Technical Note

95 Bothwell Street,
Glasgow
G2 7HX
0141 243 8000
www.jacobs.com

Subject	**Musselburgh Flood Protection Scheme** **Interim Hydrology Report**		
Ref:	MFPS-S3-JEC-ZZZ-XXX-TN-Z-0001	**Status**	Issued for Comment
Attention	Conor Price, East Lothian Council	**Version**	1.0
From	Olivia Burns		
Date	2nd May 2019		
Copies to	Nadia Othman (ELC)		

1. Introduction

The purpose of this Technical Note is to record how the River Esk catchment has been schematised, the hydrological analysis undertaken to provide the inflows to the hydraulic and hydrological models, give an overview of how the hydrological model has been developed, provide a summary of the initial flow estimates and set out the proposed approach to calibration of the hydrological model. This analysis of flows will then inform a Flood Protection Scheme option assessment and design for the town of Musselburgh.

This document is to facilitate discussion and agreement for the proposed approaches with East Lothian Council (ELC) and SEPA prior to finalisation of the hydrological inflows to the hydraulic model.

The details of the hydraulic modelling approach and associated calibration of flows within the hydraulic model are provided in a separate report.

Due to on-going works within the catchment to improve the hydrological data available, the hydrological estimates and model will need to be updated once new/revised data becomes available.

2. Study Area

The watercourses flowing into Musselburgh are shown in Figure 1, Appendix A. The main catchment, the River Esk, covers approximately 322km^2, and comprises the River North Esk and the River South Esk. The Pinkie Burn has an area of approximately 5km^2, and is culverted along much of its lower reaches. It flows into the River Esk from the east, via a historical (culverted) mill lade, just below its tidal limit in Musselburgh. The exact catchment boundary of the Pinkie Burn, as well as the exact location of all of the culverted reaches, is in the process of being confirmed through site-survey work. In the mean-time, the catchment boundary for the Pinkie Burn has been taken from available LiDAR and OS map topographic data.

The catchment soils are generally free draining Brown Earth, with areas of gleying focused on higher ground within the mid- to lower-catchment. Superficial deposits are predominantly glacial tills in the upper catchment and on higher ground, with areas of glacial sands and gravels, along with alluvium, in river valleys in the mid- to lower-catchment. There are limited peat deposits in the headwaters of the North Esk, and raised marine deposits along the shoreline in Musselburgh.

The solid geology is sedimentary, composed of the Scottish Coal Measures Group, Clackmannan Group, and the Strathclyde Formation, except for the southwestern reaches of the catchment, which intercepts the northern extent of the Pentland Hills, which are formed of igneous bedrock of unnamed extrusive formations. The area beneath the catchment is highly faulted and has been extensively mined for coal.

The catchments are predominantly rural in their upper reaches, with urban areas concentrated around Penicuik, Loanhead, Lasswade, Dalkeith, Newtongrange and Musselburgh in the mid- to lower-reaches of the catchment. Initial impressions are that this pattern of development may result in localised impacts on flow responses, which may result in local flood issues, but at the catchment scale, the impact is likely to be less marked.

3. Available Data

Previous Studies

Two recent flood studies that have been reviewed as part of this hydrological assessment of the River Esk, both of which were undertaken for East Lothian Council:

- Kaya Musselburgh Flood Study Mathematical Modelling Report, 2015
- Jacobs Musselburgh Flood Study Report, 2012

The studies focus on modelling flood flows from the River Esk as it flows through Musselburgh, in combination with tidal events and climate change. The 2015 Kaya study identified two further flood studies undertaken in Musselburgh, which were not independently reviewed as part of this assessment; a Kaya Flood Study for a private client in 2009, and a flood study undertaken by Wardell and Armstrong for a private client in 2007.

All these studies constructed models of the river channel through Musselburgh, using either Flood Modeller, HEC RAS or Mike 11 software, based on river channel survey data, and LiDAR data.

Hydrological Data

The following data sources were used to inform the hydrological catchment characteristics required to undertake the flow estimations:

- FEH Catchment Descriptors from the FEH online web service;
- NRFA Peak Flows Database version 7 (released October 2018);
- WINFAP v3 software;
- Flood Modeller Pro v4.3;
- River flow gauge and rainfall gauge data from relevant locations within, and around, the River Esk catchment, provided by SEPA; and

- Additional AMAX data from the NFRA web site.

Spatial Data

There are an increasing number of sources of mapped data that can be accessed and used to inform hydrological assessments of watercourses. Within this study, the following sources have been used to inform the characterisation of the River Esk catchment, to both corroborate other sources of data used in flow estimation and to inform the modelling process:

- OS base maps (various scales)
- OS Open Data: Rivers
- James Hutton Institute 25k Soil Maps
- OS Terrain5: 5m resolution DTM
- BGS Geology of Britain viewer[1]
- National Library of Scotland historical maps[2]

Historical Floods

The Chronology of British Hydrological Events database was used to identify historical floods listed in Musselburgh, however, only one event that specifically referenced Musselburgh was identified. The review of the previous flood study reports, general internet searches and historical database searches was used to construct a more complete list of significant flood events in Musselburgh, as summarised in Table 1.

Table 1: Historical Floods

Event	Source	Description
14th July 1879	Chronology of British Hydrological Events	"North Esk Reservoir (XIII). Great flood doing much damage" – British Rainfall 1879, Pg12
20th September 1891	Kaya 2015 and Chronology of British Hydrological Events	"Rainfall observer at Gorebridge (Middleton), near Edinburgh, noted 'Terrible gale and 3.35in. of rain, causing great and destructive floods" South Esk. – British Rainfall for 1891 pg28

[1] http://www.bgs.ac.uk/discoveringgeology/geologyofbritain/viewer.html?src=topNav

[2] https://maps.nls.uk/geo/explore/#zoom=5&lat=56.0000&lon=-4.0000&layers=1&b=1

Event	Source	Description
17th August 1920	Chronology of British Hydrological Events (The Scotsman newspaper)	"The River Esk at Musselburgh was in high flood yesterday, and several sheep were drowned in a low-lying field just outside the town. One of the tiers of the iron bridge over the river, in the heart of the town, was knocked clear away by a water-borne tree ... Great flooding also took place at Penicuik. The roadway at Valleyfield Mill was completely under water, which poured into the lower parts of the mill, papermaking having to be suspended ... One of the worst [rail] delays occurred on the branch line at Penicuik, where a landslide between Auchendinny and Rosslyn Castle caused a complete block of the line ... [R. Esk]" – Scotsman newspaper
13th August 1948	Kaya, 2015, SEPA – Forth Estuary LPD PVA 10/21 Summary 2015	"Evacuation required in Musselburgh after flooding from the River Esk occurred in Eskside West, Eskside East, Shorthope Street, Millhill and areas of the High Street."
30th March 2010	Kaya, 2015, SEPA – Forth Estuary LPD PVA 10/21 Summary 2015	"A tidal surge coinciding with the highest mean tides of the year caused extensive flooding along the east coast of Scotland, with the Firth of Forth being one of the worst affected areas. Locations within this coastal area affected included Leith, Musselburgh, Prestonpans, Port Seton, Dunbar and North Berwick. Impacts included flooding of properties, damage to harbours, seawalls and roads. "
7th February 2011	Kaya, 2015	No further details obtained.
7th July 2012	Kaya, 2015 and BBC news web site	Flooding across central Scotland, including the River Esk through Musselburgh. BBC video footage[3] shows flood levels through the centre of Musselburgh, including flows under the Shorthope Street footbridge. Also, footage available on YouTube.[4]

[3] https://www.bbc.co.uk/news/uk-scotland-18752225 accessed 10th January 2019

[4] https://www.youtube.com/watch?v=KIDxRgSSh44 accessed 10th January 2019

Event	Source	Description
4th January 2014	Kaya, 2015	Notable wet period, combined with several tidal surges between December 2013 – January 2014. Flooding on 4th January caused by tidal surge[5] rather than peak river flows.

The Forth Estuary LPD PVA 10/21 Summary document also notes a history of groundwater flooding within Musselburgh, particularly around the Pinkie Burn area, though no further details are provided.

Several of the historical floods are noted as being the result of high-tides and storm surges, and therefore, are not considered suitable for calibration for the hydrological routing model, which only deals with flows upstream of Musselburgh, unless the events coincide with high flow events in the North and/or South Esk rivers. However, these events will be very relevant to the calibration of the 1D-2D hydraulic model of Musselburgh.

Where they exist, it may be possible to use photographic evidence and video footage to verify modelled flood events to aid in calibration/validation.

4. Data Quality and Review

Review of hydrological data

There are several river gauges and rainfall gauges within the River Esk catchment, as shown in Figure 2, Appendix A, that were reviewed as part of this assessment. Data for all of these gauges was obtained from SEPA, the NRFA and Met Office. The quality of the data sources were assessed for suitability of use, the results of which are summarised in Table 2 and 3. The AMAX data series for each of the five gauging stations located within the catchment are provided in Appendix B, and an overview of the AMAX data is provided in Table 4.

Table 2: Fluvial Data

Data	Source	Description	Quality
AMAX data	NFRA[6]	AMAX data and quality assessment of all gauging stations within the UK.	Not all stations up-to-date with latest data supplied by relevant regulatory authority (SEPA). Only use when SEPA data not available.

[5] https://www.bbc.co.uk/news/uk-scotland-25598846 accessed 10th January 2019

[6] https://nrfa.ceh.ac.uk/data/search

Data	Source	Description	Quality
GS - Musselburgh	SEPA	River Esk in Musselburgh, Q15, level and AMAX data from 1962 to 2013.	SEPA only holds electronic data for this GS post 2006. Information prior to 2006, the data was held by NRFA High Flows database. SEPA advises that this site is due for a rating curve review in October 2018.
GS - Dalkeith	SEPA	River North Esk Q15, level and AMAX data from 2006 to 2013.	SEPA only holds electronic data for this GS post 2006. Information prior to 2006, the data was held by NRFA High Flows database. There are four years of AMAX data missing from the record: 1975 and 2006-2008. SEPA questions the reliability of this GS record and advises not to use for flow estimation and considers the site not suitable for Pooling.
GS - Dalmore	SEPA	River North Esk Q15, level and AMAX data from 1992 to 2006	SEPA advises that this station is pending a rating curve review.
GS – Cowbridge	SEPA	River South Esk Q15, level and AMAX data from 1991 to 2018.	SEPA advises that simple extrapolation of gauges has possibly led to an overestimation of peak flows and the site has been listed for review.
GS – Prestonholm	NRFA	AMAX data from 1963 to 1989.	No digital record held by SEPA for this GS. Suspect quality, as specific discharge for site much lower than the other four GS in the catchment.

AMAX data for the gauging station on the River Esk at Musselburgh and the River North Esk at Dalkeith comes from two sources, though supplied by SEPA. The AMAX data from 1962-2005 is from the NFRA High Flows database, while from 2006 onwards, the AMAX data is held by SEPA.

It is noted that SEPA is planning to review the rating curve for this station, along with all the other flow gauging stations within this catchment in the near future. When these reviews have been completed, the updated data will trigger a review of the catchment hydrology within this report.

Due to concerns regarding the current quality of the flow gauge data available within the River Esk catchment, it is considered that only Dalmore on the North Esk and Cowbridge on the South Esk are suitable for use in estimating peak flows within the respective river catchments. For the inflows to the

hydraulic model from the lower tributaries and urbanised sub-catchments, the gauging station in Musselburgh is also considered suitable for use.

Data from Dalkieth and Prestonholm gauging stations may still have some value in assessing the timing of peak flows when calibrating the hydrological routing model, as uncertainty regarding peak flow measurements are not relevant when calibrating the timing of the flood wave as it progresses through the catchment.

Rainfall data was also provided by SEPA for instantaneous and daily rain gauges, as summarised in Table 3 below. The quality of the data varies for each station over the period of the record collected for each gauge, however the quality of the individual records relating to each of the proposed calibration results will be evaluated separately during the calibration process, as required.

Table 3: Rainfall Data

Gauging Station	Source	Description	Period of Record
Bush	SEPA	Q15 rainfall data.	2011 - 2018
Crichton	SEPA	Q15 rainfall data.	1994 - 2018
Gladhouse	SEPA	Q15 rainfall data.	1989 - 2018
Harelaw	SEPA	Q15 rainfall data.	2001 - 2018
Skedsbush	SEPA	Daily rainfall data.	1989 - 2004
Gladhouse	SEPA	Daily rainfall data	1989 - 2006
Prestonpans	SEPA	Daily rainfall data	1989 - 2006

Historic mining

SEPA note that historical mining has been known to affect flows in the area historically, up until the 1980s when pumping of mine water ceased. However, there are few details available regarding the historic pumping regime and the effect on river flows, so it is only possible to undertake very high-level checks for potential influences on gauged flow data and note this as a source of uncertainty in the data.

As SEPA noted that mining may have influenced flows up until the late 1980s, a basic check was undertaken to note any influences on the recorded AMAX data. This involved calculating QMED based on the pre- and post-1990 AMAX data series. The results of which are provided in Table 4.

Table 4: Pre and Post 1990 AMAX values

Gauging Station	Pre-1990		Post-1990		All AMAX	
	Qmed (m^3/s)	Record length (yrs)	Qmed (m^3/s)	Record length (yrs)	Qmed (m^3/s)	Record length (yrs)
Musselburgh	71.03	29	86.96	27	73.75	56
Dalkeith	32.74	28	54.94	16	37.46	44
Dalmore	19.02	30	21.25	27	19.49	57
Cowbridge	**25.95*	*0*	38.56	25	38.56	25
Prestonholm	19.11	26	**28.39*	*0*	19.11	26

*The two gauging stations on the River South Esk do not have AMAX data sets that span 1990, with Prestonholm record ending in 1989 and Cowbridge starting in 1991. However, to provide an approximate value for comparison the QMED values for each gauging station based on the known period of data for one station has been scaled using specific discharge and the catchment area to produce a QMED estimate for the missing period of data at the other gauging station.

The analysis shows that all the gauging stations in the catchment, with the exception of Dalmore, appear to be affected by the cessation of mine water pumping in the late 1980s. This is demonstrated by the higher QMED estimates based on post 1990 AMAX records, which would be expected as groundwater levels rebound, contributing more water to baseflows within river reaches. Cowbridge is not technically affected, as the gauging station only became operational post 1990, though it is believed that historically the River South Esk has been affected by mine water pumping.

The negligible effect on flows recorded at Dalmore gauging station, pre- and post-1990, appears to be consistent with the location of historic mining in the catchment, which predominantly took place downstream of the Dalmore gauging station according to historic mining maps[7].

This very high-level assessment of the possible effects the cessation of mine water pumping has on flows pre- and post-1990 indicates that there is a significant increase in flows along the River South Esk and the lower River North Esk, with resulting impacts on flows through Musselburgh. Therefore, for the purposes of this study, only AMAX data post-1990 will be used for flow calculations for the affected stations. This will not affect the approach to the hydrological model, as the Dalmore gauging station is

[7] https://maps.nls.uk/geo/explore/#zoom=11&lat=55.9167&lon=-3.1277&layers=10coal&b=1 accessed 14th January 2018.

unaffected, and the data for the Cowbridge is all post 1990. However, when calibrating the hydraulic model, only post-1990 data should be used for Musselburgh.

There is the possibility that the changes in flows observed, shown in Table 4, could also be influenced by changes in rainfall trends in the region. However, this analysis is outwith the remit of this report and, as it is proposed to only use post-1990 data which results in a more conservative estimate of QMED, it is believed that this approach is acceptable, especially considering the high permeability within the catchment, as discussed in Section 5.

5. Catchment Schematisation

The River Esk catchment has been subdivided into the sub-catchments as shown in Figure 3, Appendix A and as defined by their downstream points. The sub-catchments have been determined to differentiate between the notable tributaries, changes in topography and/or land use, and within Musselburgh, rural and urban areas.

The approach to schematisation has two objectives:

- To facilitate the estimation of inflows from the downstream urban areas to the hydraulic flood model of Musselburgh; and
- Form the basis of the 1D flow routing model that will derive the inflows to the upstream extent of the hydraulic model, and to inform a high-level assessment of flow synchronisation within the catchment to identify where wider catchment water management measures may be effective at managing flood risk downstream in Musselburgh.

The catchment descriptors for the sub-catchment and intervening catchment areas have been reviewed and defined as part of the hydrological analysis to better represent the hydrological response of each area within the modelling process. These are summarised in Appendix C.

The sub-catchment boundaries for the upstream, largely rural sub-catchments, were reviewed against OS data to check for errors and to account for likely changes due to infrastructure (e.g. rail and roads). A more detailed review has been undertaken for the downstream areas, with catchment boundaries assessed against LiDAR data.

A summary of the Catchment Descriptors for the four main catchments within the modelled area are provided in Table 5.

Table 5: Summary of Catchment Descriptors for main catchments

	River Esk	North Esk	South Esk	Pinkie Burn
Description	*Whole catchment to tidal boundary*	*Catchment to confluence with River South Esk*	*Catchment to confluence with River North Esk*	*Whole catchment to tidal boundary*
AREA (km^2)	323.4325	133.495	155.8975	5.2875
ASPVAR	0.24	0.25	0.34	0.68

	River Esk	North Esk	South Esk	Pinkie Burn
BFIHOST	0.568	0.551	0.56	0.702
DPLBAR	25.36	22.71	16.22	3.45
DPSBAR	94.7	121	83.8	37.3
FARL	0.944	0.965	0.916	1
FPEXT	0.0437	0.0329	0.0418	0.2024
PROPWET	0.49	0.49	0.49	0.49
SAAR	836	907	818	608
SPRHOST	34.04	37.14	32.4	30.48
URBEXT2000	0.0338	0.0259	0.0321	0.0943
Urban classification	Slightly Urbanised	Essentially Rural	Essentially Rural	Moderately Urbanised

The catchment descriptors in Table 5 and in Appendix C show that the area has moderate to high permeability across the majority of the River Esk catchment, demonstrated by the low SPRHOST values and high BFIHOST values, as shown in Figure 4 and 5, Appendix A. The areas of lower SPRHOST values approximate the location of a band of sedimentary bedrock, part of the Clackmannan Group, which were formed in fluvial environments, and therefore are comprised mainly from sand and gravel. Superficial deposits are also predominantly sand and gravel fluvial deposits within the catchment valleys, with glacial deposits along valley sides. The low SPRHOST and high BFIHOST values have been considered when determining the appropriate methodology to adopt for flow estimation.

The FARL values for the main catchments also reflect the fact that there are several reservoirs in the area. These include Gladhouse, Glencorse, Rosebery and Edgelaw reservoirs, which are part of the water supply network for Edinburgh and are also used for fishing. As these reservoirs are generally kept full and will be considered within part of the hydrological routing model, when local flow data is being used, it is not considered necessary to consider them specifically when selecting a suitable methodology for flow estimation.

6. Flow Estimation

Flow estimations will only use post 1990 AMAX data from Musselburgh, Dalmore and Cowbridge gauging stations for flow estimation, for the reasons set out in Section 4.

The estimation of flows within the sub catchments of the River Esk provides a particular challenge. The sub catchments are small, urban in most cases, and several of them are very permeable. Within the FEH Statistical method, permeable catchments are defined as having an SPRHOST of <20%, corresponding

roughly to a BFIHOST of >0.75. EA Guidelines also highlight that FEH Rainfall Runoff is not suited for use in such catchments[8], though ReFH may be used with caution, due to its improved baseflow model.

FEH is not considered suitable for use on highly urbanised catchments, where ReFH is preferable, as tools allow for flow peaks from paved and unpaved areas to be modelled. However, the dataset on which ReFH was formed did not contain many small urbanised catchments in highly permeable areas.

The design flow estimates for inputs to the hydrological routing model and hydraulic model were derived using the FEH Statistical and ReFH methods as follows:

- The sub-catchments within the study area were defined using the FEH online catchment descriptors and checked against the spatial datasets, then used to estimate peal flows using the FEH Statistical method.
- URBEXT1990 and URBEXT2000 were updated to 2018 using best practice for both QMED estimates and Growth Curve estimates, noting the permeability within the sub catchments.
- The ReFH rainfall-runoff method was used to estimate hydrograph shapes and provide inflow boundaries for each inflow to the hydraulic model, within Flood Modeller.
- ReFH inflows for the sub-catchments within the hydrological routing model will be reconciliated to FEH statistical estimates.
- The majority of inflows to the sub-catchments flowing into the hydraulic model are predominantly urban, and therefore flows from these areas will be calculated using ReFH in Flood Modeller, with urban areas modelled to account for influences on catchment responses and facilitate modelling of short term, intense, summer storms on Musselburgh.
- The Pinkie Burn flows into the River Esk downstream of the tidal limit. The lower half of the catchment is heavily urbanised and culverted along most of its reach, though the underlying geology is very permeable in the lower reaches, while the upper catchment is less so. Because off the greater effects of urbanisation on permeable catchments, it was decided to use ReFH to estimate flows in this catchment, as it can better account for the urbanisation in the lower half than the Statistical method can, and the catchment parameters within the upstream half are considered suitable for use with the ReFH method.
- Critical storm duration analysis was undertaken in Flood Modeller for the 200yr return event storm, based on the outflow of the hydrological routing model, using ReFH units and a winter storm profile. The analysis showed that there was a variation in optimal storm duration for different return periods, and therefore three different storm durations have been adopted for different return periods. A storm duration of 48.5hrs has been adopted for return periods 5-100yrs, 32.5hrs for a 200yr return period and a 85.5hrs storm for a 1000yr+ return period event.
- Flow estimates for the reconciliation points shown in Figure 3 will be estimated using the FEH Statistical Method.

Considering the above, it is important to note that flows within the River Esk catchment presents conflicting issues regarding suitable choices of flow estimation method. The uncertainty in methods can be reduced by the use of local flow data in flow estimation and model calibration. Should additional data from other stations be considered suitable for use at a later date, this should be included within a review

[8] EA Flood Estimation Guidelines

of the hydrology presented within this report, to ascertain if it can be used to further increase confidence in flow estimates.

Table 6: Summary of flow estimate methods for different sub-catchments

Sub-catchments	Peak Flow Estimate Method	Model Inflow
NE10 – 30, SE10 – 30, TB3 – 5, RE6	ReFH scaled to FEH Statistical	Hydrological Routing Model
TB1-2	ReFH scaled to FEH Statistical	Hydraulic Model
RE 1 – 5, PB1 – 2	ReFH with urban subdivisions	Hydraulic Model

A final hydrology report will summarise the final inflows used in both models after calibration and reconciliation and will be distributed to East Lothian Council (ELC) and SEPA for comment prior to flow estimates being used in the flood modelling process. There is a 10-day period within the programme for comments to be provided.

FEH Statistical Method

Current FEH statistical methods, in line with improvements to the FEH methods, were used to undertake the assessment of flows[9] [10] for the sub-catchments outlined in Table 6. As the catchment is gauged, two approaches were used to estimate QMED. Firstly, using j catchment descriptors (CD) for all sub-catchments, and then using the calculated flows for the Musselburgh, Cowbridge and Dalmore gauging stations. The flow estimates for these stations, including details of the reviewed pooling groups, are provided in Appendix D.

The flow estimates for these gauging stations were then used to adjust the CD estimated QMED for each sub-catchment using either Cowbridge or Dalmore stations as a donor.

Growth Curves were then developed for each gauging station, using WINFAP v3 and NFRA Peak Flows dataset 7. A suitable growth curve was then adopted for each sub-catchment, which was then used to estimate the Flood Frequency Curve for that sub-catchment.

The flow estimates derived for each subcatchment, using flow estimates from the gauging stations, are provided in Appendix E. These will form the initial inflows to the hydrological routing model, or hydraulic model, prior to calibration. The final calibrated flows for each of the sub-catchments will be provided in the final hydrological modelling report.

[9] Improving the FEH statistical procedures for flood frequency estimation. Environment Agency, Science Report SC050050, 2008.

[10] Estimating flood peaks and hydrographs for small catchments: Phase 1. Environment Agency, Science Report SC090031, 2012.

ReFH Method

Within the hydrological routing model, the ReFH method is used to provide hydrographs for each subcatchment, which will then be scaled to match the FEH Statistical flow estimates.

ReFH will also be used for inflows from the sub catchments in the hydraulic model, using catchment descriptors, however, these will be adjusted during the hydraulic model calibration process to account for the urban subdivisions within the Flood Modeller ReFH unit for each sub-catchment. The initial flow estimates for these sub-catchments, prior to calibration and using ReFH with the urban subdivisions, are provided in Appendix E.

7. Hydrological Routing Model

The flow estimates for sub-catchments in the North Esk (NE) and South Esk (SE), along with Tributary 5 (TB5) and the River Esk just below the confluence of the North and South Esk (RE6) will be routed through a 1D flow routing model. Tributaries TB1 – 4 and the River Esk RE1 - 5 are not included in the hydrological model, but provide point and lateral inflows to the 1D-2D hydraulic model.

The aim of the hydrological routing model is to provide the upstream inflows to the Musselburgh hydraulic model and to provide an assessment tool for potential catchment management measures for reducing flows reaching Musselburgh, including NFM. This is in line with the Environment Agency's recently published 'Working With Natural Processes' evidence base[11], which identifies a 1D routing model with limited survey data (e.g. cross sections extracted from LiDAR) is suitable for undertaking a high-level catchment assessment of the viability of different water management measures to influence peak flows and synchronisation. The cross sections were taken from the OS Terrain 5 data, which has a 5m resolution.

The 1D flow routing model has been developed based on the schematised catchment using Flood Modeller software and the Variable Parameter Muskingham-Cunge (VPMC) unit models with VPMC cross sections.

The initial roughness coefficient used in the cross sections is 0.035. This will be adjusted during the calibration process and the final values adopted will be provided in the Final Hydrology report.

8. Calibration and Validation of Hydrological Model

For the hydrological routing model, the Cowbridge and Dalmore gauging stations form the key hydrological data sources of peak flow data on which the model will be calibrated. The hydraulic model will be calibrated separately based on the Musselburgh gauging station.

The AMAX records for Cowbridge and Dalmore were assessed to identify events based on data availability and suitability of events occurring in the whole catchment. The AMAX data for the overlapping period of complete hydrological years between the two gauges (1992-2016), and then each AMAX event was ranked from highest (1) to lowest (25), as shown in Appendix B.

Table 7 summarises the calibration and validation events identified as suitable for use from the data available. It is noted that in a previous study, a calibration event of March 2010 was used to calibrate the hydraulic model. However, this event is not recorded as an AMAX event for that year at either the Dalmore or Cowbridge gauging stations, and so has not been included as a calibration event for the

[11] https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk

hydrological model. It will, however, be included as a calibration event for the Musselburgh hydraulic model.

Table 7: Calibration and Validation Events for Hydrological Model

Event	Calibration/Validation	Justification
26/04/2000	Calibration	Highest ranked AMAX at both Dalmore and Cowbridge*.
22/10/2002	Calibration	6th and 3rd highest AMAX event for Dalmore and Cowbridge*.
11/08/2011	Validation	13th and 5th highest AMAX event for Dalmore and Cowbridge*.
22/12/2014	Calibration	2nd and 8th highest AMAX event for Dalmore and Cowbridge*.
26/12/2015	Calibration	4th highest AMAX event for Cowbridge**.

*For the overlapping AMAX events between 1992 and 2016

** In December 2015, Dalmore AMAX event occurred on the 5th December, with a peak of 21.251 cumecs. Another peak flow of 20.173 cumecs occurred on 26th December however, and this flow has been used for the calibration of the 2015 event.

The focus of the hydrological routing model will be timing of peak flows, as well as the peak flows themselves. This means that where gauging data may not be suitable for peak flow calibration, data regarding the timing of peak flows may still be of value/use (e.g. Dalkeith GS).

Details of the final calibrated flows and parameters will be provided in the Final Hydrology Report.

Details of the calibration of the hydraulic model will be provided in the final Modelling Report, including the calibration events used.

9. Sensitivity Testing

Once the model has been calibrated, sensitivity testing will be applied to investigate the impact of uncertainty on model parameters and estimated flows within the hydrological routing model. This will include uncertainty in peak flow estimates, roughness and Tp.

10. Assumptions

The following assumptions have been made regarding the proposed catchment schematisation:

- That the online reservoirs are largely kept at capacity, and therefore can be reasonably modelled as natural lakes.
- If/when modelling the import/export of drainage from urban areas in ReFH, it is assumed that sewer networks in urban areas will have an influence up to capacity, which will be assumed to be 10 years in the absence of reliable local data. Capacity will be finalised after consultation with Scottish Water and ELC.
- No hydraulic modelling of the sewer or surface water drainage network will be undertaken, with the exception of culverted sections of the Mill Lade and Pinkie Burn, where data was extracted from the Edinburgh ICS project.
- Where no mine water flow or level data is available, they will not be included within the assessment, however a qualitative assessment of contributing flood risk will be noted within the final report.

- The influence of any current mine water discharges into the local water environment does not significantly add to fluvial flood flows, and the observed historical influence on flows has stabilised post 1990, since the cessation of mine water pumping.

11. Recommendations

The following recommendations are made in relation to future works to improve flow estimation capabilities within the study area going forward:

- That the hydrology presented within this report is revisited when the review of the gauging stations by SEPA are completed, particularly if the review results in the two gauging stations excluded from this study (Dalkeith on the North Esk and Prestonholm on the South Esk) being considered suitable for use.
- That flow gauging is undertaken on the Pinkie Burn. Ideally this should include flows within the culverted reach and, particularly, flows immediately upstream of the culverted reaches.
- Groundwater data is obtained and analysed in relation to AMAX data and floods to ascertain the contribution of groundwater to flooding within the catchment, particularly within the Pinkie Burn catchment, where it is understood that issues with groundwater flooding have been reported previously.
- Information regarding the operation and cessation of minewater within the catchment is obtained any analysed in order to understand in more detail the relation to the effects on local flows and how this may be taken into account at gauging stations to increase confidence in flows.
- Analysis of rainfall trends in the region, to understand how any trends may affect local river flows, so that these affects can be included within flow analysis of gauged data.
- Confirmation of the operation of the lochs within the schematised catchment are obtained, and included in the model if required.

12. Reporting

The Final Hydrological Report will include the finalised, calibrated inflows to the hydrological routing model and the hydraulic model. It will be included as part of the final flood modelling report as Technical Appendices, with a summary of the methods and results included within the main body of the report.

APPENDIX A: Figures

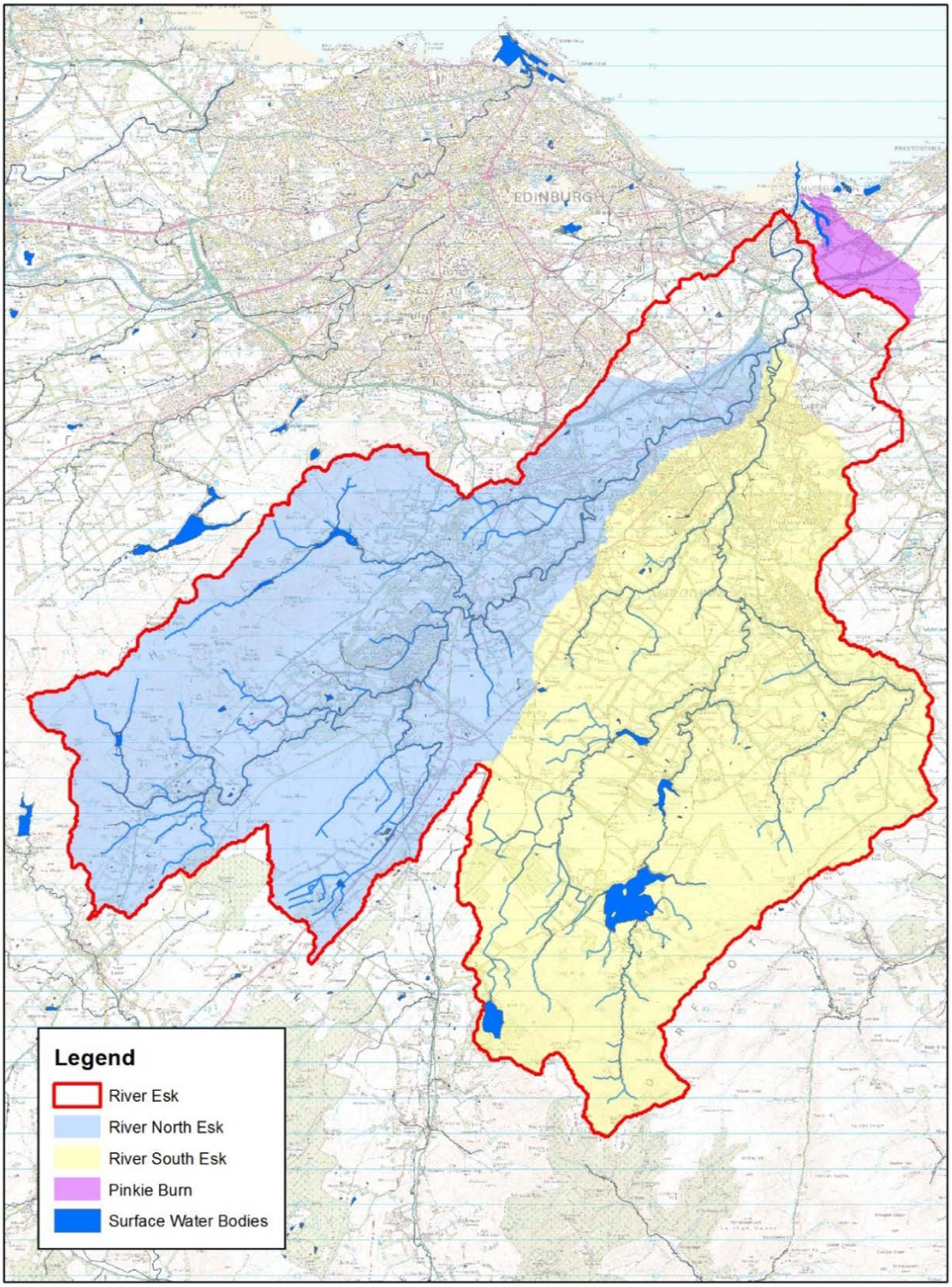


Figure 1: Catchment overview

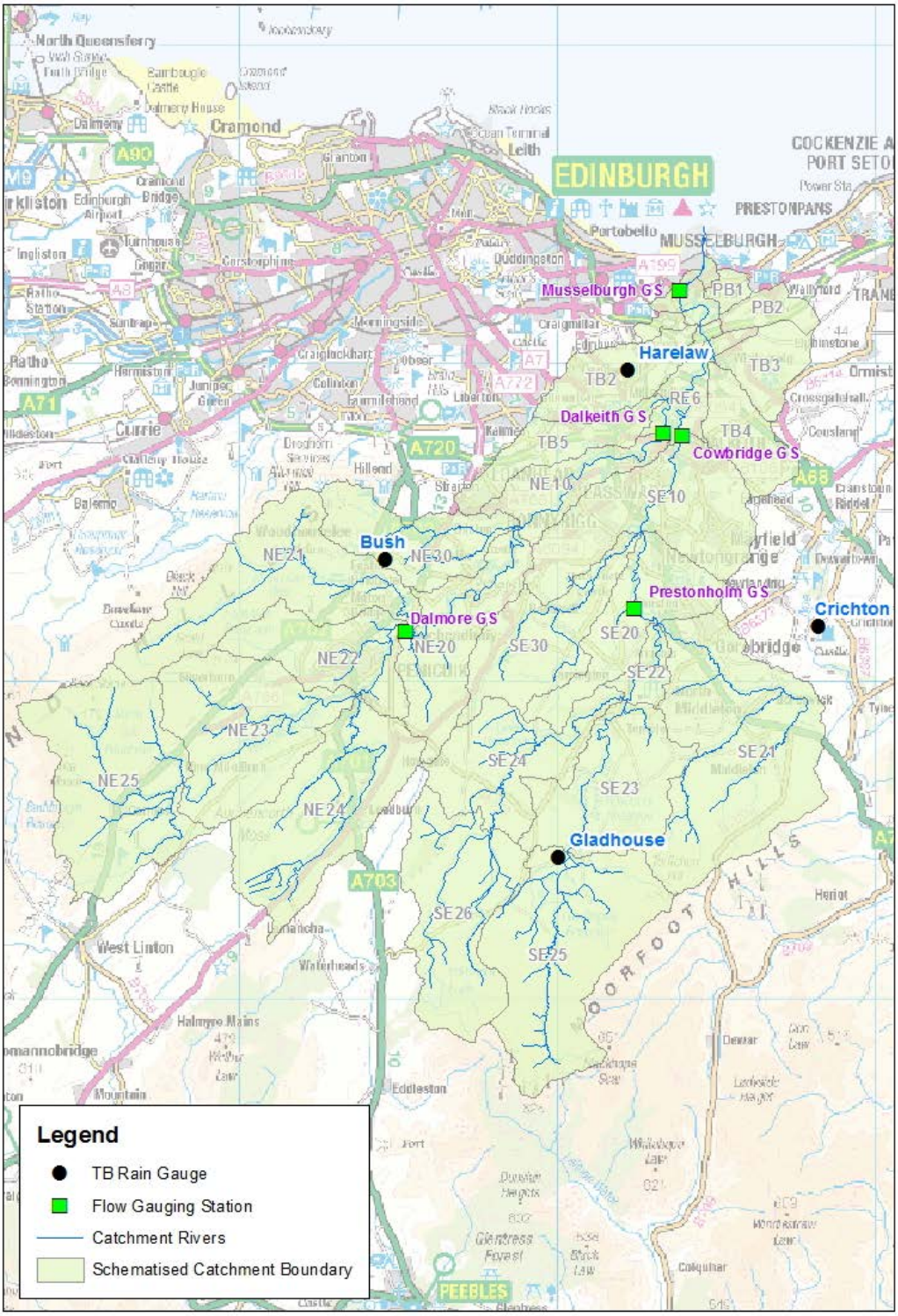


Figure 2: Location of river flow gauging stations and tipping-bucket rain gauges

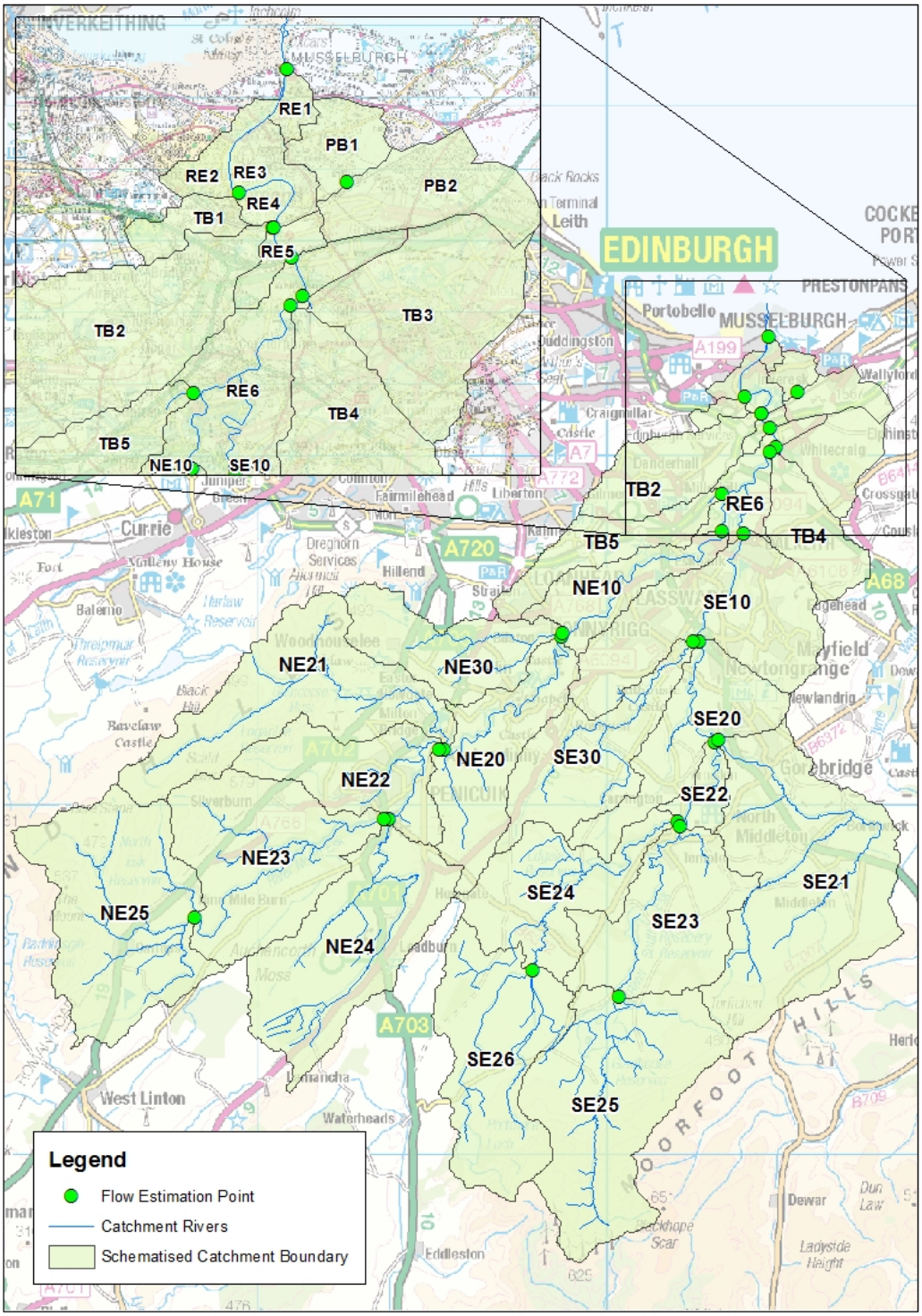


Figure 3: Catchment schematisation and flow estimation points

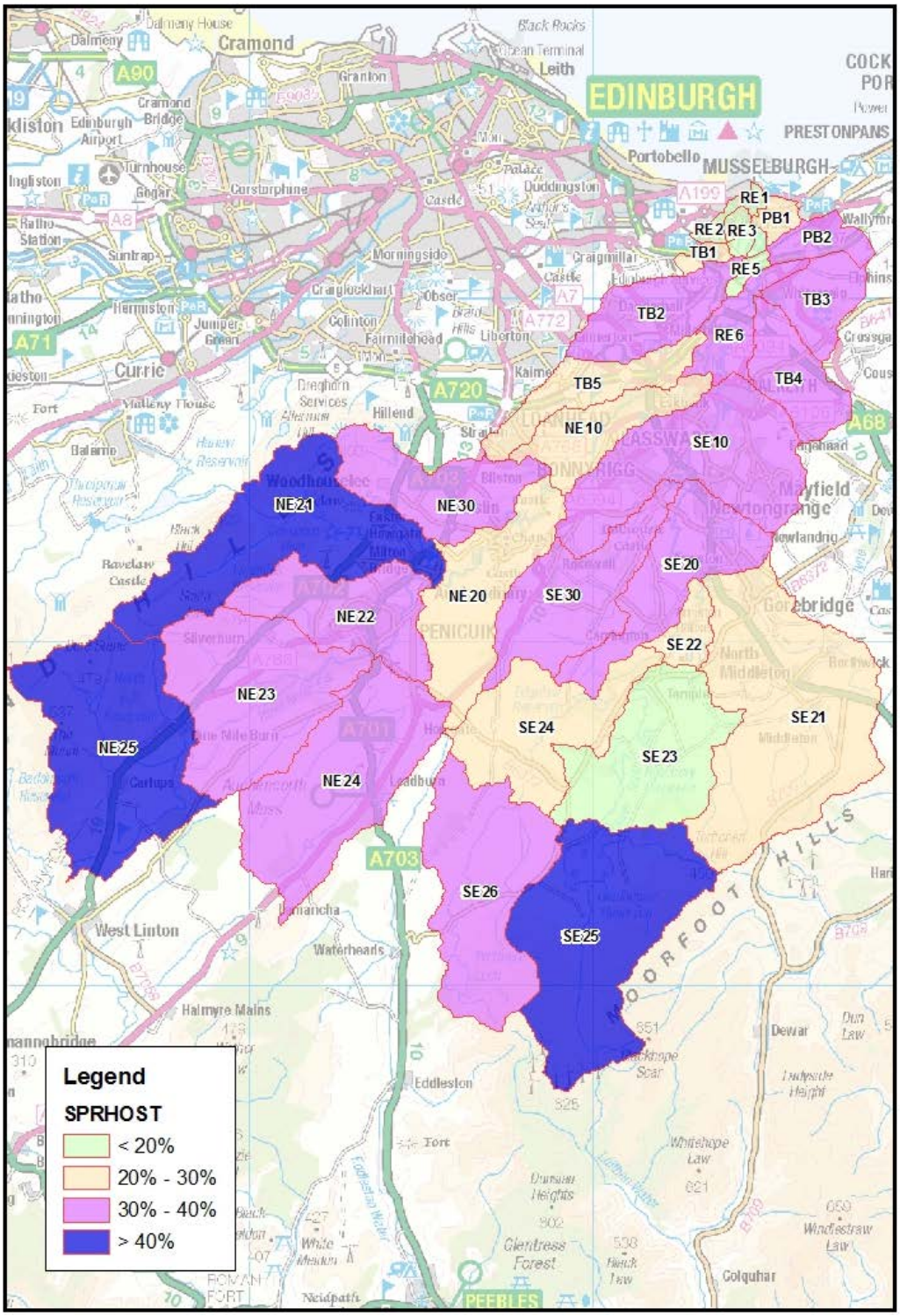


Figure 4: Variation of SPRHOST across sub catchments

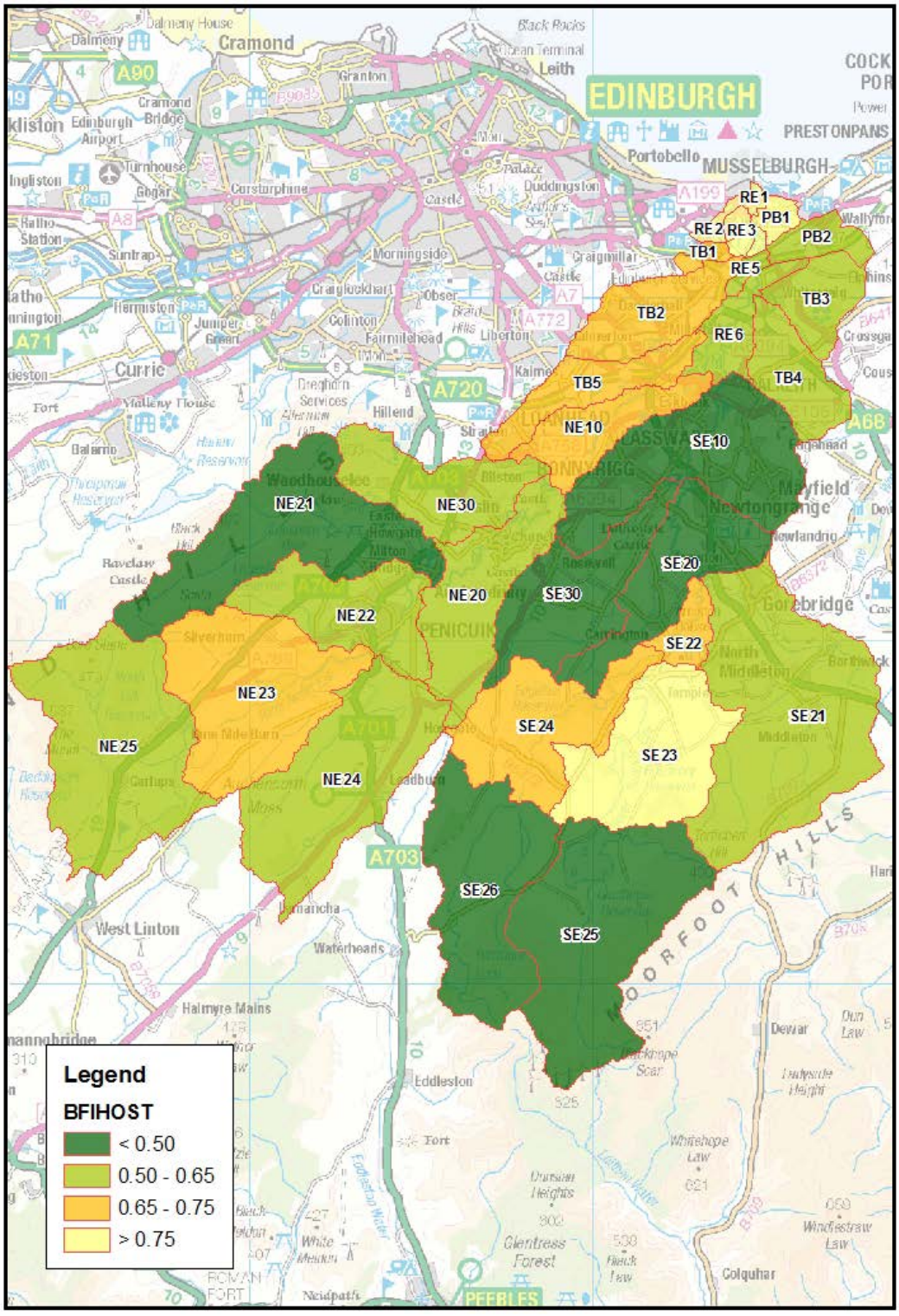


Figure 5: Variation in BFIHOST across sub catchments

APPENDIX B: GAUGING STATION AMAX SERIES

95 Bothwell Street,
Glasgow
G2 7HX
0141 243 8000
www.jacobs.com

Musselburgh AMAX			
Water Year	**Q m^3/s**	**Date/Time**	**Post-1990 Rank**
1961	87.823	11/09/1962 09:00	-
1962	71.027	05/03/1963 09:00	-
1963	78.894	23/11/1963 09:00	-
1964	94.492	26/09/1965 09:00	-
1965	154.603	13/08/1966 09:00	-
1966	56.054	19/12/1966 09:00	-
1967	91.974	05/05/1968 09:00	-
1968	69.483	01/11/1968 09:00	-
1969	73.361	22/11/1969 09:00	-
1970	70.254	31/10/1970 09:00	-
1971	33.821	17/02/1972 09:00	-
1972	17.842	11/12/1972 09:00	-
1973	48.28	17/03/1974 09:00	-
1974	70.254	18/09/1975 09:00	-
1975	30.754	03/04/1976 09:00	-
1976	74.144	25/01/1977 09:00	-
1977	42.848	30/10/1977 09:00	-
1978	52.478	15/11/1978 09:00	-
1979	65.668	08/12/1979 09:00	-
1980	110.011	25/11/1980 09:00	-
1981	114.443	03/01/1982 09:00	-
1982	118.927	23/11/1982 09:00	-
1983	78.974	04/02/1984 09:00	-
1984	166.726	03/11/1984 09:00	-
1985	71.802	21/12/1985 09:00	-
1986	61.917	30/12/1986 09:00	-
1987	56.777	02/01/1988 09:00	-
1988	49.668	11/01/1989 09:00	-
1989	74.144	17/02/1990 09:00	-
1990	216.407	06/10/1990 09:00	1
1991	134.171	08/01/1992 09:00	4
1992	113.909	15/05/1993 09:00	6
1993	130.634	10/10/1993 09:00	5

Musselburgh AMAX			
Water Year	Q m^3/s	Date/Time	Post-1990 Rank
1994	104.327	12/12/1994 09:00	10
1995	42.382	16/11/1995 09:00	26
1996	53.33	21/02/1997 09:00	23
1997	34.57	11/12/1997 09:00	27
1998	80.335	03/11/1998 09:00	15
1999	180.44	27/04/2000 09:00	2
2000	108.077	07/11/2000 09:00	8
2001	50.576	24/01/2002 09:00	25
2002	110.981	22/10/2002 09:00	7
2003	58.89	02/02/2004 09:00	22
2004	95.336	08/01/2005 09:00	11
2005	59.33	12/10/2005 09:00	21
2006	53.138	16/11/2006 01:30	24
2007	90.191	07/08/2008 05:30	13
2008	66.058	04/09/2009 12:30	18
2009	69.283	30/03/2010 20:30	17
2010	106.798	11/08/2011 16:15	9
2011	142.697	07/07/2012 11:45	3
2012	86.956	12/10/2012 10:45	14
2013	64.642	30/12/2013 18:00	20
2014	80.015	22/12/2014 07:45	16
2015	93.452	26/12/2015 21:45	12
2016	65.287	22/11/2016 13:30	19

	Cowbridge AMAX					Dalmore AMAX				
Water Year	Q m^3/s	Quality	Date	Time	Rank	Q m^3/s	Quality	Date	Time	Rank
1992	33.363	50 (G) calc	14/05/1993	22:30:00	16	22.223	50 (G) calc	14/05/1993	01:27:07	9
1993	62.301	50 (G) calc	10/10/1993	01:45:00	2	22.616	50 (G) calc	05/10/1993	08:47:20	8
1994	40.823	50 (G) calc	12/12/1994	07:45:00	12	23.359	50 (G) calc	11/12/1994	20:30:00	6
1995	18.193	50 (G) calc	16/11/1995	04:15:00	24	16.469	50 (G) calc	15/11/1995	20:00:00	24
1996	27.545	50 (G) calc	21/02/1997	05:45:00	19	18.881	50 (G) calc	20/02/1997	22:00:00	17
1997	19.157	50 (G) calc	11/12/1997	15:30:00	23	15.718	50 (G) calc	08/01/1998	07:00:00	25

	Cowbridge AMAX					Dalmore AMAX				
Water Year	**Q m^3/s**	**Quality**	**Date**	**Time**	**Rank**	**Q m^3/s**	**Quality**	**Date**	**Time**	**Rank**
1998	44.595	50 (G) calc	03/11/1998	04:00:00	9	20.770	50 (G) calc	02/11/1998	02:00:00	13
1999	87.362	200 (V) calc	26/04/2000	21:00:00	1	41.136	50 (G) calc	26/04/2000	20:30:00	1
2000	37.749	200 (V) calc	05/11/2000	19:15:00	14	27.289	50 (G) calc	07/11/2000	10:15:00	3
2001	24.179	50 (G) calc	24/01/2002	08:00:00	21	17.277	50 (G) calc	02/08/2002	03:15:00	22
2002	61.441	50 (G) calc	22/10/2002	20:15:00	3	24.867	50 (G) calc	21/10/2002	08:00:00	4
2003	23.028	50 (G) calc	01/02/2004	23:30:00	22	19.395	50 (G) calc	24/06/2004	10:00:00	15
2004	47.24	50 (G) calc	08/01/2005	05:30:00	7	24.512	50 (G) calc	07/01/2005	02:45:00	5
2005	8.917	50 (G) calc	14/09/2006	19:00:00	25	16.556	100 (E) calc	14/09/2006	23:00:00	23
2006	31.796	50 (G) calc	19/08/2007	08:15:00	17	17.548	50 (G) calc	15/11/2006	23:45:00	21
2007	38.564	50 (G) calc	21/11/2007	18:00:00	13	21.590	50 (G) calc	07/08/2008	02:30:00	10
2008	31.761	50 (G) calc	04/09/2009	10:45:00	18	18.487	50 (G) calc	25/10/2008	22:15:00	18
2009	43.265	50 (G) calc	16/01/2010	14:45:00	10	17.718	50 (G) calc	05/04/2010	14:45:00	20
2010	50.988	50 (G) calc	11/08/2011	14:15:00	5	21.347	200 (V) calc	11/08/2011	14:30:00	11
2011	48.621	50 (G) calc	07/07/2012	08:00:00	6	35.854	50 (G) calc	07/07/2012	07:45:00	2
2012	35.766	100 (E) calc	12/10/2012	09:45:00	15	19.700	50 (G) calc	12/10/2012	08:15:00	14
2013	25.2	100 (E) calc	28/12/2013	02:30:00	20	18.004	200 (V) calc	30/12/2013	16:00:00	19
2014	45.234	100 (E) calc	22/12/2014	06:45:00	8	22.690	50 (G) calc	22/12/2014	05:45:00	7
2015	59.171	100 (E) calc	26/12/2015	21:00:00	4	21.251	50 (G) calc	05/12/2015	06:15:00	12
2016	42.706	100 (E) calc	22/11/2016	11:30:00	11	19.067	50 (G) calc	25/02/2017	09:15:00	16

	Dalkeith AMAX				Prestonholm AMAX		
Water Year	Date	Q m^3/s	Post-1990 Rank	Pre-1990 Rank	Date	Q m^3/s	Rank
1961	11-Sep-62	47.653	-	6	-	-	-
1962	05-Mar-63	29.035	-	18	-	-	-
1963	23-Nov-63	36.593	-	11	24/11/1963	28.47	6
1964	29-Jul-65	39.796	-	9	26/09/1965	31.169	4
1965	13-Aug-66	91.337	-	1	13/08/1966	65.045	2
1966	19-Dec-66	19.596	-	25	16/05/1967	19.143	13
1967	05-May-68	41.987	-	8	05/05/1968	24.74	10
1968	01-Nov-68	34.002	-	14	01/11/1968	22.299	12
1969	22-Nov-69	46.498	-	7	20/08/1970	14.305	19
1970	31-Oct-70	37.12	-	10	24/03/1971	28.996	5
1971	17-Feb-72	15.223	-	26	16/02/1972	8.391	23
1972	24-May-73	6.37	-	28	18/02/1973	2.208	26
1973	17-Mar-74	12.134	-	27	12/01/1974	4.772	25
1974	25-Jan-75	23.918	-	21	25/01/1975	17.797	16
1975	-	-	-	-	03/04/1976	7.487	24
1976	26-Jan-77	35.548	-	13	26/01/1977	17.278	17
1977	31-Oct-77	20.434	-	24	28/01/1978	10.959	21
1978	15-Nov-78	24.821	-	20	25/03/1979	18.858	15
1979	26-Nov-79	30.495	-	17	25/03/1980	11.812	20
1980	25-Nov-80	57.886	-	4	25/11/1980	27.381	8
1981	01-Oct-81	52.376	-	5	03/01/1982	34.337	3
1982	23-Nov-82	60.4	-	3	23/11/1982	28.021	7
1983	04-Feb-84	31.482	-	15	04/02/1984	25.499	9
1984	03-Nov-84	90.598	-	2	03/11/1984	82.969	1
1985	21-Dec-85	35.548	-	12	04/03/1986	10.544	22
1986	30-Dec-86	28.078	-	19	19/07/1987	15.76	18
1987	17-Oct-87	21.286	-	22	01/02/1988	22.791	11
1988	11-Jan-89	20.434	-	23	09/03/1989	19.084	14
1989	04-Feb-90	30.987	-	16	-	-	-
1990	06-Oct-90	116.123	3	-	-	-	-
1991	08-Jan-92	57.886	8	-	-	-	-
1992	15-May-93	47.016	12	-	-	-	-
1993	09-Dec-93	33.797	16	-	-	-	-
1994	12-Dec-94	57.474	9	-	-	-	-
1995	16-Nov-95	29.323	19	-	-	-	-

	Dalkeith AMAX				Prestonholm AMAX		
Water Year	**Date**	**Q m^3/s**	**Post-1990 Rank**	**Pre-1990 Rank**	**Date**	**Q m^3/s**	**Rank**
1996	20-Feb-97	37.796	15	-	-	-	-
1997	09-Jan-98	29.748	18	-	-	-	-
1998	27-Dec-98	40.144	13	-	-	-	-
1999	26-Apr-00	121.935	1	-	-	-	-
2000	07-Nov-00	68.623	6	-	-	-	-
2001	03-Aug-02	62.673	7	-	-	-	-
2002	22-Oct-02	103	4	-	-	-	-
2003	24-Jun-04	57.474	10	-	-	-	-
2004	08-Jan-05	97.976	5	-	-	-	-
2005	22-May-06	19.864	20	-	-	-	-
2006	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-
2009	05-Apr-10	40.080	14	-	-	-	-
2010	11-Aug-11	52.411	11	-	-	-	-
2011	07-Jul-12	118.600	2	-	-	-	-
2012	12-Oct-12	32.430	17	-	-	-	-

95 Bothwell Street,
Glasgow
G2 7HX
0141 243 8000
www.jacobs.com

APPENDIX C: Catchment Descriptors

95 Bothwell Street,
Glasgow
G2 7HX
0141 243 8000
www.jacobs.com

FEH Catchment Descriptors for Sub Catchments

Gauging Stations within the River Esk Catchment						
Sub-catchment Ref #	**Whole Esk Catchment**	**NE @ Dalmore**	**NE@Dalkieth**	**SE@Prestonholm**	**SE@Cowbridge**	**RE@Musselburgh**
Name of Waterbody	River Esk	North Esk	North Esk	South Esk	South Esk	River Esk
DS NGR	NT 34350 72800	NT 25200 61600	NT 33200 67600	NT 32450 62350	NT 33850 67600	NT 33850 72350
Centroid	NT 27555 59739	NT 19829 57686	NT 21719 59958	NT 31182 55405	NT 31277 57433	NT 27538 59704
QMED(AMAX)	-	19.49	54.94	19.1135	38.56	86.96
Urban Category	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Slightly Urbanised	Slightly Urbanised
$QMED_{CDrural}$	36.67	16.68	23.53	11.88	17.15	36.81
PRAUF	1.02	1.01	1.01	1.00	1.02	1.02
UAF	1.04	1.02	1.03	1.01	1.04	1.04
$QMED_{CDurban}$	38.17	17.02	24.21	11.95	17.82	38.26
AREA	323.4325	79.845	133.4125	113.5375	154.19	322.53
ALTBAR	238	299	272	286	247	239
ASPBAR	27	91	83	353	359	27
ASPVAR	0.24	0.26	0.25	0.35	0.34	0.23
BFIHOST	0.568	0.561	0.551	0.592	0.561	0.567
DPLBAR	25.36	11.31	22.51	12.48	16.25	24.75
DPSBAR	94.7	112	121	93.9	84.1	94.8
FARL	0.944	0.975	0.965	0.888	0.915	0.944
FPEXT	0.0437	0.0316	0.0328	0.0418	0.0414	0.0433
FPDBAR	0.387	0.285	0.326	0.363	0.351	0.382
FPLOC	0.839	0.949	0.879	1.011	0.991	0.843
LDP	45.16	21.3	36.77	23.8	30.83	44.49
PROPWET	0.49	0.49	0.49	0.49	0.49	0.49
RMED-1H	8.6	8.7	8.7	8.9	8.7	8.6
RMED-1D	35.9	38.3	38	37.2	35.8	35.9

Gauging Stations within the River Esk Catchment						
Sub-catchment Ref #	**Whole Esk Catchment**	**NE @ Dalmore**	**NE@Dalkieth**	**SE@Prestonholm**	**SE@Cowbridge**	**RE@Musselburgh**
RMED-2D	49.8	52.3	52.1	50.8	49.6	49.9
SAAR	836	949	907	859	819	837
SAAR4170	852	971	920	883	838	853
SPRHOST	34.04	37.22	37.15	31.01	32.37	34.09
URBCONC1990	0.747	0.64	0.672	-999999	0.78	0.741
URBEXT1990	0.0243	0.0182	0.0209	0.0032	0.0258	0.0236
URBLOC1990	0.616	0.35	0.634	-999999	0.306	0.626
URBCONC2000	0.822	0.805	0.789	-999999	0.828	0.818
URBEXT2000	0.034	0.0185	0.0258	0.0043	0.0309	0.0325
URBEXT2018	0.035	0.019	0.027	0.004	0.032	0.034
URBLOC2000	0.57	0.323	0.575	-999999	0.317	0.58
C	-0.01584	-0.01641	-0.01639	-0.01557	-0.01571	-0.01585
D1	0.45402	0.4735	0.47255	0.45456	0.44967	0.45418
D2	0.53425	0.51491	0.51692	0.53444	0.54323	0.53427
D3	0.23221	0.23229	0.23151	0.21953	0.22591	0.23205
E	0.24334	0.24819	0.24684	0.24301	0.2421	0.24336
F	2.19666	2.20279	2.20346	2.22914	2.20777	2.1969
C(1 km)	-0.014	-0.017	-0.014	-0.016	-0.014	-0.014
D1(1 km)	0.393	0.493	0.413	0.433	0.398	0.406
D2(1 km)	0.521	0.54	0.574	0.578	0.581	0.522
D3(1 km)	0.295	0.217	0.25	0.25	0.251	0.276
E(1 km)	0.237	0.248	0.235	0.24	0.235	0.237
F(1 km)	2.112	2.187	2.133	2.137	2.114	2.122

River North Esk Sub-catchments									
Sub-catchment Ref #	**Whole Esk Catchment**	**NE10**	**NE20**	**NE21**	**NE22**	**NE23**	**NE24**	**NE25**	**NE30**
Name of Waterbody	River Esk	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk
DS NGR	NT 34350 72800	NT 33300 67800	NT 28700 64800	NT 25350 61600	NT 25200 61600	NT 23600 59600	NT 23750 59600	NT 18200 56750	NT 28750 64900
Centroid	NT 27555 59739	NT 21726 59963	NT 20843 59125	NT 20943 62991	NT 19829 57686	NT 17817 57659	NT 22549 55967	NT 16005 56951	NT 25348 64579
QMED(AMAX)	-	-	-	-	-	-	-	-	-
Urban Category	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Slightly Urbanised
$QMED_{CDrural}$	36.67	0.51	2.35	6.59	3.28	3.92	5.05	8.45	2.01
PRAUF	1.02	1.16	1.01	1.00	1.06	1.00	1.00	1.00	1.03
UAF	1.04	1.27	1.02	1.01	1.13	1.00	1.01	1.00	1.06
$QMED_{CDurban}$	38.17	0.65	2.40	6.63	3.71	3.93	5.08	8.45	2.14
QMED DT Station	Musselburgh	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore
$QMED_{DT}$	-	0.75	2.75	7.59	4.25	4.50	5.82	9.68	2.45
GC DT Station	-	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore
SUBCATCH AREA		7.2	13.35	22.004	11.79	20.98	21.488	25.586	11.096
UPSTREAM AREA	323.43	133.495	115.1975	22.005	79.845	46.5675	21.49	25.5875	11.0975
ALTBAR	238	90.94	183.02	317	250.67	283.31	267	361	213
ASPBAR	27	-999	-999	92	-999	-999	27	110	102
ASPVAR	0.24	-999	-999.00	0.18	-999.00	-999.00	0.27	0.34	0.5
BFIHOST	0.568	0.75	0.60	0.398	0.55	0.66	0.534	0.509	0.598
DPLBAR	25.36	4.58	6.66	7.88	3.99	5.64	6.62	4.33	4.33
DPSBAR	94.7	89.3	87.40	195.5	119.67	126.22	49.5	149.3	99.4
FARL	0.944	0.999	1.00	0.892	1.00	0.99	0.973	0.962	0.984
FPEXT	0.0437	-999	-999	0.0123	-999	-999	0.0454	0.0197	0.0472
FPDBAR	0.387	-999	-999	0.136	-999	-999	0.333	0.209	0.364

River North Esk Sub-catchments									
Sub-catchment Ref #	**Whole Esk Catchment**	**NE10**	**NE20**	**NE21**	**NE22**	**NE23**	**NE24**	**NE25**	**NE30**
FPLOC	0.839	-999	-999	0.721	-999	-999	1.163	0.856	0.9
LDP	45.16	7.62	8.08	14.21	3.83	8.75	12.31	8.72	7.79
PROPWET	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
RMED-1H	8.6	6.95	8.74	9.2	8.88	8.58	8.6	8.8	8.8
RMED-1D	35.9	31.29	35.70	40.4	39.91	39.50	37.2	37.5	38.2
RMED-2D	49.8	44.87	50.93	54.7	57.01	55.09	50.8	49.1	51.6
SAAR	836	687	789.96	946	894.59	948.44	877	1035	811
SAAR4170	852	681	784.91	953	901.09	972.31	914	1050	805
SPRHOST	34.04	21.00	28.30	48.18	34.14	32.57	37.87	41.91	35.78
URBCONC1990	0.747	-999	-999.00	-999999	-999.00	-999.00	0.337	-999999	0.738
URBEXT1990	0.0243	0.0842	0.01	0.0039	0.10	0.01	0.0054	0.0016	0.0479
URBLOC1990	0.616	-999	-999	-999999	-999	-999	1.004	-999999	0.578
URBCONC2000	0.822	-999	-999	0.566	-999	-999	0.538	-999999	0.83
URBEXT2000	0.0338	0.14	0.01	0.0057	0.11	0.00	0.0059	0	0.0559
URBEXT2018	0.04	0.15	0.02	0.01	0.11	0.00	0.01	0.00	0.06
URBLOC2000	0.57	-999	-999	0.2	-999	-999	1.186	-999999	0.589
C	-0.01584	-0.0158	-0.02	-0.01644	-0.02	-0.02	-0.01667	-0.01606	-0.0158
D1	0.45402	0.47894	0.47	0.4852	0.49	0.49	0.46426	0.46246	0.47894
D2	0.53425	0.50782	0.54	0.49593	0.54	0.53	0.52607	0.48451	0.50782
D3	0.23221	0.23536	0.23	0.21772	0.20	0.22	0.20656	0.27706	0.23536
E	0.24334	0.24145	0.25	0.24811	0.25	0.25	0.24769	0.24792	0.24145
F	2.19666	2.21262	2.18	2.24136	2.21	2.20	2.19491	2.20898	2.21262
C(1 km)	-0.014	-0.016	-999.00	-0.017	-999.00	-999.00	-0.017	-0.017	-0.016
D1(1 km)	0.393	0.436	-999.00	0.493	-999.00	-999.00	0.494	0.494	0.436
D2(1 km)	0.521	0.572	-999.00	0.54	-999.00	-999.00	0.539	0.501	0.572
D3(1 km)	0.295	0.268	-999.00	0.217	-999.00	-999.00	0.196	0.257	0.268
E(1 km)	0.237	0.239	-999.00	0.248	-999.00	-999.00	0.248	0.252	0.239
F(1 km)	2.112	2.138	-999.00	2.187	-999.00	-999.00	2.184	2.19	2.138

River South Esk Sub-catchments										
Sub-catchment Ref #	**Whole Esk Catchment**	**SE10**	**SE20**	**SE21**	**SE22**	**SE23**	**SE24**	**SE25**	**SE26**	**SE30**
Name of Waterbody	River Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk
DS NGR	NT 34350 72800	NT 33900 67700	NT 32650 64700	NT 33150 61850	NT 33050 61800	NT 32100 59400	NT 32000 59500	NT 30250 54650	NT 27900 55300	NT 32500 64650
Centroid	NT 27555 59739	NT 31318 57535	NT 31263 55932	NT 35447 57842	NT 29430 54257	NT 30734 53463	NT 27521 54777	NT 30168 51473	NT 26821 52775	NT 29461 61400
Urban Category	Slightly Urbanised	Heavily Urbanised	Slightly Urbanised	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural
$QMED_{CDrural}$	36.67	3.04	2.38	4.19	0.33	1.16	1.81	4.28	5.35	3.10
PRAUF	1.02	1.09	1.03	1.01	1.00	1.00	1.00	1.00	1.00	1.01
UAF	1.04	1.23	1.08	1.02	1.00	1.00	1.00	1.00	1.00	1.02
$QMED_{CDurban}$	38.17	3.73	2.56	4.26	0.33	1.16	1.81	4.28	5.35	3.15
DT Station	Musselburgh	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge
$QMED_{DT}$	-	8.07	5.53	9.23	0.72	2.51	3.92	9.27	11.58	6.82
GC DT Station	-	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge
SUBCATCH AREA	-	19.25	12.09	31.789	2.6875	16.33	14.2675	26.55	19.751	13.176
UPSTREAM AREA	323.4325	155.8975	123.47	31.79	79.5875	42.88	34.02	26.55	19.7525	13.1775
ALTBAR	238	246	275	247	306	334	285	389	314	168
ASPBAR	27	358	353	340	2	352	22	342	355	39
ASPVAR	0.24	0.34	0.35	0.44	0.32	0.39	0.25	0.39	0.31	0.51
BFIHOST	0.568	0.56	0.582	0.649	0.57	0.572	0.558	0.424	0.457	0.459
DPLBAR	25.36	16.22	14.74	8.19	12.96	8.73	10.18	4.51	4.35	6.21
DPSBAR	94.7	83.8	91.5	81.7	99.8	117	78	141	81.5	57.4
FARL	0.944	0.916	0.896	1	0.844	0.792	0.902	0.76	0.934	0.992
FPEXT	0.0437	0.0418	0.0412	0.0369	0.0439	0.0293	0.0604	0.0287	0.0774	0.0239
FPDBAR	0.387	0.353	0.357	0.317	0.381	0.259	0.492	0.282	0.61	0.161
FPLOC	0.839	0.982	1.019	1.097	0.977	0.849	1.022	0.623	0.693	1.139

River South Esk Sub-catchments										
Sub-catchment Ref #	**Whole Esk Catchment**	**SE10**	**SE20**	**SE21**	**SE22**	**SE23**	**SE24**	**SE25**	**SE26**	**SE30**
LDP	45.16	30.96	26.99	15.33	22.7	16.77	18.69	9.9	9.93	10.67
PROPWET	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
RMED-1H	8.6	8.7	8.9	8.7	9	9.2	8.9	9.6	9	8.3
RMED-1D	35.9	35.7	36.8	35.4	38	38.6	37.7	39.8	38.7	34
RMED-2D	49.8	49.6	50.4	49.9	51.2	51.7	50.9	53.1	52	48
SAAR	836	818	847	804	884	907	867	959	892	748
SAAR4170	852	837	870	827	909	937	888	1003	924	750
SPRHOST	34.04	32.4	31.36	27.36	32.45	32.39	32.98	40.81	38.64	38.12
URBCONC1990	0.747	0.781	0.75	0.595	-999999	-999999	-999999	-999999	-999999	0.75
URBEXT1990	0.0243	0.0265	0.0071	0.0072	0.0007	0.0013	0	0	0	0.0166
URBLOC1990	0.616	0.304	0.236	0.263	-999999	-999999	-999999	-999999	-999999	1.003
URBCONC2000	0.822	0.83	0.827	0.821	-999999	-999999	-999999	-999999	-999999	0.807
URBEXT2000	0.034	0.032	0.009	0.012	0.000	0.000	0.000	0.000	0.000	0.016
URBEXT2018	0.035	0.033	0.010	0.012	0.000	0.000	0.000	0.000	0.000	0.016
URBLOC2000	0.57	0.312	0.247	0.293	-999999	-999999	-999999	-999999	-999999	0.991
C	-0.01584	-0.0157	-0.0156	-0.01539	-0.01566	-0.01562	-0.01568	-0.01589	-0.01583	-0.0172
D1	0.45402	0.44916	0.45324	0.4444	0.45921	0.46007	0.45906	0.46204	0.4597	0.45294
D2	0.53425	0.54378	0.53689	0.55898	0.52352	0.52107	0.52426	0.51807	0.52054	0.54926
D3	0.23221	0.22602	0.22126	0.22385	0.21738	0.22272	0.20957	0.22239	0.20623	0.23709
E	0.24334	0.24202	0.24268	0.24148	0.24377	0.24426	0.24336	0.24611	0.24524	0.24367
F	2.19666	2.20694	2.22291	2.21049	2.23856	2.24939	2.22989	2.27156	2.24803	2.16575
C(1 km)	-0.014	-0.014	-0.016	-0.016	-0.016	-0.017	-0.016	-0.015	-0.015	-0.016
D1(1 km)	0.393	0.398	0.441	0.428	0.428	0.448	0.455	0.465	0.465	0.44
D2(1 km)	0.521	0.581	0.575	0.596	0.596	0.547	0.536	0.521	0.52	0.581
D3(1 km)	0.295	0.251	0.24	0.24	0.24	0.231	0.24	0.214	0.202	0.252
E(1 km)	0.237	0.235	0.24	0.24	0.24	0.244	0.24	0.241	0.241	0.24
F(1 km)	2.112	2.114	2.126	2.149	2.149	2.183	2.169	2.237	2.236	2.127

		Tributaries and Pinkie Burn						
Sub-catchment Ref #	**Whole Esk Catchment**	**TB1**	**TB2**	**TB3**	**TB4**	**TB5**	**PB1**	**PB2**
Name of Waterbody	River Esk	River Esk Tributary	River Esk Tributary	River Esk Tributary	River Esk Tributary	River Esk Tributary	Pinkie Burn	Pinkie Burn
DS NGR	NT 34350 72800	NT 33950 71650	NT 34400 71200	NT 34850 70250	NT 34700 70100	NT 33300 68900	NT 34650 73400	NT 35400 71750
Centroid	NT 27555 59739	NT 32474 71004	NT 31800 69596	NT 36438 69631	NT 35863 67760	NT 29893 67350	NT 36349 71511	NT 36516 71062
QMED(AMAX)	-	-	-	-	-	-	-	-
Urban Category	Slightly Urbanised	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Moderately Urbanised	Moderately Urbanised	Essentially Rural
$QMED_{CDrural}$	36.67	0.10	0.67	0.44	1.01	0.56	0.34	0.29
PRAUF	1.02	1.06	1.04	1.01	1.00	1.07	1.06	1.01
UAF	1.04	1.10	1.09	1.02	1.01	1.14	1.13	1.01
$QMED_{CDurban}$	38.17	0.11	0.73	0.45	1.01	0.64	0.39	0.29
QMED DT Station	Musselburgh	Musselburgh	Dalmore	Dalmore	Dalmore	Musselburgh	Musselburgh	Dalmore
$QMED_{DT}$	-	0.05	0.83	0.52	1.16	1.45	0.42	0.31
GC DT Station	-	Musselburgh	Dalmore	Dalmore	Dalmore	Musselburgh	Musselburgh	Dalmore
AREA	323.4325	1.4375	8.4475	3.4875	6.6025	6.975	5.29	3.18
ALTBAR	238	41	60	79	103	102	46	57
ASPBAR	27	70	70	306	316	73	306	298
ASPVAR	0.24	0.62	0.66	0.8	0.72	0.51	0.68	0.67
BFIHOST	0.568	0.749	0.674	0.569	0.519	0.719	0.702	0.649
DPLBAR	25.36	1.91	3.8	2.1	3.34	4.61	3.45	1.78
DPSBAR	94.7	30.1	27.1	55.8	48.9	37.4	37.3	40.7
FARL	0.944	1	0.993	0.994	1	0.992	1	1
FPEXT	0.0437	0.0922	0.1178	0.0982	0.0666	0.0534	0.2024	0.1327
FPDBAR	0.387	0.449	0.637	0.642	0.377	0.436	1.222	1.097
FPLOC	0.839	0.776	0.846	0.636	0.95	0.812	0.614	0.453
LDP	45.16	3.76	7.23	3.5	6	9.17	6.05	3.7
PROPWET	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49

		Tributaries and Pinkie Burn						
Sub-catchment Ref #	**Whole Esk Catchment**	**TB1**	**TB2**	**TB3**	**TB4**	**TB5**	**PB1**	**PB2**
RMED-1H	8.6	7.8	7.8	7.9	7.9	8	7.9	8
RMED-1D	35.9	27.6	27.9	28.6	28.5	29.5	29.1	29.1
RMED-2D	49.8	40	40.8	43.1	43.5	43.3	42.8	43.1
SAAR	836	619	643	630	649	685	608	614
SAAR4170	852	641	654	654	661	686	639	644
SPRHOST	34.04	23.58	30.69	37.32	36.54	26.36	30.48	34.64
URBCONC1990	0.747	0.677	-999999	0.5	-999999	0.73	0.713	-999999
URBEXT1990	0.0243	0.0226	0.0006	0.0079	0	0.0282	0.0452	0.002
URBLOC1990	0.616	0.15	-999999	1.175	-999999	1.798	0.52	-999999
URBCONC2000	0.822	0.818	0.745	0.759	0.455	0.928	0.829	0.737
URBEXT2000	0.034	0.060	0.069	0.016	0.006	0.092	0.094	0.011
URBEXT2018	0.035	0.062	0.071	0.017	0.006	0.096	0.098	0.011
URBLOC2000	0.57	0.259	1.277	0.337	0.707	1.748	0.63	0.9
C	-0.01584	-0.014	-0.0143	-0.014	-0.01415	-0.01524	-0.01372	-0.01391
D1	0.45402	0.39759	0.3992	0.40444	0.3993	0.41368	0.4102	0.41138
D2	0.53425	0.53593	0.54777	0.5643	0.58801	0.55773	0.54261	0.54849
D3	0.23221	0.27513	0.27687	0.24342	0.23705	0.27757	0.24631	0.24277
E	0.24334	0.23554	0.23566	0.23499	0.23398	0.23805	0.23506	0.23499
F	2.19666	2.11482	2.11703	2.12094	2.12899	2.13122	2.12417	2.12306
C(1 km)	-0.014	-0.014	-0.014	-0.014	-0.014	-0.014	-0.013	-0.014
D1(1 km)	0.393	0.406	0.409	0.406	0.406	0.4	0.409	0.409
D2(1 km)	0.521	0.522	0.531	0.545	0.545	0.551	0.513	0.525
D3(1 km)	0.295	0.276	0.273	0.252	0.252	0.272	0.269	0.266
E(1 km)	0.237	0.237	0.236	0.235	0.235	0.235	0.235	0.236
F(1 km)	2.112	2.122	2.121	2.12	2.12	2.112	2.118	2.122

Modified Catchment Descriptors for Intervening Catchment Areas

The following catchment descriptors were used in the calculation of ReFH flows within Flood Modeller for the smaller urbanized catchments towards the downstream reaches of the River Esk.

Name	RE1	RE2	RE3	RE4	RE5	PB1	Comment
Outlet Easting	334350	334350	334350	334350	334350	334650	
Outlet Northing	672800	672800	672800	672800	672800	673400	
Centroid Easting	334718	333635	334404	334301	334489	335349	
Centroid Northing	672875	672185	671996	671546	670778	672367	
AREA	0.40	0.76	0.92	0.36	0.71	1.28	Updated based on GIS measurements
BFIHOST	0.79	0.90	0.79	0.92	0.56	0.90	FEH POINT DATA used instead.
DPLBAR	0.61	0.86	0.96	0.57	0.83	1.14	Use FEH formula: Area^0.548
DPSBAR	27.38	27.38	27.38	27.38	6.59	32.17	
FARL	1.00	1.00	1.00	1.00	1.00	1.00	Updated based on review of OS maps
PROPWET	0.49	0.49	0.49	0.49	0.49	0.49	
SAAR	611.61	611.61	611.61	607.62	845.00	598.95	
URBLOC1990	0.02	0.02	0.02	0.02	0.02	0.02	
C	-0.01	-0.01	-0.01	-0.01	-0.02	-0.01	
D1	0.40	0.40	0.40	0.41	0.42	0.41	
D2	0.53	0.53	0.53	0.53	0.53	0.53	
D3	0.28	0.28	0.28	0.27	0.26	0.25	
E	0.24	0.24	0.24	0.24	0.23	0.24	
F	2.12	2.12	2.12	2.12	2.15	2.13	

95 Bothwell Street,
Glasgow
G2 7HX
0141 243 8000
www.jacobs.com

APPENDIX D: Reviewed Pooling Groups

River Esk @ Musselburgh Flow Calculations

River Esk @ Musselburgh reviewed pooling group (Post 1990 data only)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
19007 (Esk @ Musselburgh)	0	27	86.956	0.249	0.228	0.193	322.53	837	0.043	0.944	0.03
22009 (Coquet @ Rothbury)	0.372	41	133.004	0.262	0.245	0.284	345.98	905	0.036	0.994	0.002
27092 (Esk @ Briggswath)	0.425	24	151.5	0.196	0.007	1.721	325.27	877	0.023	0.999	0.004
10002 (Ugie @ Inverugie)	0.44	35	45.871	0.291	0.243	0.768	325.72	812	0.075	0.984	0.004
8009 (Dulnain @ Balnaan Bridge)	0.543	54	94.451	0.169	0.097	1.062	272.2	1012	0.051	0.994	0.001
55029 (Monnow @ Grosmont)	0.548	43	155.954	0.141	0.036	1.162	355.01	956	0.072	0.997	0.003
10001 (Ythan @ Ardlethen)	0.574	46	50.18	0.179	0.116	0.816	457.12	830	0.043	0.992	0.001
9001 (Deveron @ Avochie)	0.655	57	130.045	0.243	0.179	0.426	444.91	988	0.034	0.998	0.002
52005 (Tone @ Bishops Hull)	0.737	55	44.756	0.2	0.078	0.38	203.66	964	0.054	0.977	0.016
21013 (Gala Water @ Galashiels)	0.754	43	51.535	0.273	0.305	1.274	205.45	930	0.035	0.999	0.001
11003 (Don @ Bridge of Alford)	0.775	33	99.286	0.201	0.172	0.365	509.94	967	0.036	0.996	0
11004 (Urie @ Pitcaple)	0.778	18	21.42	0.306	0.268	1.003	195.44	870	0.046	0.996	0.003
203018 (Six-mile Water @ Antrim)	0.796	46	81.622	0.178	0.22	1.856	277.78	1075	0.089	0.993	0.025
236005 (Colebrooke @ Ballindarragh Bridge)	0.802	37	107.878	0.114	-0.028	2.691	313.58	1156	0.082	0.987	0.001
Total		559									
Weighted means				0.152	0.006						

Pooling group review

Rejected Station	Justification
42010 (Itchen @ Highbridge & Allbrook Total)	Artificial influences and SPRHOST too low and QMED too low
23008 (Rede @ Rede Bridge)	Reservoir controls 11.6% of the catchment.
22007 (Wansbeck @ Mitford)	Font Reservoir affects flood flows through drawdown and attenuation.
7004 (Nairn @ Firhall)	Water abstraction and 7% of upper catchment drained to Loch.
20001 (Tyne @ East Linton)	Significant floodplain storage influencing FFC. Runoff reduced by abstraction.
53007 (Frome (somerset) @ Tellisford)	Substantial G/W abstractions.
27050 (Esk @ Sleights)	Not gauged above QMED
45012 (Creedy @ Cowley)	Influenced by G/W abstraction.
39006 (Windrush @ Newbridge)	Influenced by G/W abstraction. SPRHOST too low and QMED too low.

Added Station
8009 (Dulnain @ Balnaan Bridge)
55029 (Monnow @ Grosmont)
10001 (Ythan @ Ardlethen)
9001 (Deveron @ Avochie)
52005 (Tone @ Bishops Hull)
21013 (Gala Water @ Galashiels)
11003 (Don @ Bridge of Alford)
11004 (Urie @ Pitcaple)

Added Station
203018 (Six-mile Water @ Antrim)
236005 (Colebrooke @ Ballindarragh Bridge)

River Esk @ Musselburgh best fit z-values

Fitting	Z value
Generalised logistic	1.2715
Generalised extreme value	-0.8352
Pearson Type III	-1.2390

River Esk @ Musselburgh growth curves

Return period (years)	Annual Exceedance Probability (%)	UPG Post-1990 AMAX	UPG Full AMAX	ESS Post-1990 AMAX	ESS Full AMAX	ESS Post-1990 AMAX	SS Post-1990 AMAX
		GL	GL	GL	GL	GL	GL
2	50%	1	1	1	1	1	1
5	20%	1.325		1.209	1.350	1.410	
10	10%	1.551		1.333	1.580	1.717	
20	5%	1.784		1.449	1.810	2.055	
25	4%	1.863		1.485	1.890	2.173	
30	3.3%	1.929		1.514	1.950	2.273	
50	2%	2.122		1.596	2.130	2.575	
75	1.3%	2.285		1.660	2.280	2.838	
100	1%	2.407		1.706	2.390	3.040	
200	0.5%	2.721		1.816	2.690	3.581	
1000	0.1%	3.190		1.963	3.380	4.439	

UPG – Ungauged pooling group

ESS – Enhanced Single Site pooling group

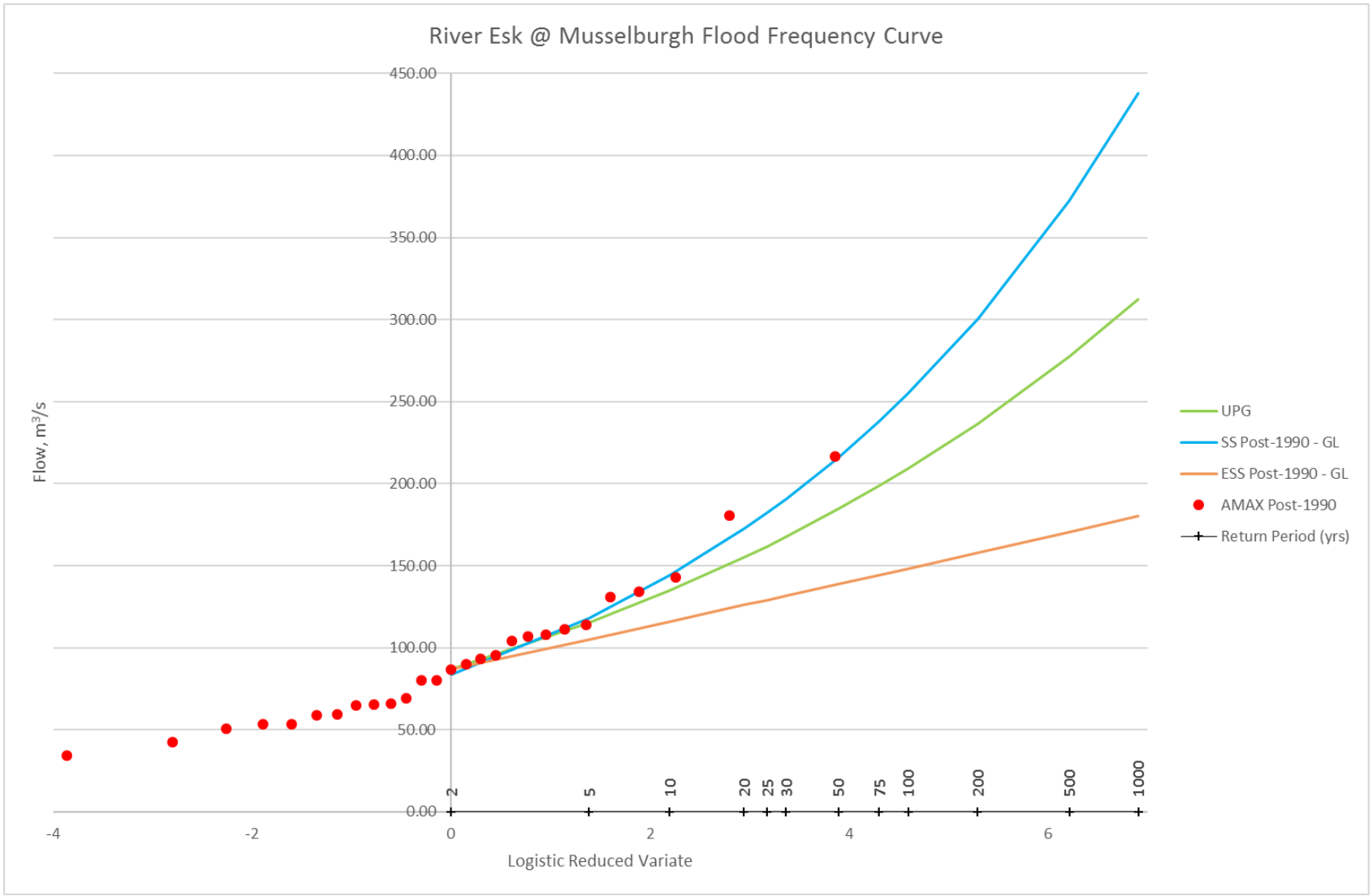
SS – Single Site analysis

GL – Generalised Logistic growth curve fitting used

River Esk @ Musselburgh flood frequency curves

Return period (years)	Annual Exceedance Probability (%)	UPG Post-1990 AMAX	ESS Post-1990 AMAX	SS Post-1990 AMAX
		GL	GL	GL
2	50%	86.96	71.03	83.91
5	20%	115.22	71.03	118.30
10	10%	134.87	87.79	144.07
20	5%	155.13	97.80	172.41
25	4%	162.00	107.11	182.30
30	3.3%	167.74	110.02	190.72
50	2%	184.52	112.44	216.02
75	1.3%	198.70	119.04	238.13
100	1%	209.30	124.30	255.05
200	0.5%	236.61	128.06	300.49
1000	0.1%	277.39	137.08	372.48

Preferred FFC: Based on the plot of FFCs against AMAX data below, the preferred FFC for Musselburgh GS is Single Site, post 1990 AMAX, with a Generalised Logistic growth curve.


River Esk @ Musselburgh Flood Frequency Curve
Flow, m³/s
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-4
-2
0
2
4
6
Logistic Reduced Variate
2
5
10
20
25
30
50
75
100
200
500
1000
UPG
SS Post-1990 - GL
ESS Post-1990 - GL
AMAX Post-1990
Return Period (yrs)

River South Esk @ Cowbridge Flow Calculations

River South Esk @ Cowbridge reviewed pooling group (AMAX record is all POST-1990)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
20003 (Tyne @ Spilmersford)	0.52	55	34.345	0.377	0.223	1.714	162.77	724	0.045	0.987	0.004
9003 (Isla @ Grange)	0.574	57	50.59	0.237	0.155	0.572	179.98	900	0.04	0.994	0.005
21024 (Jed Water @ Jedburgh)	0.594	34	71.477	0.216	0.151	0.319	139.95	914	0.028	0.997	0.006
21027 (Blackadder Water @ Mouth Bridge)	0.618	32	40.298	0.321	0.268	0.527	155.34	774	0.07	0.997	0.004
11004 (Urie @ Pitcaple)	0.623	18	21.42	0.306	0.268	0.44	195.44	870	0.046	0.996	0.003
206001 (Clanrye @ Mountmill Bridge)	0.651	41	20.497	0.173	0.206	0.595	120.47	975	0.064	0.972	0.004
9004 (Bogie @ Redcraig)	0.656	26	31.622	0.312	0.274	0.511	182.43	955	0.031	0.998	0.001
13001 (Bervie @ Inverbervie)	0.656	27	35.577	0.212	0.141	0.577	124.47	890	0.059	0.998	0.002
203024 (Cusher @ Gamble's Bridge)	0.658	40	50.194	0.111	0.122	1.442	170.89	996	0.058	0.992	0.004
21016 (Eye Water @ Eyemouth Mill)	0.673	39	36.964	0.275	0.151	2.879	118.93	730	0.036	0.997	0.002
55013 (Arrow @ Titley Mill)	0.677	48	27.435	0.193	0.175	0.425	125.9	962	0.038	0.999	0.005
76010 (Petteril @ Harraby Green)	0.686	44	33.117	0.225	0.274	0.992	157.58	940	0.077	0.993	0.007
21013 (Gala Water @ Galashiels)	0.712	43	51.535	0.273	0.305	2.006	205.45	930	0.035	0.999	0.001
Total		504									
Weighted means				0.249	0.207						

Pooling group review

Rejected Station	Justification
40009 (Teise @ Stonebridge)	Influenced by abstractions
7005 (Divie @ Dunphail)	Flows influenced by loch.
41005 (Ouse @ Gold Bridge)	Flows influenced by reservoir.
39035 (Churn @ Cerney Wick)	Influenced by groundwater abstractions, low SPR.
28061 (Churnet @ Basford Bridge)	Flows influenced by reservoir.
21025 (Ale Water @ Ancrum)	Flows influenced by loch.
19011 (North Esk @ Dalkeith Palace)	SEPA stated unsuitable for pooling.
19008 (South Esk @ Prestonholm)	SEPA stated unsuitable for use.
43018 (Allen @ Walford Mill)	SPR too low.
27086 (Skell @ Ripon Alma Weir)	Swallow holes influence flows and no significant high flow gauges.
39025 (Enborne @ Brimpton)	Influenced by groundwater abstractions.

Added Station
9003 (Isla @ Grange)
21024 (Jed Water @ Jedburgh)
21027 (Blackadder Water @ Mouth Bridge)
11004 (Urie @ Pitcaple)
206001 (Clanrye @ Mountmill Bridge)
9004 (Bogie @ Redcraig)

Added Station
13001 (Bervie @ Inverbervie)
203024 (Cusher @ Gamble's Bridge)
21016 (Eye Water @ Eyemouth Mill)
55013 (Arrow @ Titley Mill)
76010 (Petteril @ Harraby Green)
21013 (Gala Water @ Galashiels)

River South Esk @ Cowbridge best fit z-values

Fitting	Z value
Generalised logistic	2.4033
Generalised extreme value	0.3840
Pearson Type III	-0.1212

River South Esk @ Cowbridge growth curves

Return period (years)	Annual Exceedance Probability (%)	UPG AMAX	ESS AMAX	SS AMAX
		GL	GL	GL
2	50%	1.00	1.00	0.984
5	20%	1.398	1.386	1.344
10	10%	1.692	1.665	1.579
20	5%	2.010	1.965	1.813
25	4%	2.121	2.068	1.891
30	3.3%	2.215	2.155	1.955
50	2%	2.495	2.414	2.138
75	1.3%	2.738	2.637	2.290
100	1%	2.923	2.806	2.401

Return period (years)	Annual Exceedance Probability (%)	UPG AMAX	ESS AMAX	SS AMAX
200	0.5%	3.417	3.252	2.681
500	0.2%	4.189	3.941	3.083
1000	0.1%	4.880	4.550	3.412

UPG – Ungauged pooling group analysis

ESS – Enhanced Single Site pooling group analysis

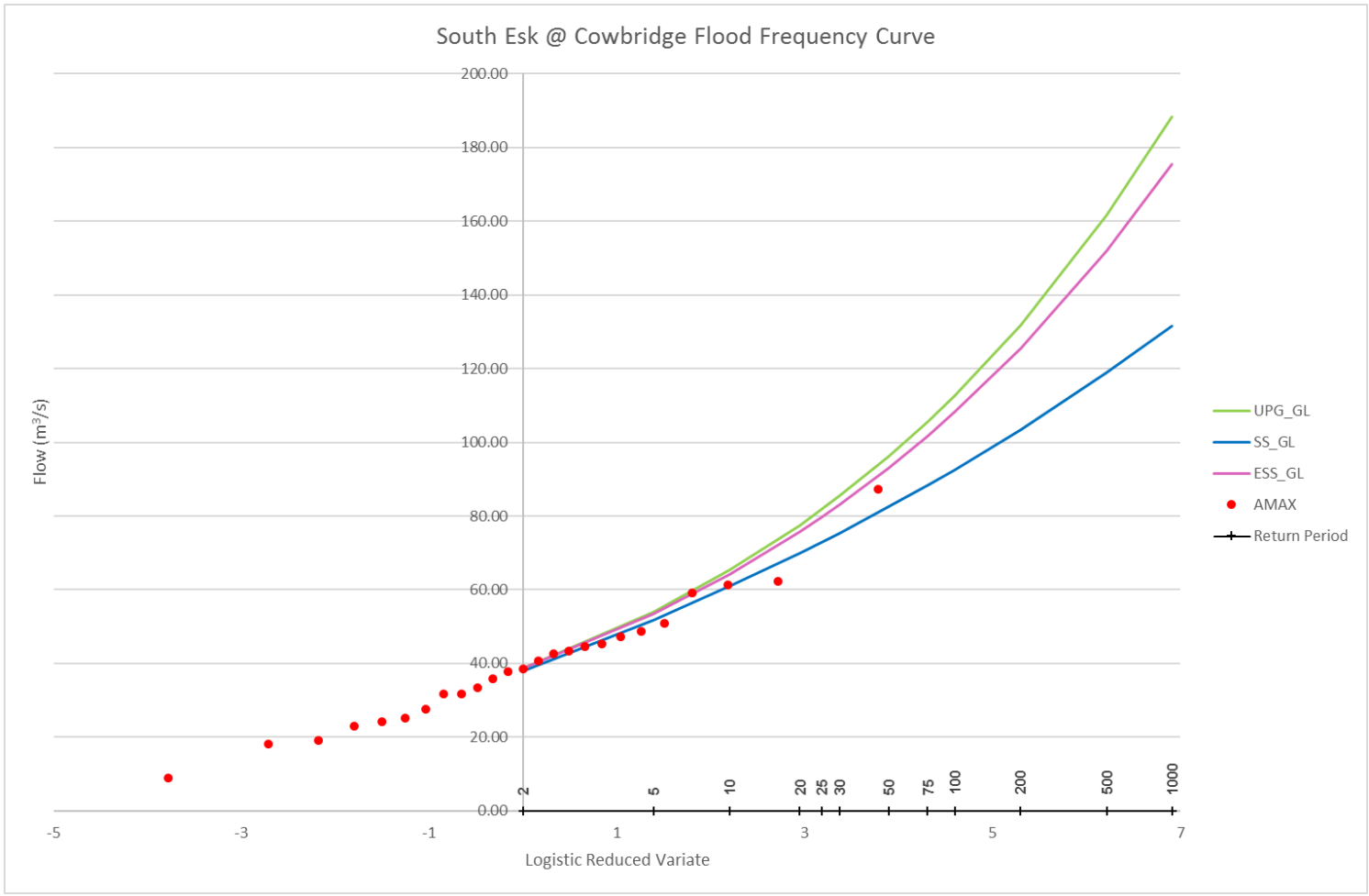
SS – Single Site analysis

GL – Generalised Logistic growth curve fitting used

River South Esk @ Cowbridge flood frequency curves

Return period (years)	Annual Exceedance Probability (%)	UPG AMAX	ESS AMAX	SS AMAX
		GL	GL	GL
2	50%	38.56	38.56	37.96
5	20%	53.91	53.45	51.81
10	10%	65.25	64.21	60.87
20	5%	77.51	75.78	69.93
25	4%	81.79	79.75	72.91
30	3.3%	85.42	83.110	75.37
50	2%	96.22	93.09	82.46
75	1.3%	105.59	101.69	88.31
100	1%	112.72	108.21	92.59
200	0.5%	131.77	125.41	103.40
500	0.2%	161.54	151.98	118.87
1000	0.1%	188.19	175.47	131.57

Preferred FFC: Based on the plot of FFCs against AMAX data below, the preferred FFC for Cowbridge GS is Enhanced Single Site, post 1990 AMAX, with a Generalised Logistic growth curve.



River North Esk @ Dalmore Flow Calculations

Analysis of the pre- and post-1990 AMAX record showed negligible changes to QMED estimates, therefore the full AMAX record was used within the flow calculations below, whereas only post-1990 data was used for the flow calculations for the River Esk @ Musselburgh and River South Esk @ Cowbridge.

River North Esk @ Dalmore reviewed pooling group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
19004 (North Esk @ Dalmore Weir)	0	56	19.595	0.184	0.228	0.656	79.85	949	0.032	0.975	0.018
66005 (Clwyd @ Ruthin Weir)	0.299	33	16.907	0.148	0.063	0.915	96.39	958	0.037	0.995	0.005
24004 (Bedburn Beck @ Bedburn)	0.319	56	25.342	0.275	0.311	0.664	74.12	895	0.011	0.999	0.001
8011 (Livet @ Minmore)	0.409	26	31.67	0.203	0.01	1.631	102.78	1001	0.024	1.000	0
45008 (Otter @ Fenny Bridges)	0.444	42	59.669	0.251	0.17	0.039	105.29	1040	0.036	0.994	0.019
20007 (Gifford Water @ Lennoxlove)	0.461	43	16.19	0.325	0.204	0.881	67.78	770	0.029	0.977	0
205008 (Lagan @ Drumiller)	0.463	42	28.364	0.15	-0.067	2.155	84.97	1016	0.069	0.992	0.001
20005 (Birns Water @ Saltoun Hall)	0.477	44	18.215	0.303	0.222	0.825	92.6	762	0.03	0.989	0
52004 (Isle @ Ashford Mill)	0.609	54	35.408	0.225	0.027	0.551	87.41	891	0.084	0.979	0.026
47008 (Thrushel @ Tinhay)	0.621	47	41.279	0.214	0.239	0.281	112.72	1144	0.036	0.999	0.001
76019 (Roe Beck @ Stockdalewath)	0.653	17	43.521	0.237	0.292	1.365	63.09	983	0.08	1.000	0
55013 (Arrow @ Titley Mill)	0.659	48	27.435	0.193	0.175	0.142	125.9	962	0.038	0.999	0.005
67005 (Ceiriog @ Brynkinalt Weir)	0.673	19	29	0.145	0.377	2.236	111.72	1198	0.023	1	0.001
20006 (Biel Water @ Belton House)	0.673	28	11.748	0.375	0.128	2.057	57.55	742	0.019	0.981	0.001
44011 (Asker @ East Bridge Bridport)	0.712	21	16.8	0.239	0.112	0.601	48.52	924	0.025	0.994	0.015

Total	576		
Weighted means		0.197	0.168

Pooling group review

Rejected Station	Justification
67009 (Alyn @ Rhydymwyn)	Swallow holes affecting flows.
51001 (Doniford Stream @ Swill Bridge)	Flows not validated beyond QMED.
27059 (Laver @ Ripon Laver Weir)	Significant GW abstraction affecting flows.
41023 (Lavant @ Graylingwell)	Significant GW abstraction affecting flows and low SPR.
42008 (Cheriton Stream @ Sewards Bridge)	Low SPR
42006 (Meon @ Mislingford)	Significant GW abstraction affecting flows and low SPR.
25006 (Greta @ Rutherford Bridge)	SPR considered to high compared to subject site.
53028 (by Brook @ Middlehill)	Influenced by abstraction and SPRHOST considered to high compared to subject site.
42009 (Candover Stream @ Borough Bridge)	Influenced by abstraction and SPRHOST too low.

Added Station
45008 (Otter @ Fenny Bridges)
20007 (Gifford Water @ Lennoxlove)
205008 (Lagan @ Drumiller)
20005 (Birns Water @ Saltoun Hall)
52004 (Isle @ Ashford Mill)

Added Station
47008 (Thrushel @ Tinhay)
76019 (Roe Beck @ Stockdalewath)
55013 (Arrow @ Titley Mill)
67005 (Ceiriog @ Brynkinalt Weir)
20006 (Biel Water @ Belton House)
44011 (Asker @ East Bridge Bridport)

River North Esk @ Dalmore best fit z-values

Fitting	Z value
Generalised logistic	3.3197
Generalised extreme value	0.6431
Pearson Type III	-0.4454

River North Esk @ Dalmore growth curves

Return period (years)	Annual Exceedance Probability (%)	UPG Full AMAX	ESS Full AMAX	SS Full AMAX
		GL	GL	GL
2	50%	1.00	1	1.01
5	20%	1.37	1.31	1.31
10	10%	1.62	1.53	1.53
20	5%	1.89	1.76	1.78
25	4%	1.98	1.84	1.87
30	3.3%	2.06	1.91	1.94
50	2%	2.28	2.11	2.16
75	1.3%	2.47	2.27	2.35
100	1%	2.61	2.40	2.50

200	0.5%	2.98	2.73	2.90
1000	0.1%	3.53	3.24	3.52

UPG – Ungauged pooling group

ESS – Enhanced Single Site pooling group

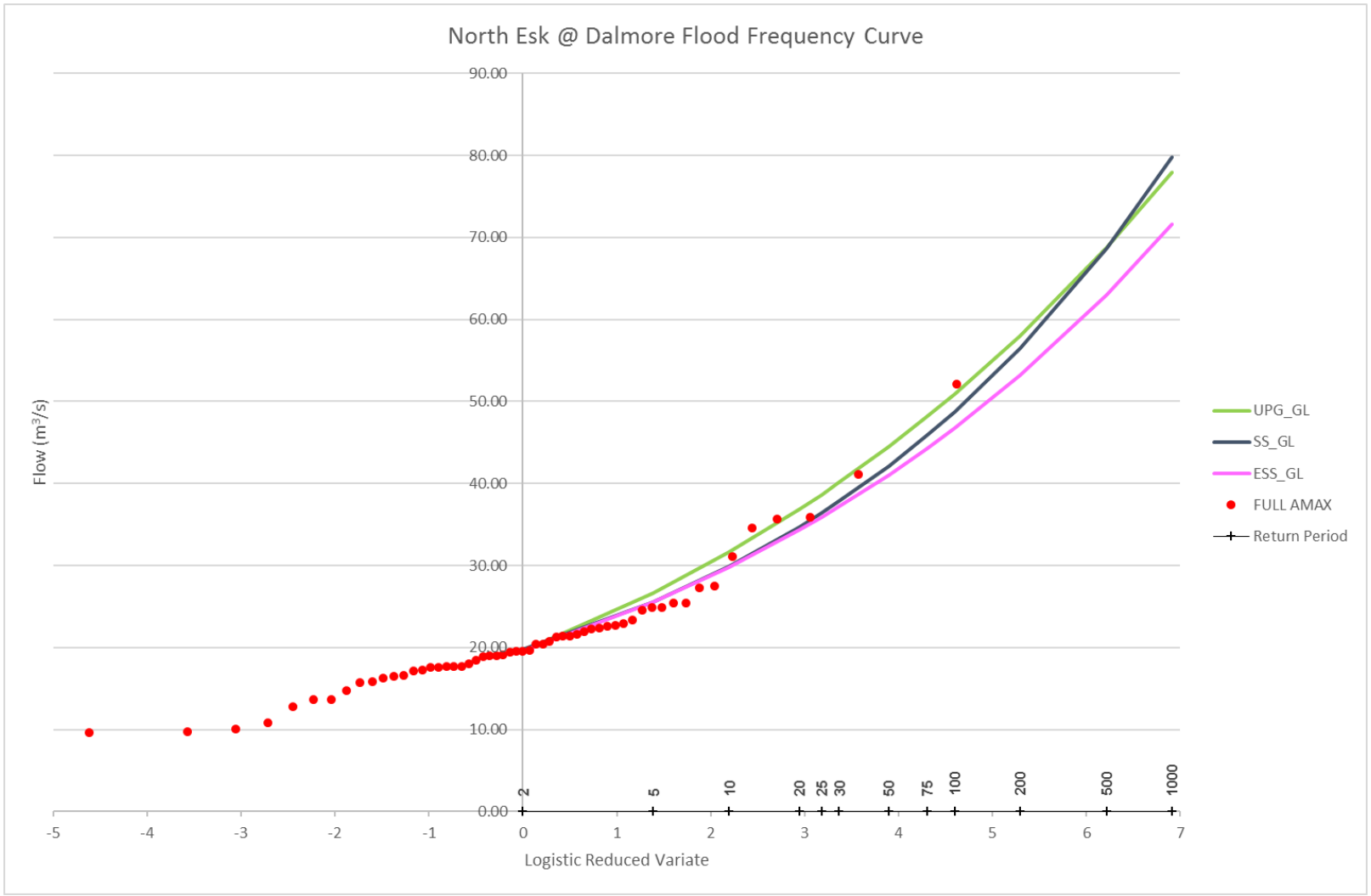
SS – Single Site analysis

GL – Generalised Logistic growth curve fitting used

River North Esk @ Dalmore flood frequency curves

Return period (years)	Annual Exceedance Probability (%)	UPG Full AMAX	ESS Full AMAX	SS Full AMAX
		GL	GL	GL
2	50%	19.49	19.49	19.739
5	20%	26.66	25.53	25.555
10	10%	31.65	29.82	29.916
20	5%	36.87	34.34	34.716
25	4%	38.63	35.88	36.392
30	3.3%	40.11	37.19	37.817
50	2%	44.45	41.02	42.106
75	1.3%	48.14	44.32	45.856
100	1%	50.89	46.77	48.724
200	0.5%	58.04	53.22	56.435
1000	0.1%	68.76	63.05	68.656

Preferred FFC: Based on the plot of FFCs against AMAX data below, the preferred FFC for Dalmore GS is Single Site, post 1990 AMAX, with a Generalised Logistic growth curve.


North Esk @ Dalmore Flood Frequency Curve
Flow (m³/s)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
2
5
10
20
25
30
50
75
100
200
500
1000
Logistic Reduced Variate
UPG_GL
SS_GL
ESS_GL
FULL AMAX
Return Period

APPENDIX E: Initial Flow Estimates

North Esk Sub Catchment Initial FEH Statistical Flow Estimates

Sub-Catch Ref	-	NE10	NE20	NE21	NE22	NE23	NE24	NE25	NE30
Name of Waterbody	Whole Esk Catchment	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk	North Esk
DS NGR	NT 34350 72800	NT 33300 67800	NT 28700 64800	NT 25350 61600	NT 25200 61600	NT 23600 59600	NT 23750 59600	NT 18200 56750	NT 28750 64900
Centroid	NT 27555 59739	NT 21726 59963	NT 20843 59125	NT 20943 62991	NT 19829 57686	NT 17817 57659	NT 22549 55967	NT 16005 56951	NT 25348 64579
QMED(AMAX)	-	-	-	-	-	-	-	-	-
Urban Category	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Slightly Urbanised
QMEDCDrural	36.67	23.54	22.80	6.59	16.68	10.82	5.05	8.45	2.01
PRAUF	1.02	1.01	1.01	1.00	1.01	1.00	1.00	1.00	1.03
UAF	1.04	1.03	1.02	1.01	1.02	1.00	1.01	1.00	1.06
QMEDCDurban	38.17	24.22	23.19	6.63	17.02	10.84	5.08	8.45	2.14
QMED DT Station	Musselburgh	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore
QMEDDT	86.77	27.74	26.55	7.59	19.49	12.41	5.82	9.68	2.45
GC DT Station	Musselburgh	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore	Dalmore
Return Period	PEAK FLOWS (m^3/s)								
2	83.72	28.09	26.89	7.68	19.74	12.57	5.89	9.80	2.48
5	118.04	36.37	34.82	9.95	25.56	16.28	7.63	12.69	3.21
10	143.75	42.57	40.76	11.64	29.92	19.05	8.93	14.86	3.76
20	172.03	49.41	47.30	13.51	34.72	22.11	10.36	17.24	4.37
25	181.91	51.79	49.58	14.17	36.39	23.18	10.86	18.08	4.58
30	190.30	53.82	51.52	14.72	37.82	24.09	11.29	18.78	4.76
50	215.55	59.92	57.36	16.39	42.11	26.82	12.57	20.91	5.30
75	237.61	65.26	62.47	17.85	45.86	29.21	13.69	22.78	5.77
100	254.49	69.34	66.38	18.97	48.72	31.03	14.54	24.20	6.13
200	299.84	80.31	76.89	21.97	56.44	35.95	16.84	28.03	7.10
500	371.67	97.71	93.54	26.72	68.66	43.73	20.49	34.10	8.64
1000	436.79	113.48	108.64	31.04	79.74	50.79	23.80	39.61	10.03

South Esk Sub Catchment Initial FEH Statistical Flow Estimates

Sub-Catch Ref	SE10	SE20	SE21	SE22	SE23	SE24	SE25	SE26	SE30
Name of Waterbody	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk	South Esk
DS NGR	NT 33900 67700	NT 32650 64700	NT 33150 61850	NT 33050 61800	NT 32100 59400	NT 32000 59500	NT 30250 54650	NT 27900 55300	NT 32500 64650
Centroid	NT 31318 57535	NT 31263 55932	NT 35447 57842	NT 29430 54257	NT 30734 53463	NT 27521 54777	NT 30168 51473	NT 26821 52775	NT 29461 61400
QMED(AMAX)	-	-	-	-	-	-	-	-	-
Urban Category	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural	Essentially Rural
QMEDCDrural	17.39	13.23	4.19	8.48	4.22	5.17	4.28	5.35	3.10
PRAUF	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.01
UAF	1.04	1.01	1.02	1.00	1.00	1.00	1.00	1.00	1.02
QMEDCDurban	18.09	13.39	4.26	8.48	4.22	5.17	4.28	5.35	3.15
QMED DT Station	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge
QMEDDT	39.16	28.97	9.23	18.36	9.13	11.20	9.27	11.58	6.82
GC DT Station	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge	Cowbridge
Return Period	PEAK FLOWS (m^3/s)								
2	39.16	28.97	9.23	18.36	9.13	11.20	9.27	11.58	6.82
5	54.27	40.16	12.79	25.44	12.65	15.52	12.85	16.05	9.45
10	65.19	48.24	15.37	30.57	15.20	18.64	15.44	19.28	11.35
20	76.94	56.93	18.14	36.07	17.94	22.00	18.22	22.76	13.40
25	80.97	59.92	19.09	37.96	18.88	23.16	19.18	23.95	14.10
30	84.38	62.44	19.89	39.56	19.67	24.13	19.98	24.96	14.69
50	94.52	69.94	22.28	44.32	22.04	27.03	22.38	27.96	16.46
75	103.25	76.40	24.34	48.41	24.07	29.53	24.45	30.54	17.98
100	109.87	81.30	25.90	51.51	25.61	31.42	26.02	32.50	19.13
200	127.33	94.22	30.02	59.70	29.69	36.42	30.16	37.66	22.17
500	154.31	114.18	36.38	72.35	35.97	44.13	36.54	45.64	26.87
1000	178.16	131.83	42.00	83.53	41.53	50.95	42.19	52.70	31.02

River Esk Sub Catchment Initial FEH Statistical Flow Estimates

Sub-Catch Ref	TB1	TB2	TB3	TB4	TB5	PB1	PB2
Name of Waterbody	River Esk Tributary	River Esk Tributary	River Esk Tributary	River Esk Tributary	River Esk Tributary	Pinkie Burn	Pinkie Burn
DS NGR	NT 33950 71650	NT 34400 71200	NT 34850 70250	NT 34700 70100	NT 33300 68900	NT 34650 73400	NT 35400 71750
Centroid	NT 32474 71004	NT 31800 69596	NT 36438 69631	NT 35863 67760	NT 29893 67350	NT 36349 71511	NT 36516 71062
QMED(AMAX)	-	-	-	-	-	-	-
Urban Category	Slightly Urbanised	Essentially Rural	Essentially Rural	Essentially Rural	Moderately Urbanised	Moderately Urbanised	Essentially Rural
QMEDCDrural	0.10	0.67	0.44	1.01	0.56	0.34	0.29
PRAUF	1.06	1.04	1.01	1.00	1.07	1.06	1.01
UAF	1.10	1.09	1.02	1.01	1.14	1.13	1.01
QMEDCDurban	0.11	0.73	0.45	1.01	0.64	0.39	0.29
QMED DT Station	Musselburgh	Dalmore	Dalmore	Dalmore	Musselburgh	Musselburgh	Dalmore
QMEDDT	0.24	0.83	0.52	1.16	1.45	0.88	0.66
GC DT Station	Musselburgh	Dalmore	Dalmore	Dalmore	Musselburgh	Musselburgh	Dalmore
Return Period				PEAK FLOWS (m^3/s)			
2	0.24	0.85	0.52	1.18	1.40	0.85	0.67
5	0.33	1.09	0.68	1.52	1.97	1.20	0.87
10	0.40	1.28	0.79	1.78	2.40	1.46	1.02
20	0.48	1.49	0.92	2.07	2.87	1.75	1.18
25	0.51	1.56	0.97	2.17	3.03	1.85	1.24
30	0.53	1.62	1.00	2.25	3.17	1.94	1.28
50	0.61	1.80	1.12	2.51	3.59	2.19	1.43
75	0.67	1.96	1.22	2.73	3.96	2.42	1.56
100	0.72	2.09	1.29	2.90	4.24	2.59	1.65
200	0.84	2.42	1.50	3.36	5.00	3.05	1.92
500	1.04	2.94	1.82	4.09	6.19	3.78	2.33
1000	1.23	3.41	2.12	4.75	7.28	4.45	2.71

River Esk Sub Catchment Initial ReFH Flow Estimates

Catchment	RE1	RE2	RE3	RE4	RE5	RE6	TB1	TB2	PB1	PB2
Paved Area (km^2)	0.21	0.41	0.35	0.01	0.06	1.06	0.21	1.60	0.46	0.66
Unpaved Area (km^2)	0.19	0.35	0.57	0.35	0.65	4.45	0.75	6.70	0.82	2.26
Storm Duration					**5.50 hrs**					
Return Period (yrs)					**Peak Flows (m^3/s)**					
2.34	0.208	0.388	0.423	0.016	0.318	2.676	0.314	2.202	0.499	0.982
5	0.265	0.494	0.538	0.02	0.401	3.241	0.398	2.747	0.636	1.232
10	0.311	0.58	0.63	0.024	0.461	3.748	0.463	3.178	0.746	1.427
20	0.362	0.676	0.732	0.028	0.52	4.252	0.534	3.65	0.869	1.636
25	0.38	0.71	0.766	0.031	0.537	4.402	0.558	3.811	0.912	1.706
30	0.395	0.738	0.797	0.033	0.554	4.55	0.579	3.951	0.949	1.768
50	0.441	0.824	0.887	0.038	0.604	4.99	0.642	4.369	1.059	1.953
75	0.481	0.899	0.964	0.042	0.644	5.343	0.695	4.728	1.155	2.111
100	0.511	0.956	1.024	0.046	0.674	5.628	0.735	5.001	1.228	2.231
200	0.592	1.109	1.183	0.056	0.761	6.43	0.845	5.736	1.424	2.555
500	0.72	1.349	1.432	0.075	0.898	7.683	1.017	6.883	1.733	3.052
1000	0.834	1.564	1.655	0.094	1.021	8.801	1.17	7.906	2.009	3.499