.041
MILL_01	0.994	0.59	0.538	36.98	4.132	110.8	1371	0.002	0.001	0.038
FEDD_01	0.982	0.59	0.475	46.83	3.068	58.6	1240	0.000	0.000	0.088
UNK_01	0.943	0.59	0.527	44.65	1.034	38.3	1195	0.000	0.000	0.074
UNK_02*	1	-	-	-	-	-	-	-	-	-
RES_01*	1	-	-	-	-	-	-	-	-	-

** Except for FARL, all other CDs are borrowed from donor catchment (UNN_01)*

Catchment area and checks on catchment boundary:

Catchment boundaries and catchment descriptors (CDs) were obtained from the FEH webservice for each of the FEPs shown in Table 3-3. LiDAR data was not available within the study area therefore catchment boundaries were reviewed and updated using Ordnance Survey (OS) Mapping with 10-meter elevation contours. Historical mapping from the National Library of Scotland[7] were also used to review watercourse alignments and likely flow pathways.

For all FEPs the revised catchment areas were selected for further hydrological calculations. Further checks and adjustments were made to ensure that catchment boundaries were fully aligned so that there was no double counting. A comparison between the original (default FEH web service) and revised catchment boundaries can be found in Appendix B.

URBEXT source and method for updating:

URBEXT2000 and URBEXT1990 were derived using the FEH catchment descriptor for each catchment. The urban coverage defined on the FEH web portal was reviewed against the latest OS mapping and judged to be appropriate with no significant urban development observed. The updates to the catchment boundaries were also all in rural locations and did not involve the removal or addition of urbanised areas. The URBEXT2000 and URBEXT1990 values were therefore updated to the current year using the urban expansion factors outlined in LIT 11832 and shown in Equation 3-1.

[7] National Library of Scotland. Accessed from [Map images - National Library of Scotland (nls.uk)]

URBEXT1990

$$UEF = 0.8165 + 0.2254\ \tan^{-1}\{(Year - 1967.5)/21.25\}$$

URBEXT2000

$$UEF = 0.7851 + 0.2124\ \tan^{-1}\{(Year - 1967.5)/20.32\}$$

Equation 3-1 Urban expansion factor equations used for the study.

The updated URBEXT1990 and URBEXT2000 can be seen in Table 3-3. The updated values are included in WINFAP5 but will be applied manually within REFH2.

BFIHOST and SPRHOST source, checks and updates:

BFIHOST and SPRHOST are based on the 29-class Hydrology Of Soil Types (HOST) classification and provide a measure of catchment responsiveness to rainfall in terms of the standard percentage of runoff. The catchments within the area of interest (see Table 3-3) all have moderate BFIHOST19 and SPRHOST values but shows some variations. BFIHOST ranges ranging from 0.607 for the upper Allan Catchment to 0.318 for the Keir Burn. SPRHOST ranges from 33.84% for the upper Allan Water Catchment to 53.96% for the Keir Burn.

BFIHOST and SPRHOST were checked against BGS and soil association mapping. The catchment is underlain predominantly by Dunblane Sandstone of the Arbuthnott-Garvock Group which is a highly productive aquifer and mixed superficial deposits of till, glaciofluvial and alluvial deposits. The catchments of the Keir Burn and Knaik however also encompass less permeable Cromlix Mudstone and low permeability peat. These geological conditions are consistent with the lower BFIHOST19 and higher SPRHOST values for the River Knaik and Keir Burn indicating that these catchments are likely to have a greater responsiveness to rainfall.

DPLBAR and DPSBAR adjustments for reservoir length and slope:

DPLBAR was updated were significant adjustments made to the catchment area from the FEH webservice (+/-5% change in area). The use of the standard power term (AREA^0.548) in some cases resulted in an increase in DPLBAR with a reduction in catchment area and decrease in DPLBAR with an increase in catchment area. Therefore, DPLBAR values were adjusted by deriving an exponent by regression on the catchment area:

Updated DPLBAR = Updated AREA ^ (LOG(Original DPLBAR)/LOG(Original AREA))

The change in topographic slope following the catchment area revision was judged to be minor hence the default DPSBAR was retained for all catchments.

Checks and revisions to other catchment descriptors:

Several catchments include ponds and reservoirs which may influence flows. Flow pathways and outflows from these reservoirs were checked using OS mapping and judged to be appropriate. Note that several ponds have multiple outlets and discharge into several watercourses. Given the lack of LiDAR data existing FEH catchment boundaries were largely retained at these locations.

No revisions were made to any of the other catchment descriptors which were judged to be appropriate.

4. Stationary statistical methods

4.1 Method overview

What is the purpose of applying these methods?

FEH Statistical analysis is required to derive design peak flow estimates at each FEP for the hydraulic model. The FEH Statistical estimates will be compared to other methods.

What methods will be used to estimate QMED and growth curves?

All watercourses within the study area are ungauged. The nearest gauging station is along the Allan Water at Kinbuck (18001) 7.5km downstream of the proposed hydraulic model extent and is therefore unsuitable to use directly for QMED estimation.

QMED will be derived from catchment descriptors using the standard regression equation with donor adjustment. The donor sites identified within WINFAP5 will be reviewed to ensure their suitability. For the residual catchment (RES_01) and the unnamed tributary downstream of the A802 (UNNK_02) QMED will be estimated using a donor catchment (UNN_01) and scaled based on the ratio of catchment areas.

The ‘ungauged pooled’ method will be used to derive a flood growth curve (FGC) using a group of hydrologically similar stations. Given the variation in catchment characteristics, three pooling groups will be derived (1) for the Allan Water catchment (ALLN_02), (2) for the River Knaik (KNAK_01) and (3) for the Feddal Burn (FEDD_01). The Feddal Burn catchment is smaller than 40km^2 hence the revised similarity distance measure (SDM) method will be used to derive this pooling group. For consistency the Feddal Burn pooling group will be applied to all tributary catchments which have an area below 40km^2. The proposed methods are summarised in Table 4-1.

Table 4-1 Methods used for QMED estimation and growth curves.

<table>
<tr><th>Site code</th><th>Methods used for QMED</th><th>Methods used for growth curves</th></tr>
<tr><td>ALLN_01</td><td rowspan="7">Catchment descriptor method with donor adjustment</td><td rowspan="3">Pooling group (standard SDM)</td></tr>
<tr><td>ALLN_02</td></tr>
<tr><td>KNAK_01</td></tr>
<tr><td>KEIR_01</td><td rowspan="6">Pooling group (Revised SDM)</td></tr>
<tr><td>MILL_01</td></tr>
<tr><td>FEDD_01</td></tr>
<tr><td>UNK_01</td></tr>
<tr><td>UNK_02</td><td rowspan="2">Donor QMED areally scaled</td></tr>
<tr><td>RES_01</td></tr>
</table>

The gauging station at Kinbuck (18001) is a peak flow rated gauge, but the NRFA indicates that this gauge is not suitable for pooling group analysis due to a lack of high flow gauging. For comparative purposes and to establish the rarity of the largest flood events both a single site and enhanced single site analysis will still be undertaken to derive flood growth curves. The FCC at the gauge will be compared with that at the downstream model extent of the current study.

4.2 QMED at ungauged subject sites

A summary of the default QMED and the final QMED following donor transfer can be seen in Table 4-2.

Table 4-2 Summary of QMED and adjustment at each FEP

Site Code	QMED (rural) from CDs (m^3/s)	Final method	Data transfer					Urban adjust-ment factor UAF	Final estimate of QMED (m^3/s)
			NRFA numbers for donor sites used (see 4.3)	Distance between centroids d_{ij} (km)	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor			
						Weight	Weighted ave. adjustment		
ALLN_01	17.098	DT	1003	5.074	1.024	-	-	1.003	17.545
ALLN_02	53.101	DT	1003	0.998	1.040	-	-	1.002	55.341
KNAK_01	33.082	DT	1003	5.928	1.022	-	-	1.001	33.864
KEIR_01	13.935	DT	1003	3.758	1.026	-	-	1.001	14.317
MILL_01	3.702	DT	1003	4.958	1.024	-	-	1.001	3.794
FEDD_01	2.882	DT	1003	1.345	1.037	-	-	1.000	2.989
UNN_01	0.669	DT	1003	0.422	1.046	-	-	1.000	0.699
UNN_02	0.277	DT	1003	0.130	1.050	-	-	1.000	0.291
RES_01	1.680	DT	1003	-	1.040	-	-	1.000	1.747

Are the values of QMED spatially consistent?		Yes.
Method used for urban adjustment for subject and donor sites		Kjeldsen (2010)[8] / WINFAP v5[9]
Parameters used for WINFAP v5 urban adjustment if applicable		
Impervious fraction for built-up areas, IF	Percentage runoff for impervious surfaces, PR_{imp}	Method for calculating fractional urban cover, URBAN
0.3	70%	From updated URBEXT2000

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width; LF – Low flow statistics.

The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment.

Review of Donor Sites:

WinFAP5 was used to identify suitable donor sites at each FEP, and these were then reviewed. The top 10 donor sites identified showed little variation between FEPs with Allan Water at Kinbuck (18001) the topmost hydraulically similar for all except the Mill Burn (MILL_01).

All stations had suitable record lengths however several were discounted due to large differences in area and artificial influences. Stations that were not gauged to QMED and/or where significant bypassing was noted were also discounted. A summary of the assessment can be seen in Table 4-3.

[8] Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

[9] Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

Table 4-3 Overview of potential donor stations identified within WINFAP5.

Station	Years of data	Area (km^2)	Adjustment Ratio*	Comments
18001 (Allan Water @ Kinbuck)	30	160	1.051	Located downstream of the subject site on the same river, with catchment area approximately 28% larger than that at the FEP (target location) in the study area, gauged to QMED and no bypassing. **Station most suitable.**
18005 (Allan Water @ Bridge of Allan)	26	210	0.908	Located along Allan Water. Close fit in terms of catchment parameters however not gauged to QMED. Noted that peak flows can be lower than at the station upstream (18001) and resulted in a reduction in QMED. **Precautionary approach taken and station discounted.**
16004 (Earn @ Forteviot Bridge)	35	784	1.117	Greater than 5 times catchment area of ALLN_01 and significant artificial influence with multiple reservoirs and flow transfer. **Station discounted.**
16001 (Earn @ Kinkell Bridge)	58	585	1.111	large catchment area compared to subject catchments. Very low FARL reflective of significant artificial influence with multiple reservoirs present. **Station discounted.**
16003 (Ruchill Water @ Cultybraggan)	52	101	1.677	Located on neighbouring catchment and gauged to QMED with no bypassing noted. Good fit in terms of key catchment characteristics however mountainous, flashy catchment with much higher SAAR and no reservoir attenuation (FARL = 1). **Station suitable**.
18014 (Bannock Burn @ Bannockburn)	30	25	1.217	Very low FARL value (FARL = 0.89) indicating significant artificial influence within catchment. This is not outlined on the NRFA website however a precautionary approach was taken. **Station discounted.**
15013 (Almond @ Almondbank)	36	173	1.205	Close fit in terms of catchment properties with no reservoir attenuation (FARL = 1), bank instability/engineering works noted. **Station suitable.**
17001 (Carron @ Headswood)	34	121	1.558	Low FARL indicating significant artificial influence within catchment. Not gauged to QMED and reservoirs and export of water can influence flows. **Station discounted.**
15023 (Braan @ Hermitage)	31	211	1.491	Gauged to QMED with no bypassing. Close fit in terms of catchment characteristics however low FARL value indicating significant artificial influences from reservoirs. **Precautionary approach taken and station discounted.**
18003 (Teith @ Bridge of Teith)	52	516	1.807	Very low FARL value (FARL = 0.76) indicating significant artificial influence within catchment. **Station discounted.**

** without moderation by power term*

Donor sites chosen and QMED adjustment factor:

Three stations were considered suitable (18001, 16003 and 15013). The station 18001 (Allan Water at Kinbuck) was found to be the most suitable and selected as it is located on the same river further downstream of the study area with catchment area just 28% higher than that at study catchment target site, and has a good record length with no bypassing noted. Station 16003 is located on a neighbouring catchment but had a more mountainous flashy catchment with a higher SAAR compared to the subject site. 15013 is located a distance away from the area of interest and was the least hydrologically similar of the three stations. For consistency station18001 (Allan Water @ Kinbuck) will be applied to all FEPs. Table 4-4 shows the key QMED characteristics and the moderated adjustment factors are shown in Table 4-2.

Table 4-4 Overview of selected donor catchment

NRFA no.	Method (AM/ POT/LF)	Adjustment for climatic variation?	QMED from flow data (m^3/s)	De-urbanised QMED from flow data (m^3/s)	QMED from catchment descriptors (m^3/s)	Adjustment ratio
18001	AM	No	71.024	70.894	67.42	1.051

Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

4.3 Estimating growth curves

Derivation of growth curves at subject sites:

Pooling groups were derived for three FEPs including ALLN_02, KEIR_01 and FEDD_01. The final pooling group and associated parameters are summarised in Table 4-5. Note that for comparative purposes growth curves were also derived at the Kinbuck (18001) gauging station on the Allan Water using the single site and enhanced single site methods.

Table 4-5 Pooling group analysis and results.

Site code	Method (SS, P, ESS, H)	If P or ESS name of pooling group	Distribution used and reason for choice	Urban/non-flood year adjustments	Parameters of distribution	0.5% AEP Growth factor
ALLN_02	P	ALLN_02 REV PG01	Kappa 3. Produced the best fit with distribution.	urban adjustment	Location: 0.95 Scale: 0.22 Shape: -0.122	2.541
KNAK_01	P	KNAK_01 REV PG01			Location: 0.949 Scale: 0.223 Shape: -0.129	2.640
FEDD_01	P	FEDD_01 REV PG01 SDM			Location: 0.94 Scale: 0.264 Shape: -0.157	3.120
Kinbuck 18001	SS	-	Kappa 3.	-	Location: 0.967 Scale: 0.146 Shape: -0.134	2.093
	ESS	KIN_ESS_REV PG01	GEV. Best fit with distribution.	urban adjustment	Location: 0.923 Scale: 0.208 Shape: -0.024	2.102

Methods: SS - Single Site; P - Pooled; ESS - Enhanced Single Site; H - Historical.

Urban adjustments are carried out using the method of Kjeldsen (2010).

Flood frequency curve plots:

The flood frequency curves can be seen on Figure 4-1 and Figure 4-2. Both the single site and enhanced single site analysis produced flatter growth curves compared to those generated using pooling analysis at the three FEPs.

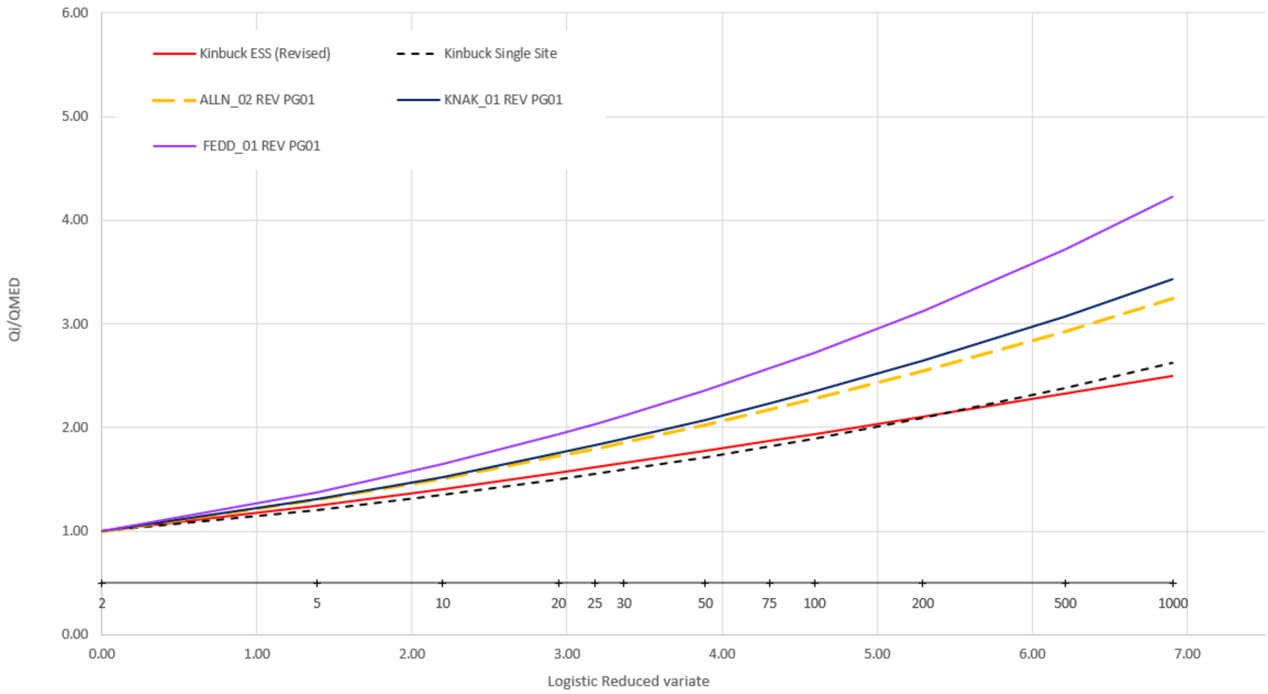


Figure 4-1 Comparison of growth curves

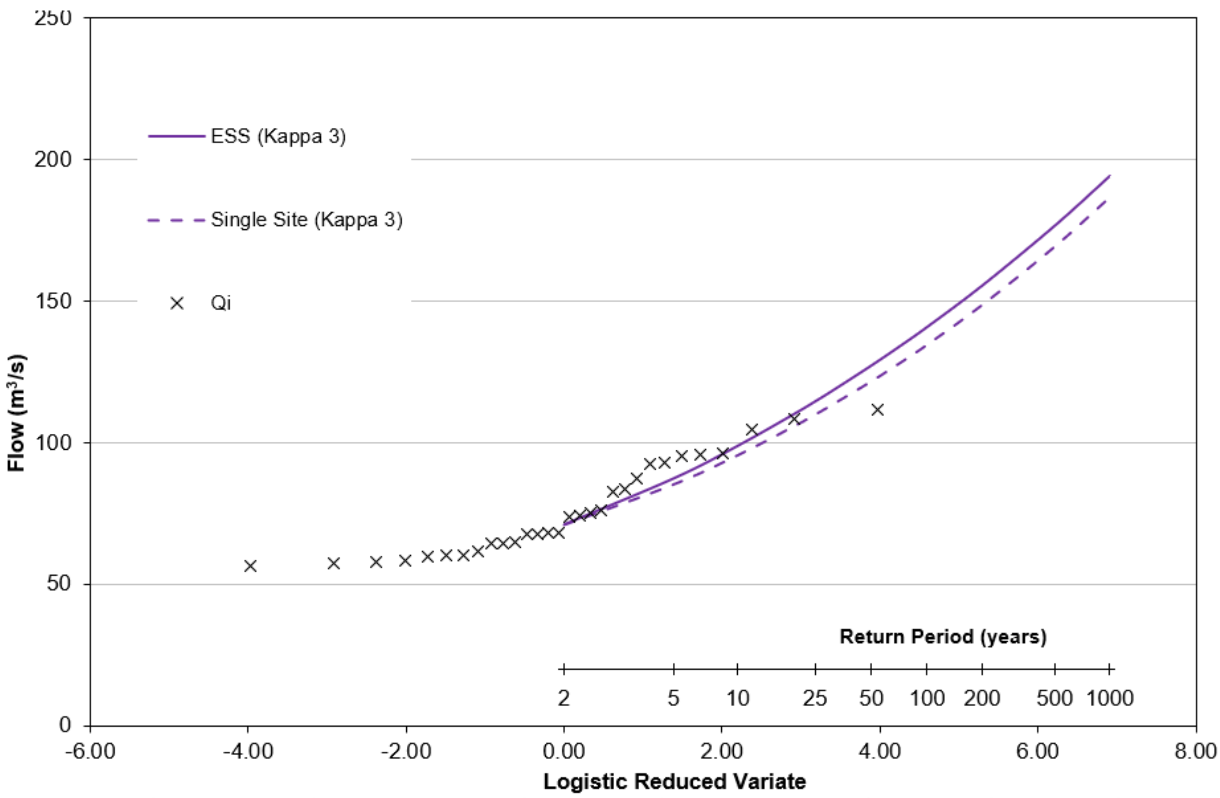


Figure 4-2 Single and Enhanced Single Site Growth curve at the Kinbuck gauge.

Derivation of Pooling Groups:

Pooling groups were derived using the procedures from Science Report SC050050 (2008)[10]. Details are presented in Table 4-6.

Table 4-6 Summary of pooling group assessment

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	URBEXT2000 threshold applied to pooling group selection?	L-moments deurbanised (including subject site for ESS)?	Small catchment pooling procedure applied?
ALLN_02 REV PG01	ALLN_02	No	0.03	Yes	No
KNAK_01 REV PG01	KEIR_01	No	0.03	Yes	No
FEDD_01 REV PG01	KNAIK_01	No	0.03	Yes	Yes
Methods: Pooling groups were derived using the procedures from Science Report SC050050 (2008). The small catchment pooling procedure is given in the report on Phase 2 of project SC090031 (2021) and implemented in WINFAP v5.					

[10] Defra / Environment Agency (2008). Improving the FEH statistical procedures for flood frequency estimation. Science Report: SC050050. ISBN: 978-1-84432-920-5 © Environment Agency – June 2008

Pooling group composition:

Details on the composition of each pooling group are presented in Appendix A and summarised in Table 4-7.

Table 4-7 Summary of pooling group assessment and changes

Name of group	Changes made to default pooling group, with reasons.		Weighted average L-moments
ALLN_02 REV PG01	**Removed:**		L-CV: 0.181 L-SKEW: 0.186
	203033 (Upper Bann @ Bannfield)	Negative L-skew value which may indicate issues with data quality. Station is not gauged to QMED, and the recent gauging's suggest that rating overestimates flow.	
	Added:		
	None	Number of gauged years remained above 500.	
KNAK_01 REV PG01	**Removed:**		L-CV: 0.185 L-SKEW: 0.199
	48001 (Fowey @ Trekeivesteps)	Not gauged to QMED and no available gauging's to validate rating. Substantial flow modification from Sibleyback Reservoir noted.	
	Added:		
	None	Number of gauged years remained above 500.	
FEDD_01 REV PG01	**Removed:**		L-CV: 0.22 L-SKEW: 0.221
	28033 (Dove @ Hollinsclough)	Noted difficulties gauging higher flows and rating may underestimates flow. Precautionary approach taken and station removed.	
	76011 (Coal Burn @ Coalburn)	Not gauged to QMED and few high flow gauging's. Rating curves deviate around QMED. Recent gauging's suggest that peak flows may be underestimated.	
	25011 (Langdon Beck @ Langdon)	Recent higher gauging's suggest rating may under-estimate peak flows and rating review is required.	
	44008 (South Winterbourne @ Winterbourne Steepleton)	Very high BFIHOST/Low SPRHOST. Catchment underlain by chalk bedrock.	
	18014 (Bannock Burn @ Bannockburn)	Low FARL indicating significant artificial influence from reservoirs.	

Name of group	Changes made to default pooling group, with reasons.		Weighted average L-moments
	Added:		
	72014 (Conder @ Galgate)	Hydrologically similar and catchment characteristics well matched with subject site. Good record length and data quality.	
	73015 (Keer @ High Keer Weir)		
	72007 (Brock @ upstream of A6)		
	76023 (Dacre Beck @ Dacre Bridge)		
KIN_ESS REV PG01	**Removed:**		L-CV: 0.141 L-SKEW: 0.186
	203022 (Blackwater @ Derrymeen Bridge)	Major arterial drainage scheme within catchment and unusual catchment geology means that the station has a flat growth curve.	
	71011 (Ribble @ Arnford)	Negative L-skew indicative of issues at the station. Noted growth curve for this station is unusually low due to storage just upstream from Arnford at Long Preston Ings.	
	78005 (Kinnel Water @ Bridgemuir)	Negative L- skew indicative of issues at the station.	
	Added:		
	79005 (Cluden Water @ Fiddlers Ford)	Located in Scotland, Close fit in terms of catchment properties, good record length and confidence in rating,	
	79004 (Scar Water @ Capenoch)		

For each site alternative pooling groups were considered involving more extensive alterations to include local (Scottish) stations. These had little impact in terms of the overall group heterogeneity and generally resulted in a slightly shallower growth curve, with some reduction in the value of 0.5% AEP growth factor. Similarly, the more extensively altered pooling groups resulted in different distributions for the best fit. To ensure continuity the pooling groups outlined above were retained.

4.4 Final choice of QMED and growth curves

Method choice and reasons

The final choice of method to derive peak flow estimates from FEH statistical method, including QMED and growth curve at each FEP is presented in Table 4-8.

Table 4-8 Final choice of method from the FEH statistical method

<table>
<tr><th>Site code</th><th>Final choice of QMED and reasons</th><th>Final choice of flood growth curve method and reasons</th></tr>
<tr><td>ALLN_01</td><td rowspan="7">Catchment descriptor method with donor adjustment using the Kinbuck gauging station on Allan Water (18001)</td><td rowspan="2">Pooling group (standard SDM) using pooling group ALLN_01 REV PG01</td></tr>
<tr><td>ALLN_02</td></tr>
<tr><td>KNAK_01</td><td>Pooling group (standard SDM) using pooling group KNAK_01 REV PG01</td></tr>
<tr><td>KEIR_01</td><td rowspan="6">Pooling group (Revised SDM) using pooling group FEDD_01 REV PG01. This provided a steeper growth curve reflective of flashier catchment response.</td></tr>
<tr><td>MILL_01</td></tr>
<tr><td>FEDD_01</td></tr>
<tr><td>UNN_01</td></tr>
<tr><td>UNN_02</td><td rowspan="2">Donor with areal scaling.</td></tr>
<tr><td>RESD_01</td></tr>
<tr><td>Kinbuck 18001</td><td>AMAX Data</td><td>Growth curve derived using the single site as well as ESS method with a rrevised pooling group</td></tr>
</table>

Final flood estimates from stationary statistical methods

The final peak flow estimates derived by the FEH Statistical method are presented in Table 4-9 and the final growth curves in Table 4-10.

Table 4-9 Final peak flow estimated from the FEH statistical method.

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events								
	50	20	10	3.33	2	1.33	1	0.5	0.1
ALLN_01	17.5	22.8	26.4	32.5	35.5	38.1	39.9	44.6	57.0
ALLN_02	55.3	71.8	83.4	103	112	120	126	141	180
KNAK_01	33.9	44.2	51.6	64.1	70.3	75.6	79.4	89.4	116
KEIR_01	14.3	19.6	23.6	30.3	33.8	36.7	38.9	44.7	60.6
MILL_01	3.79	5.20	6.24	8.03	8.95	9.74	10.3	11.8	16.1
FEDD_01	2.99	4.10	4.92	6.33	7.05	7.67	8.13	9.33	12.6
UNN_01	0.699	0.959	1.15	1.48	1.65	1.80	1.90	2.18	2.96
UNN_02	0.291	0.398	0.478	0.615	0.686	0.746	0.790	0.907	1.23
RESD_01	1.75	2.40	2.87	3.70	4.12	4.48	4.75	5.45	7.39

Table 4-10 Adopted final growth curves from the FEH statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events								
	50	20	10	3.33	2	1.33	1	0.5	0.1
ALLN_01 ALLN_02	1.00	1.30	1.51	1.85	2.03	2.17	2.27	2.54	3.25
KNAK_01	1.00	1.31	1.52	1.89	2.08	2.23	2.35	2.64	3.43
KEIR_01 MILL_01 FEDD_01 UNN_01 UNN_02 RESD_01	1.00	1.37	1.65	2.12	2.36	2.57	2.72	3.12	4.23

5. Revitalised flood hydrograph 2 (ReFH2) method

5.1 Method Overview

ReFH2 will be used in this study to compare with the FEH statistical peak flow estimates, to derive the 0.1% AEP statistical peak flow and to derive the hydrograph shape for preparing model inflow for use in an updated numerical hydraulic model of the Allan Water and its tributaries in the vicinity of the study area. The ReFH2 derived hydrograph shapes for the Allan Water main stem will be compared with those derived using the Archers method at Kinbuck gauging station (outlined in Section 6).

In addition, the ReFH2.3 peak flows will also be utilised to extend the final flood frequency curve for the flood event rarer than 0.5% AEP event, following the latest flood estimation guidance.

Version of ReFH2 applied

ReFH2.3 version 4.1.8, which utilises FEH22 rainfall data.

Rural and urban catchment sub-divisions

All catchments are classified as essentially rural, as the largest value of URBEXT2000 is 0.002.

5.2 Model Parameters

The model parameters used for each of the FEP are shown in Table 5-1.

Table 5-1 ReFH2 model parameters used for each of the FEP.

Site code	Method	Tp (hours) Default	Tp (hours) LAG	Cmax (mm)	BL (hours)	BR	PRimp %
ALLN_01	LAG	2.575	3.494	536.463	30.776	1.983	0.7
ALLN_02	LAG	2.672	3.626	443.383	32.457	1.906	0.7
KNAK_01	LAG	2.555	3.467	371.137	33.449	1.192	0.7
KEIR_01	LAG	2.547	3.456	290.927	30.574	0.507	0.7
MILL_01	LAG	1.889	2.563	463.543	25.791	2.030	0.7
FEDD_01	LAG	2.177	2.954	405.655	24.019	1.831	0.7
UNN_01	LAG	1.768	2.399	452.871	18.081	2.145	0.7
UNN_02	LAG	1.584	2.149	-	-	-	0.7
RESD_01	DT	1.866	2.532	-	-	-	0.7

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

Analysis undertaken to derive model parameters:

Lag analysis was undertaken to estimate time to peak (Tp) using 15-minute flow data from the gauging station at Kinbuck (18001) and 15-minute rainfall data from the Dandruff rain gauge. Calculation details are included in 'Tp from Data Allan Water – Manual.xlsx'. A summary of the AMAX series used to calculate lag are included in Table 5-2. Note that multiple AMAX events were removed due to poor quality data or having bimodal storms.

Table 5-2 Summary of Lag Analysis for key events

Water Year	Max Flow (m3/s)	Date	Lag	Tp
1996-1997	65.091	28/10/1996	9.31	7.34
1997-1998	59.62	11/02/1998	9.27	7.30
1999-2000	68.315	30/11/1999	20.92	15.84
2006-2007	108.365	14/12/2006	9.43	7.42
2013-2014	61.634	30/12/2013	10.06	7.90
2015-2016	92.409	05/12/2015	6.38	5.12
2018-2019	58.404	31/08/2019	11.12	8.69
2019-2020	95.919	21/02/2020	8.67	6.85
2020-2021	57.546	27/12/2020	10.55	8.26
Geometric Mean			**10.117**	**7.939**

The Tp value estimated from the lag analysis was compared to the Tp calculated from the FEH catchment descriptors equation and used to derive an adjustment factor based on the formula outlined in Volume 4 of the FEH ($Tp(0) = 0.879{*}LAG^{0.951}$). The resultant adjustment factor is outlined in Table 5-3 and the default and adjusted Tp values are shown in Table 5-1.

Table 5-3 Estimated adjustment factor.

Method	Tp(0) (hrs)
Flood event analysis (Lag analysis)	7.94
FEH Tp(0) CDs equation	5.85
ReFH Tp(0) CDs equation	4.05
Adjustment factor	**1.357**

The use of local data to inform lag analysis, makes the Tp value calculated a recommended approach. Further checks were undertaken by comparison the adjusted ReFH2 hydrograph for the ALLN_01 with that calculated using the Archers Method at the Kinbuck gauging station. The results are outlined in Section 6.1 and the hydrograph shape show a close similarity. The adjusted Tp values were therefore applied for all ReFH2 analysis.

5.3 Model inputs for design events

As noted previously, the following hydraulic model runs were used to examine the flood risk across the modelled reaches:

- Run 1 - a distributed catchment modelling approach to determine the 0.5% AEP (200-year) flood risk to the project area dominated by the flooding from Alan Water, and in which a single storm duration as that of Allan Water will be applied across all sub-catchments; and
- Run 2 - a lumped catchment modelling approach to determine the flood risk for range of AEP from the lateral watercourses in the vicinity of the project area, and in which the model inflows are derived for the individual watercourse's critical durations

Assessment of critical storm duration for all catchments

The storm durations calculated automatically within ReFH2.3 ranged from 9.5-hours for the River Knaik (KNAK_01) to 5.5-hours for the Unnamed Watercourse. The critical storm duration was identified by iteratively varying the storm duration within ReFH2 for each FEP. The duration which provided the largest design 0.5% AEP peak flow was adopted for the study. The critical storm durations were found to be approximately double the default values.

Design events for lumped catchments:

The optimised critical storm durations for the individual catchment (Run 2) are outlined in Table 5-4. The lumped flows were generated using the storm duration relevant to each lumped catchment. No adjustments have been made to the default Cini and BFI values.

Table 5-4 Design events for the lumped catchment approach (Run 2)

Site code	Rainfall DDF model	Urban or rural	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO
ALLN_01	FEH22	Urban	Winter	23.5	81.497	1.929
ALLN_02				23.5	99.152	5.653
KNAK_01				17.5	119.064	2.486
KEIR_01				12.5	152.966	0.874
MILL_01				15.5	94.717	0.229
FEDD_01				12.5	108.653	0.176
UNN_01				10.5	97.015	0.04
UNN_02				10.5	-	-
RESD_01				10.5	-	-

Design events for sub-catchments and intervening areas:

The distributed catchment method (Run 1) involves the assessment of longer duration events critical to the Allan Water full catchment area. For this scenario all FEPs were set to the critical duration and areal reduction factor of Allan Water (ALLN_02, 23.5 hours). The parameters for the distributed approach are outlined in Table 5-5 and the final results in Section 7.3.

Table 5-5 Design events for the distributed catchment approach (Run 1)

Site code(s)	Rainfall DDF model	Season of design event	Storm duration (hrs)	Storm area for ARF	Areal reduction factor (ARF)	Reason for selecting storm
All FEPs	FEH22	Winter	23.5	-	0.939	23.5-hr is the critical storm duration for the Allan Water (ALLN_01)

Storm duration sensitivity analysis within hydraulic model

The storm durations identified above do not explicitly account for hydraulic constraints such as culverts within the area of interest. Further testing will be undertaken as part of the hydraulic model build to assess sensitivity to flood volume and storm duration. This will be undertaken by varying the storm duration for the lumped 0.5% AEP event (Run 2) by +/-25% within ReFH2.

The ReFH2 hydrograph will be scaled to the 0.5% AEP target peak flow (Run 2) which will be adjusted using the same scaling factor as that for the critical storm duration. This will mean that the peak for +/-25% of CSD would be slightly smaller than target peak flow, but the hydrograph base will be wider/narrower based on whether it is +25% or -25%. Should the results be found to be sensitive to flood volume additional analysis may be considered. Further details will be provided within the hydraulic modelling report.

5.4 Final choice of ReFH2 flow estimates

Method choice and reasons:

The final choice of methods for model parameters and design inputs for the ReFH2 analysis are outlined in Table 5-6. Note that as both lumped and distributed modelling will be undertaken multiple choices of methods are outlined.

Table 5-6 Summary of selected approach for the ReFH2 method

Site code	Final choice of ReFH2 design inputs and model parameters
ALLN_01 ALLN_02	Model parameters from catchment descriptors with T_P scaled based on the result of lag analysis, critical storm duration 23.5 hours for both Run 1 and Run 2.
KNAK_01	Model parameters from catchment descriptors with TP from lag analysis, critical storm duration 23.5 hours for the Run 1 and 17.5 hours for Run 2.
KEIR_01	Model parameters from catchment descriptors with TP from lag analysis, critical storm duration 23.5 hours for Run 1 and 12.5 hours for Run 2.
MILL_01	Model parameters from catchment descriptors with TP from lag analysis, critical storm duration 23.5 hours for Run 1 and 15.5 hours for Run 2.
FEDD_01	Model parameters from catchment descriptors with TP from lag analysis, critical storm duration 23.5 hours for Run 1 and 12.5 hours for Run 2.
UNN_01	Model parameters from catchment descriptors with TP from lag analysis, critical storm duration 23.5 hours for Run 1 and 10.5 hours for Run 2.
UNN_02	Peak flows estimated using donor station (UNN_01) and areal scaled.
RESD_01	Hydrographs generated using model parameters from catchment descriptors with T_P from lag analysis, critical storm duration 23.5 hours for Run 1 and 10.5 hours for Run 2.

Final flood estimates from ReFH2 method:

The final peak flow estimates derived by the ReFH2 method for the lumped model approach (run 2 – with assessed critical storm duration) can be seen in Table 5-7.

Table 5-7 Lumped Flood Peak for each catchment area

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events								

	50	20	10	3.33	2	1.33	1	0.5	0.1
ALLN_01	14.6	18.8	22.0	28.0	31.3	34.3	36.5	42.2	57.3
ALLN_02	48.8	61.5	70.9	87.8	96.9	105	111	127	169
KNAK_01	24.1	30.3	34.8	42.3	46.3	49.9	52.6	59.9	80.4
KEIR_01	8.86	11.3	13.0	15.9	17.4	18.6	19.6	22.2	29.4
MILL_01	2.14	2.76	3.21	4.01	4.44	4.81	5.09	5.83	7.81
FEDD_01	1.77	2.27	2.64	3.26	3.59	3.87	4.08	4.64	6.18
UNN_01	0.446	0.582	0.682	0.854	0.942	1.02	1.08	1.23	1.66
UNN_02	0.141	0.184	0.216	0.270	0.298	0.322	0.340	0.389	0.525

The ReFH2 results for the distributed model (run 1) with the critical duration for all watercourses set to 23.5-hours can be found in Table 7-5 within Section 7.3.

6. Other Rainfall-Runoff or Hydrograph Method

6.1 Averaged Hydrograph Shapes

The Archers method was used to derive an average hydrograph shape for the River Allan for comparison to the hydrograph shape generated using ReFH2.3 model. The flow hydrographs and associated rainfall hyetographs for the top 30 AMAX events were obtained from the Kinbuck (18001) and Dandruff gauges using the SEPA API database. Events which did not contain sufficient rainfall or flow data, or which included multiple peaks were removed. With this a total of 10 events hydrographs were selected from which the following hydrograph was derived (ref Figure 6-1).

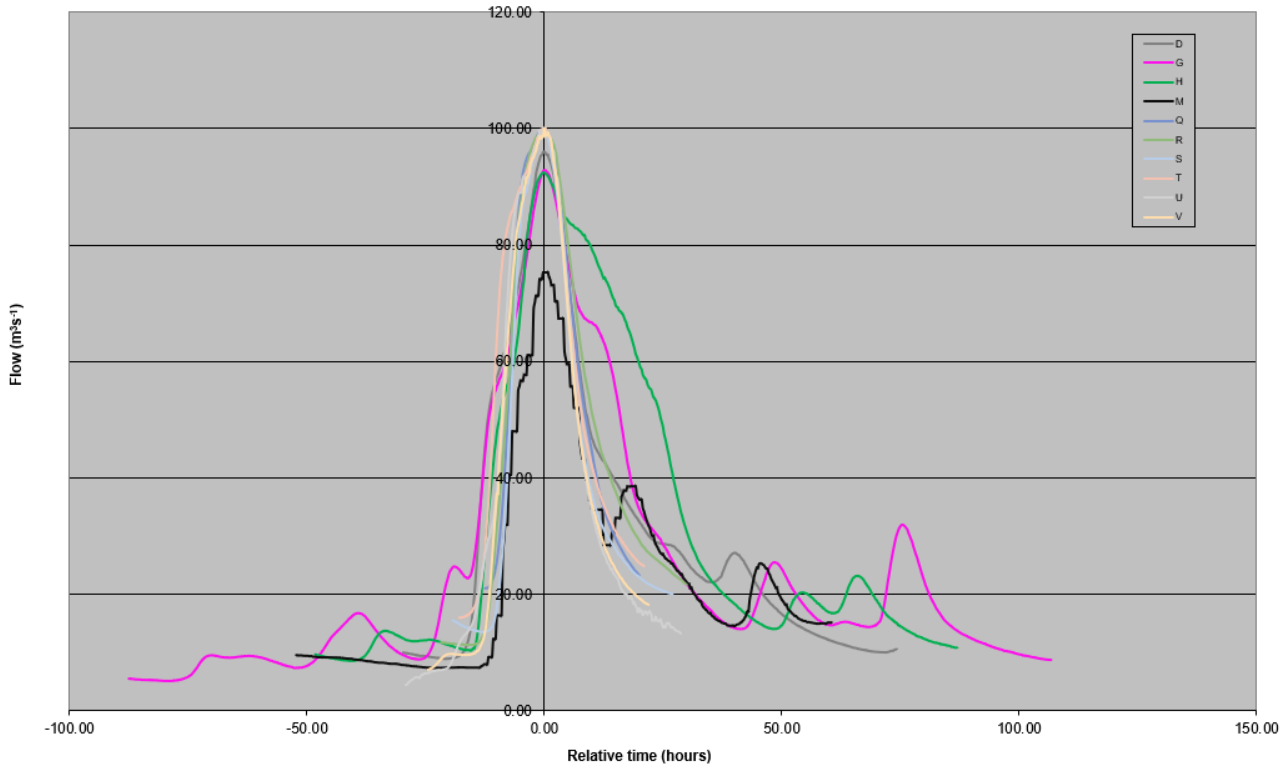


Figure 6-1 Events hydrographs used for Archers Hydrograph Analysis

The full dataset (with bimodal peaks removed) archers hydrograph was compared to the hydrograph generated using ReFH2 with both scaled to the selected 50% and 0.5% AEP estimates at ALLN_02. The results, shown in Figure 6-2, indicated a close fit between the Tp adjusted ReFH2 hydrograph and the Archers method hydrograph shape. It was therefore decided to use the ReFH2 hydrographs with Tp adjustment through lag analysis.

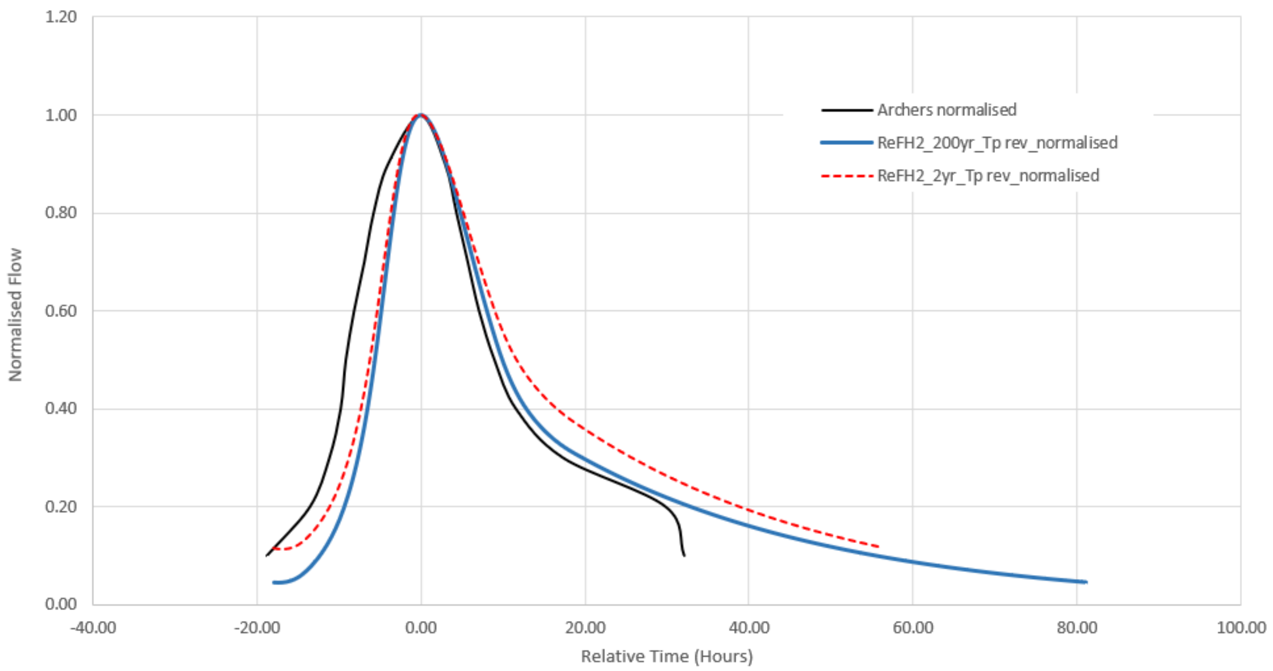


Figure 6-2 Comparison of Archer's hydrograph shape and ReFH2 hydrograph shape for the Allan Water

7. Discussion and summary of results

7.1 Comparison of results from different methods

A comparison between the peak flow estimates from the ReFH2 (lumped) method with those from the FEH Statistical method can be seen in Table 7-1. The FEH statistical estimates are greater than the ReFH2 estimates for all watercourses. The differences between the peak flow values are most pronounced for the small catchments with areas below 30km^2.

Table 7-1 Comparison of FEH statistical and ReFH2 peak flow estimates

Site code	FEH Statistical Peak Flow (m3/s)		ReFH2 Peak Flow (m3/s)		Ratio between ReFH and Statistical Peak	
	50% AEP	0.5% AEP	50% AEP	0.5% AEP	50% AEP	0.5% AEP
ALLN_01	17.5	44.6	14.6	42.2	0.834	0.947
ALLN_02	55.3	141	48.8	127	0.882	0.901
KNAK_01	33.9	89.4	24.1	59.9	0.712	0.67
KEIR_01	14.3	44.7	8.86	22.2	0.619	0.497
MILL_01	3.79	11.8	2.14	5.83	0.564	0.492
FEDD_01	2.99	9.33	1.77	4.64	0.592	0.498
UNN_01	0.699	2.18	0.446	1.23	0.638	0.564
UNN_02	0.291	0.907	0.141	0.389	0.485	0.429

7.2 Final choice of method

Choice of method and reasons:

Although Alan Water is gauged further downstream of the study area, the tributaries of Alan Water are not gauged, and hence for the estimation of design peak flows the FEH statistical (pooling group) and ReFH2.3 methods were applied. Both methods are suitable for the catchments, which are rural, have a moderate BFIHOST19 value and minor attenuation due to reservoirs. The FEH statistical method provided the highest peak flow estimates and was favoured as it is based on a larger dataset of flood events and has been more directly calibrated to reproduce flood frequency on UK catchments. The method will better accounts for local conditions in that nearby gauging stations were used in the donor adjustment process and are included in the pooling group. The FEH statistical method also accounts for the attenuation from ponds and lakes noted in the catchment review.

The FEH statistical method adopted the Kinbuck gauge on the Alan Water as the donor catchment for QMED adjustment, and three revised pooling groups were used to derive the flood growth curves. For consistency the same donor was used for all catchments and the Kappa-3 distribution was selected as this provided the best fit with all the revised pooling groups.

How will the 0.1% AEP flows be estimated?

The ReFH2 flood frequency curve has been used to derive the final flood growth factor for the 0.1% AEP event. The rainfall-runoff method was favoured as there is greater confidence in rainfall frequency curves compared to a statistical flood frequency curves for very rare events (long return periods). To maintain continuity ReFH2 was used to obtain the ratio of the 0.1% to 0.5% AEP flow which was then applied to the preferred 0.5% AEP statistical estimate.

7.3 Final results

Table 7-2 presents the final adopted peak flow estimates for each FEP derived from FEH statistical method. Note that for RESD_01 and UNN_02 these are derived by areal scaling of flows of UNN_01.

Table 7-2 Adopted peak flow estimates (target flow) for each watercourse from FEH statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000*
	Flood peak (m^3/s) for the following AEP (%) events								
	50	20	10	3.33	2	1.33	1	0.5	0.1*
ALLN_01	17.5	22.8	26.4	32.5	35.5	38.1	39.9	44.6	60.5
ALLN_02	55.3	71.8	83.4	103	112	120	126	141	187
KNAK_01	33.9	44.2	51.6	64.1	70.3	75.6	79.4	89.4	120
KEIR_01	14.3	19.6	23.6	30.3	33.8	36.7	38.9	44.7	59.2
MILL_01	3.79	5.20	6.24	8.03	8.95	9.74	10.3	11.8	15.9
FEDD_01	2.99	4.10	4.92	6.33	7.05	7.67	8.13	9.33	12.4
UNN_01	0.699	0.959	1.15	1.48	1.65	1.80	1.90	2.18	2.94
UNN_02	0.291	0.398	0.478	0.615	0.686	0.746	0.790	0.907	1.22
RESD_01	1.75	2.40	2.87	3.70	4.12	4.48	4.75	5.45	7.36

**The 0.1% AEP peak flows are derived from 0.5% AEP peak flow multiplied by the ratio of the ReFH2 0.1% and 0.5% AEP peaks flows.*

Climate change allowances

A climate change allowance will be applied to the 0.5% AEP peak flows (Table 7-2) based on the most recent SEPA guidance (November 2023) for the Forth River Basin Region. As per the SEPA guidance, a 56% uplift will be applied to inflows for watercourses with catchments greater than 50km². Similarly, for watercourses with catchment smaller than 30km² a 39% CC uplift will be applied on rainfall intensity. As the statistical method does not use rainfall intensity, equivalent CC uplift to be used on the fluvial flow have been derived using the CC for rainfall intensity directly within the ReFH2 rainfall-runoff model. These equivalent CC uplift values vary from 1.47 to 1.52 and will be applied on the fluvial peak flow. For watercourses with catchments between 30 km² and 50km² both flow and rainfall CC allowances will be compared and the most conservative applied.

For the distributed model (Run 1) which focuses on the full River Allan catchment the CC 56% allowance will be applied to all FEP inflows. For the lumped model (Run 2) with individual critical durations the individual equivalent CC uplifts appropriate for the size of each catchment will be applied. The final 0.5% AEP peak flow with CC are highlighted yellow in Table 7-3.

Table 7-3 Climate change analysis

Catchment	Area (km^2)	0.5% AEP ReFH2 Peak Flow (m^3/s)	0.5% AEP Peak Flow + 56% CC (m^3/s)	39% Rainfall Intensity Allowance	
				0.5% Peak Flow (m^3/s)	% change in flow
ALLN_01	63.008	42.235	65.886	n/a	
ALLN_02	128.289	126.738	197.711		
KNAK_01	40.111	59.867	93.392	89.949	50%
KEIR_01	11.875	22.190	n/a	32.636	47%

Catchment	Area (km^2)	0.5% AEP ReFH2 Peak Flow (m^3/s)	0.5% AEP Peak Flow + 56% CC (m^3/s)	39% Rainfall Intensity Allowance	
				0.5% Peak Flow (m^3/s)	% change in flow
MILL_01	5.627	5.829		8.842	52%
FEDD_01	4.142	4.641		6.83	47%
UNN_01	1.132	1.231		1.831	49%

How will the flows be applied to a hydraulic model?

The model inflow locations are detailed in Section 3 and shown on Figure 3-2. As outlined in Section 2, two approaches will be applied when generating model inflow hydrographs, namely, Run1 and Run 2.

For Run 1 (distributed model), the ReFH2 hydrographs for all catchments derived using a 23.5-hour storm duration (the critical storm duration estimated for the Allan Water (ALLN_02)) will be applied. These are outlined in Table 7-4. A flow reconciliation exercise will be undertaken as part of the hydraulic modelling to ensure that peak flows and hydrograph shape match those estimated at the target location ALLN_02. A global scaling factor may be applied until a suitable (+/-5%) correspondence to the target flow is obtained. Table 7-5 below provides a summary of the initial global scaling factor for each AEP event. The actual scaling factor required to reconcile the flow are presented in Braco Hydraulic Modelling Report.

Table 7-4 Distributed Flood Peak for each catchment area – 23.5 hours

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events								
	50	20	10	3.33	2	1.33	1	0.5	0.1
ALLN_01	14.8	19.0	22.2	28.3	31.7	34.6	36.9	42.7	58.0
ALLN_02	48.8	61.5	70.9	87.8	96.9	105	111	127	169
KNAK_01	22.8	28.3	32.3	39.3	43.0	46.3	48.9	55.7	74.3
KEIR_01	8.14	10.2	11.6	14.2	15.5	16.7	17.6	20.0	26.4
MILL_01	2.04	2.60	3.02	3.79	4.20	4.56	4.83	5.53	7.32
FEDD_01	1.74	2.20	2.53	3.13	3.45	3.72	3.93	4.46	5.86
UNN_01	0.438	0.558	0.647	0.807	0.894	0.969	1.03	1.17	1.56
UNN_02	0.135	0.172	0.199	0.248	0.275	0.298	0.316	0.361	0.479
RESD_01	0.819	1.04	1.21	1.51	1.67	1.81	1.92	2.19	2.91

Table 7-5 Model inflows for run 1 with initial estimated global scaling factors.

Site code	*Peak flow (m^3/s)*				
	2-year	*50- year*	*100-year*	*200-year*	*1000-year*
	50% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
ReFH2 Run 1 total	50.833	100.691	115.359	132.085	176.812
FEH target flow	55.34	112.12	125.85	140.62	179.64
Scaling factor	***1.089***	***1.114***	***1.091***	***1.065***	***1.066***

For Run 2, a hybrid approach will be taken in which ReFH2 hydrographs will be generated for individual watercourse critical duration and scaled to the corresponding FEH statistical target peak flow outlined in Table 7-2. In this simulation, for the Allan Water (ALLN_01) and residual catchment (RESD_01) a constant QMED flow will be applied to the model. As the individual watercourse hydrographs are already scaled to the corresponding statistical peak flow, no flow reconciliation will be required. Sense checks will be undertaken to ensure that the hydrographs along the model are sensible.

7.4 Checks

Growth factor checks

The 0.5% AEP growth factors appear sensible and are within expected values. In the Flood Studies Report's regional growth curves, the ratio of the 100-year to the 2-year flow varied from 2.1 to 4.0.

Table 7-6 Comparison of final growth curves

Site Code	0.5% AEP growth factor	0.1% AEP / 0.5% AEP ratio
ALLN_01	2.541	1.358
ALLN_02		1.330
KNAK_01	2.640	1.342
KEIR_01	3.120	1.326
MILL_01		1.339
FEDD_01		1.332
UNN_01		1.349

Specific discharge

Table 7-7 provides a summary of specific discharge for each FEP and for AEP events. The specific discharge values are within the range expected but notably higher for the Keir Burn, likely due to the more impermeable geology outlined in Section 2.2.

Table 7-7 Flood peak in l/s/ha for the return periods in years of AEP (%) events.

Site code	Flood peak (l/s/ha) for the following return periods (in years)								
	2	5	10	30	50	75	100	200	1000
	Flood peak (l/s/ha for the following AEP (%) events								
	50	20	10	3.33	2	1.33	1	0.5	0.1
ALLN_01	3	4	4	5	6	6	7	7	10
ALLN_02	4	6	6	8	9	9	10	11	15
KNAK_01	8	11	13	16	17	19	20	22	29
KEIR_01	12	16	19	25	28	30	32	37	49
MILL_01	7	9	11	14	16	17	18	21	28
FEDD_01	7	10	12	16	18	19	20	23	31
UNN_01	6	8	10	13	15	16	17	19	26
UNN_02	9	12	14	18	20	22	23	27	36

RESD_01	4	6	7	9	10	11	12	13	18

Spatial consistency of results

The peak flow along the river reach is spatially consistent, as the same donor catchment has been applied to adjust the QMED for all catchments. The QMED at the target location (downstream modelling extent) is consistent with the QMED at Kinbuck gauging station.

Pooling groups have been applied based on catchment properties with FEDD_01 used for all catchments below 30km^2. This provides a steeper FCC compared to those of the Allan Water and River Knaik.

To derive model inflows for the Run 1, a consistent 23.5-hour storm duration has been applied to all watercourses. For Run 2, the ReFH2.3 hydrographs differ in terms of duration between the catchments (ranging from 23.5-hours to 12-hours). Further assessment will be undertaken during the modelling stage of the project to determine sensitivity to storm duration.

Return periods for notable historic floods.

The table below shows the estimated return periods for the top 5 flood events in the Kinbuck at Allan Water AMAX series. This was calculated using the flood statistics calculator within WINFAP5 for the ESS as well as SS analysis flood frequency curves. The results indicate that the largest recorded flood event has a rarity of approximately 20-years and 30-years from the ESS and SS respectively (refer to Table 7-8).

Table 7-8 Estimated return period for the top 5 AMAX events at Kinbuck

Rank	water year	Date	Peak Flow (m^3/s)	ESS - Estimated return period (years)	SS – Estimated return periods (years)
1	1992-1993	16/01/1993	112	21	29
2	2006-2007	14/12/2006	108	17	24
3	2007-2008	26/01/2008	104	13	19
4	2011-2012	29/11/2011	96.0	8	11
5	2019-2020	21/02/2020	95.9	8	11

Compatibility with longer-term flood history

There is limited information regarding past flood events with no recorded flood outlined held by SEPA or PKC. Model outputs will however be compared to photographs of the 2006 flood event and SEPA flood mapping to provide an indication of suitability. It is recommended that a detailed sensitivity analysis is undertaken to provide greater confidence in the model results.

Comparisons with previous studies

Two previous flood studies were identified within or close to the study area and are detailed in Section 2.3. A comparison between the 50% and 0.5% AEP estimated peak flows can be seen in Table 7-9. The results show that the QMED estimates are generally consistent with the Halcrow (2011) NFM study although the River Knaik flows are approximately 20% lower. Both the 50% and 0.5% peak flows are larger than the values estimated within the Greenloaning Flood Study.

Table 7-9 Comparison of estimated 50% and 0.5% AEP peak flows

Site code	50% AEP Peak Flow (m3/s)			0.5% AEP Peak Flow (m3/s)	
	Jacobs 2024 Study	Halcrow (2011) Allan Water NFM Study	Halcrow (2012) Greenloaning Study	Jacobs 2024 Study	Halcrow (2012) Greenloaning Study
ALLN_01	17.55	18	-	-	-
ALLN_02	55.34	-	45.696*	140.62	111.949*
KNAK_01	33.86	42	-	-	-
KEIR_01	14.32	16	-	-	-

*Upscaled by 6.5% to match catchment area of ALLN_02.

A comparison of the 0.5% AEP growth factors shown in Table 7-10. The results show a high degree of similarity however there is greater variation for the tributaries, which likely reflects the small catchment method used to derive the pooling group.

Table 7-10 Comparison of 0.5% AEP growth factor

<table>
<tr><th rowspan="2">Site code</th><th colspan="3">0.5% AEP Growth Factor</th></tr>
<tr><th>Jacobs 2024 Study</th><th>Halcrow (2011) Allan Water NFM Study</th><th>Halcrow (2012) Greenloaning Flood Study</th></tr>
<tr><td>ALLN_01</td><td rowspan="2">2.541</td><td rowspan="6">2.674</td><td rowspan="6">2.450</td></tr>
<tr><td>ALLN_02</td></tr>
<tr><td>KNAK_01</td><td>2.64</td></tr>
<tr><td>KEIR_01</td><td rowspan="3">3.12</td></tr>
<tr><td>MILL_01</td></tr>
<tr><td>FEDD_01</td></tr>
</table>

Checks on hydraulic model results.

Given the lack of flow data or information on previous flood events checks on the model results will be undertaken to ascertain if it is producing realistic results, i.e., does the QMED flow cause extensive out of bank flooding, or does the 0.5% AEP flow remain in bank. The preliminary results of hydraulic analysis indicate that the flows / flood extents appear to be reasonable.

A detailed sensitivity analysis will be undertaken to improve confidence in the model results. The model sensitivity to flood volume will be assessed by varying storm duration for the 0.5% AEP event by +/-25%. Should the model results be found to be sensitive within the area of interest a more in-depth assessment should be undertaken to identify the model critical duration.

7.5 Assumptions, limitations, and uncertainty

The following outlines the specific assumptions and limitations applicable to the design peak flow estimates and design inflow hydrographs.

Assumptions (specific to this study)

- It was assumed that AMAX data within NRFA peak flows dataset version 12.1 was reliable for the catchments in the pooling groups.

- The FEH statistical method was prioritised over ReFH2.3 because it was assumed to better account for local conditions and was based on a larger dataset of flood events. The ReFH2 method was judged suitable for hydrograph shape (the Allan Water historic event hydrograph shapes are matching closely to the ReFH2.3 hydrograph shapes).
- It was assumed that the revised catchment areas (and associated descriptor adjustments) are representative of the catchment.
- There is limited information available on the local drainage network. It was assumed that during periods of significant flooding that runoff would follow the natural topography. The calculations do not account for inflow from outside the catchment boundary into the reservoir.
- It was assumed that the 1000-year growth factor is best estimated from a rainfall-runoff approach (ReFH2), given that confidence is greater in rainfall growth curves than in flood growth curves for longer return periods.
- The FEH and ReFH2 rainfall runoff approach assume uniform rainfall across the whole catchment (assumed to be valid up to 1000km^2).
- It is assumed that the catchment Tp calculated through lag analysis (for the River Alan) at the Kinbuck gauge and Danduff rain gauge are representative of the study catchment and can be applied to all watercourse catchments.
- Two approaches to model inflows were applied to check sensitivity to storm duration and combination of peak flows. For the lumped model (Run 2) a simplistic approach was taken with multiple storm durations across all the catchments was assumed.

Limitations

- Although the Alan Water is gauged further downstream of the study area, the watercourses in the study area are considered ungauged and limited information regarding past flooding within the area was identified. It was therefore not possible to verify the peak flow estimated by this assessment.
- Information on the sewer network was not available. A precautionary approach was taken to incorporate potential urban areas draining towards the catchments of interest.
- No LiDAR or detailed topographic data was available for the assessment. Catchment boundary was reviewed using OS mapping and coarse 10m contours.

Uncertainty

Confidence intervals are outlined within the latest EA Flood Estimation Guidelines (2022). The report presents results for rural catchments (URBEXT2000 <0.03) and moderately urbanised catchments (0.03 ≤ URBEXT2000 < 0.15). The 95% confidence limits for a rural catchment ungauged catchment with donor adjustment of QMED (one donor) are presented below.

Table 7-11 Upper and lower 95% confidence bounds for the flood peak

Site ID	Peak Flow (m^3/s)					
	50% AEP		2% AEP		0.5% AEP	
	Lower	Upper	Lower	Upper	Lower	Upper
ALLN_01	8.77	35.4	17.1	74.6	21.0	95.9
ALLN_02	27.7	112	53.8	235	66.1	302
KNAK_01	16.9	68.4	33.8	148	42.0	192
KEIR_01	7.16	28.9	16.2	70.9	21.0	96.0
MILL_01	1.90	7.66	4.30	18.8	5.56	25.4

FEDD_01	1.49	6.04	3.38	14.8	4.38	20.1
UNN_01	0.350	1.41	0.792	3.46	1.03	4.69
UNN_02	0.145	0.587	0.329	1.44	0.426	1.95
RES_01	0.874	3.53	1.98	8.66	2.56	11.7

Suitability of results for future studies

The results made use of the most up-to-date data and guidelines at the time of hydrological analysis for this study. The design peak flow estimates and hydrographs for this assessment have been derived to inform an FRA to support the planning application of the Braco West Electrical substation.

If peak flow estimates and hydrographs are required for different purposes it is recommended that, at a minimum, a review of the results is carried out and any recent flow data incorporated into the calculations.

Recommendations for future work

Future work within the catchment should consider closely monitoring flood levels and future flood extents within the project area.

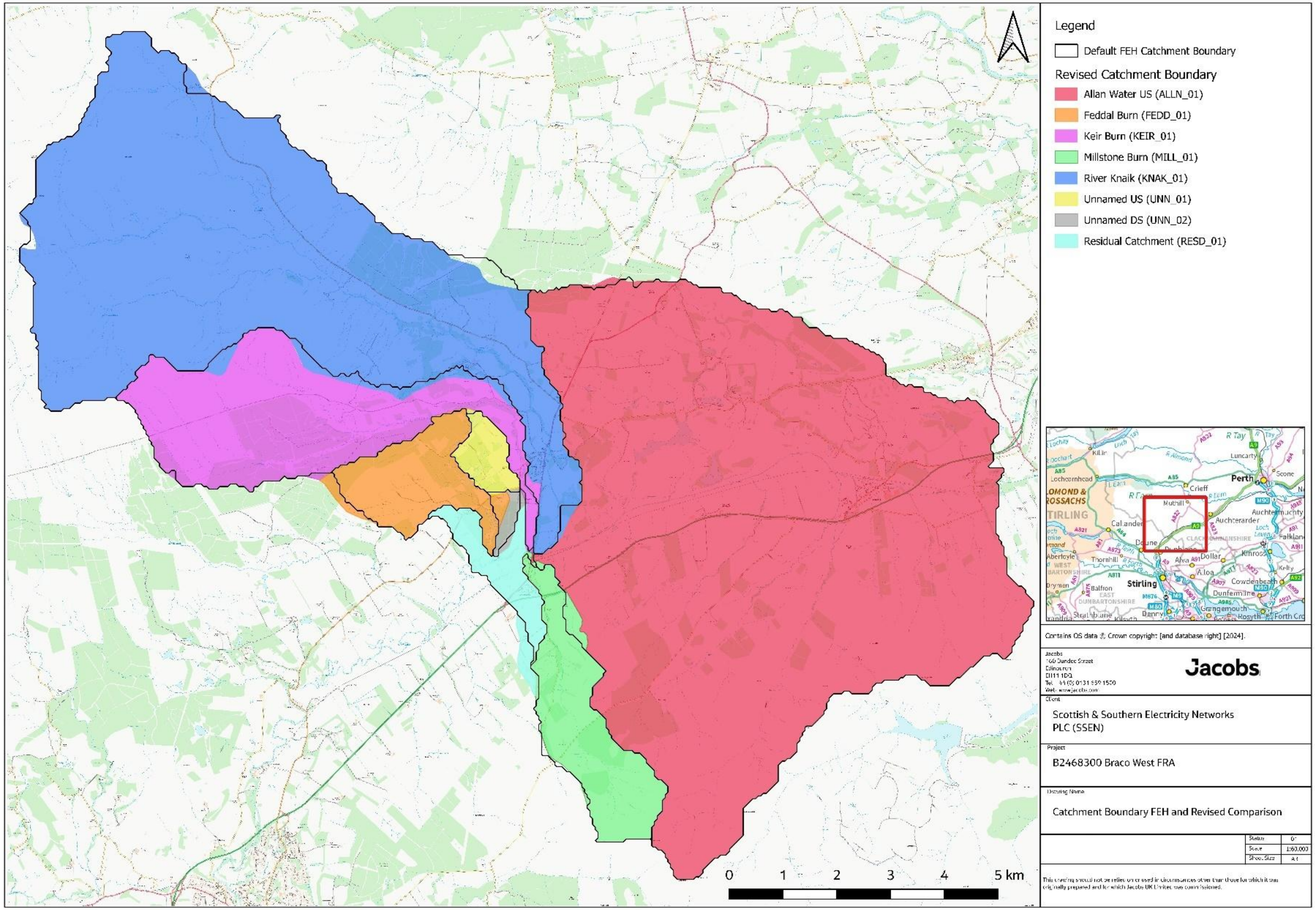
Appendix A. 13th December 2006 Flood Photos

Aerial Photograph at the confluence between the River Allan and Knaik taken during the receeding limb of the 12th December 2006 event

Aerial Photograph downstream of Greenloaning taken during the receeding limb of the 12th December 2006 event

Aerial Photograph taken by SEPA upstream of Kinbuck taken during the receeding limb of the 12th December 2006 event

Appendix B. Catchment Boundary Overview


Legend
Default FEH Catchment Boundary
Revised Catchment Boundary
Allan Water US (ALLN_01)
Feddal Burn (FEDD_01)
Keir Burn (KEIR_01)
Millstone Burn (MILL_01)
River Knaik (KNAK_01)
Unnamed US (UNN_01)
Unnamed DS (UNN_02)
Residual Catchment (RESD_01)
0 1 2 3 4 5 km
Contains OS data © Crown copyright [and database right] [2024].
Jacobs
160 Dundee Street
Edinburgh
EH11 1DQ
Web: www.jacobs.com
Jacobs
Client
Scottish & Southern Electricity Networks PLC (SSEN)
Project
B2468300 Braco West FRA
Drawing Name
Catchment Boundary FEH and Revised Comparison
Status
Scale
1:60,000
Sheet Size
This drawing should not be relied on or used in circumstances other than those for which it was originally prepared and for which Jacobs UK Limited was commissioned.

Appendix C. Pooling Group Details

Allan Water Revised Pooling Group

Station	Distance	Years of data	QMED AM	L-CV (observed)	L-SKEW (observed)	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 200	BFIHOST19	SPRHOST	Mann Kenda	MKZ Signific
73008 (Bela @ Beetham)	0.332	53	37	0.212	0.302	1.231	127.427	1294	0.093	0.952	0.01	0.489		2.46	5
72015 (Lune @ Lunes Bridge)	0.386	43	198.8	0.152	0.114	1.65	140.83	1630	0.055	0.993	0.002	0.392		2.03	5
47004 (Lynher @ Pillaton Mill)	0.431	57	45.8	0.223	0.311	1.353	135.292	1423	0.034	0.996	0.008	0.481		0.78	None
81003 (Luce @ Airyhemming)	0.438	56	133.1	0.131	0.103	1.234	170.697	1504	0.058	0.977	0	0.295		0.83	None
47005 (Ottery @ Werrington Park)	0.44	39	61.293	0.193	0.214	0.393	121.66	1199	0.046	0.999	0.005	0.421		-1.06	None
201007 (Burn Dennet @ Burndennet)	0.477	47	81.178	0.182	0.13	0.451	147.137	1186	0.046	0.994	0	0.432		3.18	5
63001 (Ystwyth @ Pont Llolwyn)	0.485	61	95.095	0.182	0.206	0.184	170.1	1456	0.047	0.99	0.001	0.43		2.71	5
203028 (Agivey @ Whitehill)	0.521	50	65.677	0.143	0.182	1.185	100.422	1270	0.093	0.999	0.003	0.342		1.04	None
47020 (Inny @ Bealsmill)	0.529	39	33.943	0.201	0.121	1.667	101.978	1429	0.036	1	0.004	0.493			
48011 (Fowey @ Restormel)	0.537	22	50.945	0.19	0.171	0.353	167.2	1435	0.035	0.985	0.003	0.45			
60006 (Gwili @ Glangwili)	0.542	54	81.325	0.174	0.163	1.299	131.143	1603	0.03	0.999	0.004	0.467		0.81	None
SUM		521	80.378	0.180	0.183	1.000	137.626	1403	0.052	0.989	0.004	0.427			
		521													

Heterogeneity, H2, value	-0.1065	Standarised text value H2
Heterogeneity, H2, description	The pooling group is acceptably homogeneous and a review of the pooling group is not required.	

	Z value	
Gen. Logistic	0.5956 *	
Gen. Extreme Value	-1.4450 *	
Pearson Type III	-2.6644	
Gen. Pareto	-6.019	
Kappa3	-0.1461 *	Best fit

* distribution gives an acceptable fit (absolute Z value < 1.645)
Lowest absolute Z value indicates best fit

River Knaik Revised Pooling Group

5. Reviewed pooling group (KNAK_01 REV PG01)

Station	Distance	Years of data	QMED AM	L-CV (observed)	L-SKEW (observed)	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST19	SPRHOST	Mann Kendal	MKZ Significa
84020 (Glazert Water @ Milton of Campsie)	0.346	37	54.245	0.132	0.075	2.36	51.925	1560	0.053	0.991	0.01	0.373	45.24	0.04	None
47014 (Walkham @ Horrabridge)	0.375	48	42.401	0.218	0.201	2.58	44.242	1665	0.023	1	0.008	0.548	26.16	3.99	5
76023 (Dacre Beck @ Dacre Bridge)	0.4	22	35.56	0.185	0.226	1.208	33.913	1429	0.072	0.999	0	0.411	36.35		
46007 (West Dart @ Dunnabridge)	0.462	41	71.559	0.169	0.139	0.533	47.495	1987	0.049	1	0.003	0.309	47.75		
72007 (Brock @ upstream of A6)	0.481	44	28.994	0.193	0.217	0.828	31.51	1361	0.053	1	0	0.318	49.42	-0.44	None
73009 (Sprint @ Sprint Mill)	0.491	53	43.46	0.175	0.188	0.081	34.695	2013	0.061	0.997	0	0.391	44.14	3.02	5
21017 (Ettrick Water @ Brockhoperig)	0.498	57	60.364	0.173	0.214	0.563	38.593	1740	0.012	1	0	0.331	43.7	2.98	5
47009 (Tiddy @ Tideford)	0.569	53	6.85	0.199	0.215	0.327	37.398	1276	0.024	1	0.011	0.536	30.81	1.32	None
47021 (Kensey @ Launceston Newport)	0.586	20	13.75	0.203	0.275	0.928	34.83	1298	0.022	0.998	0.017	0.514	32.41		
73011 (Mint @ Mint Bridge)	0.669	53	57.446	0.186	0.193	0.71	65.442	1599	0.061	0.993	0.001	0.468	36.87	2.24	5
54025 (Dulas @ Rhos-y-pentref)	0.678	53	23.485	0.198	0.278	0.883	53.333	1268	0.024	1	0.001	0.396	40.26	2.95	5
SUM		481	39.829	0.185	0.202	1.000	43.034	1563	0.041	0.998	0.005	0.418	39.374		

Heterogeneity, H2, value	-1.8309	Standarised text value H2
Heterogeneity, H2, description	The pooling group is acceptably homogeneous and a review of the pooling group is not required.	

	Z value	
Gen. Logistic	0.7683 *	
Gen. Extreme Value	-0.9536 *	
Pearson Type III	-2.1968	
Gen. Pareto	-4.8883	
Kappa3	0.1513 *	best fit

* distribution gives an acceptable fit (absolute Z value < 1.645)
Lowest absolute Z value indicates best fit

Feddal Burn Revised Pooling Group

5. Reviewed pooling group Small SDM Method (FEDD_01 REV PG01

Station	Distance	Years of data	QMED AM	L-CV (observed)	L-SKEW (observed)	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000	BFIHOST19	SPRHOST	Mann Kenda	MKZ Significa
45816 (Haddeo @ Upton)	0.399	29	3.248	0.289	0.432	3.064	6.808	1210	0.011	1	0.005	0.535		-0.83	None
47022 (Tory Brook @ Newnham Park)	0.996	27	6.176	0.246	0.151	0.774	13.432	1403	0.023	0.942	0.014	0.353			
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	1.181	12	4.924	0.266	0.268	2.501	16.08	1044	0.023	0.991	0.006	0.562			
27051 (Crimple @ Burn Bridge)	1.193	50	4.641	0.218	0.133	0.41	8.172	855	0.013	1	0.006	0.329		1.51	None
206006 (Annalong @ Recorder)	1.344	48	15.33	0.189	0.052	1.726	14.438	1704	0.023	0.981	0	0.267		2.25	10
27010 (Hodge Beck @ Bransdale Weir)	1.364	41	9.42	0.224	0.293	0.269	18.82	987	0.009	1	0.001	0.303		-2.1	5
27032 (Hebden Beck @ Hebden)	1.393	54	4.086	0.198	0.197	0.149	22.245	1433	0.021	0.997	0	0.272		0.92	None
71003 (Croasdale Beck @ Croasdale Flume)	1.412	37	10.9	0.212	0.323	0.51	10.71	1882	0.016	1	0	0.283			
25003 (Trout Beck @ Moor House)	1.468	49	15.12	0.165	0.298	1.864	11.395	1905	0.041	1	0	0.255			
72014 (Conder @ Galgate)	1.545	54	16.971	0.23	0.135	0.519	28.992	1183	0.082	0.975	0.006	0.427		1.62	None
73015 (Keer @ High Keer Weir)	1.58	32	12.59	0.205	0.179	0.127	30.043	1158	0.074	0.976	0.003	0.455		3.68	5
72007 (Brock @ upstream of A6)	1.627	44	28.994	0.193	0.217	0.62	31.51	1361	0.053	1	0	0.318		-0.44	None
76023 (Dacre Beck @ Dacre Bridge)	1.712	22	35.56	0.185	0.226	0.468	33.913	1429	0.072	0.999	0	0.411			

Heterogeneity, H2, value	0.3455	Standarised text value H2
Heterogeneity, H2, description	The pooling group is acceptably homogeneous and a review of the pooling group is not required.	

	Z value	
Gen. Logistic	0.5840 *	
Gen. Extreme Value	-1.1219 *	
Pearson Type III	-2.5444	
Gen. Pareto	-5.0847	
Kappa3	**-0.0198 ***	**best fit**