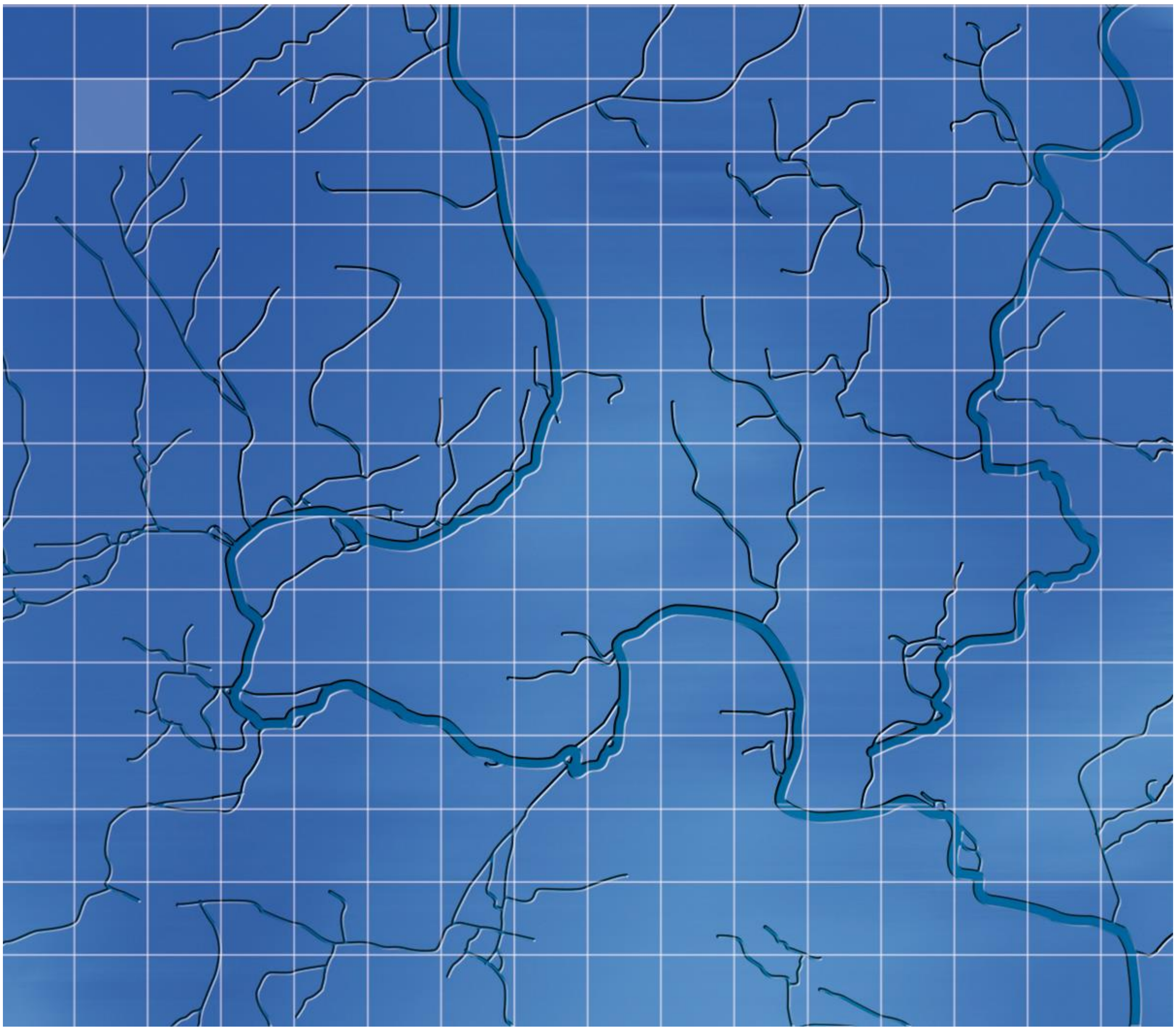
Chiltern Railways

January 2014

Langford Lane Hydrology Report



Wallingford HydroSolutions Limited

Chiltern Railways

Langford Lane Hydrology Report

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For and on behalf of Wallingford HydroSolutions Ltd.

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Date 24/01/2014

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Contents

1 Introduction

Wallingford HydroSolutions Ltd. (WHS) are completing a Level 3 Flood Risk Assessment (FRA) to comply with the requirements of an Order under the Transport and Works Act 1992 (TWA). The TWA Application was made to the Secretary of State for Transport, for statutory powers to authorise the Evergreen3 (EG3) project, comprising the redevelopment and operation of the railway between Oxford and Bicester.

WHS have completed the Level 2 FRA, including a revision in July 2010. The Level 3 FRA work will build upon this work to assess flood risk impacts at the proposed Langford Lane access road and an access road adjacent to the M40. The current document outlines the hydrological input to the hydraulic model which will be used to complete the Level 3 FRA work.

The extent of the hydraulic model is presented in Figure 1. The upstream point is on the Langford Brook just downstream of Bicester, the downstream point is on the River Ray.

Flood hydrographs are required for a number of key tributaries to define boundary conditions for the hydraulic model. These locations are presented in Figure 1 and represent sites on the main rivers (Langford Brook and River Ray) and the main tributaries (Gagle Brook, Wendlebury Brook and Merton Ditch). Flood design hydrographs are required for the 1 in 5, 1 in 20, 1 in 100, 1 in 100 year + climate change and 1 in 1000 year design events. A 20% increase in peak flow is used to allow for climate change as per Planning and Policy Statement 25 (PPS25)[1].

[1] Communities and Local government (CLG), 2010, Planning Policy Statement 25.

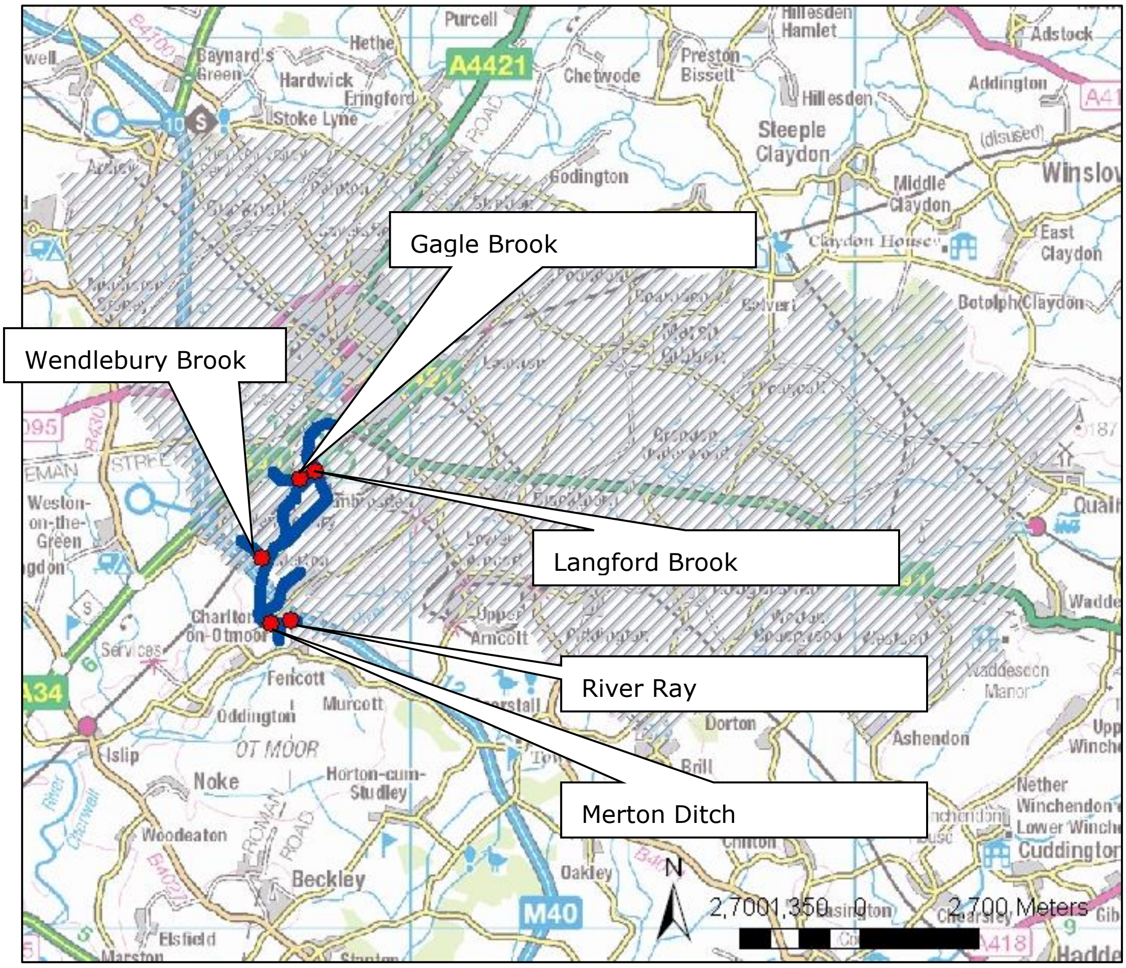

Figure 1. Extents of the Hydraulic model (thick blue line) with the catchments for which hydrology is required shown. The shaded area represents the contributing area associated with the catchments. Contains Ordnance Survey Data © Crown copyright and database right 2013

1.1 Summary of Catchments

The sites for which hydrology is required for input to the hydraulic model are associated with two main catchments. The western catchment drains into the Langford Brook, whilst the eastern catchment is associated with the River Ray. Gagle Brook, Wendlebury Brook and Merton Ditch are tributaries into the Langford Brook. Details of the catchments are within Table 1.

Table 1 Site characteristics of the catchments

Catchment	X	Y	Area (km^2)	BFIHOST[2]	SPRHOST
Langford Brook	457850	220250	40.1	0.71	21.89
Gagle Brook	457500	220100	17.6	0.93	7.8
Wendlebury Brook	456650	218300	7.05	0.60	29.9
Merton Ditch	456850	216850	2.59	0.61	35.13
River Ray	457300	216900	131.51	0.28	49.63

The Langford Brook catchment contains the town of Bicester. Within the lower reaches the M40 motorway intersects with the catchment. The western half of the Langford Brook catchment includes Oolitic limestone (Great Oolite) at the eastern edge of their occurrence. The Oolitic limestones are well-cemented and have a low intergranular permeability. Consequently matrix porosities are low and primary aquifer storage is limited. The response of these limestones to rainfall is highly variable and can be relatively rapid as localised fracturing can offer quick flow paths for rainfall to reach river systems. The baseflow index estimated using HOST (BFIHOST)[2] within the Langford Brook catchment can be high (the Gagle Brook catchment has a BFIHOST of 0.93) however, for the aforementioned reasons, the response of the limestones may be more rapid than this suggests.

The River Ray catchment is more rural than the Langford Brook and largely consists of mudstones overlain by alluvium deposits. As such this catchment is relatively impermeable (BFIHOST = 0.283) and provides a rapid response to rainfall events.

The Cherwell valley has no record of significant flooding, however there have been large events measured in the past at nearby gauging stations. The Ray at Islip is downstream of the study area (the catchment area is 290.1km^2). This gauging station recorded peak flows of 22.2m^3/s for the April 1998 event. The gauging station on the Cherwell at Enslow Mill is on a parallel tributary (the catchment area is 557km^2) and recorded peak flows of 114m^3/s for the same event. This event is likely to be more than the 1 in 100 year return period. In 2007 an event of 85.5m^3s^{-1} was recorded on the Cherwell at Enslow Mill.

[2] Boorman, D. B., Hollis, J. M. and Lilly, A., (1995). Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology Report 126.

2 Flood Estimation Approach

The Flood Estimation Handbook (FEH) Statistical Methods[3] and Revitalised Rainfall Runoff method (ReFH)[4] are best practice flood estimation tools for UK flood hydrology. The following sections outline some of the issues, relevant to the catchments required for this study, that need to be taken into account when applying these methodologies.

2.1 Small Catchments

Recent research into flood estimation in small catchments[5] suggests that the FEH statistical method and the Revitalised Flood Hydrograph (ReFH) event-based method both outperform older methods for estimating floods in small catchments, for example the IH 124 method and ADAS 345 method. The research notes that there is little evidence to suggest that the accuracy of the FEH methods when applied to ungauged catchments is particularly scale dependent and recommends the use of current versions of the FEH statistical approach or the ReFH rainfall-runoff model except on highly permeable (BFIHOST > 0.65) or urban catchments (URBEXT2000>0.15) where the results of the ReFH model can be less reliable. Within the study catchments Merton Ditch is a small catchment (< $5km^2$) with a BFIHOST of 0.61. Following the advice provided it is appropriate to use the FEH methods within this catchment.

2.2 The FEH statistical method

The FEH Statistical method allows the estimation of flood peaks for user provided return periods. The methodology is in two parts. The QMED (median annual flood peak) is first estimated. A growth curve, the rate at which the flow peaks increase for increasingly rare events, is then estimated based on the growth curves associated with a selection of similar catchments (referred to as the pooling group). The QMED and growth curve are combined to provide peaks flows for the required return periods. In the absence of local data catchment descriptors, derived from the FEH CD ROM[6], can be used to apply the methodology.

2.2.1 Urban Adjustment Factor

The presence of urban areas within a catchment generally causes an increase in flood peaks. This is captured within the statistical methodology through the adjustment of the rural QMED, using Equation 1, Equation 2 and Equation 3.

$$\mathrm{QMED} = \mathrm{UAF} \times \mathrm{QMED}_{\mathrm{rural}}$$

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[3] Robson, A.J. and Reed, D.W. 1999. Statistical procedures for flood frequency estimation.Volume 3 of the Flood Estimation Handbook. Centre for Ecology & Hydrology.
[4] Kjeldsen, T.R. 2007. The Revitalised FSR/FEH rainfall-runoff method. Flood Estimation Handbook Supplementary Report No. 1. Centre for Ecology and Hydrology.
[5] Environment Agency, 2012, Estimating flood peaks and hydrographs for small catchments: Phase 1, SC090031
[6] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.

Equation 1

Where QMED is the adjusted QMED, UAF is the urban adjustment factor and $QMED_{rural}$ is the rural QMED (usually calculated from catchment descriptors).

$$\mathrm{UAF} = (1 + \mathrm{URBEXT}_{2000})^{0.37}\mathrm{PRUAF}^{2.16}$$

Equation 2

Where $UBREXT_{2000}$ is the urban extent from the year 2000 and PRUAF is as per Equation 3.

$$\mathbf{PRUAF} = \mathbf{1} + \mathbf{0.47} \times \mathbf{URBEXT_{2000}}\left(\frac{\mathbf{70}}{\mathbf{SPRHOST}} - \mathbf{1}\right)$$

Equation 3

Where SPRHOST is the standard percentage runoff calculated using HOST.

This methodology is implemented within WINFAP FEHv3 and was applied to all catchments. For catchments where the $URBEXT_{2000}$ is less than 3% the impact on the QMED will be minimal. WINFAP FEHv3 also applies an adjustment procedure to the growth curves, based on the urban extent value.

2.2.2 Permeable adjustment procedure

It is necessary to apply the permeable adjustment procedure to catchments within a pooling group which have a SPRHOST value < 20% (standard percentage runoff estimated using HOST) as recommended by Environment Agency guidance[7]. This methodology is based on the assumption that in permeable catchments a 'flood' may not occur every year and the growth curve may be affected by data from non flood years. By removing the non flood year peak flows, a more accurate growth curve for the donor catchment can be derived. It is also necessary to rescale the 'stretched' curve to ensure that the resulting curve retains a growth factor of 1 at a return period of 2 years. The permeable adjustment procedure was applied to all permeable catchments identified within pooling groups during the flood estimation process.

2.2.3 Local Data

The FEH guidance states that local data should be used where available to enhance the estimation methodology.

[7] Environment Agency. 2012. Flood Estimation Guidelines: Operational Instruction 197_08.

FEH methodologies recommend the use of local data to improve the estimation of flood estimates. No measured flow data is available at any of the hydrology sites to improve estimates however, nearby local gauging stations may be used to enhance the QMED equation. As a general rule of thumb the gauging station being considered as a donor should have an area that does not differ by more than a factor of 5 from the target station and the soil and wetness (e.g. SAAR and SPRHOST) should not be different by more than a factor of 1.1. In addition the catchment should have a FARL (index of flood attenuation attributable to reservoirs and lakes) greater than 0.95 and if urbanised additional procedures will need to be applied.

If a suitable donor gauging station is available Equation 4 is used to adjust the QMED for the catchment.

$$\mathbf{QMED_{s,adj}} = \mathbf{QMED_{s,cds}} \left(\frac{\mathbf{QMED_{g,obs}}}{\mathbf{QMED_{g,cds}}}\right)^{\mathbf{a_{sg}}}$$

Equation 4

Where $QMED_{s,ag}$ is the adjusted QMED for the site, $QMED_{s,cds}$ is the catchment descriptor QMED for the site, $QMED_{g,obs}$ is the QMED observed at the gauging station, $QMED_{g,cds}$ is the catchment descriptor QMED and a_{sg} is the exponent.

The exponent, a_{sg}, is related to the model error variance and the sampling error associated with the donor gauging station. In general, where long records are available, the sampling error is much smaller than the model error thus this is related only to the model variance and simplifies to Equation 5.

$$a_{sg} = 0.4598\exp(-0.0200d_{sg}) + (1 - 0.4598)\exp(-0.4785d_{sg})$$

Equation 5

Where d_{sg} is the geographic distance between the centroids of the target and donor gauge.

The Ray at Islip (39140), 290.1km^2 is downstream of all the hydrology sites with a BFIHOST of 0.49. The area and the BFIHOST means that it is not appropriate to use as a donor gauge at any of the sites.

Similarly, the Ray at Grendon Underwood (19017), 19.7km^2 is within the Ray catchment with a BFIHOST of 0.238. With an area of 131km^2 for the Ray catchment within the study, the gauge is not suitable for use as a donor gauge.

Level only gauges are present on the Langford Brook (Bicester) at Langford Village and Wendlebury Brook at Wendlebury. The former of these was utilised as part of a previous study undertaken for the Environment Agency as part of the Strategic Flood Risk Management Framework and is discussed in greater detail in Section 3.

The level only gauge at Wendlebury Brook has been active since 2006. This is a level only gauge thus further work would need to be completed in order to develop rating curves since check gauges are required in order that this can be transformed to estimates of flow. The EA has confirmed following a formal data request that no flow data exist for this gauge. . However, even if reliable flow estimates are available the maximum length of data which would be available would be 6 years and guidance on flood estimation recommends a length of 14 years to estimate the QMED. In addition, the hydrology within the Wendlebury Brook is unlikely to have significant impact on the flooding within the site of interest.

The value of the data from the Wendlebury gauge is limited, given the issues associated with the quality and length of data and the lack of importance for the particular study site is therefore limited and the gauge was not considered to be suitable for use as a donor gauge.

There are therefore no appropriate gauging stations for use as donor gauges.

An existing hydraulic model developed on the Langford Brook was produced by Peter Brett Associates (PBA) in 2009[8] for the Environment Agency (EA) as part of the Strategic Flood Risk Management (SFRM) framework. A summary of this and the applicability of using some of the hydrology data as local data is presented in Section 3.

2.3 The Revitalised FEH Rainfall Runoff method

The Revitalised FEH rainfall runoff methodology (ReFH) allows the estimation of a flood hydrograph, using catchment descriptors, for any return periods. The ReFH spreadsheet[9] applies the method by creating a 'design storm' from the FEH CD-ROM 3 rainfall statistics and routes it through a simple catchment model to produce a design flood hydrograph.

2.3.1 High Permeability

The ReFH methodology is not recommended for estimating peak flows within the catchments which are highly permeable (SPRHOST<20%)[10]. For the Gagle Brook (SPRHOST is 7.8), peak flows were estimated using the statistical methodology peak flows to rescale the ReFH flood hydrographs. In addition, ReFH is not recommended for use within catchments dominated by storage, where the shape of the hydrograph is less likely to resemble the simple ReFH hydrograph[10]. The Gagle Brook catchment is mostly limestone where groundwater flow is predominantly more rapid fracture flow (rather than storage dominated) thus the ReFH hydrograph is considered to be appropriate.

[8] Peter Brett Associates, 2009, Bicester Flood Risk Mapping Study, Ref 15945/006.
[9] NERC (CEH). 2005.Revitalised FSR/FEH rainfall runoff method. Spreadsheet application version 1.4.http://www.ceh.ac.uk/feh2/SpreadsheetimplementationofReFH.html
[10] Environment Agency. 2012. Flood Estimation Guidelines: Operational Instruction 197_08.

2.3.2 Catchment generic events

In order that the hydrographs represent the same event for use within the hydraulic model it is important that the sub catchment hydrographs are based on the same duration events. The critical duration was set using the Langford Brook hydrology site on the main river to be 14.5 hours.

3 Assessment of Previous Studies

3.1 Summary

A previous study developed a hydraulic model developed on the Langford Brook which coincides with the upper parts of the Langford Brook within the current study area. The work was undertaken for the Environment Agency as part of the Strategic Flood Risk Management Framework. The purpose of the study was to develop flood maps to help inform the spatial planning process.

The hydrology within the PBA report broadly follows the FEH methodology, however a non-standard method of estimating the QMED was used due to the short length of observed hydrometric data. The estimation methodology used 15 minute data from Langford Brook Level Gauge, and Bure Brook Level Gauge at Bicester Village. The locations of these are presented in Figure 2.

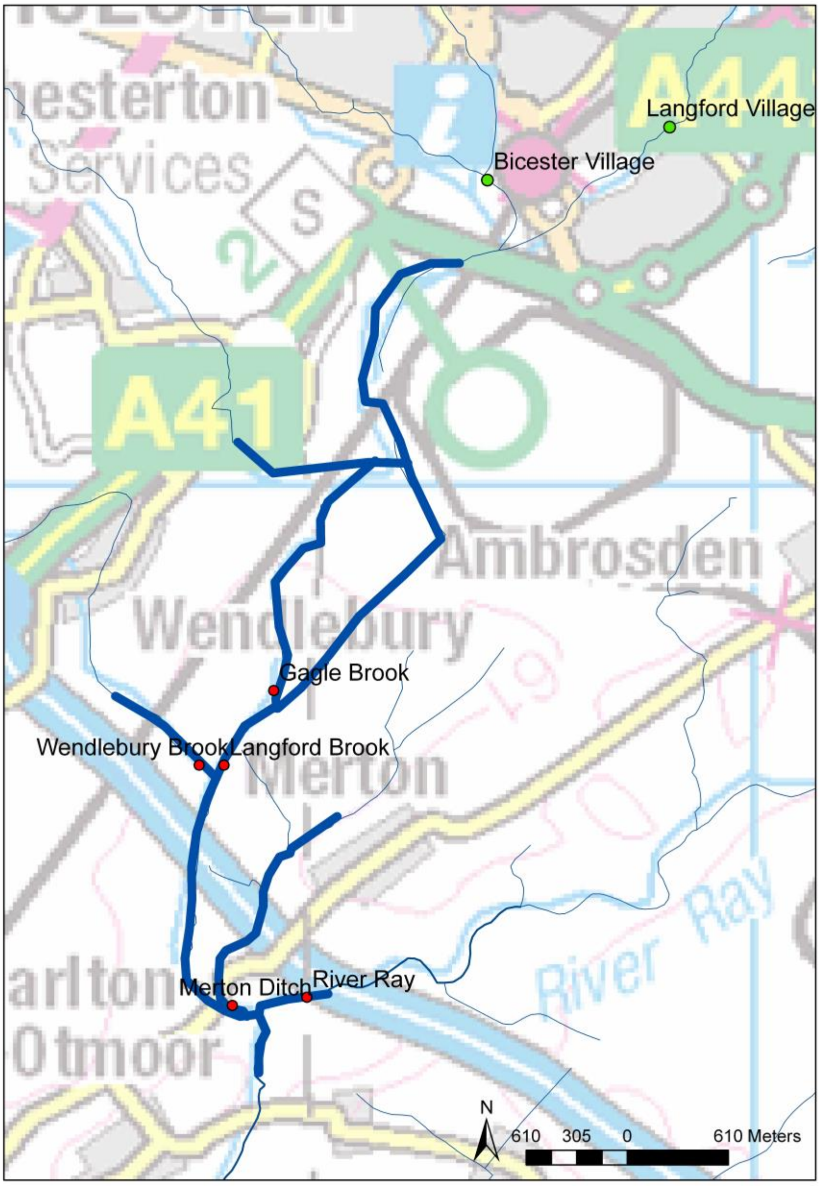

Figure 2 Location of the Bicester Village and Langford Village level gauges relative to the hydrology sites. Contains Ordnance Survey Data © Crown copyright and database right 2013

Spot flow data was utilised, within the framework of the hydraulic model, to produce stage-discharge relationships at the two points. It should be noted that the majority of spot gauges were taken at lower flows.

The QMED was estimated for the two gauged sites, using the 4 years of level data, to be 2.4m^3/s at Bicester village and 4.4m^3/s at Langford village. It was concluded, given comparison with the rainfall data, and the impact on the hydraulic model when QMED was routed through it, that this was likely to be an overestimate of the QMED. The final QMED value used was an 'engineered QMED', generated through a combination of rainfall record analysis and routing through the hydraulic model. It was ultimately chosen through hydrological judgement and no indication of hydrological uncertainty was provided. The report notes that the main uncertainty in the study is in the design flow estimates and recommends a review of these in the future. The QMED values were adjusted to be 1.75m^3/s at Bicester Village and 2.25m^3/s at Langford Village. These will be referred to as the PBA QMED values.

3.2 Assessment of the QMED values

WHS have undertaken an assessment of the QMED values from the aforementioned report. For comparison the QMED was calculated utilising the catchment descriptors from the FEH CD ROMv3[11]. The catchment descriptor QMED values, together with the 68 percentile confidence limits (the Factorial Standard Error (F.S.E) associated with the estimation of the QMED from catchment descriptors is 1.431) are presented alongside the QMED values in Table 2. Note that these are slightly different to those quoted within the PBA report (0.5 and 1.2 respectively) and were calculated from the FEH CD ROMv3. As the catchments are classed as urban (UrbExt2000 within the catchment descriptors is greater than 3%) the catchment descriptor QMED has been adjusted to take this into account. Note that the 68 percentile confidence limits are those associated with the rural estimate of QMED thus will be an underestimate of the total uncertainty (as the uncertainty associated with the urban adjustment factor is not taken into account).

Table 2 PBA QMED estimate, Catchment Descriptor QMED and confidence intervals

Catchment	UrbExt 2000 (%) (from FEH CD ROM)	PBA QMED estimate (cumecs)	FEH Catchment Descriptors QMED (cumecs) with urban adjustment. 68% confidence limits of the rural QMED model are presented in brackets
Bicester Village	7.7	1.75	0.62 (0.35 – 0.88)
Langford Village	9.3	2.25	1.28 (0.73 – 1.84)

Table 2 indicates that the PBA QMED values are high in comparison with the QMED derived using the catchment descriptor methodology. The values are also outside the confidence limits associated with the catchment descriptor technique, although it is noted that the confidence limits are an underestimate of the total uncertainty.

3.3 Use of the PBA QMED values as local data

The hydrology within the PBA hydraulic model has been accepted by the Environment Agency as appropriate for use. Local data was used in the calculation of the flood hydrology values hence it is good practice to use the data if possible.

[11] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.

The donor transfer methodology is therefore applied to the QMED catchment descriptor values using the PBA QMED values. This will be applied to the Langford Brook as this is directly downstream of the level gauges. The Bicester Village and Langford Village catchments are impacted by upstream urban developments. Guidance indicates that the transfer methodology should only be applied in exceptional circumstances when either catchment is impacted by urbanisation. The methodology is only recommended where the data is of good quality, the donor and subject catchment are hydrologically similar and the urbanisation and drainage provision are similar. In this case the Langford Brook catchment is directly downstream of the level gauges and impacted by the same urban area (Bicester). The UrbExt2000 is just over 6% within the Langford Brook catchment. The transfer methodology is therefore utilised ensuring that the rural catchment descriptor QMED values are used for both the Langford Brook catchment and the Bicester and Langford Village level gauges. The ratio of the QMED observed and QMED rural for the Bicester and Langford Village level gauges captures both the uncertainty within the catchment descriptor QMED model and the impact of urbanisation within the catchments.

The uncertainty associated with the PBA QMED values is unknown, and cannot be calculated since these were ascertained using hydrological judgement. In applying the donor transfer model it is necessary to assume that the uncertainty associated with the level records is equivalent to a long record (i.e. the error is far less than the model error). This assumption is unlikely to be true given the uncertainties associated with the PBA QMED values acknowledged within the PBA report and the findings of the WHS analysis. A greater weighting than is necessarily appropriate is therefore placed on the PBA QMED values and as such these are likely to be high and are interpreted as a conservative scenario. Both PBA QMED values were used in the donor transfer method to determine the final Scenario QMED values.

4 Flood Estimation Methodology

A summary of the flood estimation methodology utilised for each hydrology site is presented within Table 3. Details on the statistical pooling group and final hydrographs utilised are presented in the Appendix.

Table 3 Summary of each catchment and the methodology used to generate flood hydrographs.

Hydrology Site	X	Y	Area (km^2)	BFIHOST	SPRHOST	Methodology (ReFH, WINFAP, PBA adjustment)
Langford Brook	457850	220250	40.1	0.71	21.89	QMED from catchment descriptors. Permeable adjustment procedure applied to appropriate catchments within the pooling group. Scenario QMED rescaled using PBA QMED values. Rescale ReFH hydrographs using both QMED values and the growth factors from WINFAP FEHv3.
Gagle Brook	457100	218750	17.6	0.93	7.8	QMED from catchment descriptors. Permeable adjustment procedure applied to appropriate catchments within the pooling group. Note that the SPRHOST is less than 20 hence ReFH is not suitable for flood peaks. Rescale ReFH hydrographs using both QMED values and the growth factors from WINFAP FEHv3.
Wendlebury Brook	456650	218300	7.05	0.60	29.9	QMED from catchment descriptors. Permeable adjustment procedure applied to appropriate catchments within the pooling group. ReFH hydrographs rescaled by WINFAP FEHv3 peak flows.
Merton Ditch	456850	216850	2.59	0.61	35.13	QMED from catchment descriptors. Permeable adjustment procedure applied to appropriate catchments within the pooling group. Note the GL distribution is used in order that the permeable adjustment procedure may be applied. ReFH hydrographs rescaled by WINFAP FEHv3 peak flows. Note the catchment is less than $5km^2$ however FEH methodologies are still appropriate.
River Ray	457300	216900	131.51	0.283	49.63	QMED from Catchment Descriptors. Permeable adjustment procedure applied to appropriate catchments within the pooling group. ReFH hydrographs rescaled by WINFAP FEHv3 peak flows.

Appendix 1

1.1 Langford Brook

The Langford Brook catchment is approximately 40.1km^2 and contains the town of Bicester. The average annual rainfall is 634mm[12] and the annual runoff 189mm[13].

The catchment is dominated by the Hydrology of Soil Type (HOST) classes 2 and 25. Characteristics of these and other significant HOST classes are described on Table 4. The base flow index value (BFIHOST) of 0.71 suggests a flow regime of high permeability, unresponsive to rainfall. However, the response of the oolitic limestones to rainfall is highly variable and can be relatively rapid as localised fracturing can offer quick flow paths for rainfall to reach river systems hence it is possible that this is not reflected within the BFIHOST value.

Table 4 Dominant HOST soil classifications occurring in the catchment

HOST class	Fractional extent (%)	Description of substrate	Description of soils	Permeability
2	55.1	Limestone	Mineral soils, no gleyed layer	High
9	1	Hard, deeply shattered rock, river colluviums, coverloam	Fine mineral soils, shallow depth to gleyed layer	High
23	7.7	Impermeable – soft massive clays	Low storage mineral soil, gleyed layer at depth	Low
25	23.1	Impermeable – soft massive clays	Mineral soil, shallow depth to gleyed layer	Low

Statistical Method

Estimate of the index flood (QMED)

Estimates of the index flood were derived from catchment characteristics. An adjustment for urbanisation is required (URBEXT=0.0614). The estimates of QMED from catchment descriptors were calculated to be;

$$QMED_{CDS\_raw} = 1.93m^3s^{-1}$$

Adjusted for urbanisation using an urban adjustment factor 1.246 gives the QMED estimate as;

$$QMED_{CDS\_urban} = 2.40m^3s^{-1}$$

[12] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.
[13] WHS LowFlows Enterprise.

Using the donor transfer methodology and the PBA estimates of QMED values for Bicester Village and Langford Village gauges, gives the QMED scenario estimate as;

$QMED_{scenario} = 4.15m^3s^{-1}$

Both the urban adjusted QMED and the QMED scenario estimate were utilised to derive alternative peak flows and hydrographs for the required return periods.

Pooling Group and Growth Curve

An initial pooling group was created for the catchment using WINFAP FEHv3. A target return period of 100 years was adopted; hence a minimum of 500 station years is desirable. The initial pooling group of 15 stations was reviewed and 11 stations were removed. Nine extra stations were then added, based on catchment similarity and appropriateness for inclusion in a pooling group, see Table 5. The final pooling group of 13 stations includes a total of 535 station years. The group is classified as having no significant heterogeneity (H_2 = 1.81).

The pooled data was calculated to fit the Generalised Extreme Value (GEV) distribution best (Z=-1.12); the Generalised Logistic (GL) distribution had a Z value of 1.3. There are a number of permeable catchments (SPRHOST < 20%) within the pooling group hence it is necessary to apply the permeable adjustment. The specifics of the methodology are presented for the GL distribution with the guidance[14]. Since the Z value is also acceptable for the GL distribution (<1.64) the GL distribution was adopted to estimate the flood growth curves for the catchment, see Figure 3.

[14] Robson, A.J. and Reed, D.W. (1999) Statistical procedures for flood frequency estimation.Volume 3 of the Flood Estimation Handbook. Centre for Ecology & Ecology.

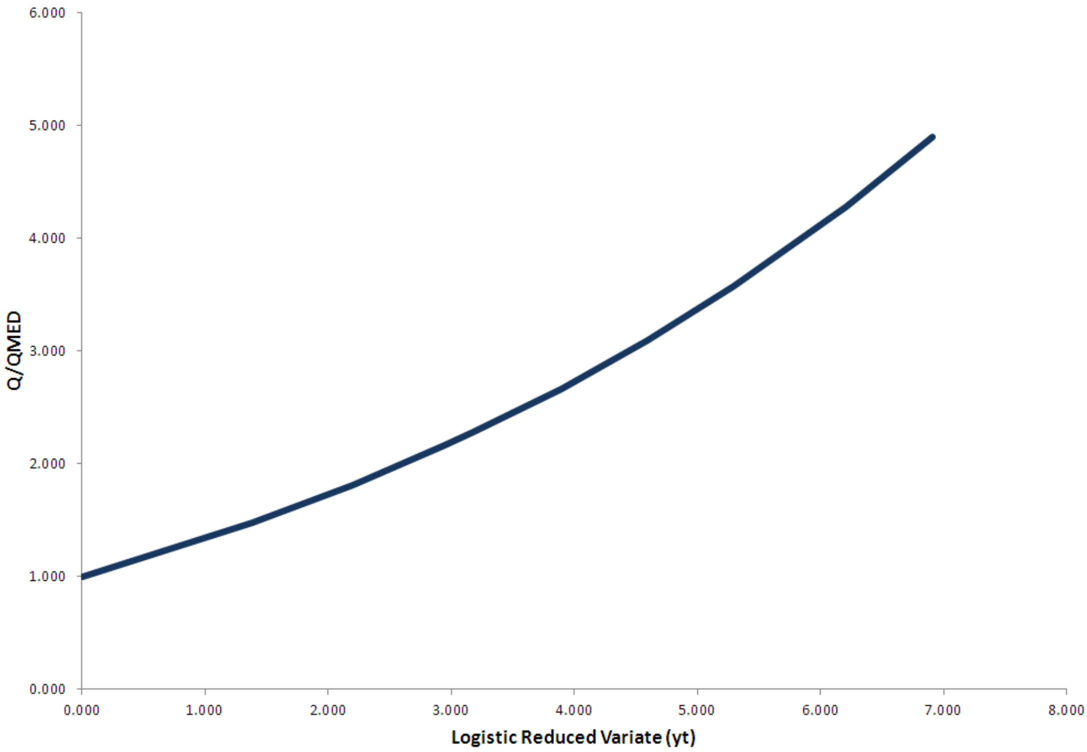

Figure 3 Adopted growth curve for target catchment

Table 5 Pooling group selection and reasons for retaining or removing from final pooling group

Station	**Distance SDM**	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
Target			***40.1***	***634***	***0.98***	***0.089***				
33054 (Babingley @ Castle Rising)	0.471	33	48.51	686	0.944	0.005	Y	Y	Retain	Permeable adjustment applied
33032 (Heacham @ Heacham)	0.592	41	56.18	688	0.983	0.006	Y	Y	Retain	Permeable adjustment applied
20002 (West Peffer Burn @ Luffness)	0.629	41	26.31	616	0.996	0.002	Y	Y	Retain	
33045 (Wittle @ Quidenham)	0.643	41	27.55	608	0.974	0.01	Y	Y	Retain	
36003 (Box @ Polstead)	0.782	46	56.46	566	0.993	0.012	Y	Y	Added	
29009 (Ancholme @ Toft Newton)	0.826	35	29.52	616	0.997	0.004	Y	Y	Added	
34005 (Tud @ Costessey Park)	0.839	48	72.12	649	0.973	0.029	Y	Y	Added	
36007 (Belchamp Brook @ Bardfield Bridge)	0.938	45	58.16	560	0.996	0.004	Y	Y	Added	
36004 (Chad Brook @ Long Melford)	0.965	42	50.32	589	1	0.006	Y	Y	Added	
41020 (Bevern Stream @ Clappers Bridge)	1.019	40	35.42	886	0.993	0.013	Y	Y	Added	
37016 (Pant @ Copford Hall)	1.082	44	63.78	588	0.997	0.009	Y	Y	Added	
39042 (Leach @ Priory Mill Lechlade)	1.192	37	77.57	736	0.971	0.003	Y	Y	Added	Permeable adjustment applied
30017 (Witham @ Colsterworth)	0.405	31	50.13	641	0.993	0.026	N	Y	Removed	Unsuitable for pooling.
54052 (Bailey Brook @ Ternhill)	0.457	36	38.38	707	0.97	0.014	N	N	Removed	Unsuitable for pooling.

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
22801 (Pont @ Stamfordham)	0.458	10	48.11	684	0.998	0.002	N	Y	Removed	Unsuitable for pooling.
33049 (Stanford Water @ Buckenham Tofts)	0.496	7	46.42	645	0.915	0.007	N	Y	Removed	Unsuitable for pooling.
35004 (Ore @ Beversham Bridge)	0.596	43	56.19	596	0.988	0.017	N	N	Removed	Unsuitable for pooling.
26010 (Driffield Canal @ Snakeholme Lock)	0.612	21	49.47	699	0.987	0.025	N	Y	Removed	Unsuitable for pooling.
30015 (Cringle Brook @ Stoke Rochford)	0.723	33	41.33	656	0.931	0.004	N	N	Removed	Unsuitable for pooling.
26003 (Foston Beck @ Foston Mill)	0.728	49	59.4	698	0.987	0.004	Y	Y	Removed	Bounded, still bounded after permeable adjustment applied.
33052 (Swaffham Lode @ Swaffham Bulbeck)	0.737	40	33.25	567	0.998	0.012	N	Y	Removed	Unsuitable for pooling.
38026 (Pincey Brook @ Sheering Hall)	0.738	35	52.85	599	0.984	0.027	N	Y	Removed	Unsuitable for pooling.

Flood Frequency Curve

A flood frequency curve for the catchment was derived using the adopted QMED estimates of $2.40m^3s^{-1}$ and $4.15m^3s^{-1}$ and the pooling group growth curve. Note the same growth curve was used for both. The resulting design flood peak flow estimates are shown on Table 6.

Table 6 Statistical Method estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})	Scenario Peak Flow (m^3s^{-1})
5	3.85	6.15
20	5.62	8.99
100	8.06	12.87
100 + 20%	9.67	15.44
1000	12.74	20.35

Flood estimation using the ReFH rainfall runoff method

The ReFH Model was used to estimate a range of return period flood event hydrographs. The resulting peak flow estimates from the design hydrographs for the catchment are shown in Table 7.

Table 7 ReFH estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	3.57
20	5.07
100	7.49
100 + 20%	8.99
1000	14.29

Summary of results

The final flood hydrographs were estimated by rescaling the ReFH hydrographs by the statistical peak flow estimates, see Figure 4. The scenario hydrographs, based on the original PBA estimates, have been adopted within the hydraulic model as these are considered to represent a conservative estimation of flood peaks, see Section 3.

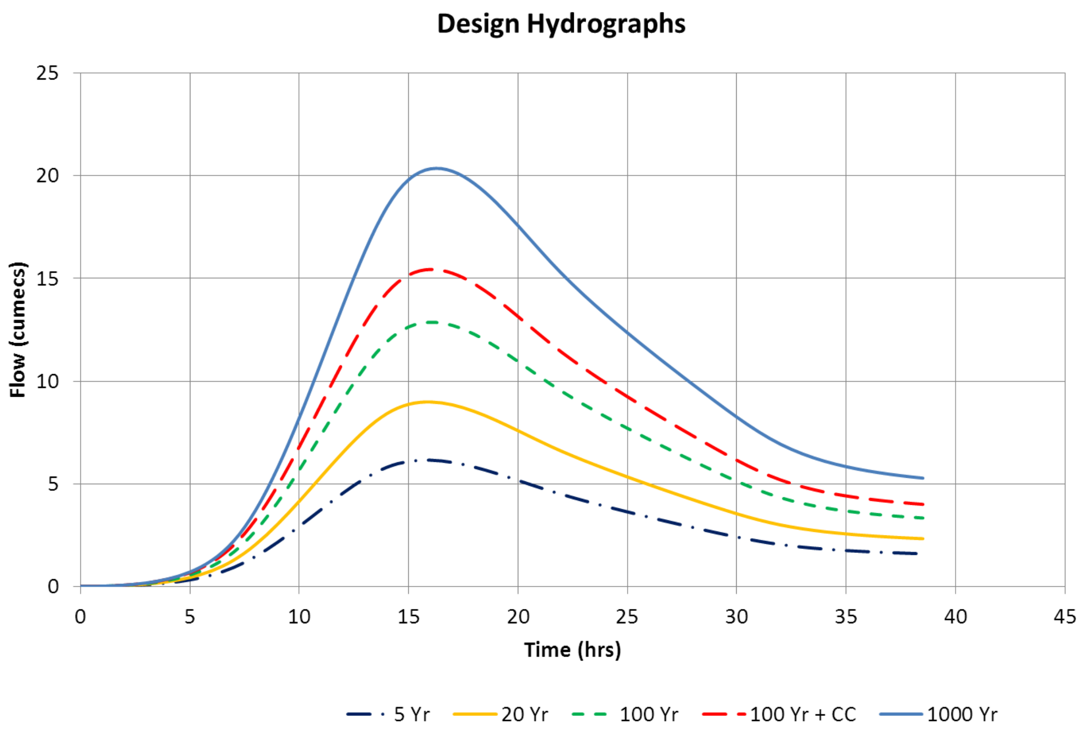

Figure 4 Final design hydrographs adopted for the scenario QMED.

1.2 Gagle Brook

The Gagle Brook catchment is approximately 17.59km^2 and encompasses an area to the west of the town of Bicester, including a section of the M40 motorway. The average annual rainfall is 652mm[15] and the annual runoff 210mm[16].

The catchment is dominated by the Hydrology of Soil Type (HOST) classes 2 and 6. Characteristics of these and other significant HOST classes are described on Table 8. The base flow index value (BFIHOST) of 0.93 suggests a flow regime of high permeability, unresponsive to rainfall. As within the Langford Brook the catchment is dominated by oolitic limestones and the response to rainfall is highly variable and can be relatively rapid as localised fracturing can offer quick flow paths for rainfall to reach river systems. It is possible that this is not reflected within the BFIHOST value.

Table 8 Dominant HOST soil classifications occurring in the catchment

HOST class	Fractional extent (%)	Description of substrate	Description of soils	Permeability
2	84.5	Limestone	Mineral soils, no gleyed layer	High
6	10.4	Colluvium, coverloam, sand	Mineral soils, no gleyed layer	High
25	2.6	Impermeable – soft massive clays	Mineral soil, shallow depth to gleyed layer	Low

[15] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.
[16] WHS LowFlows Enterprise.

Statistical Method

Estimate of the index flood (QMED)

Estimates of the index flood were derived from catchment characteristics using WINFAP FEHv3. An adjustment for urbanisation is not necessarily required, but was completed (URBEXT=0.0082). The estimates of QMED from catchment descriptors were calculated to be;

$QMED_{CDS\_raw} = 0.34m^3s^{-1}$

Adjusted for urbanisation using an urban adjustment factor 1.075 gives the QMED estimate as;

$QMED_{CDS\_urban} = 0.37m^3s^{-1}$

Pooling Group and Growth Curve

An initial pooling group was created for the catchment using WINFAP FEHv3. A target return period of 100 years was adopted; hence a minimum of 500 station years is desirable. The initial pooling group of 15 stations was reviewed and 11 stations were removed. Thirteen extra stations were then added, based on catchment similarity and appropriateness for inclusion in a pooling group, see Table 9. The final pooling group of 17 stations includes a total of 536 station years. The group is classified as being heterogeneous (H_2 = 3.34).

The pooled data fitted the Generalised Logistic (GL) distribution best, and this was adopted to estimate the flood growth curves for the catchment, see Figure 5.

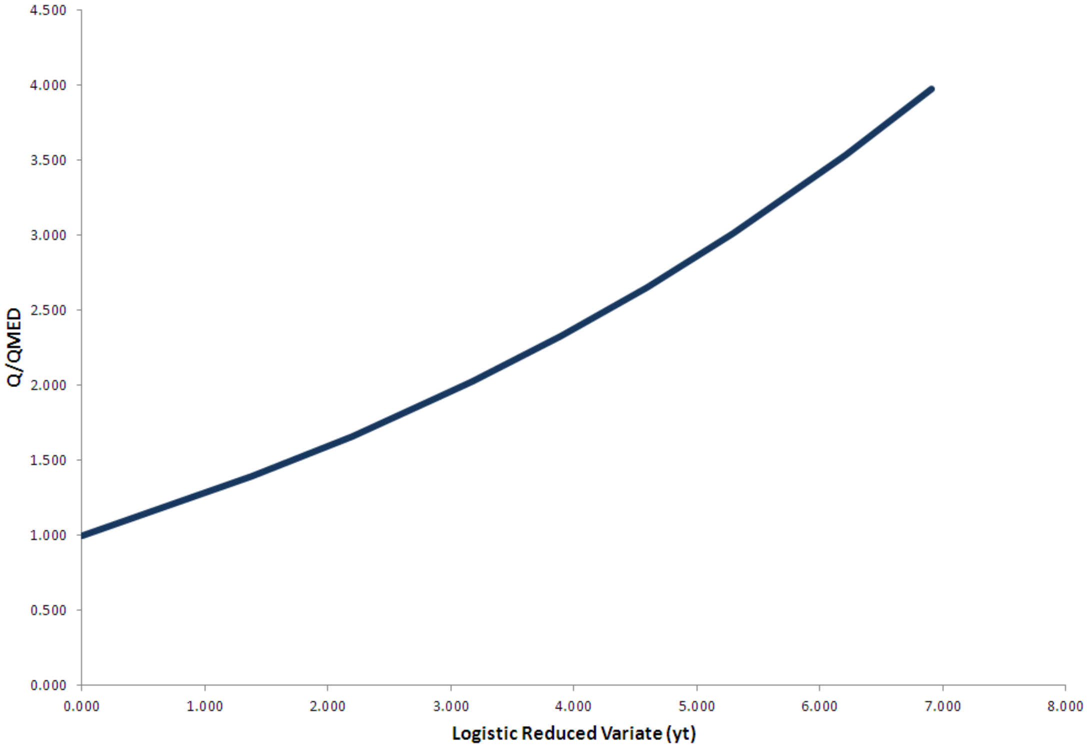

Figure 5 Adopted growth curve for target catchment

Table 9 Pooling group selection and comments on reasons for retaining or removing from final pooling group and application of the permeable adjustment methodology.

Station	**Distance SDM**	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
Target			***17.59***	***652***	***0.97***	***0.0087***				
26802 (Gypsey Race @ Kirby Grindalythe)	0.544	10	15.85	757	1	0	Y	Y		
36010 (Bumpstead Brook @ Broad Green)	0.723	42	27.58	588	0.999	0.007	Y	Y		
25019 (Leven @ Easby)	0.753	31	15.07	830	1	0.004	Y	Y		
20002 (West Peffer Burn @ Luffness)	0.911	41	26.31	616	0.996	0.002	Y	Y		
203046 (Rathmore Burn @ Rathmore Bridge)	0.982	27	22.51	1043	1	0	Y	Y	Added	
27010 (Hodge Beck @ Bransdale Weir)	1.036	41	18.84	987	1	0.001	Y	Y	Added	
44008 (Sth Winterbourne @ W'bourne Steepleton)	1.051	30	20.17	1012	1	0.004	Y	Y	Added	
41020 (Bevern Stream @ Clappers Bridge)	1.154	40	35.42	886	0.993	0.013	Y	Y	Added	
44006 (Sydling Water @ Sydling st Nicholas)	1.176	35	12.06	1030	0.944	0.005	Y	Y	Added	
22003 (Usway Burn @ Shillmoor)	1.195	13	21.87	1056	1	0	Y	Y	Added	
203049 (Clady @ Clady Bridge)	1.216	27	29.38	1079	1	0	Y	Y	Added	
44809 (Piddle @ Little Puddle)	1.298	16	31.27	1004	1	0.004	Y	Y	Added	
27051 (Crimple @ Burn Bridge)	1.345	37	8.15	855	1	0.006	Y	Y	Added	

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
72014 (Conder @ Galgate)	1.348	42	28.99	1183	0.975	0.006	Y	Y	Added	
54034 (Dowles Brook @ Oak Cottage, Dowles)	1.385	38	38	9.548	0.455	1.439	Y	Y	Added	
206004 (Bessbrook @ Carnbane)	1.389	25	25	9.646	0.37	1.068	Y	Y	Added	
33045 (Wittle @ Quidenham)	1.396	41	41	1.147	0.166	0.388	Y	Y	Added	
41016 (Cuckmere @ Cowbeech)	0.761	42	19.09	855	0.966	0.027	N	Y	Removed	Not suitable for pooling
31025 (Gwash South Arm @ Manton)	0.825	31	23.93	663	0.995	0.006	N	Y	Removed	Not suitable for pooling
39036 (Law Brook @ Albury)	0.979	42	16.05	819	0.96	0.008	N	Y	Removed	Not suitable for pooling
36009 (Brett @ Cockfield)	0.781	39	25.62	598	1	0.005	Y	Y	Removed	Remove as bounded curve and data is of questionable quality.
41028 (Chess Stream @ Chess Bridge)	0.65	45	24.92	849	0.983	0.014	N	Y	Removed	Not suitable for pooling
52015 (Land Yeo @ Wraxall Bridge)	0.84	30	23.33	906	0.933	0.017	N	Y	Removed	Not suitable for pooling
52016 (Currypool Stream @ Currypool Farm)	0.977	39	15.7	934	1	0	N	Y	Removed	Not suitable for pooling
30014 (Pointon Lode @ Pointon)	0.809	37	10.94	591	1	0.014	N	Y	Removed	Not suitable for pooling
7006 (Lossie @ Torwinny)	0.977	19	20.62	956	0.956	0	N	N	Removed	Not suitable for pooling
54060 (Potford Brook @ Sandyford Bridge)	0.838	32	22.37	677	0.998	0.001	N	Y	Removed	Not suitable for pooling

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
40017 (Dudwell @ Burwash)	0.926	40	26.32	887	0.994	0.01	N	N	Removed	Not suitable for pooling

Flood Frequency Curve

A flood frequency curve for the catchment was derived using the adopted QMED estimate of 0.37m^3s^{-1} [1] and the pooling group growth curve. The resulting design flood peak flow estimates are shown on Table 10.

Table 10 Statistical Method estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	0.51
20	0.71
100	0.98
100 + 20%	1.17
1000	1.47

Flood estimation using the ReFH rainfall runoff method

The Revitalised Flood Hydrograph (ReFH) Model was used to estimate a range of return period flood event hydrographs. The resulting peak flow estimates from the design hydrographs for the catchment are shown in Table 11. Note that peak flows within the Gagle Brook are not reliable estimates of the peak flows as the SPRHOST is less than 20.

Table 11 ReFH estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	0.18
20	0.36
100	0.76
100 + 20%	0.91
1000	2.19

Summary of results

The final flood hydrographs were estimated by rescaling the ReFH hydrographs by the statistical peak flow estimates, see Figure 6.

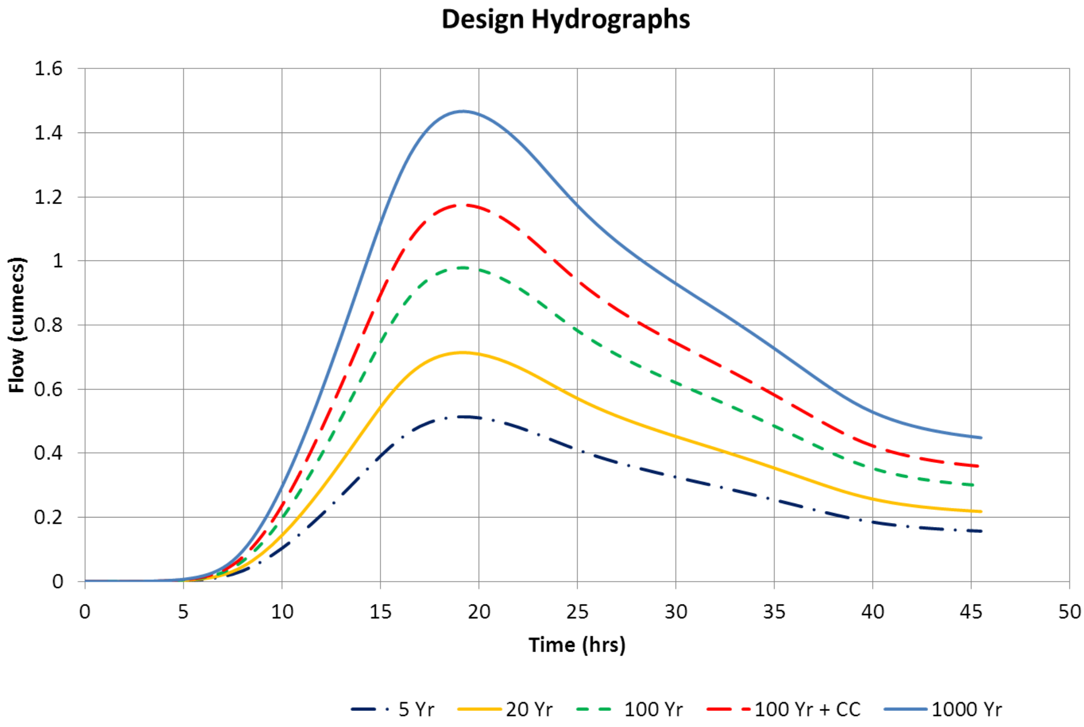

Figure 6 Final design hydrographs adopted for the baseline QMED.

1.3 Wendlebury Brook

The Wendlebury Brook catchment is approximately 7.05km^2 and contains the village of Wendlebury and a section of the M40 motorway. The average annual rainfall is 625mm[17] and the annual runoff 178mm[18].

The catchment is dominated by the Hydrology of Soil Type (HOST) classes 2 and 25. Characteristics of these and other significant HOST classes are described on Table 12. The base flow index value (BFIHOST) of 0.596 suggests a flow regime of average permeability, relatively responsive to rainfall.

Table 12 Dominant HOST soil classifications occurring in the catchment

HOST class	Fractional extent (%)	Description of substrate	Description of soils	Permeability
2	39.5	Limestone	Mineral soils, no gleyed layer	High
9	5.6	Hard, deeply shattered rock, river colluviums, coverloam	Fine mineral soils, shallow depth to gleyed layer	High
20	7.5	Impermeable – soft massive clays	High storage mineral soil, gleyed layer at depth	Medium
25	34.0	Impermeable – soft massive clays	Mineral soil, shallow depth to gleyed layer	Low

Statistical Method

Estimate of the index flood (QMED)

Estimates of the index flood were derived from catchment characteristics using WINFAP FEHv3. An adjustment for urbanisation is not necessarily required, but was completed (URBEXT=0.0082). The estimates of QMED from catchment descriptors were calculated to be;

$$QMED_{CDS\_raw} = 0.42m^3s^{-1}$$

Adjusted for urbanisation using an urban adjustment factor 1.055 gives the QMED estimate as;

[17] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.
[18] WHS LowFlows Enterprise.

$QMED_{CDS\_urban} = 0.44m^3s^{-1}$

Pooling Group and Growth Curve

An initial pooling group was created for the catchment using WINFAP FEHv3. A target return period of 100 years was adopted; hence a minimum of 500 station years is desirable. The initial pooling group of 15 stations was reviewed and eleven stations were removed. Thirteen extra stations were then added, based on catchment similarity and appropriateness for inclusion in a pooling group, see Table 13. The final pooling group of 17 stations includes a total of 521 station years. The group is classified as being strongly heterogeneous (H_2 = 6.4754), however it was not possible to reduce the heterogeneity without compromising the validity of the pooling group.

The pooled data fitted the Generalised Logistic (GL) distribution best, and this was adopted to estimate the flood growth curves for the catchment, see Figure 7.

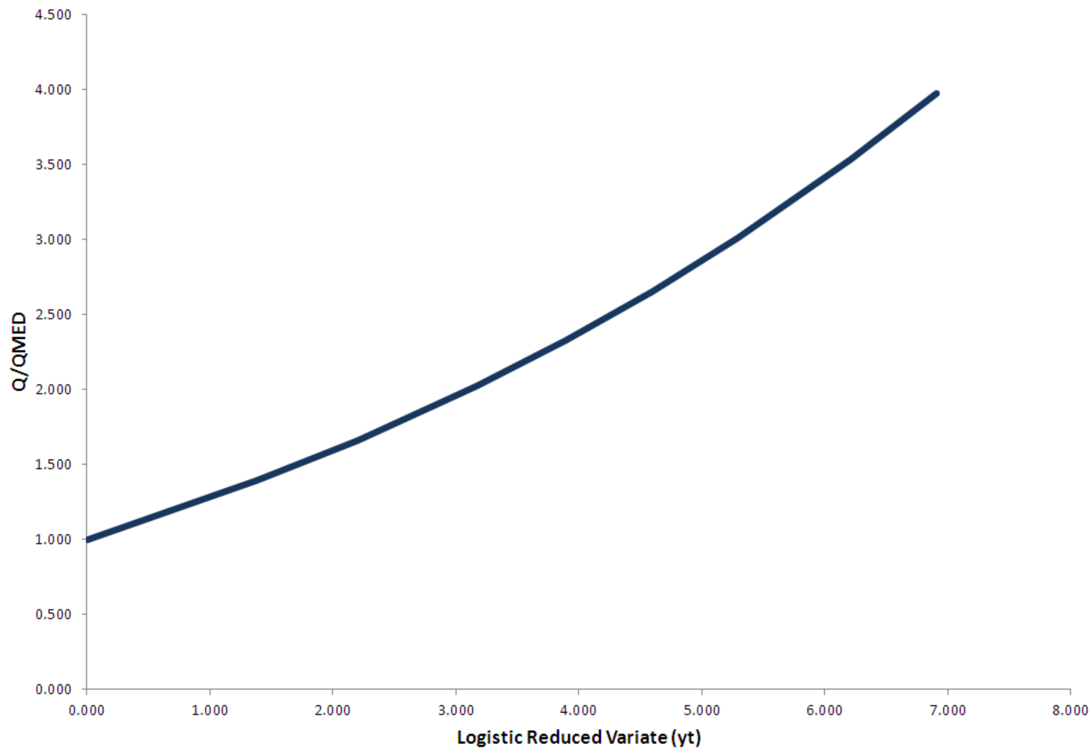

Figure 7 Adopted growth curve for target catchment

Table 13 Pooling group selection and comments on reasons for retaining or removing from final pooling group and application of the permeable adjustment methodology.

Station	**Distance SDM**	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
Target			***18.8***	***650***	***0.97***	***0.0082***				
36009 (Brett @ Cockfield)	0.543	39	25.62	598	1	0.005	Y	Y	Retain	
20002 (West Peffer Burn @ Luffness)	0.64	41	26.31	616	0.996	0.002	Y	Y	Retain	
36010 (Bumpstead Brook @ Broad Green)	0.8	42	27.58	588	0.999	0.007	Y	Y	Retain	
26802 (Gypsey Race @ Kirby Grindalythe)	0.809	10	15.85	757	1	0	Y	Y	Retain	Permeable adjustment not possible as all years are flood years.
203046 (Rathmore Burn @ Rathmore Bridge)	0.981	27	22.51	1043	1	0	Y	Y	Added	
25019 (Leven @ Easby)	1.007	31	15.07	830	1	0.004	Y	Y	Added	
41020 (Bevern Stream @ Clappers Bridge)	1.09	40	35.42	886	0.993	0.013	Y	Y	Added	
33045 (Wittle @ Quidenham)	1.093	41	27.55	608	0.974	0.01	Y	Y	Added	
44008 (Sth Winterbourne @ W'bourne Steepleton)	1.229	30	20.17	1012	1	0.004	Y	Y	Added	Permeable adjustment applied.
27010 (Hodge Beck @ Bransdale Weir)	1.238	41	18.84	987	1	0.001	Y	Y	Added	
73015 (Keer @ High Keer Weir)	1.3	19	30.06	1158	0.976	0.003	Y	Y	Added	
72014 (Conder @ Galgate)	1.3	42	28.99	1183	0.975	0.006	Y	Y	Added	
22003 (Usway Burn @ Shillmoor)	1.368	13	21.87	1056	1	0	Y	Y	Added	

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
33054 (Babingley @ Castle Rising)	1.37	33	48.51	686	0.944	0.005	Y	Y	Added	Permeable adjustment applied.
44006 (Sydling Water @ Sydling st Nicholas)	1.386	35	12.06	1030	0.944	0.005	Y	Y	Added	Permeable adjustment applied.
44809 (Piddle @ Little Puddle)	1.406	16	31.27	1004	1	0.004	Y	Y	Added	Permeable adjustment applied.
50009 (Lew @ Norley Bridge)	1.414	21	20.16	1195	1	0.001	Y	Y	Added	
54060 (Potford Brook @ Sandyford Bridge)	0.542	32	22.37	677	0.998	0.001	N	Y	Remove	Unsuitable for pooling
41028 (Chess Stream @ Chess Bridge)	0.65	45	24.92	849	0.983	0.014	N	Y	Remove	Unsuitable for pooling
41016 (Cuckmere @ Cowbeech)	0.761	42	19.09	855	0.966	0.027	N	Y	Remove	Unsuitable for pooling
39017 (Ray @ Grendon Underwood)	0.761	42	21.15	622	0.982	0.004	N	Y	Remove	Unsuitable for pooling
30014 (Pointon Lode @ Pointon)	0.809	37	10.94	591	1	0.014	N	Y	Remove	Unsuitable for pooling
31025 (Gwash South Arm @ Manton)	0.825	31	23.93	663	0.995	0.006	N	Y	Remove	Unsuitable for pooling
52015 (Land Yeo @ Wraxall Bridge)	0.84	30	23.33	906	0.933	0.017	N	Y	Remove	Unsuitable for pooling
43019 (Shreen Water @ Colesbrook)	0.96	36	30.36	884	0.993	0.015	N	Y	Remove	Unsuitable for pooling
7006 (Lossie @ Torwinny)	0.977	19	20.62	956	0.956	0	N	N	Remove	Unsuitable for pooling
52016 (Currypool Stream @ Currypool Farm)	0.977	39	15.7	934	1	0	N	Y	Remove	Unsuitable for pooling
39036 (Law Brook @ Albury)	0.979	42	16.05	819	0.96	0.008	N	Y	Remove	Unsuitable for pooling

Flood Frequency Curve

A flood frequency curve for the catchment was derived using the adopted QMED estimate of $0.44m^3s^{-1}$ and the pooling group growth curve. The resulting design flood peak flow estimates are shown on Table 14.

Table 14 Statistical Method estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	0.94
20	1.40
100	2.10
100 + 20%	2.51
1000	3.65

Flood estimation using the ReFH rainfall runoff method

The Revitalised Flood Hydrograph (ReFH) Model was used to estimate a range of return period flood event hydrographs. The resulting peak flow estimates from the design hydrographs for the catchment are shown in Table 15.

Table 15 ReFH estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	1.26
20	1.70
100	2.37
100 + 20%	2.84
1000	4.11

Summary of results

The final flood hydrographs were estimated by rescaling the ReFH hydrographs by the statistical peak flow estimates, see Figure 8.

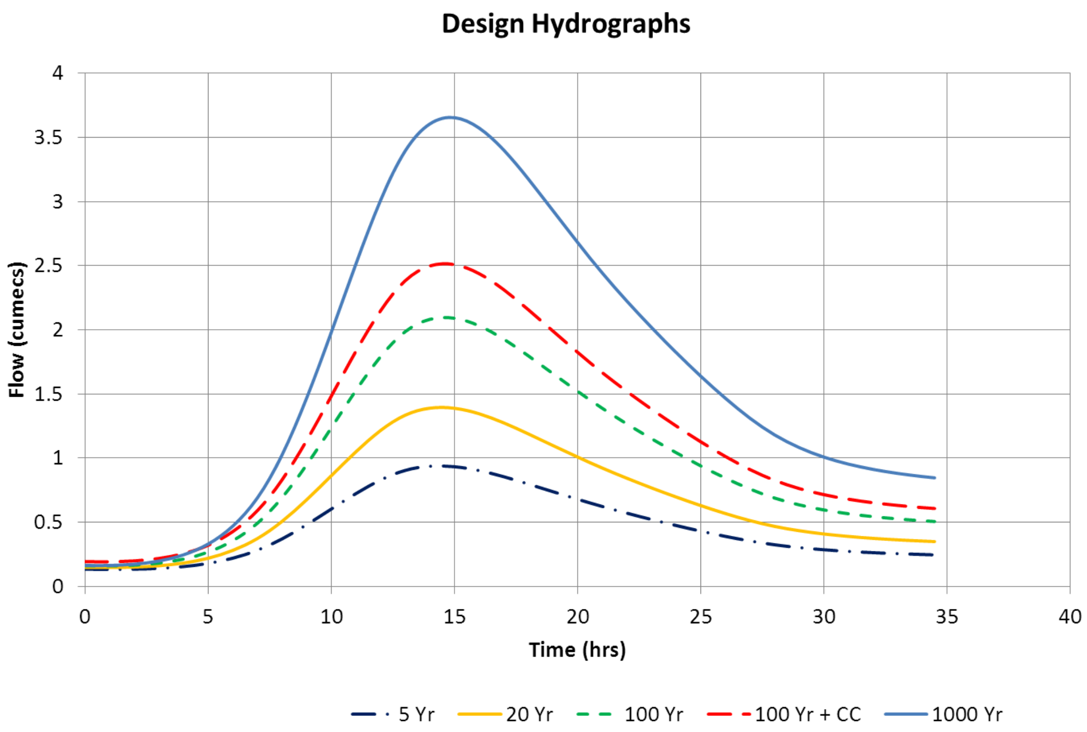

Figure 8 Final design hydrographs adopted

1.4 Merton Ditch

The Merton Ditch catchment is approximately 2.59km^2 and contains the village of Merton and a section of the M40 motorway. The average annual rainfall is 613mm[19] and the annual runoff 173mm[20].

The catchment is dominated by the Hydrology of Soil Type (HOST) classes 8 and 9. Characteristics of these and other significant HOST classes are described on Table 16. The base flow index value (BFIHOST) of 0.61 suggests a flow regime of average permeability, relatively responsive to rainfall.

Table 16 Dominant HOST soil classifications occurring in the catchment

HOST class	Fractional extent (%)	Description of substrate	Description of soils	Permeability
9	44.1	Hard, deeply shattered rock, river colluviums, coverloam	Fine mineral soils, shallow depth to gleyed layer	High
8	20.8	Hard, deeply shattered rock, river colluviums, coverloam	Mineral soils, with or without gleyed layer	Medium
25	14.8	Impermeable – soft massive clays	Mineral soil, shallow depth to gleyed layer	Low
7	9.4	Blown sand, gravel, sand	Mineral soils, with or without gleyed layer	High

Statistical Method

Estimate of the index flood (QMED)

Estimates of the index flood were derived from catchment characteristics using WINFAP FEHv3. An adjustment for urbanisation is not necessarily required, but was completed (URBEXT=0.0068). The estimates of QMED from catchment descriptors were calculated to be;

$$QMED_{CDS\_raw} = 0.25m^3s^{-1}$$

Adjusted for urbanisation using an urban adjustment factor 1.009 gives the QMED estimate as;

$$QMED_{CDS\_urban} = 0.25m^3s^{-1}$$

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[19] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.
[20] WHS LowFlows Enterprise.

Pooling Group and Growth Curve

An initial pooling group was created for the catchment using WINFAP FEHv3. A target return period of 100 years was adopted; hence a minimum of 500 station years is desirable. The initial pooling group of 16 stations was reviewed and thirteen stations were removed. Twelve extra stations were then added, based on catchment similarity and appropriateness for inclusion in a pooling group, see Table 5. The final pooling group of 16 stations includes a total of 542 station years. The group is classified as being heterogeneous (H_2 = 3.5206).

The pooled data was calculated to fit the Generalised Extreme Value (GEV) distribution best (Z=-0.66), and the Generalised Logistic (GL) distribution second-best (Z=1.06). There are a number of permeable catchments (SPRHOST < 20%) within the pooling group hence it is necessary to apply the permeable adjustment. The specifics of the methodology are presented for the GL distribution with the guidance[21]. Since the Z value is also acceptable for the GL distribution (<1.64) the GL distribution was adopted to estimate the flood growth curves for the catchment, see Figure 9.

[21] Robson, A.J. and Reed, D.W. (1999) Statistical procedures for flood frequency estimation.Volume 3 of the Flood Estimation Handbook. Centre for Ecology & Ecology.

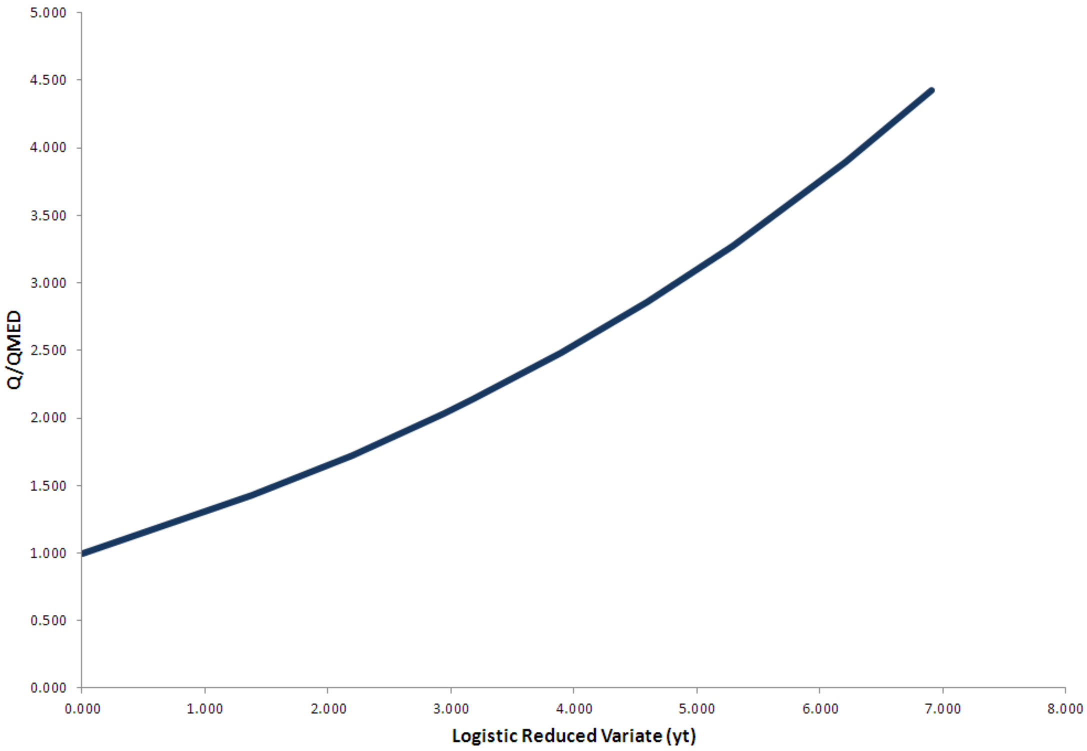

Figure 9 Adopted growth curve for target catchment

Table 17 Pooling group selection and reasons for retaining or removing from final pooling group.

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
Target			***2.59***	***613***	***0.97***	***0.0068***				
27073 (Brompton Beck @ Snainton Ings)	5.973	29	8.06	721	1	0.008	Y	Y	Retain	Permeable adjustment applied
29009 (Ancholme @ Toft Newton)	6.98	35	29.52	616	0.997	0.004	Y	Y	Retain	
33045 (Wittle @ Quidenham)	2.067	41	27.55	608	0.974	0.01	Y	Y	Retain	
20002 (West Peffer Burn @ Luffness)	7.688	41	26.31	616	0.996	0.002	Y	Y	Added	
34005 (Tud @ Costessey Park)	8.102	48	72.12	649	0.973	0.029	Y	Y	Added	
33054 (Babingley @ Castle Rising)	8.181	33	48.51	686	0.944	0.005	Y	Y	Added	Permeable adjustment applied
72014 (Conder @ Galgate)	8.302	42	28.99	1183	0.975	0.006	Y	Y	Added	
33032 (Heacham @ Heacham)	8.305	41	56.18	688	0.983	0.006	Y	Y	Added	Permeable adjustment applied
45817 (Rhb Trib to Haddeo @ Upton (trib))	8.329	16	1.74	1207	1	0.002	Y	Y	Added	
44009 (Wey @ Broadwey)	8.409	32	7.95	894	1	0.022	Y	Y	Added	Permeable adjustment applied
41020 (Bevern Stream @ Clappers Bridge)	8.422	40	35.42	886	0.993	0.013	Y	Y	Added	
26802 (Gypsey Race @ Kirby Grindalythe)	8.459	10	15.85	757	1	0	Y	Y	Added	Permeable adjustment not possible as all years are flood years.
36010 (Bumpstead Brook @ Broad Green)	8.566	42	27.58	588	0.999	0.007	Y	Y	Added	
25019 (Leven @ Easby)	8.566	31	15.07	830	1	0.004	Y	Y	Added	

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
203042 (Crumlin @ Cidercourt Bridge)	8.57	30	54.47	991	1	0.005	Y	Y	Added	
28033 (Dove @ Hollinsclough)	8.596	30	7.93	1346	1	0	Y	Y	Added	
33048 (Larling Brook @ Stonebridge)	6.529	32	21.99	635	0.907	0.003	N	Y	Remove	Unsuitable for pooling
68011 (Arley Brook @ Gore Farm)	6.685	9	33.76	831	0.998	0.021	N	Y	Remove	Unsuitable for pooling
33052 (Swaffham Lode @ Swaffham Bulbeck)	7.109	40	33.25	567	0.998	0.012	N	Y	Remove	Unsuitable for pooling
29004 (Ancholme @ Bishopbridge)	7.128	41	59.03	615	0.996	0.004	N	Y	Remove	Unsuitable for pooling
27038 (Costa Beck @ Gatehouses)	7.181	39	7.98	722	0.99	0.022	N	Y	Remove	Unsuitable for pooling
39017 (Ray @ Grendon Underwood)	7.249	42	21.15	622	0.982	0.004	N	Y	Remove	Unsuitable for pooling
31026 (Egleton Brook @ Egleton)	7.358	31	2.3	645	1	0.011	N	Y	Remove	Unsuitable for pooling
54052 (Bailey Brook @ Ternhill)	7.418	36	38.38	707	0.97	0.014	N	N	Remove	Unsuitable for pooling
30014 (Pointon Lode @ Pointon)	7.508	37	10.94	591	1	0.014	N	Y	Remove	Unsuitable for pooling
54060 (Potford Brook @ Sandyford Bridge)	7.547	32	22.37	677	0.998	0.001	N	Y	Remove	Unsuitable for pooling
52011 (Cary @ Somerton)	7.558	44	84.62	715	1	0.024	N	Y	Remove	Unsuitable for pooling
32029 (Flore @ Experimental Catchment)	7.617	5	8.34	624	1	0.002	Y	Y	Remove	Short record

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
29005 (Rase @ Bishopbridge)	7.678	38	63.37	641	0.996	0.017	N	N	Remove	Unsuitable for pooling

Flood Frequency Curve

A flood frequency curve for the catchment was derived using the adopted QMED estimate of $0.25m^3s^{-1}$ and the pooling group growth curve. The resulting design flood peak flow estimates are shown on Table 18.

Table 18 Statistical Method estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	0.36
20	0.54
100	0.81
100 + 20%	0.97
1000	1.40

Flood estimation using the ReFH rainfall runoff method

The Revitalised Flood Hydrograph (ReFH) Model was also used to estimate a range of return period flood event hydrographs. The resulting peak flow estimates from the design hydrographs for the catchment are shown in Table 19.

Table 19 ReFH estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s^{-1})
5	0.48
20	0.65
100	0.91
100 + 20%	1.10
1000	1.61

Summary of results

The final flood hydrographs were estimated by rescaling the ReFH hydrographs by the statistical peak flow estimates, see Figure 10.

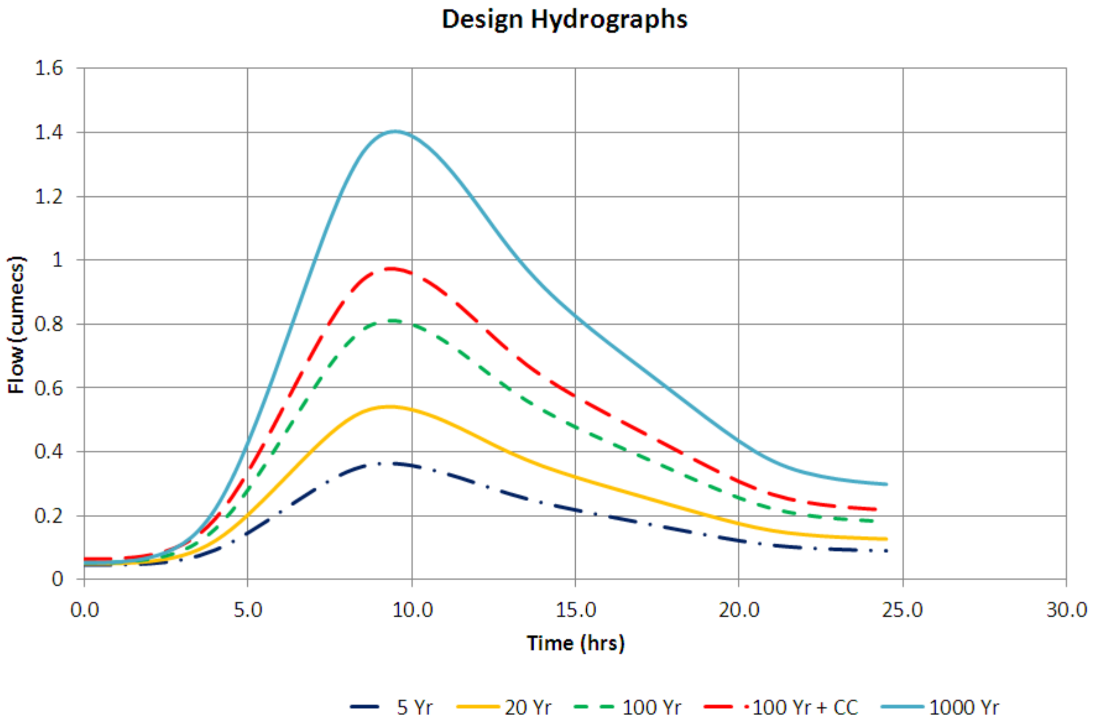

Figure 10 Final design hydrographs adopted

1.5 River Ray

The River Ray catchment is approximately 131.51km^2, extending to the west and south west of Bicester. The average annual rainfall is 625mm[22] and the annual runoff 160mm[23].

A hydrologically-based classification of the soils of the United Kingdom was developed by the Institute of Hydrology[24] that describes both the soils and their hydrological response. The catchment is dominated by the Hydrology of Soil Type (HOST) classes 23 and 25. Characteristics of these and other significant HOST classes are described on Table 20. The base flow index value (BFIHOST) of 0.283 suggests a flow regime of low permeability, relatively responsive to rainfall.

Table 20 Dominant HOST soil classifications occurring in the catchment

HOST class	Fractional extent (%)	Description of substrate	Description of soils	Permeability
25	60.1	Impermeable – soft massive clays	Mineral soil, shallow depth to gleyed layer	Low
23	16.8	Impermeable – soft massive clays	Low storage mineral soil, gleyed layer at depth	Low
20	7.5	Impermeable – soft massive clays	High storage mineral soil, gleyed layer at depth	Medium

Statistical Method

Estimate of the index flood (QMED)

Estimates of the index flood were derived from catchment characteristics using WINFAP FEHv3. An adjustment for urbanisation is not necessarily required, but was completed (URBEXT=0.0078). The estimates of QMED from catchment descriptors were calculated to be;

$$QMED_{CDS\_raw} = 19.62m^3s^{-1}$$

Adjusted for urbanisation using an urban adjustment factor 1.006 gives the QMED estimate as;

$$QMED_{CDS\_urban} = 19.74m^3s^{-1}$$

[22] NERC (CEH). 2009. Flood Estimation Handbook CD-ROM 3.
[23] WHS LowFlows Enterprise.
[24] Boorman, Hollis & Lilly. 1995. Report No. 126 Hydrology of soil types.

Pooling Group and Growth Curve

An initial pooling group was created for the catchment using WINFAP FEHv3. A target return period of 100 years was adopted; hence a minimum of 500 station years is desirable. The initial pooling group of 13 stations was reviewed and eleven stations were removed. Eleven extra stations were then added, based on catchment similarity and appropriateness for inclusion in a pooling group, see Table 21. The final pooling group of 13 stations includes a total of 516 station years. The group is classified as being strongly heterogeneous (H_2 = 5.481), however it was not possible to reduce the heterogeneity.

The pooled data was calculated to fit the Generalised Logistic (GL) distribution best, and this was adopted to estimate the flood growth curves for the catchment, see Figure 11.

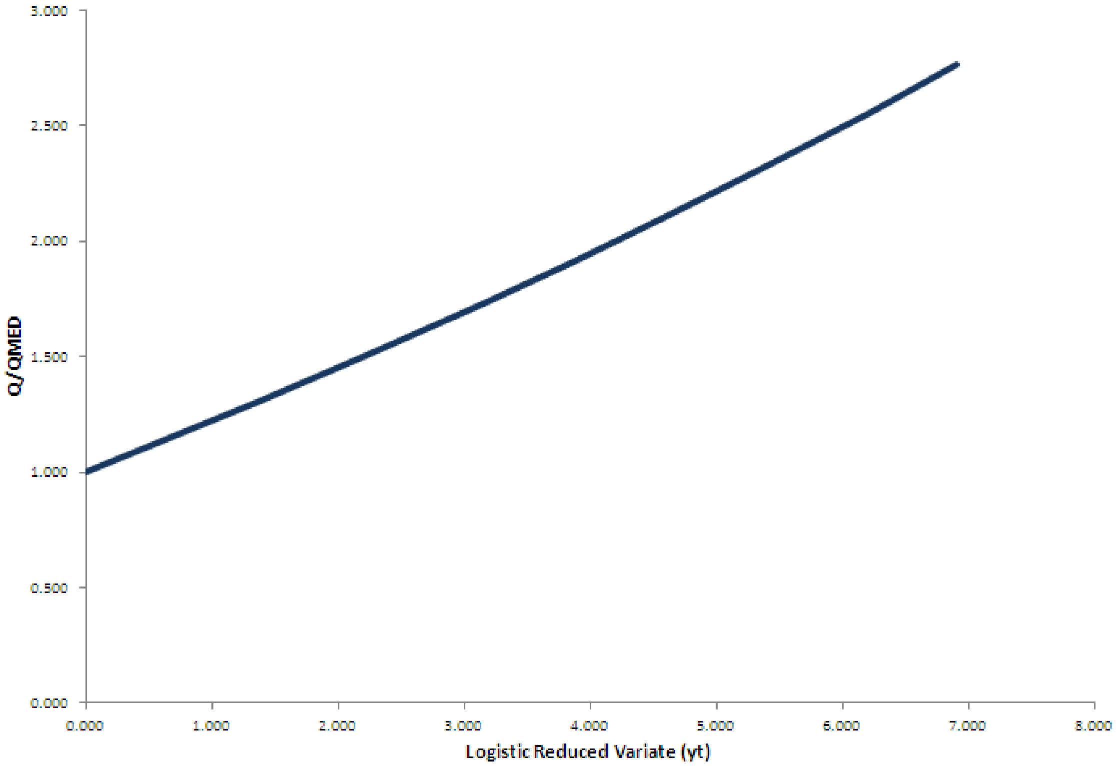

Figure 11 Adopted growth curve for target catchment

Table 21 Pooling group selection and reasons for retaining or removing from final pooling group.

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
Target			***131.51***	***625***	***0.99***	***0.0078***				
54020 (Perry @ Yeaton)	1.151	46	188.05	739	0.954	0.014	Y	Y	Retain	
54016 (Roden @ Rodington)	1.16	48	261.94	693	0.981	0.014	Y	Y	Retain	
33057 (Ouzel @ Leighton Buzzard)	1.335	28	122.39	643	0.991	0.025	Y	Y	Added	
33063 (Little Ouse @ Knettishall)	1.457	29	103.32	595	0.982	0.01	Y	Y	Added	
33011 (Little Ouse @ County Bridge Euston)	1.459	48	130.1	596	0.985	0.008	Y	Y	Added	
68005 (Weaver @ Audlem)	1.48	40	201.44	719	0.95	0.007	Y	Y	Added	
40005 (Beult @ Stile Bridge)	1.483	42	278.05	691	0.992	0.015	Y	Y	Added	
68020 (Gowy @ Bridge Trafford)	1.49	30	148.7	729	0.994	0.017	Y	Y	Added	
34005 (Tud @ Costessey Park)	1.572	48	72.12	649	0.973	0.029	Y	Y	Added	
33019 (Thet @ Melford Bridge)	1.58	49	311.37	620	0.932	0.014	Y	Y	Added	
33021 (Rhee @ Burnt Mill)	1.629	47	306.06	559	0.994	0.021	Y	Y	Added	
203019 (Claudy @ Glenone Bridge)	1.792	38	126.36	1131	0.992	0.004	Y	Y	Added	
15008 (Dean Water @ Cookston)	1.815	53	176.63	840	0.973	0.015	Y	Y	Added	
33029 (Stringside @ Whitebridge)	0.716	37	95.53	628	0.991	0.007	Y	Y	Removed	Bounded

Station	Distance SDM	Years of Rec.	AREA	SAAR	FARL	URBEXT 2000	Suitable for pooling	Suitable for QMED	Decision	Notes
52011 (Cary @ Somerton)	0.813	44	84.62	715	1	0.024	N	Y	Removed	Unsuitable for pooling
33046 (Thet @ Red Bridge)	0.867	42	143.43	624	0.944	0.016	N	Y	Removed	Unsuitable for pooling
33027 (Rhee @ Wimpole)	0.926	44	128.42	558	1	0.013	N	Y	Removed	Unsuitable for pooling
39040 (Thames @ West Mill Cricklade)	0.967	36	187.44	773	0.886	0.008	N	N	Removed	Unsuitable for pooling
34010 (Waveney @ Billingford Bridge)	1.057	41	150.1	603	0.999	0.018	N	N	Removed	Unsuitable for pooling
34007 (Dove @ Oakley Park)	1.087	43	139.39	585	0.996	0.012	N	N	Removed	Unsuitable for pooling
28017 (Devon @ Cotham)	1.115	18	280.48	592	0.98	0.013	N	N	Removed	Unsuitable for pooling
39081 (Ock @ Abingdon)	1.154	30	233.6	639	0.986	0.018	N	Y	Removed	Unsuitable for pooling
29004 (Ancholme @ Bishopbridge)	1.166	41	59.03	615	0.996	0.004	N	Y	Removed	Unsuitable for pooling
68007 (Wincham Brook @ Lostock Gralam)	1.221	47	148.28	818	0.942	0.02	N	Y	Removed	Unsuitable for pooling

Flood Frequency Curve

A flood frequency curve for the catchment was derived using the adopted QMED estimate of 19.74m^3s^{-1} and the pooling group growth curve. The resulting design flood peak flow estimates are shown on Table 22.

Table 22 Statistical Method estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s-^{1})
5	25.78
20	33.10
100	41.52
100 + 20%	49.82
1000	54.57

Flood estimation using the ReFH rainfall runoff method

The Revitalised Flood Hydrograph (ReFH) Model was used to estimate a range of return period flood event hydrographs. The resulting peak flow estimates from the design hydrographs for the catchment are shown in Table 23.

Table 23 ReFH estimated flood flows for a range of design return period events

Return Period	Peak Flow (m^3s-^{1})
5	30.22
20	40.44
100	55.66
100 + 20%	66.80
1000	94.56

Summary of results

The final flood hydrographs were estimated by rescaling the ReFH hydrographs by the statistical peak flow estimates, see Figure 12.

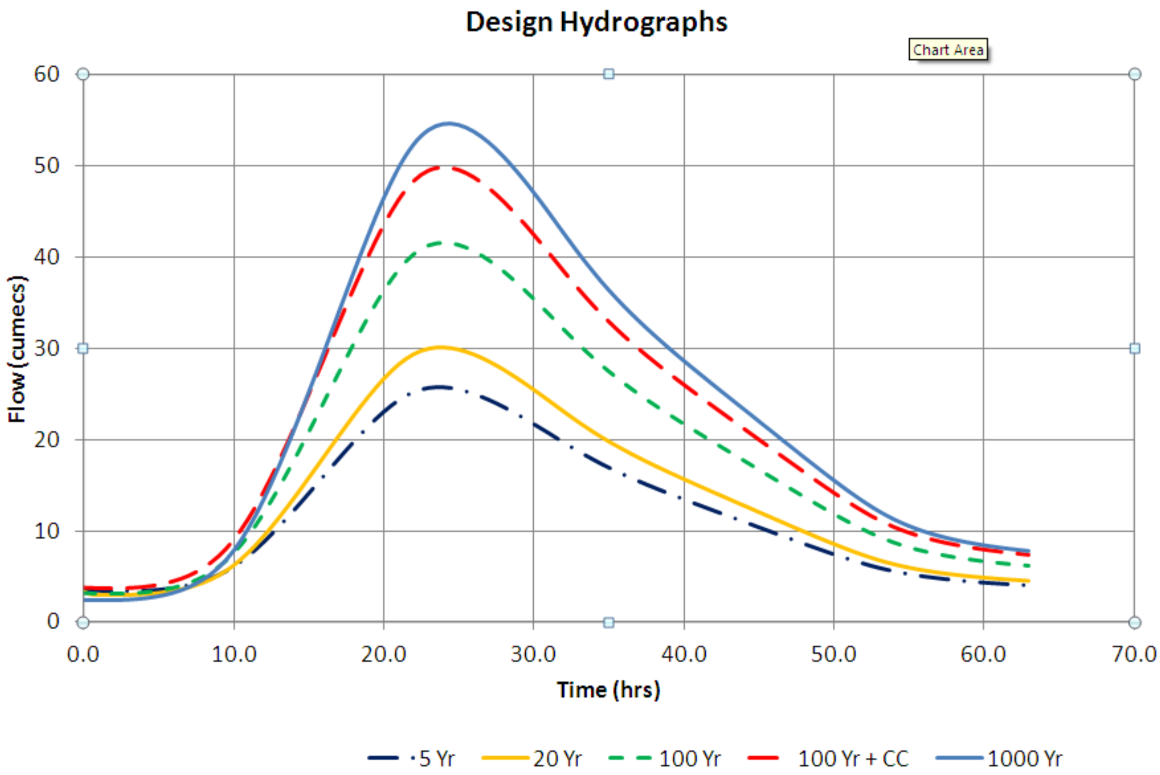

Figure 12 Final design hydrographs adopted