A9.2 Surface Water Hydrology

1 Introduction

1.1.1 This appendix provides the technical information in support of the assessment of surface water hydrology reported in Chapter 9 (Water Environment), including calculations of baseline flood risk and drainage design parameters.

1.1.2 The watercourses that could potentially be impacted by the proposed scheme are Swine burn, Niddry Burn, Tributary of Swine Burn, Tributary of Niddry Burn, River Almond, Dolphington Burn and Ferry Burn.

1.1.3 Section 2 of this appendix describes the methodologies adopted for the estimation of different surface water parameters, Section 3 presents a summary of design flows estimated for each catchment and a comparison between the two main methods used, and Section 4 contains a summary of the hydrological parameters estimated or extracted from the FEH CD-ROM v.2(2006) for each watercourse.

2 Methodology

2.1.1 The following abbreviations/definitions are used within this appendix:

- AREA - Catchment Drainage Area (km^2);
- AEP - Annual Exceedence Probability;
- SAAR 1961-90 - Standard Period Average Annual Rainfall (mm);
- BFIHOST Base Flow Index derived using the HOST classification;
- SPRHOST Standard Percentage Runoff (%) derived using HOST classification;
- FARL Index of Flood Attenuation due to Reservoirs and Lakes;
- URBEXT2000 FEH index of fractional urban extent for 2000;
- Q95 - Flow that is expected to be exceeded 95% of the time (m^3/s);
- Q50 - Flow that is expected to be exceeded 50% of the time (m^3/s);
- Q_{MED} - Median Flood Flow (m^3/s) (flow with a two year return period);
- Q_{BAR} - Mean Annual Flood (m^3/s); and
- Q-Tyr (e.g. Q-5yr) - Flood flow associated with a T-year return period (e.g. five year flow).

2.1.2 Hydrological pressures and flood risk impacts arising from the proposed scheme were assessed using the catchment parameters and methodologies shown in Table 2.1. These parameters were calculated for catchments in the absence of the proposed scheme and then recalculated assuming scheme implementation.

Table 2.1: Hydrological Parameters and Methodologies

Description	Parameter	Proposed Methodology
Median annual maximum flood	QMED	Estimation of median annual maximum flood flow (QMED) was required in order to determine flood design peak flows and was estimated for all watercourses. The latest QMED guidance and equation quoted by the Environment Agency (Environment Agency, 2008) was used for all the watercourses, except for the River Almond, which is gauged. FEH guidance on the degree of uncertainty associated with QMED estimates from catchment descriptors is ± 55%. This methodology provides a baseline characteristic for each watercourse. Potential impacts may also be assessed using this method if there is an increase or decrease in catchment size caused by the proposed scheme.
Mean annual maximum flood	QBAR	Estimation of average annual maximum flood (QBAR) was required in order to determine flood design peak flows and as a comparison to the calculated QMED values. For all catchments QBAR was estimated using the methodology of the Institute of Hydrology Report No.124 (IH124) (Institute of Hydrology, 1994). IH124 guidance on the degree of uncertainty associated with QBAR estimates from catchment descriptors is ± 65%. This methodology provides a baseline characteristic for each watercourse. Potential impacts may also be assessed using this method if there is an increase or decrease in catchment size caused by the proposed scheme.
Flood design peak flows	Q-Tyr	Standard application of the FEH statistical pooling group method was used on a sub set of catchments to determine flood frequency curves for each burn. The curve was refined using the following % AEP: 50%, 20%, 10%, 2%, 1%, 0.5% AEP (design return periods: 2, 5, 10, 50, 100, 200-years). Based upon the similarity of the growth curves and the apparent similarity in catchment characteristics across the area of interest, a single average growth curve was derived and applied to the other catchments. No formal quantification of Q-Tyr uncertainty is provided in the FEH but it is likely to be at least in the order of the QMED uncertainty ± 55% and in some circumstance will be appreciably larger. For comparison purposes and to fulfill the requirements of the DMRB the IH124 method was also followed, using the regional growth curve of the Flood Studies Supplementary Report No.14 (FSSR14). For completeness, a comparison of the results of the FEH (Institute of Hydrology, 1999) and IH124 (Institute of Hydrology, 1994) is included in Section 1.3 (Summary of High Flow Calculations). The 0.5% AEP (200-year return period) design flow was further used for culvert design. Comparison was made with bankfull flows to give an indication of stream capacities and potential flooding. High flows were provided to support fluvial geomorphological assessments. This methodology provides baseline conditions as well as providing the potential impacts for the removal or culverting of any watercourses along the proposed scheme. These values will also provide the mitigation values to correctly size any structures across watercourses.
50-percentile & 95-percentile flow	Q50 Q95	Q50and Q95 values are baseline conditions and were provided to support water quality, ecological and geomorphological assessments. 50-percentile (Q50) and 95-percentile flow (Q95) for ungauged watercourses were supplied by the Centre for Ecology and Hydrology (CEH) Wallingford using the Low Flows 2000 software*. CEH Wallingford states that the predictive uncertainty associated with the estimate is within a 68% confidence limit on the estimated natural values.
Greenfield runoff rate	q green	In order to provide an estimate of greenfield runoff rates (q green) for each of the drainage outfall locations the average of four methodologies was used. These methodologies are the, IH124 catchment area method, FEH catchment area method, FEH rainfall runoff method and the Rational Method. SEPA guidance is given in the booklet 'Guidance for Developers and Regulators Drainage Impact Assessment' (DP 300 3/02) (SEPA, 2003) and states, that in general the 50% AEP (two-year return period) one hour rainfall event should be used to determine the pre-development runoff for the existing site (i.e. predevelopment or as a 'greenfield site'). According to CIRIA 609 (CIRIA, 2004) common values used for greenfield runoff rates vary between 5 to 7 l/s/ha. However, care should be taken if applying these values, as they may not be applicable to individual sites, since the runoff rate is dependent on factors that include soil type and site gradient. Thus, to provide more site specific estimates of greenfield runoff the average of the IH124 catchment area method, FEH catchment area method, FEH Rainfall Runoff method, and the Rational Method was applied to the outfall locations on the proposed scheme. The IH124 catchment area method uses the 50% AEP (2-year return period or QBAR, see above method for calculation of annual average maximum flood flow) IH124 flow estimate at

Description	Parameter	Proposed Methodology
		the drainage outfall location divided by the area of the catchment to this point to derive a greenfield runoff rate in litres/second/hectare. The FEH catchment area method uses the 50% AEP (2-year return period or QMED, see above method for calculation of median flood flow) FEH flow estimate at the drainage outfall location divided by the area of the catchment to this point to derive a Greenfield runoff rate in litres/second/hectare. FEH rainfall runoff method uses catchment descriptors to route the design rainfall 50% AEP storm through the catchment at the drainage outfall location. The peak flow is then sub divided by the catchment area to derive greenfield runoff rate in litres/second/hectare The Rational Method assumes a 1 hectare (ha) catchment and a 60 minute storm duration. The basic form of this method is the following equation: Peak Flow (l/s) = 2.78 * C * I (mm/hr) * A (ha) Where: C is the coefficient of runoff I is the intensity of rainfall A is the area under consideration Values of C are described as varying from 0.05 to represent flat lawns with sandy soils to a maximum of 0.95 representing almost completely impermeable heavily urbanised areas (Maidment, 1993). In this case, the value of C was set at 0.25 for the south section to represent rural land with heavy soils and 0.35 to the North to represent rural land with some residential development. The rainfall intensity value, I, is determined by dividing the rain depth (mm) for various return periods by the 'Time of Concentration' or storm duration. The rain depth for each return period is determined using the FEH Depth Duration Frequency (DDF) model. Uncertainty within these methods is likely to be at least in the order of the QMED uncertainty ± 55% and in some circumstance will be appreciably larger.
SEPA Indicative River and Coastal Flood Map (Scotland)	n/a	Where available, flood risk assessments for the proposed scheme river crossing points have been carried out using the SEPA 'Indicative River and Coastal Flood Map (Scotland)' (SEPA, 2009). The SEPA indicative flood risk maps have been designed to show the flood extent from watercourses and the sea of the 0.5% AEP (1:200-year flood event). The SEPA flood risk maps, however, do not show the flood risk for watercourses smaller than 3km². More information regarding the 'Indicative River and Coastal Flood Map (Scotland)' can be found at http://www.sepa.org.uk/flooding/flood_map/how_to_use_it.aspx and http://www.multimap.com/clients/places.cgi?client=sepa Areas not covered by the SEPA 'Indicative River and Coastal Flood Map (Scotland)' have been assessed using information obtained during a site visit and a desktop assessment of 1:25,000 Ordnance Survey Maps.
ISIS	n/a	Detailed flood risk analysis has been carried out at proposed watercourse crossing locations and culvert extensions using the ISIS modelling software. This is a one dimensional (1D) hydrodynamic modelling software package that simulates flow, depths, and velocities with considerations of channel capacity, floodplain storage, and interactions with hydraulic structures. The developed models were used to provide an assessment of inundation extents, depths and velocities of watercourses for both the pre and post-development conditions at the proposed scheme crossing locations. More detailed explanation of the methodology used to develop the ISIS models is provided in Appendix A9.3 (Flood Modelling and Culvert Sizing Methodology).

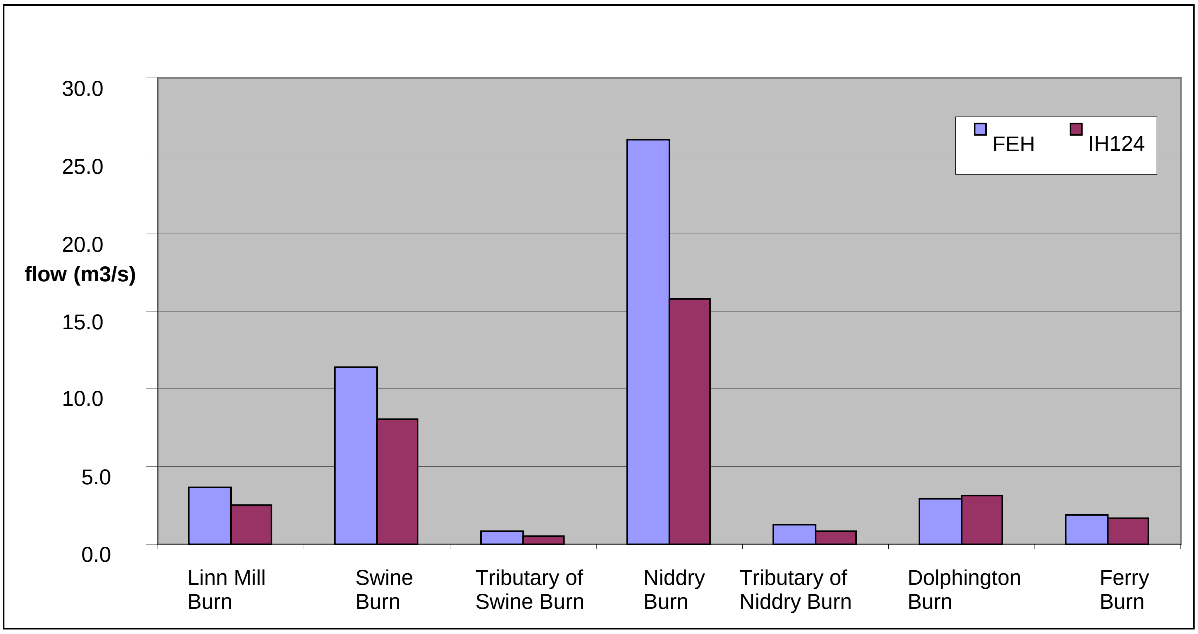
* The Low Flows 2000 estimates were supplied by CEH Wallingford. Basic input information such as catchment area and boundaries were checked and where necessary refined in line with understanding gained during site visits and mapped information.

2.1.3 The catchment areas shown represent the downstream end of the respective watercourses. For this reason, the flows presented below are considered conservative and do not necessarily coincide with the expected flows at different outfall and/or culvert locations along these watercourses as used in other sections of this study.

3 Summary of High Flow Calculations

3.1.1 Since the DMRB Volume 4, Section 2, Part 1 HA 106/04 (Highways Agency et al., 2004a) advocates the use of the IH 124 method for 'Drainage runoff from natural catchments' and the DMRB Part 4 HA 107/04 (Highways Agency et al., 2004b) advocates the use of the FEH method for the 'Design of outfall and culvert details' both approaches were used. A comparison between the 0.5% AEP derived through the FEH statistical method and the IH124 method of high flow estimation for small catchments is shown below on Diagram 3.1. Hydrological analysis results for the River Almond are not included in the comparison as this river has a catchment area of approximately 380km^2; therefore it is not considered a small catchment and the IH124 methodology cannot be applied.

Diagram 3.1: Comparison on 0.5% AEP Flows Derived by FEH and IH124



3.1.2 The differences between IH124 and FEH are generally relatively small apart for the Niddry Burn.

3.1.3 The FEH flow analysis results were used in further analysis. The FEH methodology is now largely adopted as the industry standard and, in this case, the FEH calculated flow values are generally more conservative (i.e. higher) than those calculated using IH124.

4 Summary of Baseline Hydrological Parameters

4.1 Introduction

4.1.1 This section presents the catchment descriptors and hydrological parameters for each of the watercourses. The catchment descriptor tables (Tables 4.1, 4.3, 4.5, 4.7, 4.9, 4.11, 4.13, 4.15) present the catchment descriptors extracted from the FEH CD-ROM v.2 (2006) and amended if necessary based on local information of the OS map. The design parameter tables (Tables 4.2, 4.4, 4.6, 4.8, 4.10, 4.12, 4.14, 4.16) present the different hydrological parameters estimated using the methodology outlined in Section 2.

4.1.2 For the baseline flood risk description for each of the watercourses the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009) were consulted and flooding information from other sources was also used, such as the City of Edinburgh Council biannual flood assessment reports (City of Edinburgh Council, 2003 & 2005), as well as information from consultations with the Edinburgh City Council and SEPA (any specific communication is quoted both in Chapter 9 and in this present document if any specific flooding issues arose for a specific watercourse).

4.2 Linn Mill Burn

Table 4.1: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 11434 78710
Area	km^2	2.99
SAAR	mm	745
BFIHOST	-	0.349
SPRHOST	%	40.88
FARL	-	1.00
URBEXT2000	-	0.008

Table 4.2: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.014	Q-25yr	m^3/s	2.3
Q_{95}	m^3/s	0.003	Q-50yr	m^3/s	2.7
QMED	m^3/s	1.18	Q-100yr	m^3/s	3.2
QBAR	m^3/s	0.90	Q-200yr	m^3/s	3.7
Q-5yr	m^3/s	1.6	Q-500yr	m^3/s	4.5
Q-10yr	m^3/s	1.9			

Baseline Flood Risk

4.2.1 The Linn Mill Burn catchment area is less than $3km^2$, therefore the potential fluvial or coastal flood risk for the 0.5% AEP (200-year return period event) for this watercourse is not included on the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009).

Swine Burn

Table 4.3: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 11490 74541
Area	km^2	9.85
SAAR	mm	816
BFIHOST	-	0.352
SPRHOST	%	39.63
FARL	-	0.969
URBEXT2000	-	0.0152

Table 4.4: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.044	Q-25yr	m^3/s	7.2
Q_{95}	m^3/s	0.009	Q-50yr	m^3/s	8.4
QMED	m^3/s	3.64	Q-100yr	m^3/s	9.8
QBAR	m^3/s	2.83	Q-200yr	m^3/s	11.4
Q-5yr	m^3/s	4.9	Q-500yr	m^3/s	13.8
Q-10yr	m^3/s	5.8			

Baseline Flood Risk

4.2.2 At the proposed section of interest (approximate location Grid Reference NT 11006 74503) the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009) predict potential risk of flooding at the 0.5% AEP (200-year return period event).

4.2.3 Following site investigations it was determined that the catchment area of Swine Burn is different to that represented within the SEPA Indicative River and Coastal Flood Map of this area. An ISIS model was developed for determining the flood extents for this river as set out in Appendix A9.3 (Hydraulic Modelling and Input to Design). There are no developments other than existing and road infrastructure in the area and the flooding predicted would occur in agricultural land.

4.3 Tributary of Swine Burn

Table 4.5: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 1071 7454
Area	km^2	0.52
SAAR	mm	742
BFIHOST	-	0.337
SPRHOST	%	40.62
FARL	-	1
URBEXT2000	-	0.000

Table 4.6: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.006	Q-25yr	m^3/s	0.5
Q_{95}	m^3/s	0.001	Q-50yr	m^3/s	0.6
QMED	m^3/s	0.27	Q-100yr	m^3/s	0.7
QBAR	m^3/s	0.2	Q-200yr	m^3/s	0.8
Q-5yr	m^3/s	0.4	Q-500yr	m^3/s	0.9
Q-10yr	m^3/s	0.4			

Baseline Flood Risk

4.3.1 The Tributary of Swine Burn catchment area is less than $3km^2$; therefore the potential fluvial or coastal flood risk for the 0.5% AEP (200-year return period event) for this watercourse is not included on the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009).

4.4 Niddry Burn

Table 4.7: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 11824 74067
Area	km^2	21.01
SAAR	mm	845
BFIHOST	-	0.339
SPRHOST	%	38.85
FARL	-	0.992
URBEXT2000	-	0.0105

Table 4.8: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.134	Q-25yr	m^3/s	16.5
Q_{95}	m^3/s	0.023	Q-50yr	m^3/s	19.3
QMED	m^3/s	8.34	Q-100yr	m^3/s	22.4
QBAR	m^3/s	5.56	Q-200yr	m^3/s	24.0
Q-5yr	m^3/s	11.3	Q-500yr	m^3/s	31.7
Q-10yr	m^3/s	13.4			

Baseline Flood Risk

4.4.1 At the section of interest (approximate location: Grid Reference NT 11998 74087) the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009) do not predict potential risk of flooding at the 0.5% AEP (200-year return period event). However, this omission is believed to be attributed to a misrepresentation of the hydrological connections in the model used to derive the SEPA flood extents. An ISIS model was therefore developed for determining the flood extents for this river (as set out in Appendix A9.3: Hydraulic Modelling and Input to Design). Based on the model developed for this burn (as set out in Appendix A9.3 Hydraulic Modelling and Input to Design), there are some residential properties in the area at risk from the 0.5% AEP flood event.

4.5 Tributary of Niddry Burn

Table 4.9: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 12050 74000
Area	km^2	0.80
SAAR	mm	738
BFIHOST	-	0.349
SPRHOST	%	40.9
FARL	-	1
URBEXT2000	-	0.02

Table 4.10: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Qmean	m^3/s	0.007	Q-25yr	m^3/s	0.8
Q_{95}	m^3/s	0.002	Q-50yr	m^3/s	0.9
QMED	m^3/s	0.4	Q-100yr	m^3/s	1.1
QBAR	m^3/s	0.3	Q-200yr	m^3/s	1.3
Q-5yr	m^3/s	0.5	Q-500yr	m^3/s	1.5
Q-10yr	m^3/s	0.6			

Baseline Flood Risk

4.5.1 The catchment area of the Tributary of Niddry Burn is less than $3km^2$; therefore the potential fluvial or coastal flood risk for the 0.5% AEP (200-year return period event) for this watercourse is not included on the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009).

4.6 River Almond

Table 4.11: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT1650 7520
Area	km^2	379.5
SAAR	mm	892
BFIHOST	-	0.399
SPRHOST	%	44.41
FARL	-	0.966
URBEXT2000	-	0.06

Table 4.12: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	3.2	Q-25yr	m^3/s	211.1
Q_{95}	m^3/s	0.97	Q-50yr	m^3/s	233.2
QMED	m^3/s	124.7	Q-100yr	m^3/s	256.0
QBAR	m^3/s	N/A	Q-200yr	m^3/s	279.7
Q-5yr	m^3/s	160.1	Q-500yr	m^3/s	312.7
Q-10yr	m^3/s	182.4			

Baseline Flood Risk

4.6.1 For the location of interest, (the area surrounding the confluence of Niddry Burn with Almond called Breast Mill) the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009) predict potential risk of flooding at the 0.5% AEP (200-year return period event). There are some developments in this area along the banks of River Almond which are located within the predicted floodplain extents.

4.7 Dolphington Burn

Table 4.13: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 14900 77100
Area	km^2	3.7
SAAR	mm	714
BFIHOST	-	0.465
SPRHOST	%	40.99
FARL	-	1.00
URBEXT2000	-	0.004

Table 4.14: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.004	Q-25yr	m^3/s	1.9
Q_{95}	m^3/s	0.001	Q-50yr	m^3/s	2.2
QMED	m^3/s	0.95	Q-100yr	m^3/s	2.6
QBAR	m^3/s	1.09	Q-200yr	m^3/s	3.0
Q-5yr	m^3/s	1.3	Q-500yr	m^3/s	3.6
Q-10yr	m^3/s	1.5			

Baseline Flood Risk

4.7.1 The Dolphington Burn catchment area is larger than 3km². SEPA mapping indicates that the potential risk of fluvial and coastal flood risk for the 0.5% AEP (200-year return period event) for this watercourse is limited to the reach of the watercourse downstream of the M9 Spur and railway line.

4.8 Ferry Burn

Table 4.15: Catchment Descriptors

Parameter	Unit	Value
Grid Reference		NT 12926 77957
Area	km^2	3.2
SAAR	mm	729
BFIHOST	-	0.391
SPRHOST	%	38.52
FARL	-	1.00
URBEXT2000	-	0.029

Table 4.16: Summary of Design Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Q50	m^3/s	0.008	Q-25yr	m^3/s	1.2
Q_{95}	m^3/s	0.002	Q-50yr	m^3/s	1.4
QMED	m^3/s	0.6	Q-100yr	m^3/s	1.6
QBAR	m^3/s	0.7	Q-200yr	m^3/s	1.9
Q-5yr	m^3/s	0.8	Q-500yr	m^3/s	2.3
Q-10yr	m^3/s	1.0			

Baseline Flood Risk

4.8.1 The catchment area of the Ferry Burn is less than 3km²; therefore the potential fluvial or coastal flood risk for the 0.5% AEP (200-year return period event) for this watercourse is not included on the Indicative River and Coastal Flood Maps (Scotland) (SEPA, 2009).

5 References

CIRIA (2004). CIRIA 609: Sustainable Drainage Systems – Hydraulic, Structural and Water Quality Advice. Construction Industry Research and Information Association.

City of Edinburgh Council (2003). Flood Assessment Report. November 2003. Accessed December 2008. Available at: http://download.edinburgh.gov.uk/Flood_Plans/flood_assessment_report2003.pdf.

City of Edinburgh Council (2005). Flood Assessment Report. November 2005. Accessed December 2008. Available at: http://download.edinburgh.gov.uk/Flood_Plans/flood_assessment_report_2005.pdf).

Environment Agency (2008). Improving the FEH statistical procedures for flood frequency estimation, Science Report: SC050050. June 2008.

Highways Agency et al. (2004a). HA 106/04 Design Manual for Roads and Bridges (DMRB) Volume 4 Section 2 Part 7 2004. Drainage of Runoff from Natural Catchments. The Highways Agency, Scottish Executive Development Department, The National Assembly for Wales and The Department of Regional Development Northern Ireland.

Highways Agency et al. (2004b). HA 107/04 Design Manual for Roads and Bridges (DMRB) Volume 4 Section 2 Part 7 2004. Design of outfall and culvert details. The Highways Agency, Scottish Executive Development Department, The National Assembly for Wales and The Department of Regional Development Northern Ireland.

Institute of Hydrology (1994). Flood Estimation for Small Catchments, Report No. 124.

Institute of Hydrology (1999). Flood Estimation Handbook.

Maidment, D.R. (1993). Handbook of Hydrology. McGraw-Hill INC. February 1993.

SEPA (2003). Drainage Impact Assessment- Guidance for Developers and Regulators (DP 300 3/02). March 2003.

SEPA (2009). The Indicative River and Coastal Flood Maps (Scotland). Accessed April 2009. Available at: http://www.multimap.com/clients/places.cgi?client=sepa.