OXFORD FLOOD ALLEVIATION SCHEME

Final Hydrology Report

Prepared for

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Contents

Acronyms and Abbreviations

AMAX	Annual Maxima
CEH	Centre of Ecology and Hydrology
ESS	Enhanced Single Site
FAS	Flood Alleviation Scheme
FEH	Flood Estimation Handbook
GEV	General Extreme Value distribution
GL	Generalised Logistic distribution
HiFlows-UK	Database of AMAX series for use in WINFAP software (http://nrfa.ceh.ac.uk)
L	Logistic distribution
NRFA	National River Flow Archive
PG	Pooling Group
Qmed	Median or 2 year return period peak flow
WINFAP	CEH software to apply FEH pooling group analysis

Introduction

1.1 Background

This Hydrology Report reviews the previous hydrological reports and analysis undertaken to inform the 2009 Oxford Strategy[1] model and the 2014 Oxford Flood Risk Mapping Study[2]. It also records the updates and changes made by CH2M, as part of the modelling for appraisal of the Oxford Flood Alleviation Scheme (FAS).

The design hydrograph and flood flows for both previous studies is based on analysis of hydrometric data at Sandford Lock. Sandford Lock was selected for analysis as the Sandford Lock tail water reflects the combined flows from all of the smaller Thames distributaries and larger tributaries, allowing for one flood frequency analysis. The absence of any direct flow measurements through Oxford has meant that previous studies have relied on a theoretical rating developed for the tail water level at Sandford Lock. This rating has then been used to derive a synthetic Annual Maximum Flow Series, which in turn, has been used to support flood frequency estimation for design events through Oxford.

The Black and Veatch study applied Archer's method to the Sandford Lock record (converting level records to flow using a derived rating), to generate a design hydrograph at Sandford. The same hydrograph shape was then used at each of the main model inflows and scaled to achieve the relevant return period peaks at Sandford Lock. More recently (in 2014) this approach was reviewed and adopted by JBA in their hydrological analysis for the Mott MacDonald study. A summary of previous studies is provided in Appendix A.

To support the modelling for appraisal of Oxford FAS, we have determined that local design hydrographs for each of the key tributaries (the River Thames, the River Evenlode, the River Ray and the River Cherwell upstream of its confluence with the Ray) should be developed. We have also updated the flood frequency analysis at Sandford, as well as extending analysis to other sites, to increase overall confidence in the design estimates of flow.

1.2 Oxford Flood Risk

The city of Oxford has a long history of flooding, being located at the confluence of the Rivers Cherwell and Thames. In recent years, 2000, 2003, 2007, 2012 and 2014 there have been several notable flood events, resulting in inundation of properties, closure of roads and railway infrastructure. The older city of Oxford is located on higher ground, but as Oxford has grown, developments have expanded generally to the east of the city centre and in to the Thames floodplain. As a result the following areas are liable to flooding; Wolvercote, Wytham, New Botley, Osney, Kennington, South Hinksey, North Hinksey, New Hinksey and the city centre areas of Jericho and Grandpont. There are an estimated 4,300 properties and businesses at risk of flooding in Oxford from the 1 in 100 year (1% annual probability) flood event; over 6,000 when the impacts of climate change are considered[3].

The water levels within the River Thames are controlled by a series of locks, used for navigation. Five locks fall within the study area: Kings; Godstow; Osney; Iffley; and Sandford. The Rivers Thames and Cherwell have large upstream catchments of approximately 1700 km^2 and 900 km^2 respectively. Due to the size of the River Thames and Cherwell, there is often a delayed response of 48 to 72 hours between the onset of rain and a noticeable increase in flows through Oxford.

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[1] Black & Veatch, Oxford Flood Risk Management Strategy, Hydrology Report, December 2009 (pub: Environment Agency)

[2] Mott MacDonald, Oxford Flood Risk Mapping Study, January 2014

[3] Oxford Flood Alleviation Scheme, Strategic Outline Case, Environment Agency, November 2014

The cause of flooding is heavy and prolonged rainfall on the upstream catchments. This causes rivers and other smaller watercourses to over-top their banks, and through connectivity into the gravel aquifer, can also lead to groundwater flooding in a number of areas. Most major floods on the River Thames and River Cherwell through Oxford occur as a result of heavy, persistent and widespread rainfall, perhaps combined with snowmelt. These events normally occur during the winter months but there are exceptions to this, for example June 1903 and more recently, July 2007.

There are numerous records of flood events in Oxford over the last 125 years. The worst flood in living memory occurred in 1947 when over 3,000 properties were inundated. The table below, is updated from the Oxford Flood Risk Management Strategy, Technical Report[4], and provides a ranking of major floods in the study area with an estimate of their severity.

Table 1-1 Major floods within the study area

Years	Estimated Return Period	Peak Discharge at Sandford Lock (m^3/s)
1894	1 in 100 years	278
1947	1 in 75 years	267
1903	1 in 20 years	229
1929	1 in 20 years	229
2007	1 in 20 years	225
1900	1 in 20 years	222
1904	1 in 15 years	217
1910	1 in 15 years	214
1933	1 in 15 years	214
1915	1 in 15 years	212
2003	1 in 15 years	212
2014	1 in 15 years	211
1926	1 in 15 years	210
2012	1 in 15 years	208

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[4] Black & Veatch, Oxford Flood Risk Management Strategy, Technical Report, December 2009 (pub. Environment Agency)

1.3 Model extent

A map of the watercourses, gauge locations, model extents and inflow locations is shown in Figure 1-1.

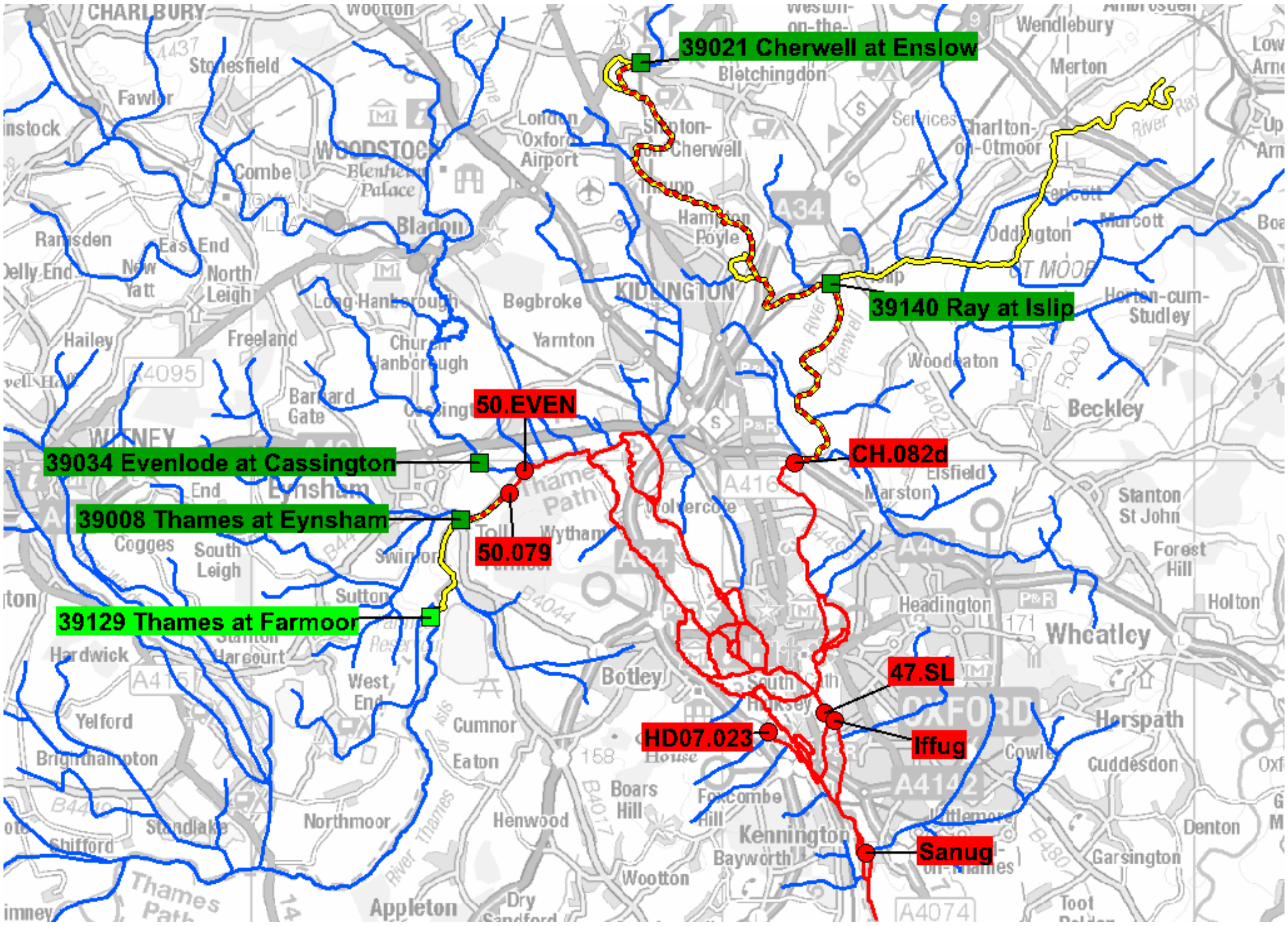

Figure 1-1 Watercourses, gauge locations, model extents and inflows required.

In the above figure:

- Gauge locations used in this study are shown by green squares. Design hydrographs for use in the hydraulic model have been produced at dark green squares.
- The extent of the hydraulic model to be used for this study is shown by red lines. Inflows to this model (with node labels) are represented by red dots.
- A flood forecasting model is available. The extents of this model are shown by yellow lines.
- The catchment areas draining to the major inflow locations are as follows:
    - 50.079 (Thames downstream of Eynsham): 1,660.04 km^2
    - 50. EVEN (Evenlode Inflow): 457.52 km^2
    - CH.082d (combined Cherwell and Ray inflow): 897.26 km^2

1.4 Flow data

A range of hydrometric data was kindly supplied by the Environment Agency. The majority of analysis detailed in this report is based on flow data from a range of gauging stations. A summary of flow series used and their derivation is provided in Table 1-2.

Table 1-2 Flow series and ratings

Data Overview

Station Number	Station Name	Origin of flow estimates	EA Rating Information
39008	Thames at Eynsham	Station consists of a complex array of gates and weirs. A flow series provided by the Environment Agency (taking into account gate movements) has been used for all analysis.	Confidence in this rating is slightly lower due to a variable backwater effect from the Evenlode (very pronounced in July 2007 at time of Evenlode peak). After July 2007, the upper segment was reduced slightly, as calculated flows were too high. The rating should be applicable for entire record. Archived lock gauge board data could be used to produce an approximate peaks over threshold series. Gate movements control levels at low flows – only valid in flood conditions. By way of confirmation, the parameters based on Eynsham Lock telemetry data (datum 57.134mAOD) are: Q = 6.3775*(h+0)^2.0819 for h<3.05 Q = 1.3181*(h+0)^3.4957 for h<3.45 Q = 0.1203*(h+0)^5.4289 for h>3.45 Source: EdenVale Modelling Services (2007) Hydraulic models for Flood Forecasting: Oxford Thames
39021	Cherwell at Enslow Mill	Cherwell at Enslow Mill is a combination of two weirs. A rating and level series have been provided by the Environment Agency and used to calculate the flows which have been used in this analysis. *The weirs, located on the old mill channel are bypassed by water spilling into the flood plain in high flows a few hundred metres upstream. As a result the total flow can increase greatly with only a small rise in level at the gauge weirs, and changes in the state of the channel and banks could greatly affect the relationship between total flow and headwater level. The tailwater rating should give a much better estimate of total flow, but levels have only been recorded since 2012. In the two biggest recorded events, 1998 and 2007, the water level in the floodplain reached the level of the water in mill channel at the gauging station.*	Information from Enslow indicated that bypassing is more likely at lower flows than it used to be in the 1980s; most likely due to declining channel condition during this time. As a result, a tailwater recorder was installed on the weir in November 2012. Tail levels rise when water begins to bypass the weir and flow down the floodplain. The rating used across the whole of the level data record in this analysis assumes a datum of 64.989mAOD: Q = 17.857*(h+0)^1.7668 for h<0.71 Q = 29.465*(h+0)^3.2291 for h<0.88 Q = 37.096*(h+0)^5.0307 for h<1.01 Q = 38.437*(h+0)^1.4625 for h>1.01 Original headwater rating: EdenVale Modelling Services (2007) Hydraulic models for Flood Forecasting: Oxford Thames
39034	Evenlode at Cassington	Evenlode at Cassington is a complex combination of weirs. A rating and level series have been provided by the Environment Agency and used to calculate the flows which have been used in this analysis. *As with Enslow, flood water spills a long way upstream and*	At Cassington, the A40 has been built within the period of record, but it is very unlikely to have affected the amount of water bypassing the gauging station. It may be possible that channel maintenance and weed-cutting regimes have changed, although Ops say no changes have been made in the last 20 or 30 years. Revised after 2007 floods. By way of confirmation, the parameters based on Cassington telemetry data (datum 60.166mAOD) are:

Table 1-2 Flow series and ratings

Data Overview

Station Number	Station Name	Origin of flow estimates	EA Rating Information
		the relationship between total flow and the head water level at the weir may be sensitive to changes in the channel and banks. It is unlikely therefore that an accurate and consistent high flow rating can be established.	Q = 20.586*(h+0)^1.879 for h<0.67 Q = 21.665*(h+0)^2.0066 for h<0.874 Q = 27.526*(h+0)^3.7843 for h<0.98 Q = 27.604*(h+0)^3.9252 for h>0.98 Original Source: EdenVale Modelling Services (2007) Hydraulic models for Flood Forecasting: Oxford Thames Revisions described in: EdenVale Young Associates (2008) July 2007 Flood Review
39129	Thames at Farmoor	Thames at Farmoor is an ultrasonic gauging station. A rating is provided, and has been used for flows above 50m^3/s when the ultrasonic gauge becomes unreliable.	The high flow rating represents total flow including bypassing, which is a different entity from the in-bank directly measured series. Therefore if high flows are calculated, they should be kept separate, and the raw in-bank directly measured series should be kept intact. The rating should be applicable over the entire period. Provided directly measured flows are above 50 m^3/s, the rating switchover is applied starting at 1.02mALD. There is a slight chance that rating relationship could be influenced by trailing gates at Pinkhill Lock, but has been verified on the July 2007 event. By way of confirmation, the parameters based on Farmoor LVL telemetry data (datum 60.00mAOD) are: Q = 55.234*(h+0)^0.7803 for h<1.33 Q = 48.364*(h+0)^1.246 for h<1.55 Q = 37.886*(h+0)^1.8032 for h<1.76 Q = 23.541*(h+0)^2.6449 for h<1.93 Q = 3.1432*(h+0)^5.7072 for h>1.93 Original Source: EdenVale Modelling Services (2007) Hydraulic models for Flood Forecasting: Oxford Thames Revisions described in: EdenVale Young Associates (2008) July 2007 Flood Review Source: EdenVale Young Associates (2008) July 2007 Flood Review
39140	Ray at Islip	Ray at Islip is an ultrasonic gauging station. No rating is available, as it is known that high flows cannot be reliably measured, due to the proximity of the gauge to the Cherwell confluence. The direct flow output from the ultrasonic gauge has therefore been used.	No rating as ultrasonic gauge and the levels are controlled mostly by the Cherwell levels in times of flood. The high levels in the Cherwell may reduce the outflow from the Ray, causing water to be stored on Otmoor. Flow measurement should be accurate, but in high floods, the bank separating the Ray from the Cherwell floodplain may be overtopped.
-	Thames @ Pinkhill	Historic level data available back to 1894 from lock keeper tackle sheets. More recent 15 min telemetered tail levels available.	A tail water level rating was derived by EdenVale Modelling Services (2007) Hydraulic models for Flood Forecasting: Oxford Thames. Q = 9.7087*(h+0)^1.8337 for h<2.7 Q = 2.8176*(h+0)^3.0792 for h<3.08 Q = 0.6859*(h+0)^4.3353 for h>3.08 Datum = 58.02mAOD

Table 1-2 Flow series and ratings

Data Overview

Station Number	Station Name	Origin of flow estimates	EA Rating Information
-	Thames @ Sandford	Historic level data available back to 1894 from lock keeper tackle sheets. More recent 15 min telemetered tail levels available. Some issues regarding changes in level of gauge board and impact on historic level data.	Sandford Tail Water Level rating developed by Black & Veatch, in Oxford Flood Risk Management Strategy, Hydrology Report, 2009. This rating has been applied to the whole data record. Q = 2.661 h ^ 2.659 for h<4.55 Q = 0.815 h ^ 3.441 for h>4.55 Datum = 48.80mAOD

In January 2016, the Environment Agency also began a programme of spot flow gauging at several key sites within the study area. At the time of writing, spot flows had been obtained on three occasions, and have been used to verify the split of flows in the hydraulic model. This is reported in a separate technical note, Oxford Flow Gauging, CH2M, February 2016.

1.5 Level data

In addition to the flow data, there is a wealth of level data on the River Thames. This often dates back to the late 1800s, as a result of records of head and tail water levels made by lock keepers in tackle sheets. Analysis of the highest recorded tail levels from Pinkhill to Abingdon has been undertaken, to establish any trends and to identify any anomalies. Analysis was based on a spreadsheet of historic lock level data supplied by the Environment Agency (AASpikey2.xls) with lock levels extended using the lock keepers tackle sheets. The information is presented in Figure 1-2 as water years, e.g., the February 1947 flood event is listed as 1946.

Lock →	Pinkhill	Eynsham	Kings	Godstow	Osney	Iffley	Sandford	Abingdon
Water Yr	1995	1902	1902	1970	1946	1946	1894	1894
	1902	1894	1894	1894	2006	1894	1946	1946
	1894	2006	1898	2006	1894	2013	1902	1929
	1946	1946	2006	1925	1902	1929	1929	2013
	2006	2002	1916	1902	2002	1899	2006	1899
	1924	2000	1903	1914	2013	2012	1899	1925
	1923	1929	1896	1927	2000	2002	1903	2012
	1960	2013	1960	1946	1929	1932	1910	2002
	1925	1960	1899	1899	1912	1903	1932	1932
	1929	1924	1907	1903	1992	1917	1914	1914
	1903	1927	1897	1907	1960	2006	1925	1910
	1914	1914	1915	1924	1958	1910	2013	2006
	1919	1932	1909	2002	2012	1914	2012	1903
	1899	1925	1910	1929	1954	1902	1917	1902
	1932	1910	1900	1979	1925	1925	1939	1917

Figure 1-2 Analysis of 15 highest recorded lock tail levels (water years)

There appears to be a correlation between the majority of historic events for Pinkhill Lock (upstream) to Abingdon Lock (downstream). The exact ranked order of the events, however, varies between the locks. This result is not unexpected, as the variations are likely to result from the differing contributions and responses from the Upper Thames, Evenlode, Cherwell and Ock. Overall there is no strong trend to be drawn from this analysis, which influences this study. The variation in severity of flood events over the 120 year period is also due to the influence of the engineering works which have been undertaken at a number of locations during this period (especially the 1930 & 40s, when the Thames was deepened adjacent to Port Meadow and the flash lock at Medley was removed[5]) to improve flood flow conveyance.

[5] Changing Flood Peak Levels on the River Thames, S. M Crooks, Proceedings of the Institute of Civil Engineers, 1994

Flood Frequency Analysis

2.1 Overview

Flood Frequency Analysis using FEH Pooling Group and Single Site analysis was undertaken at the following gauged locations. Of the seven locations, five are flow gauging stations, whereas at Sandford and Pinkhill there is a derived flow record from the level only data, where the majority of the level record has been derived from lock-keeper tackle sheets.

- 39008 Thames @ Eynsham
- 39129 Thames @ Farmoor
- 39021 Cherwell @ Enslow Mill
- 39034 Evenlode @ Cassington
- 39140 Ray @ Islip
- Thames @ Sandford
- Thames @ Pinkhill

Table 2-1 Overview of gauged locations catchment descriptors

	39008 Thames @ Eynsham	**39129 Thames @ Farmoor**	**39021 Cherwell @ Enslow Mill**	**39034 Evenlode @ Cassington**	**39140 Ray @ Islip**	**Thames @ Sandford**
Area	1626.71	1607.5	555.43	427.14	290.00	3085.68
BFIHOST	0.686	0.688	0.590	0.699	0.490	0.646
DPLBAR	58.09	56.36	39.32	35.13	17.67	63.84
DPSBAR	39.0	39.1	46.7	46.5	17.9	38.7
FARL	0.946	0.948	0.976	0.965	0.984	0.958
FPEXT	0.1923	0.1912	0.0942	0.0682	0.2832	0.1713
PROPWET	0.32	0.32	0.30	0.32	0.32	0.31
SAAR	730	731	664	691	630	697
SPRHOST	24.09	23.98	31.41	24.10	36.93	27.13
URBEXT2000	0.0268	0.0267	0.0244	0.0141	0.0212	0.0289
Suitability for QMED	Yes	-	Yes	Yes	-	-
Suitability for Pooling	No	-	Yes	Yes	-	-

From above it can be seen that all catchments can be considered to be medium to large (by UK standards). All catchments have a notable groundwater influence (as shown by the BFIHOST values), but none fall into the category of permeable (as defined by FEH), as each has an SPRHOST value greater than 20. All catchments are classified as essentially rural (URBEXT2000 < 0.30).

All analysis was undertaken using WINFAP v3 software and is discussed for each of the 7 locations in turn below. AMAX data was obtained from a number of sources including the NRFA (National River Flow Archive hosted by CEH) HiFlows-UK database, 15 minute flow and level data supplied by the Environment Agency (from WISKI) and the AMAX series published in Appendix B of the Black & Veatch report (B&V, 2009). As can be seen from the following AMAX data comparisons, there is not always consistency between all data sets. This often results from different ratings being used, and in some cases (such as B&V 2009) the use of hydraulic models to estimate peak flows.

Prior to the flood frequency analysis all data series were reviewed to identify the longest AMAX series for each gauged location, ensuring that the source of all data was known and the rating used identifiable. For each of the seven gauged locations a preferred AMAX series is identified and sources stated in the relevant sections that follow. The ratings used have been identified in Table 1-2 and the preferred AMAX series used in this analysis can be found in Appendix B.

All Enhanced Single Site (ESS) and Pooling Group (PG) analysis was carried out using the WINFAP-FEH v3.3.4 dataset. For the Enhanced Single Site and Pooling Group analysis, pooling groups were reviewed, with stations removed if they were hydrologically dissimilar, located up or downstream of other gauges within the pooling group, or if they were outliers to the main pooling group. The pooling group analysis was carried out using the assumption that the subject site was ungauged, consequently none of the subject sites appear in the pooling group analysis. In each analysis it was ensured that the final pooling group had at least 500 station years of data in accordance with FEH and Environment Agency guidance. Details of the pooling group reviews undertaken can be found in Appendix C.

For all analysis the Generalised Logistic (GL) distribution, recommended for application in UK, Generalised Extreme Value (GEV) and Logistic (L) distributions were used in fitting Enhance Single Site, Pooling Group and Single Site analysis. Though only the GL is reported below for the Enhanced Single Site and Pooling Group analysis, and GL and Logistic distribution fits are presented for the Single Site analysis.

Flood frequency estimates were derived assuming all catchments were not permeable and essentially rural.

In each of the following sections, detail is provided on:

- AMAX data and its source data
- AMAX data plot
- Flood Frequency Estimates
    - Graphical comparison with observed AMAX data
    - Tabulated estimates

For each of gauged locations a recommendation is made regarding the preferred flood frequency estimate.

The flows derived in this section will inform inflow to the Oxford FAS hydraulic model. All hydrological analysis is being undertaken at gauged locations, but the area covered by the hydraulic model does not extend to cover all gauging stations where inflows are being derived. In order to route flows into the Oxford FAS model, a version of the Oxford Flood Forecasting model has been used to route flows and generate appropriate inflow hydrographs for the FAS model. The benefit of using the flood forecasting model is that it captures the flow routing process of the upper channels, and is much quicker to run than the full 1D-2D FAS model.

2.2 39008 Thames @ Eynsham

There are four sources of AMAX data for the Eynsham gauge

- AMAX flood data from the NRFA website, 1991 to date
- B&V 2009 AMAX series, 1987 - 2005
- Environment Agency tail water level data, converted to AMAX series flow via rating, from 1999 to date
- Environment Agency peaks-over-threshold (PoT) level data extracted for lockkeepers tackle sheets, converted to AMAX flow series via rating (1894 – 2006)

The rating used in deriving all inflows from observed levels is as reported in Table 1-2. Using this rating a comparison of all overlapping AMAX records was made and shown in Table 2-2. A summary of the AMAX series is shown in Figure 2-1. Note this is provided for 1987 and onwards. The PoT data has a much longer record, from 1894. The extended record has been used as the 'preferred' estimate, and is detailed in Appendix B.

Table 2-2 Comparison of AMAX series Thames @ Eynsham from 1987

Peak flow (m^3/s)

Water Year	NRFA	B&V 2009	AMAX from PoT level	WISKI TWL with rating
1987		70.7	68.49	
1988		55.0	54.00	
1989		76.5	76.54	
1990		48.8		
1991	33.07	39.0		
1992	81.635	82.0	85.25	
1993	78.484	78.5	79.08	
1994	79.532	80.0	80.81	
1995	74.867	75.0	74.88	
1996	40.358	40.4		
1997	72.413	73.0	68.41	
1998	83.066	84.0	85.43	
1999	77.624	75.5	70.37	
2000	91.572	109.1	104.17	107.96
2001	62.028	65.0	62.50	64.12
2002	91.796	108.9	104.17	110.67
2003	55.000	54.8		34.98
2004	50.900	50.9		52.87
2005	49.000	49.0		46.40
2006	102.504		136.61	142.81
2007	87.587			109.14

Table 2-2 Comparison of AMAX series Thames @ Eynsham from 1987

Peak flow (m^3/s)

Water Year	NRFA	B&V 2009	AMAX from PoT level	WISKI TWL with rating
2008	75.795			76.29
2009	60.135			66.73
2010	51.896			47.26
2011	66.552			59.15
2012				97.99
2013				105.97
2014				55.95
Qmed	74.867	73.0	75.71	66.73

Although there are differences between the AMAX series there is a good correlation between datasets. The NRFA data is considered least reliable, as the associated published water levels do not correlate to the most recent rating.

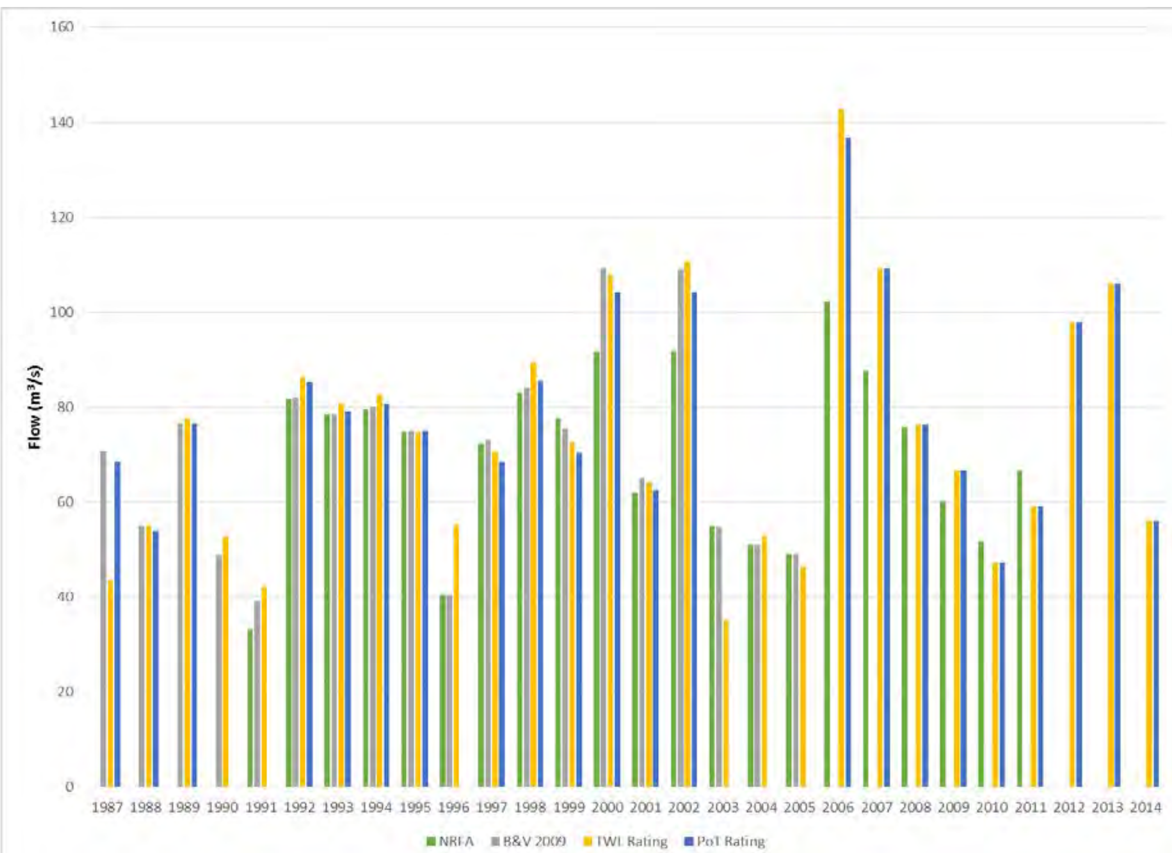

Figure 2-1 Thames @ Eynsham AMAX series

Greatest confidence in flows are those obtained from the Eynsham TWL gauged record. This was taken as the basis of the AMAX record. This was then extrapolated back using the PoT lock level data, and the Eynsham rating, with gaps infilled, for years when levels were not high enough to be in the PoT data record.

The infilled flows from the B&V record were used, as the B&V published values and the PoT derived flows are very similar in the early period of overlap as shown above.

There will be uncertainties associated with the flows derived for the period prior to 1999 due to the coarseness of the base tackle sheet data, and the assumption that the same rating is applicable throughout the 100+ year period of record.

The preferred AMAX series used in the analysis at Eynsham for this study is in Appendix B.

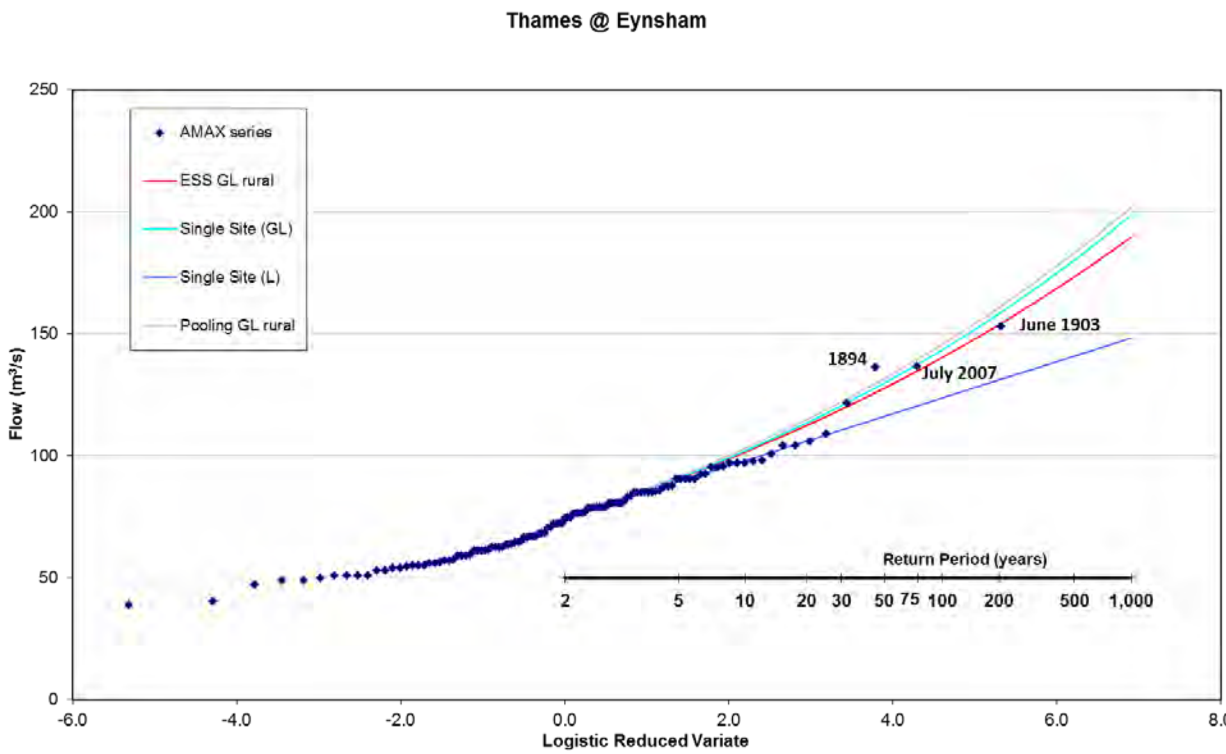

Figure 2-2 Thames @ Eynsham Flood Frequency Estimates

There is a good correlation of return period flow estimates and the observed data up to the 20 year return period event, though there is divergence in estimates most notably in the single site logistic estimate. In comparing the flood frequency analysis in all the figures in the section against the observed data, care should be taken as plotting positions of the AMAX data is a statistical relationship only, based on length of the flow record and not an absolute estimate, especially for the extreme events.

There have been some historical concerns regarding the accuracy of the flow record at Eynsham, likely due to the close proximity of the gauge to the confluence of the River Evenlode. The Evenlode inflows can result in some backwater effects on the River Thames, and affect flow estimates. It is interesting that although virtually all the floods were in the winter months, the two highest ones were in the summer. Neither of these were very significant downstream of Oxford.

There is additional uncertainty in the estimate of rarer events due to:

- Accuracy of peak flood levels recorded back to 1894
- The assumption that the current Eynsham rating is valid across the whole data record and any channel modifications during this period have had no impact of the level flow relationship.

There is also inherent uncertainty in the pooling group approach in taking an average of the growth factors of similar catchments, as illustrated in Figure 2-3 comparing the pooled growth curve with the non-dimensionalised AMAX data for each of the pooling group component stations. Any hydrological analysis is uncertain, and impacts of uncertainty to the Oxford FAS will be tested by a series of hydraulic model sensitivity runs.

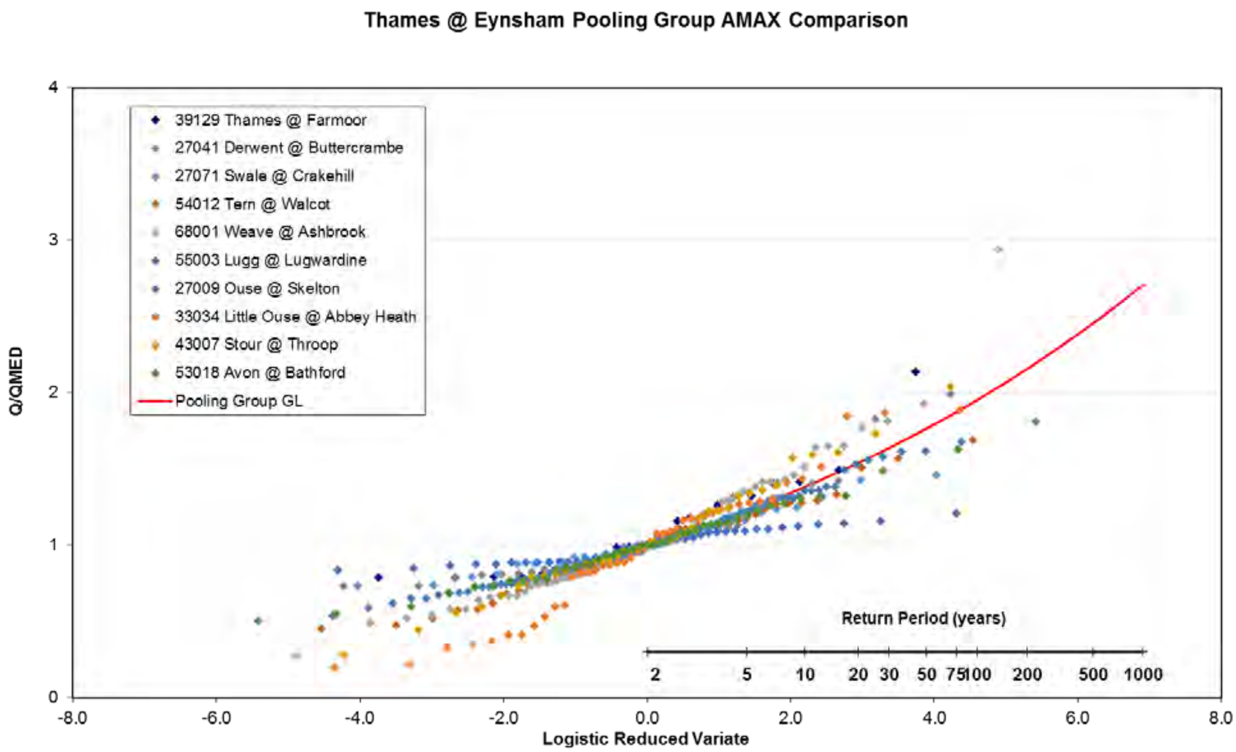

Figure 2-3 Thames @ Eynsham Comparison of AMAX components of pooling group

Based on Eynsham flood frequency analysis only, the preferred flood frequency estimates selected for this study are the Pooling Group, as there is uncertainty regarding the flow estimates of the larger events, and the impact of the River Evenlode on flow recording. Using this estimate, the July 2007 event has approximately a 100 year return period event, which is consistent with other recorded estimates for this event in this area.

It would be expected that flood frequency analysis at Eynsham, Farmoor and Pinkhill would demonstrate similar responses, and the comparison of flood flow estimates is discussed later in this section.

Table 2-3 Eynsham Flood Frequency Estimates

Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	74.55	74.55	74.55	74.55
5	90.70	90.88	89.31	91.53
10	101.46	101.98	97.96	103.04
20	112.35	113.39	105.94	114.83
30	118.96	120.47	110.48	122.05
50	127.64	129.72	116.07	131.59
75	134.85	137.54	120.47	139.59
100	140.16	143.29	123.60	145.51

Table 2-3 Eynsham Flood Frequency Estimates

Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
200	153.68	158.20	131.06	160.70
500	173.30	180.11	140.82	183.02
1000	189.62	198.60	148.21	201.81

2.3 39129 Thames @ Farmoor

The Farmoor gauge is an ultrasonic gauge, and there is not necessarily a standard relationship between level records and flows estimated, especially at low flows before all weir gates are opened. This equally applies to ratings based on lock levels. There are three sources of AMAX data at Farmoor:

- Environment Agency 15 minute flow series as recorded in WISKI
- Environment Agency 15 minute level series as recorded in WISKI with rating applied
- B&V 2009 AMAX series

As an ultrasonic gauge, the Farmoor gauge is not a NRFA HiFlows-UK gauge and as a result there is no HiFlows-UK data available. During the earlier B&V study there was concern noted that the Farmoor ultrasonic gauge was under-estimating flows for larger events, especially when flows were out of bank. This was confirmed by hydraulic modelling and consequently EdenVale Young developed a rating for Farmoor to better estimate peak flows. The preferred AMAX data listed below has been derived using the WISKI AMAX level data and the application of the rating as detailed in Table 1-2, which was considered to be the best estimate of peak flows at Farmoor gauge.

Table 2-4 AMAX series Thames @ Farmoor

Peak flow (m^3/s)

Water Year	15 min data	B&V 2009	Rating from WISKI Level Data	Water Year	15 min data	B&V 2009	Rating from WISKI Level Data
1991	37.72		76.91	**2003**	54.77	54.8	61.849
1992	78.09	78.1	92.45	**2004**	48.6	48.6	66.89
1993	90.78	90.8	90.62	**2005**	50.3	50.3	66.27
1994	76.19	76.2	93.46	**2006**	69.03	133.3	167.05
1995	67.9	67.9	78.16	**2007**	69.73		102.75
1996	48.18	48.2	61.72	**2008**	65.92		80.02
1997	72.18	72.2	78.10	**2009**	59.26		64.34
1998	73.08	73.1	98.53	**2010**	48.39		62.52
1999	70.95	71.0	77.30	**2011**	54.26		63.72
2000	71.89	110.7	110.77	**2012**	69.43		103.39
2001	66.28	66.3	68.68	**2013**	70.59		116.58

Table 2-4 AMAX series Thames @ Farmoor

Peak flow (m^3/s)

Water Year	15 min data	B&V 2009	Rating from WISKI Level Data	Water Year	15 min data	B&V 2009	Rating from WISKI Level Data
2002	73.3	109.9	109.80	**2014**	52.96		61.64
Qmed					69.03	72.2	71.60

Note: Red text: estimated by hydraulic modelling

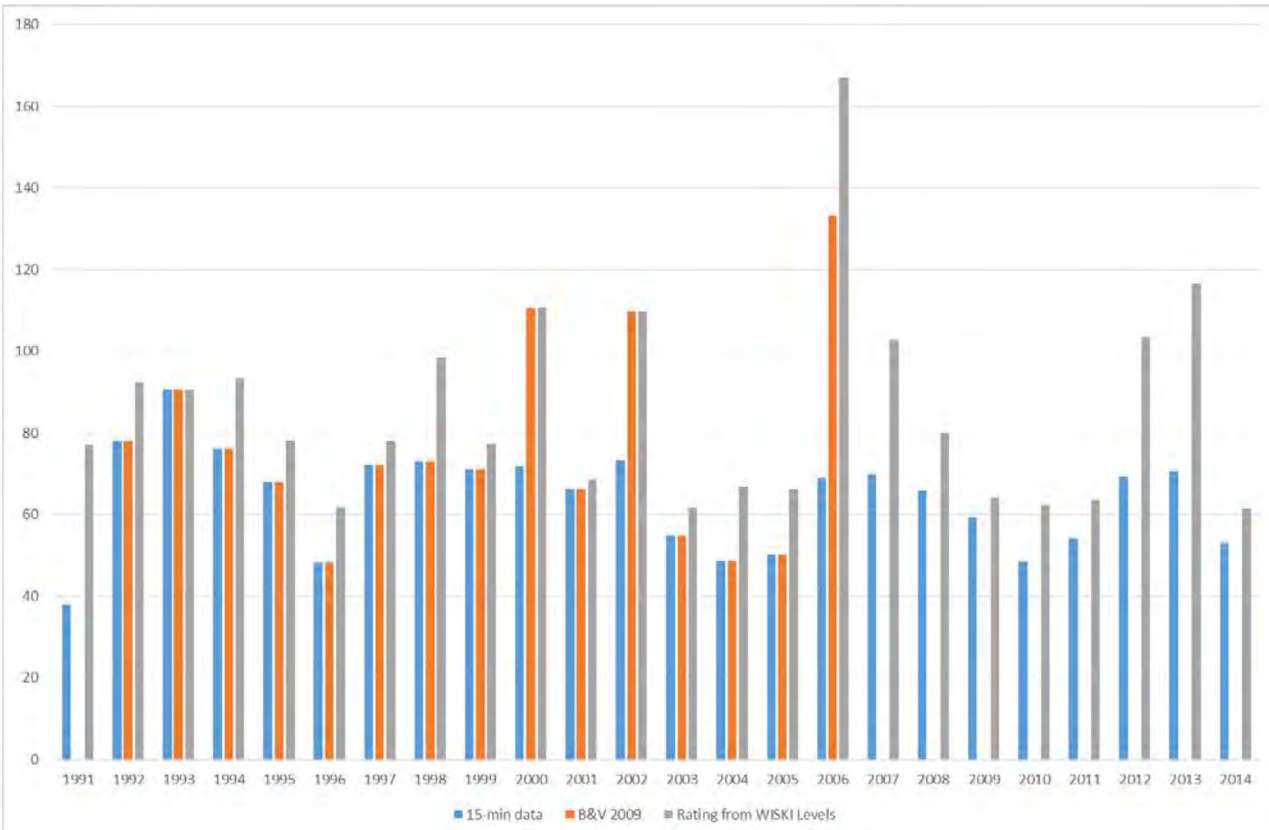

Figure 2-4 Thames @ Farmoor AMAX series

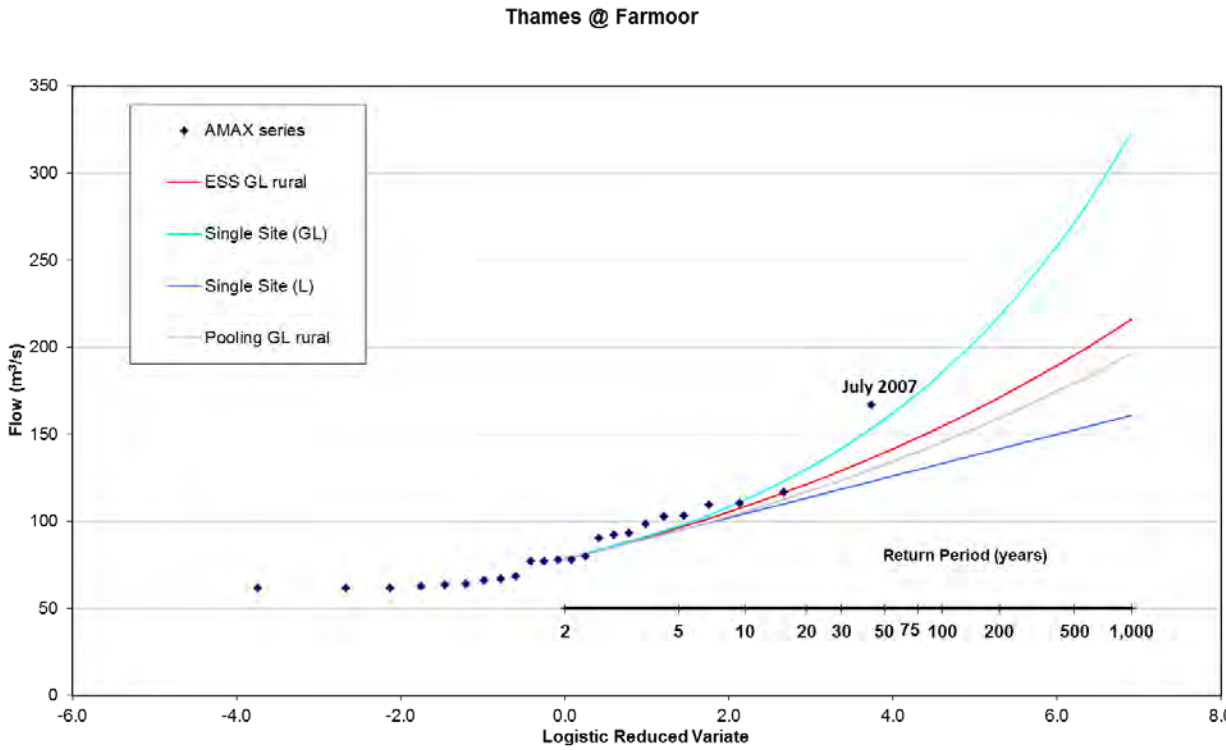

Figure 2-5 Thames @ Farmoor Flood Frequency Estimates

The Farmoor AMAX record, at 23 years, is one of the shortest analysed in this study. FEH guidance recommends the use of single site analysis to be used for estimating return period up to half the duration of the AMAX record, in this case the 10 year return period. From the above figure there is good correlation in growth curves up to the 10 year return period event, and beyond this there is a divergence in flood frequency curves.

Farmoor gauging station is located a short distance upstream of Eynsham gauging station, and it would be expected that both gauging stations show similar flood frequency. There are some concerns with the Farmoor flow record especially at high flows, and as a result the rated levels flow estimates have been used instead of the ultrasonic recorded flows. The gauging station is predominantly used to monitor abstraction to Farmoor pumped-storage reservoir, and hence its focus on in-channel flows.

The pooling group component station scatter plot in Figure 2-6 shows that there is a consistency in data between each of the pooled stations, and the Farmoor growth curve does fit closely the Eynsham AMAX record. A further discussion on comparison for Farmoor, Pinkhill and Eynsham flow estimates can be found in the following section on Pinkhill flood frequency estimates.

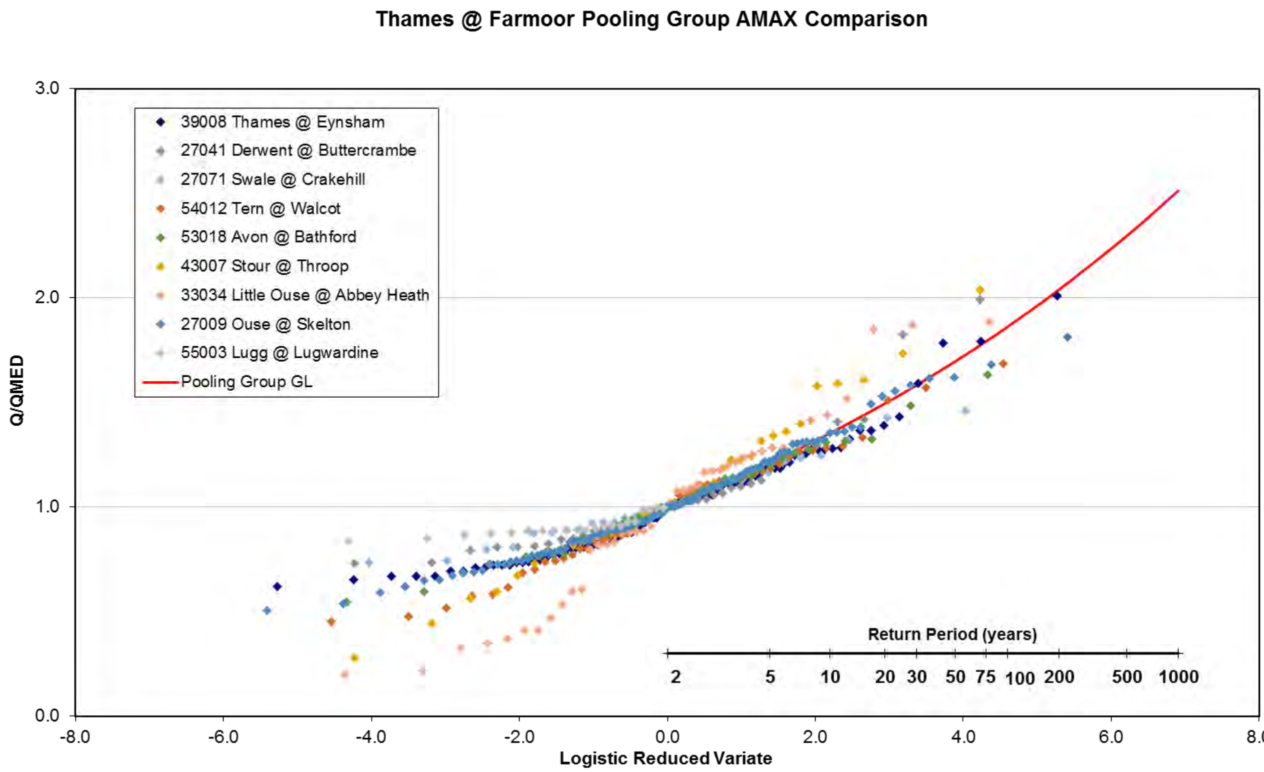

Figure 2-6 Thames @ Farmoor Comparison of AMAX components of pooling group

Based on evidence presented above the preferred peak flow estimates for Farmoor would be those obtained using the Pooling Group with the Generalised Logistic distribution.

Table 2-5 AMAX series Thames @ Farmoor

Peak Flow (m^3/s)

Return Period (years)	ESS GL rural	Single Site (GL)	Single Site (L)	Pooling GL
2	78.13	78.13	78.13	78.13
5	96.25	97.19	94.77	94.66
10	108.61	112.43	104.46	105.69
20	121.29	130.01	113.37	116.85
30	129.09	141.73	118.45	123.63
50	139.41	144.56	112.99	132.54
75	125.49	158.56	117.60	139.95
100	130.26	169.50	120.86	145.40
200	171.03	217.59	141.57	159.30
500	195.40	271.66	152.51	179.48
1000	215.99	322.99	160.87	196.28

2.4 Thames @ Pinkhill

Black and Veatch (B&V) developed an AMAX series for the Thames at Pinkhill as part of the Oxford Flood Risk Management Strategy, based on a rating developed for tail water levels. Records of tail water levels (TWL) are available back to 1891. Using the rating (as detailed in Table 1-2), it has been possible to confirm the B&V AMAX series and extend to the 2014 water year. The full AMAX flow record is presented in Appendix B and summarised in Figure 2-7.

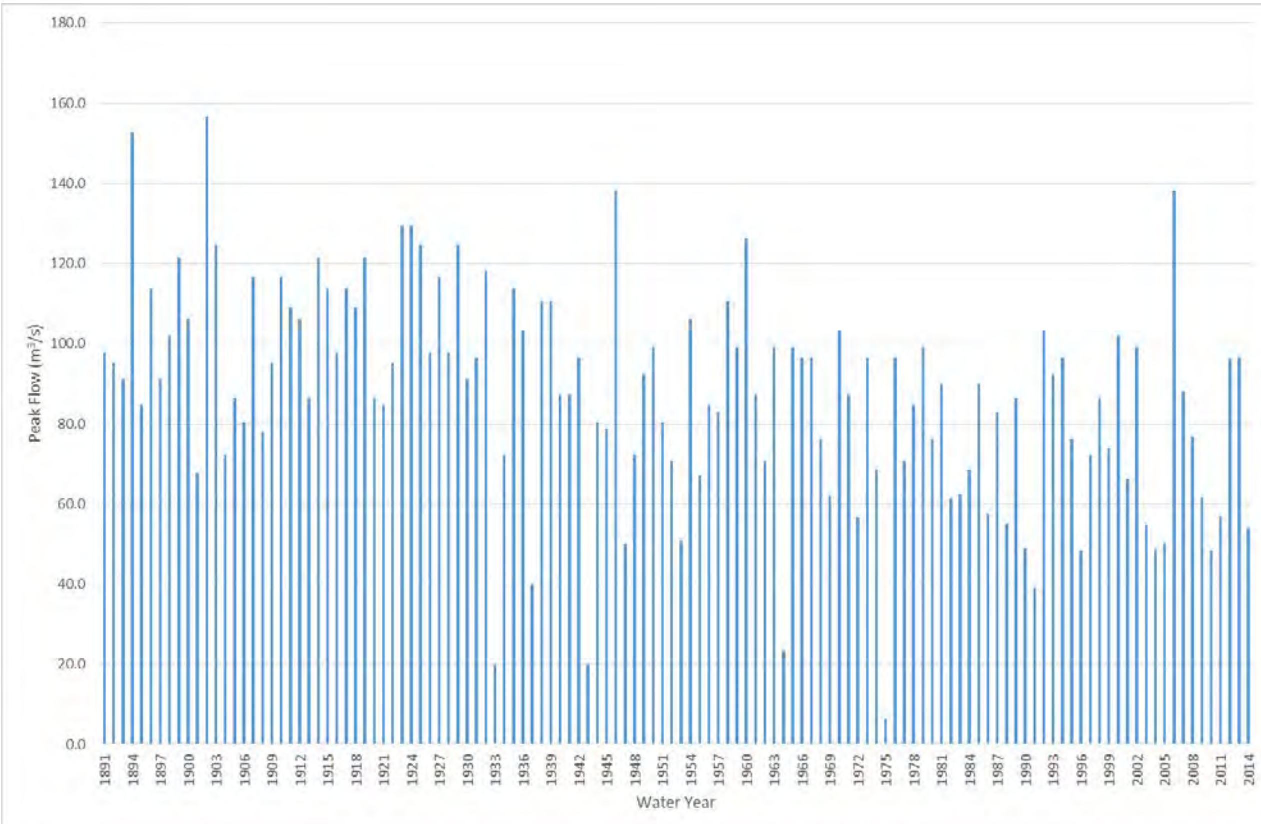

Figure 2-7 Thames @ Pinkhill Lock AMAX series

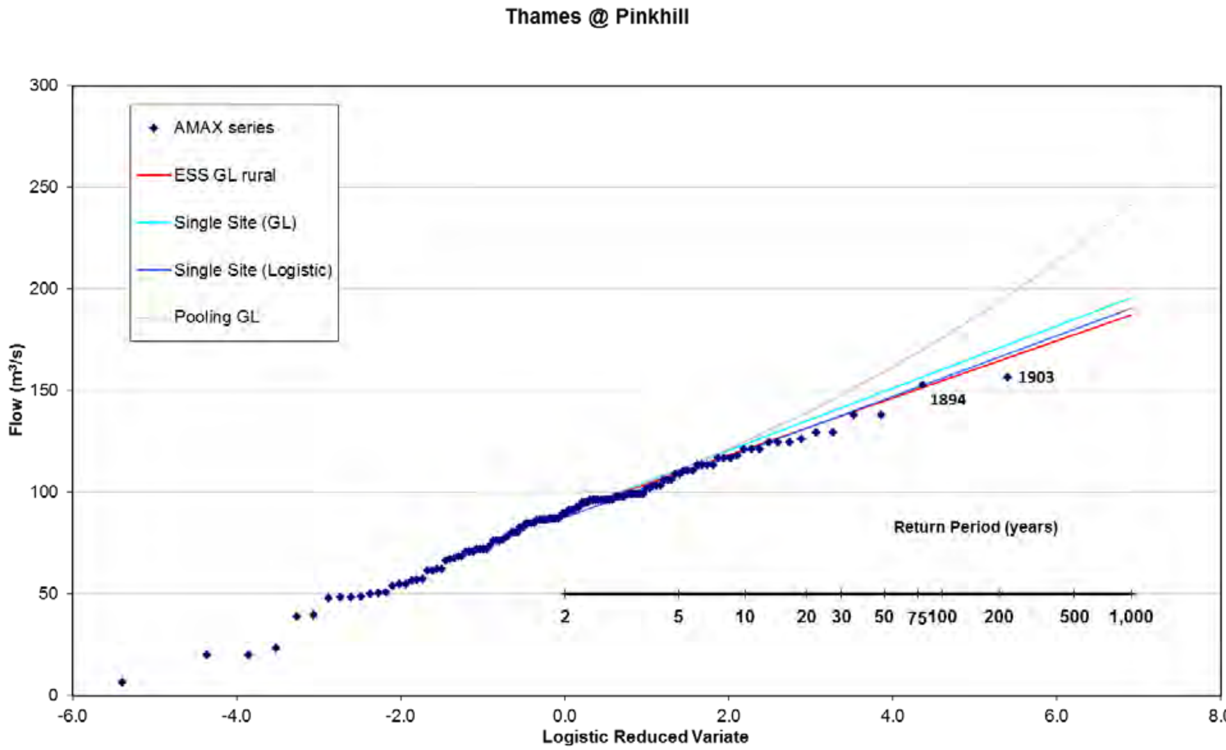

Figure 2-8 Thames @ Pinkhill Flood Frequency Estimates

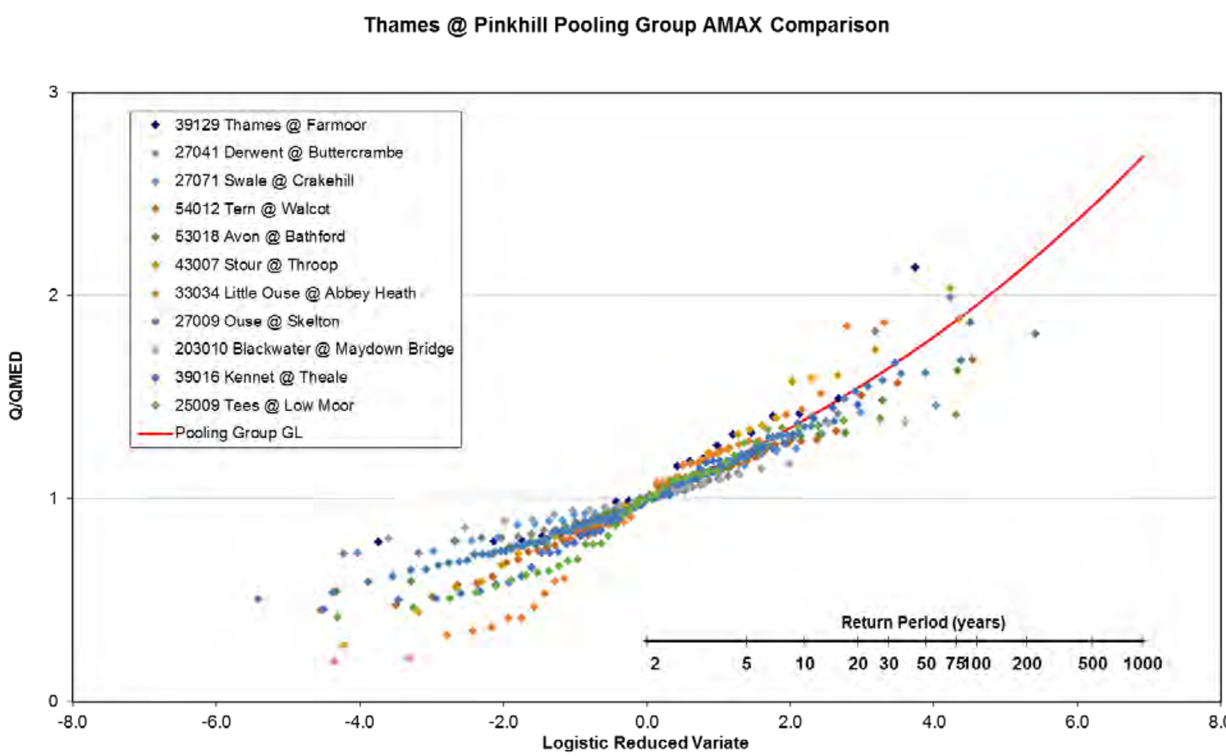

Figure 2-9 Thames @ Pinkhill Comparison of AMAX components of pooling group

Flood frequency analysis was performed at the Pinkhill gauge. From discussions with the EA and reviewers there is some concern over the accuracy of the Pinkhill gauge. In Figure 2-8 it is seen that the pooling group estimates appear to be over-estimating flood frequency when compared with the observed data. With the AMAX data having a much flatter growth rate than other data in the area. From the pooling group component station scatter plot, the growth curve is representative of the pooling group records, but not representative of the AMAX data. Based on the AMAX data alone, and flood frequency analysis the preferred flood frequency estimate and most representative of the data would be the Enhanced Single Site (GL) estimate.

Table 2-6 Comparison of Pinkhill Flood Frequency Estimates

Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	90.01	90.01	87.58	90.01
5	109.62	111.25	108.28	110.96
10	121.07	123.67	120.34	125.01
20	131.61	135.10	131.50	139.26
30	137.57	141.58	137.80	147.94
50	144.96	149.59	145.63	159.35
75	150.76	155.89	151.75	168.87
100	154.85	160.39	156.07	175.88
200	164.67	171.01	166.51	193.78
500	177.57	185.14	180.19	219.86
1000	187.30	195.77	190.54	241.62

2.5 Comparison of flood frequency estimates at Farmoor, Eynsham and Pinkhill.

The three gauged locations are in very close proximity, with no tributaries contributing additional flows between any of the locations. All are located very close to the upstream boundary of the hydraulic model and it is important that there is a representative inflow to the Thames using all available information. It would be expected that there is a similarity of AMAX data and flood frequency estimates between the locations. A comparison of the flow estimates and data and tabulated and plotted below.

Table 2-7 Comparison of preferred flood frequency estimates at Farmoor, Eynsham and Pinkhill

Peak flow (m^3/s)

Return Period (years)	Farmoor (PG)	Eynsham (PG)	Pinkhill (ESS)
2	78.13	74.55	90.01
5	94.66	91.53	109.62
10	105.69	103.04	121.07
20	116.85	114.83	131.61
30	123.63	122.05	137.57
50	132.54	131.59	144.96

75	139.95	139.59	150.76
100	145.40	145.51	154.85
200	159.30	160.70	164.67
500	179.48	183.02	177.57
1000	196.28	201.81	187.30

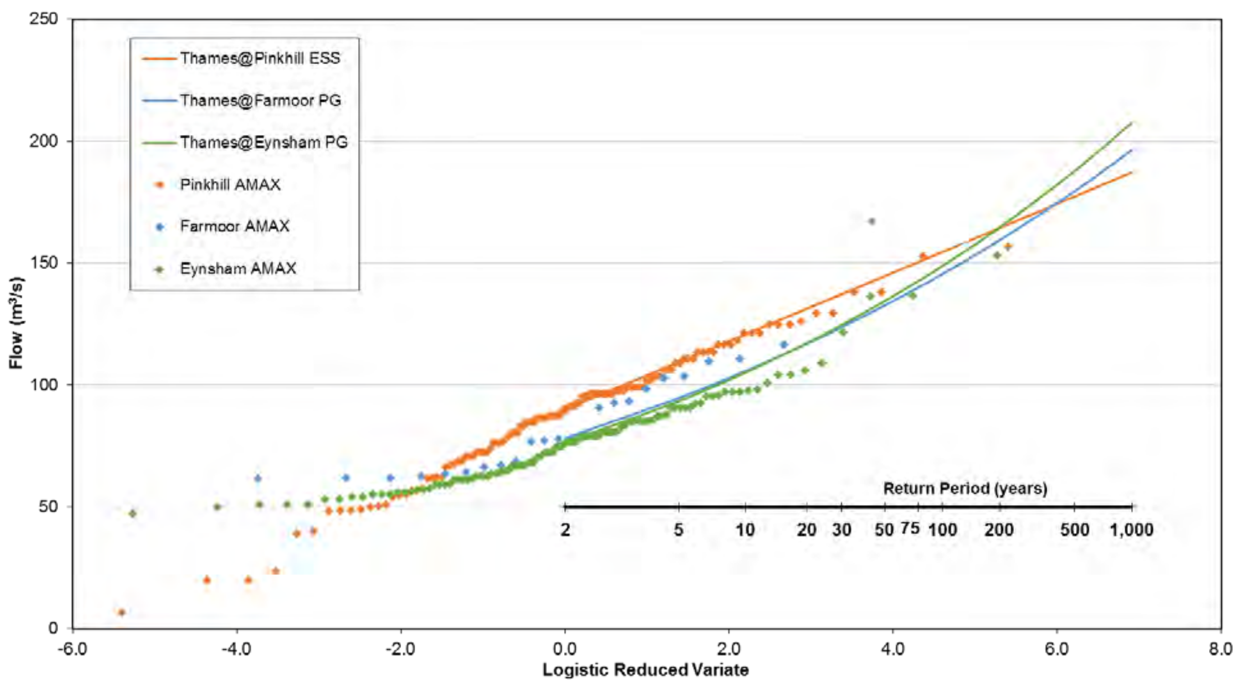

Figure 2-10 Comparison of Flood Frequency Estimates at Farmoor, Eynsham and Pinkhill

There is a strong positive correlation in flows and flood frequency estimates between Farmoor and Eynsham, with Pinkhill showing a different relationship. From Figure 2-10 it almost appears that the flood frequency estimate at Pinkhill is upper-bounded. Given that there are known concerns regarding the rating at Pinkhill, it is recommended that the Pinkhill flood frequency estimate is not used to inform the inflow boundary, and that the Eynsham flood frequency curve is used as a basis to deriving the inflow boundaries. As it is consistent with the Farmoor estimates and produces the more conservative peak flow estimate.

Table 2-8 Preferred Thames inflow boundary flood frequency curve

Peak flow (m^3/s)

Return Period (years)	Flow	Growth factors
2	74.55	1.000
5	91.53	1.228
10	103.04	1.382
20	114.83	1.540
30	122.05	1.637

50	131.59	1.765
75	139.59	1.872
100	145.51	1.952
200	160.70	2.156
500	183.02	2.455
1000	201.81	2.707

2.6 39021 Cherwell @ Enslow Mill

Enslow Mill gauging station is a compound Crump weir with a side spill weir on the River Cherwell upstream of Oxford and the Ray confluence. It is a HiFlows-UK station which is suitable for pooling and Qmed. There are four sources of AMAX data for the Enslow Mill gauge:

- NFRA HiFlows-UK data
- Environment Agency 15 minute flow series (WISKI)
- B&V 2009 AMAX series
- Environment Agency 15 minute level series (WISKI) with Cherwell rating applied

Reviewing the data available it was confirmed that B&V and post-2006 Environment Agency 15-minute flow data was derived using the rating listed in Table 1-2, with a datum of 64.989mAOD. B&V extended the AMAX series using peak level data held by the NRFA (but not by the Environment Agency), and also estimating peak levels from the original Environment Agency rating (which did not take floodplain bypass flows into account). There is some difference in the NRFA record, and the AMAX series used in the analysis was based on the B&V 2009 record extended to 2014 water year using Environment Agency data. The full AMAX series in included in Appendix B.

Table 2-9 AMAX series Cherwell @ Enslow Mill

Peak flow (m^3/s)

Water Year	NRFA	15 min data	B&V 2009	Water Year	NRFA	15 min data	B&V 2009
1964	10.5		11.9	**1990**	19.8	15.668	19.8
1965	19.9		35.3	**1991**	38.2	20.805	38.2
1966	19		33.2	**1992**	36.2	19.101	36.2
1967	24.5		43.8	**1993**	27.9	17.755	27.9
1968	21.5		40.5	**1994**	25.1	16.5	25.1
1969	19.1		34.8	**1995**	18.6	14.704	18.6
1970	35.7		36.5	**1996**	9.7	9.313	9.7
1971	41.5		41.9	**1997**	114	103.227	114
1972	19.8		39	**1998**	33.9	16.22	33.9
1973	41.4		41	**1999**	37.7	16.821	37.7
1974	47		46.6	**2000**	34.6	19.95	34.6

Table 2-9 AMAX series Cherwell @ Enslow Mill

Peak flow (m^3/s)

Water Year	NRFA	15 min data	B&V 2009	Water Year	NRFA	15 min data	B&V 2009
1975	3.7		2.7	**2001**	18.8	15.432	18.8
1976	39.3		35.3	**2002**	32.833	18.11	32.8
1977	40.8		40.8	**2003**	23.2	14.439	23.2
1978	43.6		43.9	**2004**	21.7	18.447	21.7
1979	50.9		51.4	**2005**	7.8	7.622	7.8
1980	39.4		39.4	**2006**	85.538	85.54	85.5
1981	39.5		39.3	**2007**	25.889	25.89	
1982	35.7		35.7	**2008**	28.357	28.36	
1983	36.1		36.1	**2009**	19.357	19.36	
1984	29.4		29.4	**2010**	14.684	14.68	
1985	30.5		30.5	**2011**	18.105	18.115	
1986	24.1		24.1	**2012**		48.48	
1987	39.3	21.197	39.3	**2013**		34.56	
1988	17.9	14.361	17.9	**2014**		16.85	
1989	34.7	19.038	34.7				
Qmed					28.88	18.11	

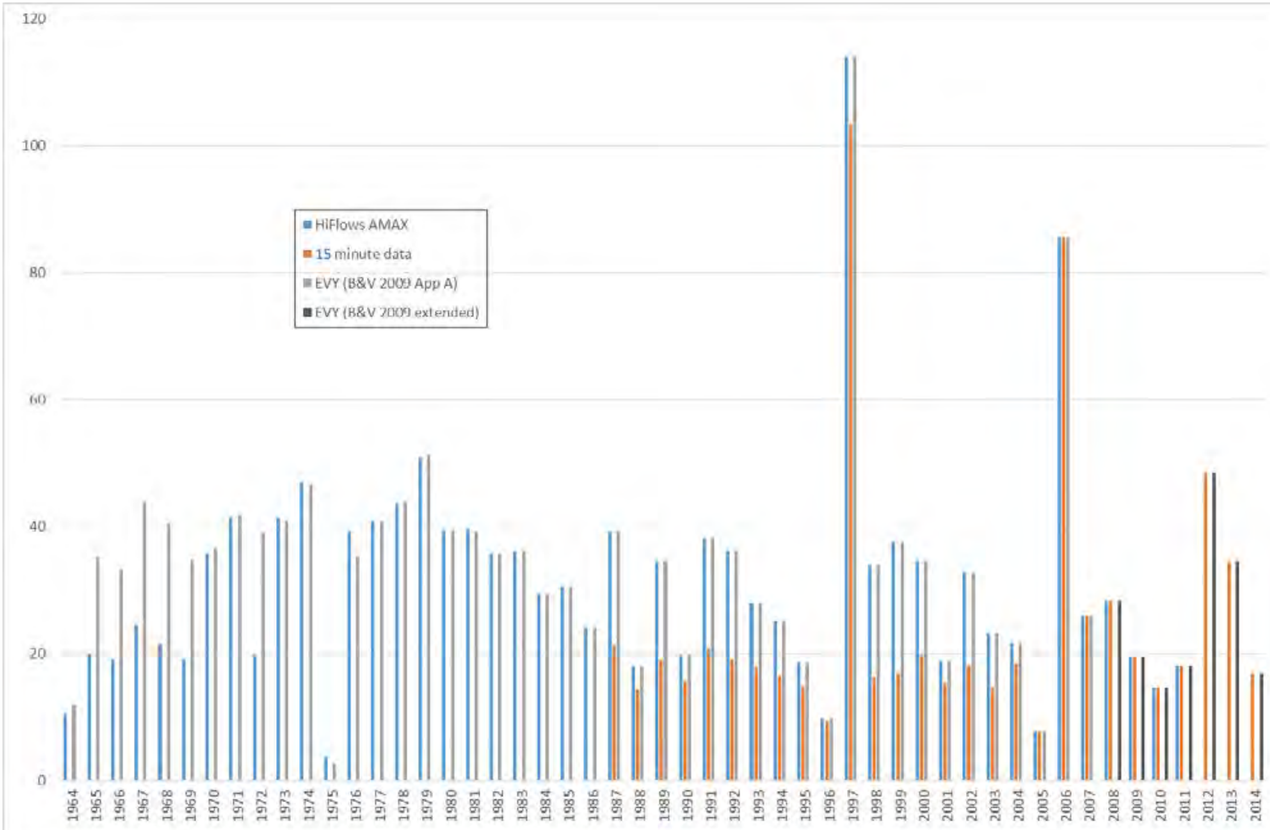

Figure 2-11 Cherwell @ Enslow AMAX series

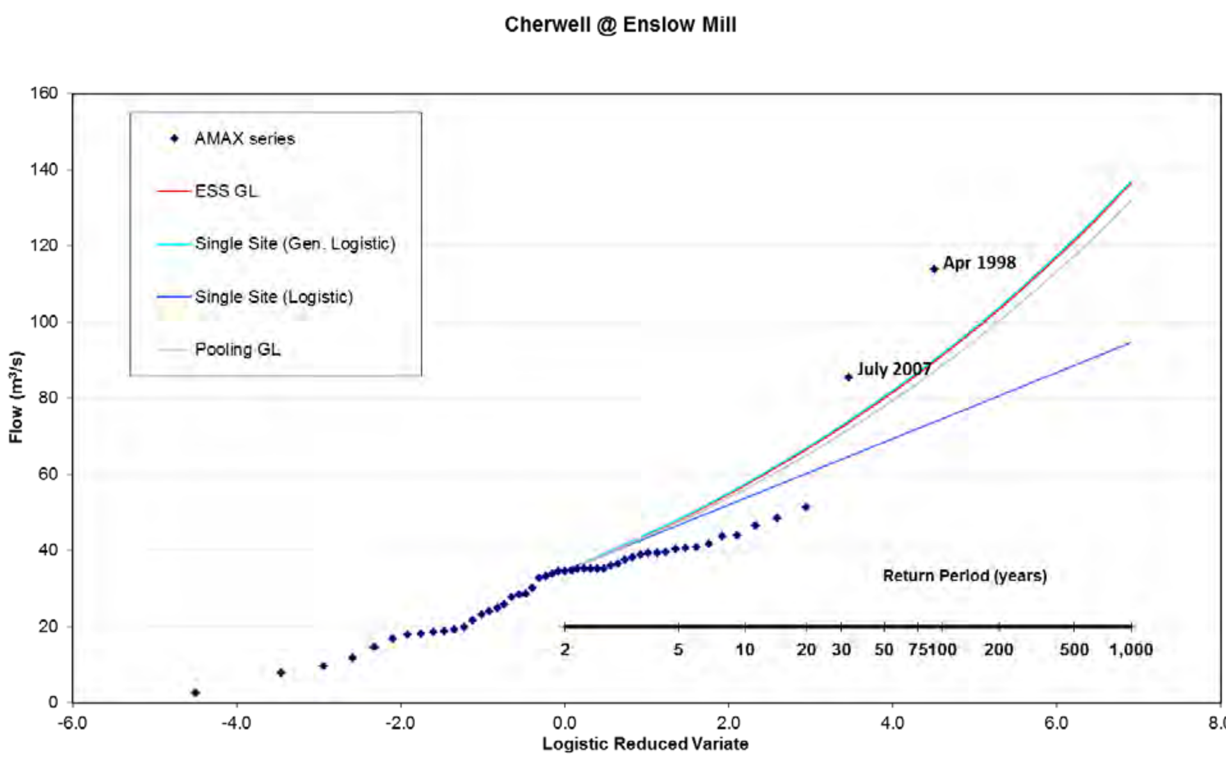

Figure 2-12 Cherwell @ Enslow Mill Flood Frequency Estimates

On the River Thames the largest flood in recent years was the July 2007 event. On the River Cherwell, the April 1998 event was the most significant. The Easter 1998 flood event, was more focused to the east and north of the Thames catchment, and did cause severe flooding, notably from the Cherwell in Banbury and Kidlington. It is generally consider that the April 1998 event had a return period of greater than 1 in 100 years, but the estimation of the rarity of any extreme event is uncertain. The pooling group component station scatter plot Figure 2-13 also demonstrate the wide range associated with flood estimation at this location.

It is recommended that the preferred flood frequency estimate is provided by the Pooling Group analysis using a Generalised Logistic distribution. The above pooling group analysis estimates the Easter 1998 event as having between a 1 in 200 and 1 in 500 year return period. It is generally accepted that this flood event rarity was closer to having a 200 year return period, and consequently the return period flows for the Cherwell may be under-estimated. The impact on the contribution of Cherwell flows to flood risk through the city of Oxford and at Sandford Lock have been tested in sensitivity runs, as reported in Section 3.6.

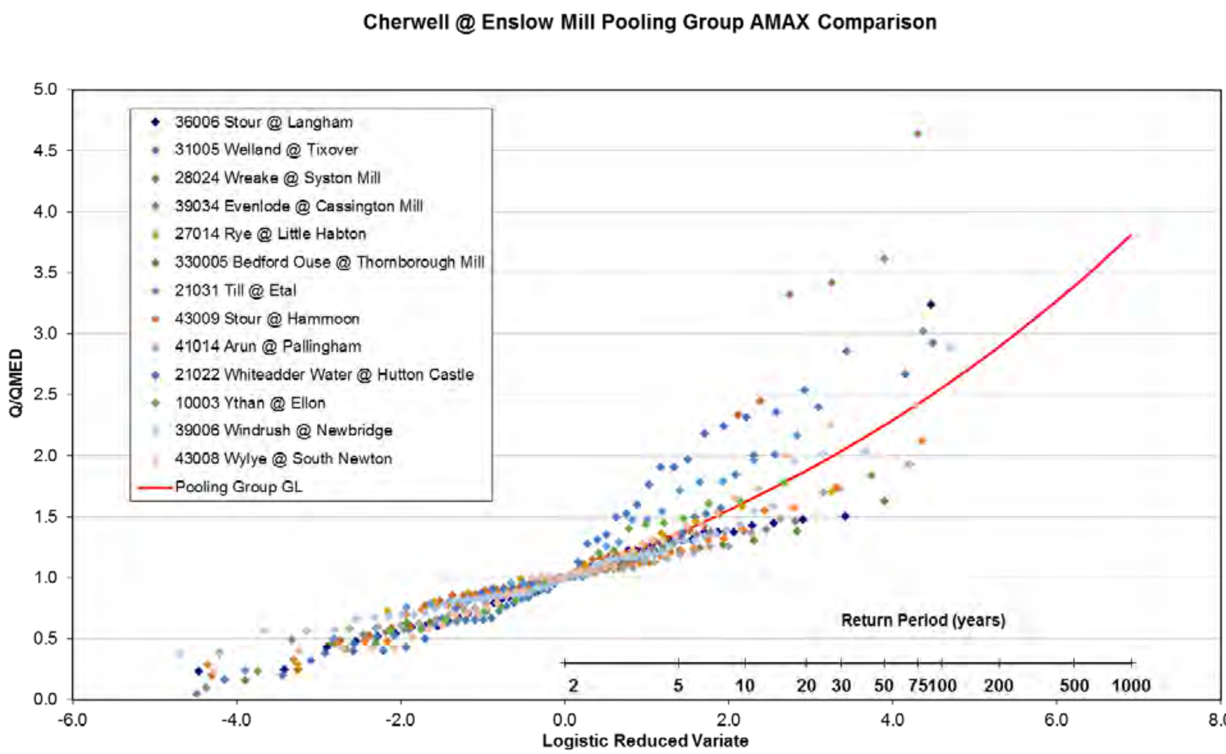

Figure 2-13 Cherwell @ Enslow Mill Comparison of AMAX components of pooling group

Table 2-10 Cherwell @ Enslow Mill Flood Frequency Estimates

Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	34.65	34.65	34.65	34.65
5	48.05	48.26	46.70	47.41
10	57.18	57.51	53.73	56.12
20	66.56	66.97	60.21	65.07
30	72.32	72.79	63.89	70.57
50	79.96	80.48	68.46	77.86
75	86.36	86.89	72.03	83.99

Table 2-10 Cherwell @ Enslow Mill Flood Frequency Estimates

Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
100	91.11	91.67	74.56	88.53
200	103.33	103.90	80.62	100.21
500	121.34	121.92	88.62	117.46
1000	136.57	137.09	94.65	132.05

2.7 39034 Evenlode @ Cassington

The Cassington gauge monitors flows on the River Evenlode a short distance upstream of it confluence with the River Thames (downstream of Eynsham). There are four sources of AMAX data for the Cassington gauge:

- NRFA HiFlows-UK data
- Environment Agency 15 minute flow series (WISKI)
- Environment Agency 15 minute level series (WISKI) with rating as listed in Table 1-2 applied
- B&V 2009 AMAX data

On reviewing the available data, there is a good consistency with all sources. The main variation is in the flow data held by the Environment Agency which appears to be using an earlier rating for flows prior to 2006. The revised rating derived by Eden Vale Young for the Black & Veatch study has not been applied retrospectively to their level data. NRFA hold peak flow data from 1970 to 1985. B&V used these to estimate peak water levels and recalculated the peak flows using the Edenvale rating.

The preferred AMAX series used in this analysis was the B&V 2009 data extrapolated to 2014 water year using Environment Agency level data and the rating. The AMAX series used in this analysis is based on the NRFA HiFlows-UK data up to 2009, and the 15 minute level data converted into an AMAX flow series using the Edenvale rating, for the events up to 2014 water year. Of all the gauging station ratings, in the study, there is concern over the accuracy of the Cassington rating, the highest recorded spot flow rating is well below Qmed and whilst the high flow rating accounts for flow bypassing the gauge upstream, the bypassing volumes have never been gauged.

Table 2-11 AMAX series Evenlode @ Cassington

Peak Flow (m^3/s)

Water Year	NRFA	15 min flow data	B&V 2009	Water Year	NRFA	15 min flow data	B&V 2009
1970	34.6		34.6	**1993**	25.7	20.621	25.7
1971	34.9		34.9	**1994**	23.9	19.81	23.9
1972	27.2		27.2	**1995**	24.4	19.976	24.4
1973	34.3		34.3	**1996**	13.9	13.498	13.9
1974	36.6		36.6	**1997**	28.4	21.781	28.4
1975	2.5		2.5	**1998**	31.7	23.101	31.7
1976	33.8		33.8	**1999**	27.9	21.373	27.9
1977	26.9		26.9	**2000**	26.9	21.27	26.9
1978	34.6		34.6	**2001**	18.2	17.403	18.2
1979	43.2		43.2	**2002**	23.2	19.731	23.2
1980	21.6		21.9	**2003**	15.5	15.281	15.5
1981	30.8		30.8	**2004**	13.4	13.248	13.4
1982	17.7		17.7	**2005**	12.5	12.271	12.5
1983	17.7		17.7	**2006**	75.457	75.457	75.5
1984	25		25	**2007**	27.604	27.604	27.6

Table 2-11 AMAX series Evenlode @ Cassington

Peak Flow (m³/s)

Water Year	NRFA	15 min flow data	B&V 2009	Water Year	NRFA	15 min flow data	B&V 2009
1985	21		21	**2008**	22.044	22.044	
1986	21.3	18.122	21.3	**2009**	22.942	22.942	
1987	26.9	20.449	26.9	**2010**	12.324	12.324	
1988	16.4	15.415	16.1	**2011**	14.454	14.454	
1989	30.1	21.528	30.1	**2012**		31.715	
1990	15.9	14.752	15.9	**2013**		26.828	
1991	23.5	18.918	23.5	**2014**		16.607	
1992	32.6	22.764	32.6				
Qmed					24.7	19.976	26.3

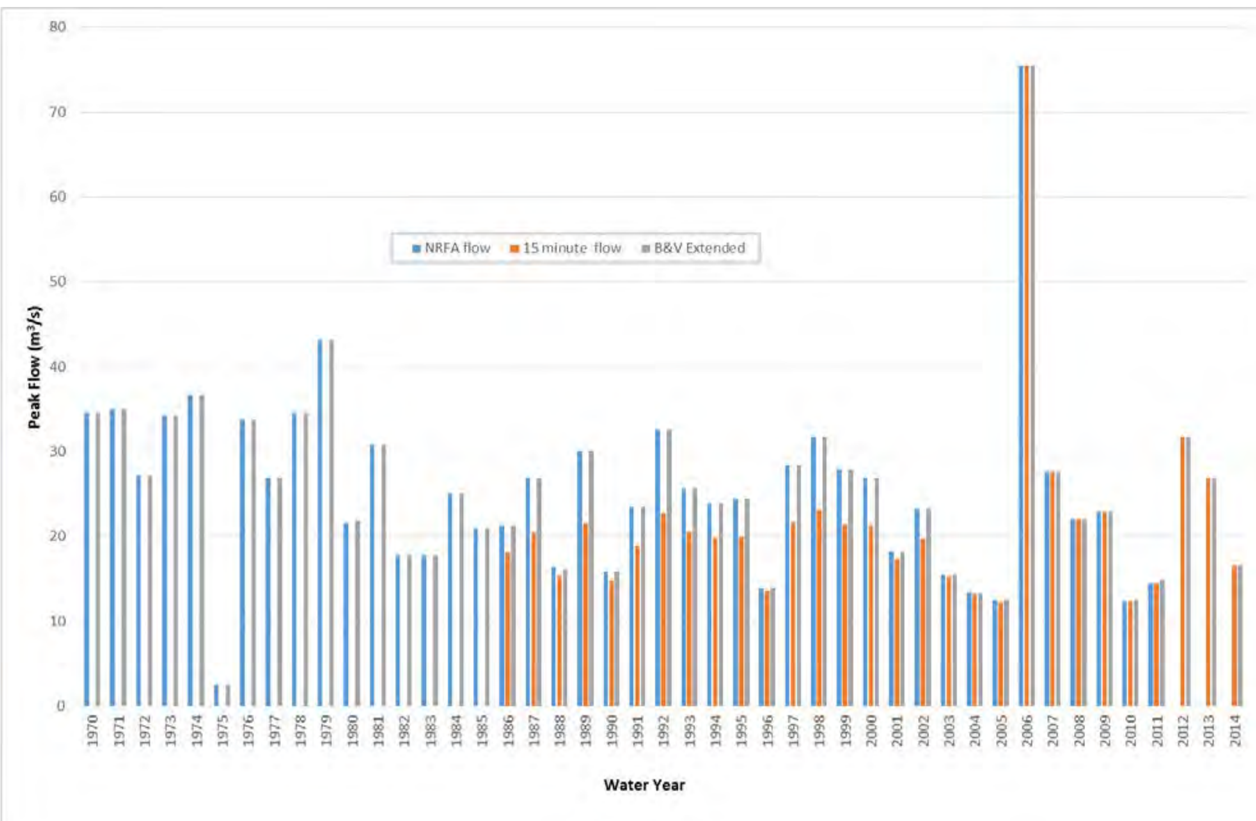

Figure 2-14 Evenlode @Cassington AMAX series

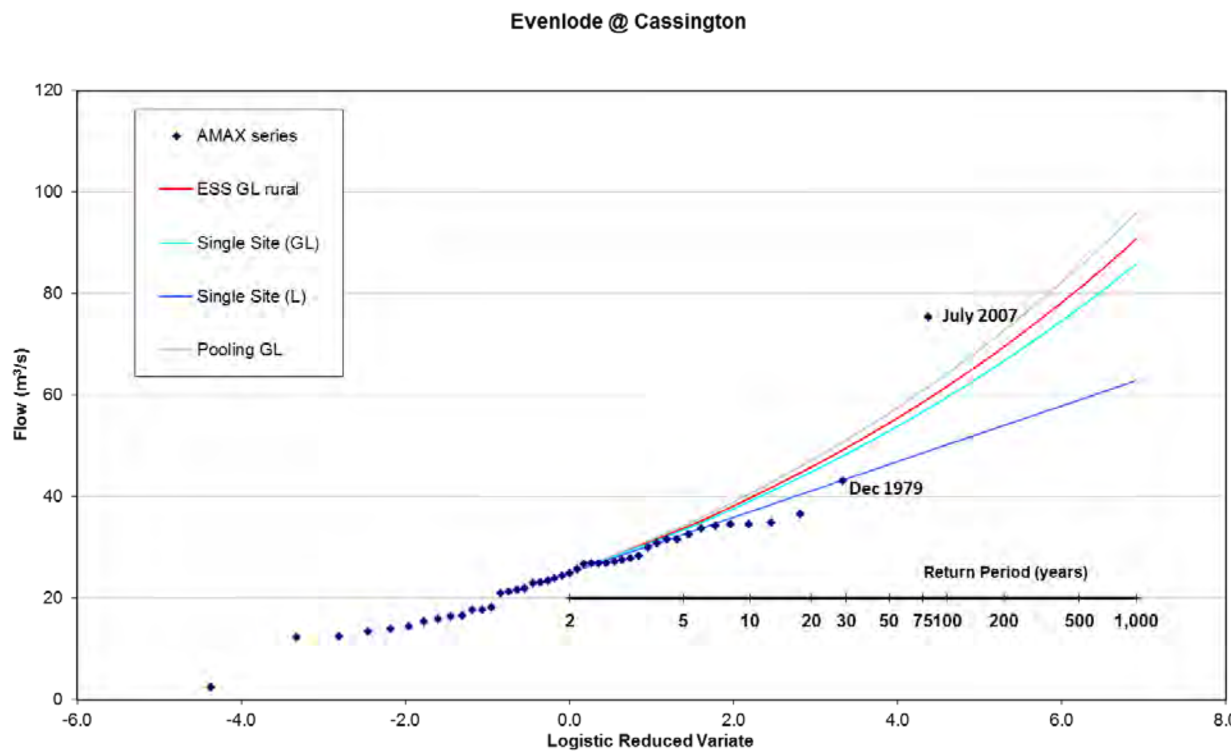

Figure 2-15 Evenlode @ Cassington Flood Frequency Estimates

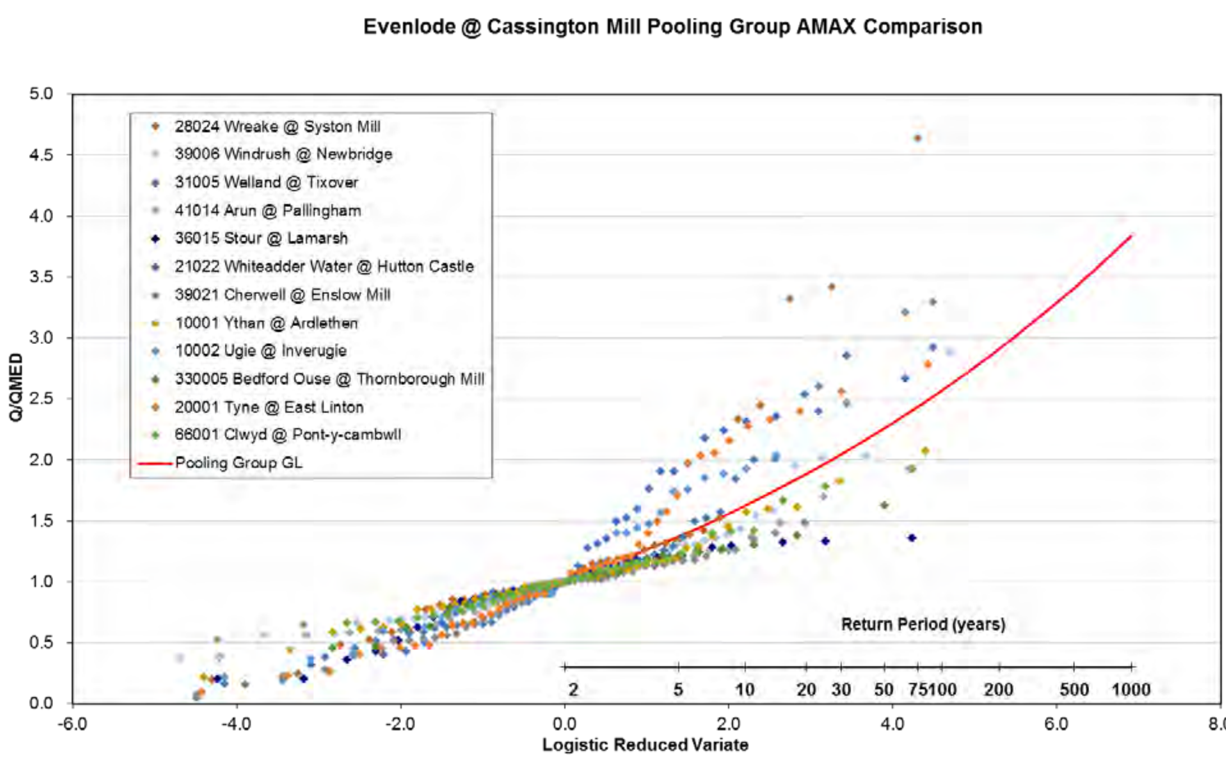

Figure 2-16 Evenlode @ Cassington Comparison of AMAX components of pooling group

There is good agreement in the peak flow estimates for both the Enhanced Single Site and Pooling Group estimates. There are some potential uncertainties with peak flow values at Cassington and further the potential variation in peak flow estimates is shown in Figure 2-16, with scatter in the component pooling group members flow data.

Although there is a large amount of uncertainty associated with the flow estimates at Cassington the preferred flood frequency estimate is that derived using Pooling Group (GL), as this approach does pool flood frequency estimates from a range of similar catchments. The 2007 flood peak return period is estimated to be just over 200 years on this curve.

As mentioned previously the impacts of uncertainty in modelled inflows will be test in the hydraulic modelling via a series of sensitivity runs.

Table 2-12 Evenlode @ Cassington Flood Frequency Estimates

Peak Flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	25.00	25.00	25.00	25.00
5	33.78	33.45	32.60	34.28
10	39.74	39.13	37.05	40.61
20	45.83	44.85	41.15	47.13
30	49.56	48.35	43.48	51.13
50	54.49	52.93	46.35	56.44
75	58.62	56.75	48.63	60.90
100	61.68	59.55	50.23	64.21
200	69.52	66.73	54.05	72.72
500	81.04	77.15	59.08	85.29
1000	90.73	85.85	62.90	95.92

2.8 39140 Ray @ Islip

The Islip gauging station is an ultrasonic gauge located on the River Ray upstream of the confluence with the River Cherwell. The only flow data source is from the ultrasonic record. During periods of high flows on the River Cherwell, flows in the Ray are reduced resulting in the storage of water in Otmoor until levels in the Cherwell subside. The flows recorded by the Islip gauge are therefore reduced. We assume that the estimate of Qmed will not be affected, but will have greater confidence in any pooled estimates than flood frequencies derived from single site analysis. Consequently there will be uncertainty with any estimated flows, but overall the contribution of the Ray catchment is relatively small compared to the study catchment area.

Table 2-13 AMAX series Ray @ Islip

Peak flow (m^3/s)

Water Year	15 min data	Water Year	15 min data
1995	13.85	**2005**	9.16
1996	8.32	**2006**	15.19
1997	11.258	**2007**	18.03

Table 2-13 AMAX series Ray @ Islip

Peak flow (m^3/s)

Water Year	15 min data	Water Year	15 min data
1998	19.67	**2008**	23.85
1999	14.78	**2009**	15.1
2000	15.56	**2010**	11.51
2001	20.92	**2011**	9.31
2002	20.9	**2012**	19.77
2003	9.76	**2013**	19.07
2004	6.03	**2014**	12.9
Qmed			**14.94**

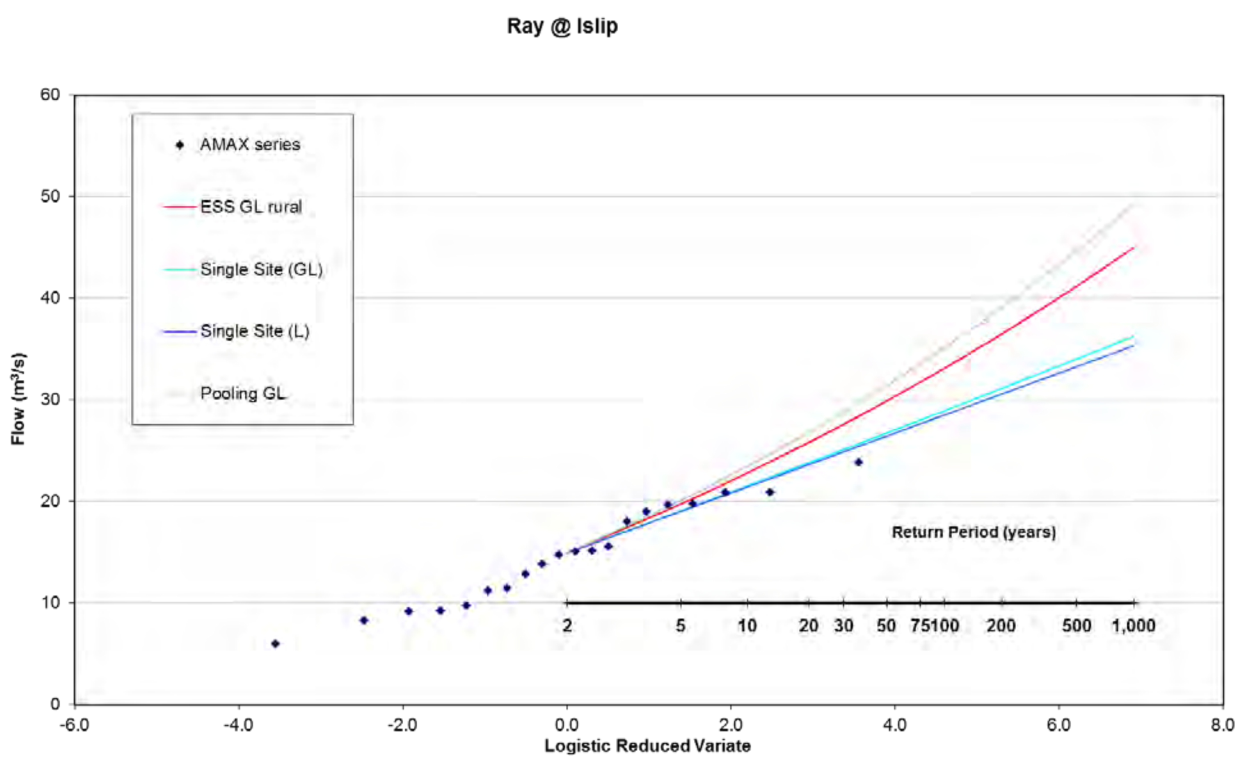

Figure 2-17 Ray @ Islip Flood Frequency Estimates

Due to the low confidence in the high flow records and the short duration of the records, it is not recommended that a single site approach be taken forward as the preferred estimate. We do have some confidence in using the AMAX series to derive Qmed, and so the preferred flood frequency estimate is that derived using pooling group analysis.

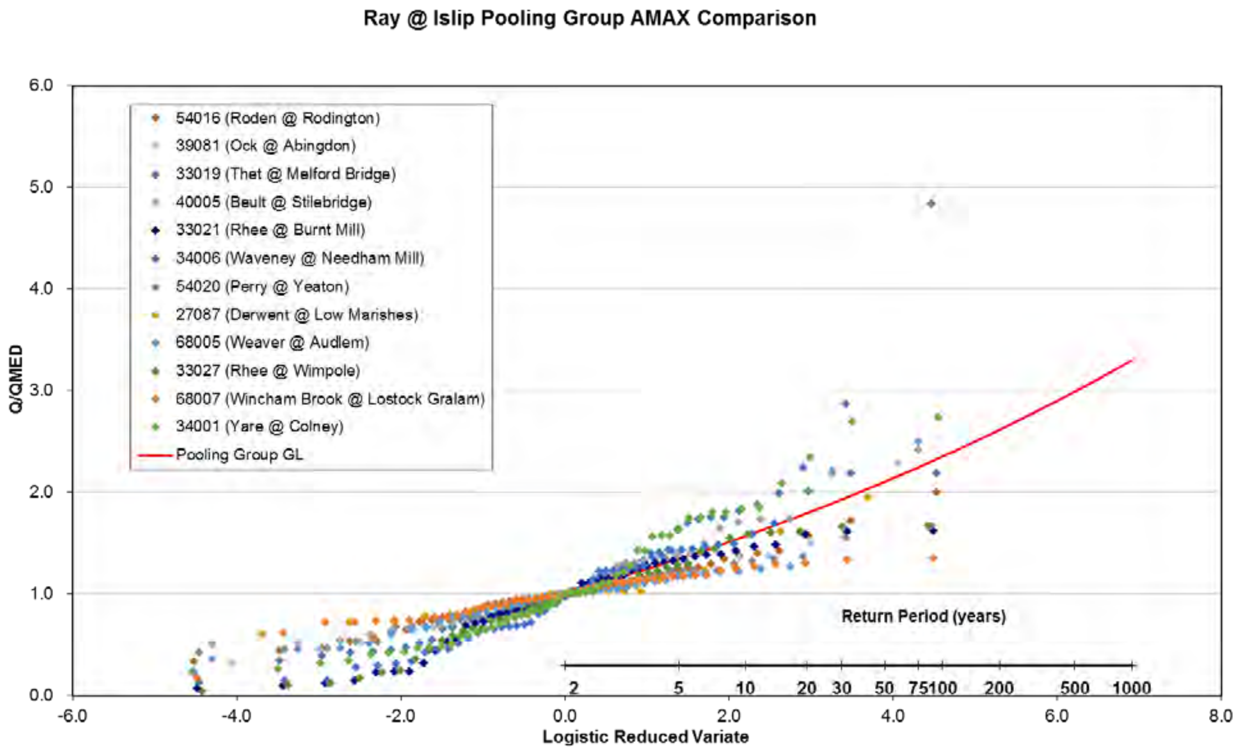

Figure 2-18 Ray @ Islip Comparison of AMAX components of pooling group

Table 2-14 Islip Flood Frequency Estimates

Peak flow (m³/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	14.94	14.94	14.94	14.94
5	19.75	19.08	19.03	20.10
10	22.82	21.54	21.43	23.46
20	25.82	23.82	23.63	26.81
30	27.60	25.12	24.88	28.81
50	29.89	26.74	26.43	31.41
75	31.75	28.02	27.65	33.56
100	33.10	28.93	28.5	35.12
200	36.47	31.12	30.57	39.06
500	41.20	34.04	33.28	44.68
1000	45.00	36.26	35.33	49.28

2.9 Thames @ Sandford

As part of the Oxford Flood Risk Management Strategy, Black and Veatch developed an AMAX series for the Thames at Sandford, based on a rating developed for tail water levels. Records of head water levels (HWL) and tail water levels (TWL) are available back to 1894. The records have been taken from lock-kept tackle sheets, though a telemetered gauge has been installed since 2013. The B&V AMAX record was extended to include the 2014 water year using observed tail water levels and the rating listed in Table 1-2. The complete AMAX record can be found in Appendix B

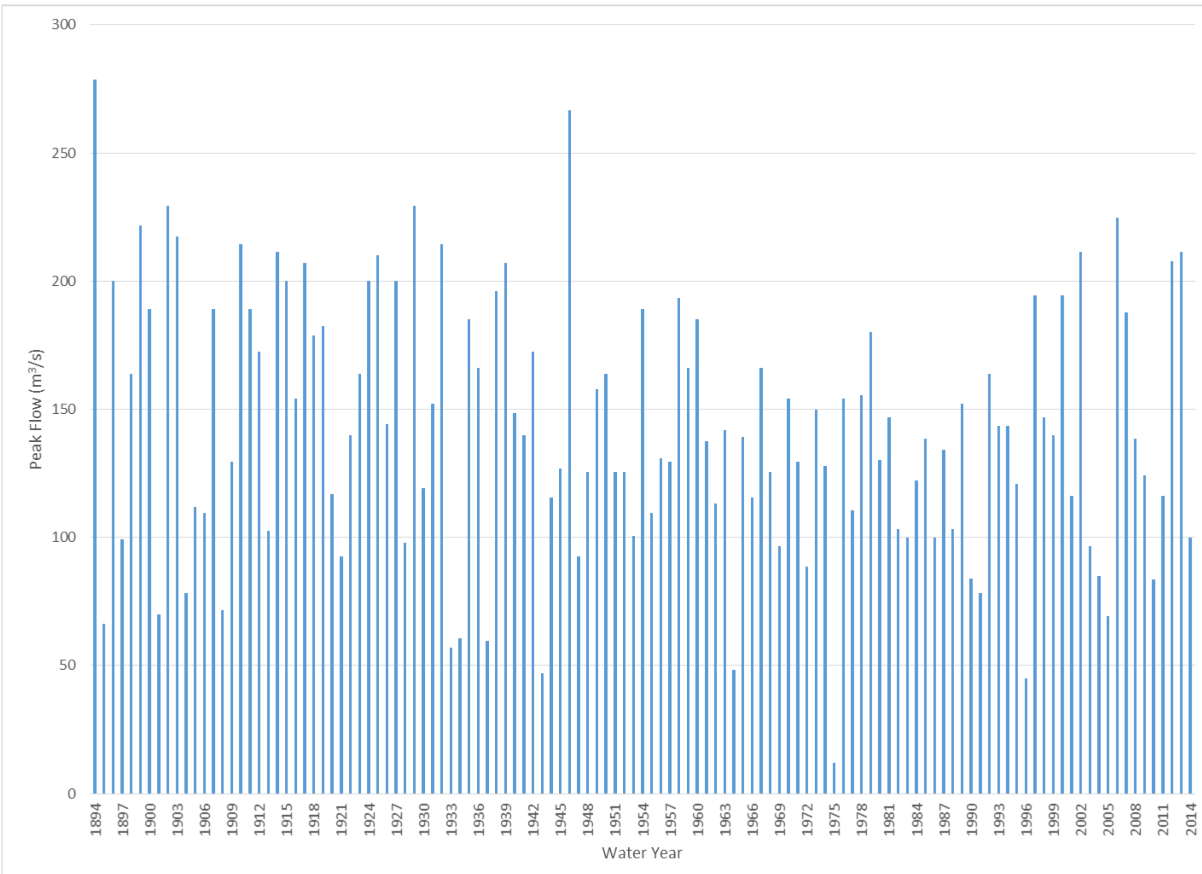

Figure 2-19 Thames @ Sandford Lock AMAX series

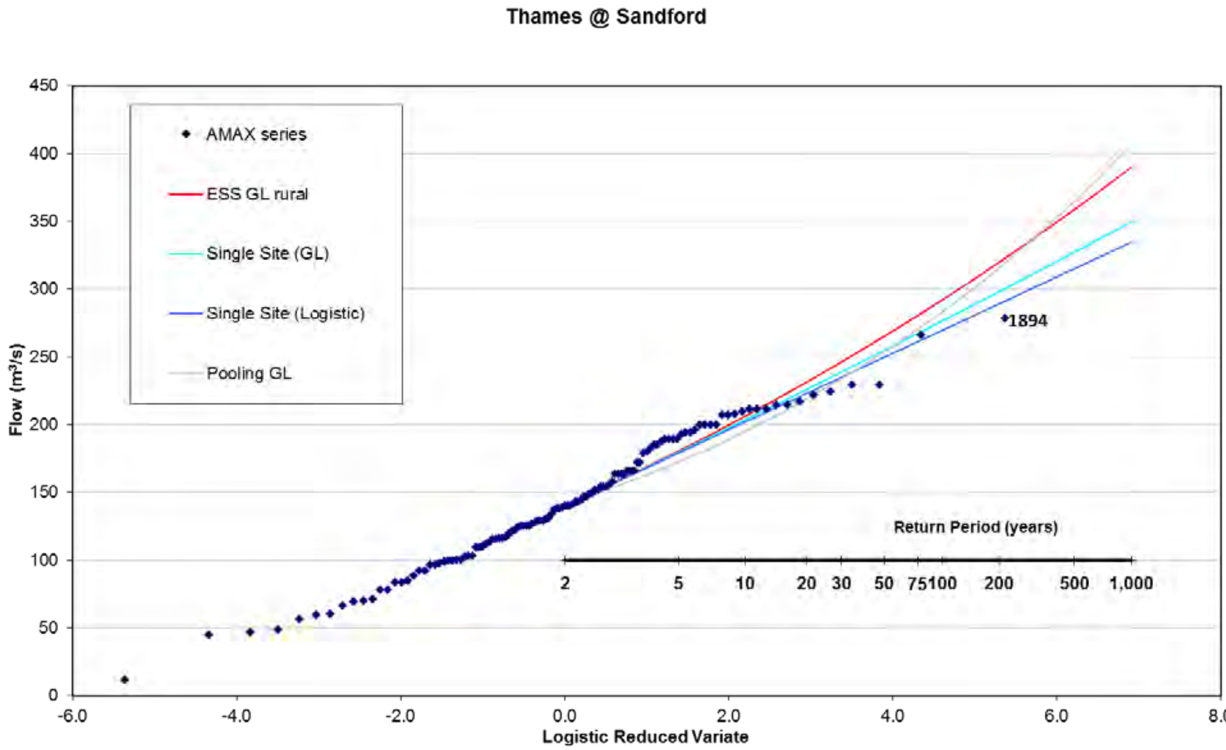

Figure 2-20 Thames @ Sandford Flood Frequency Estimates

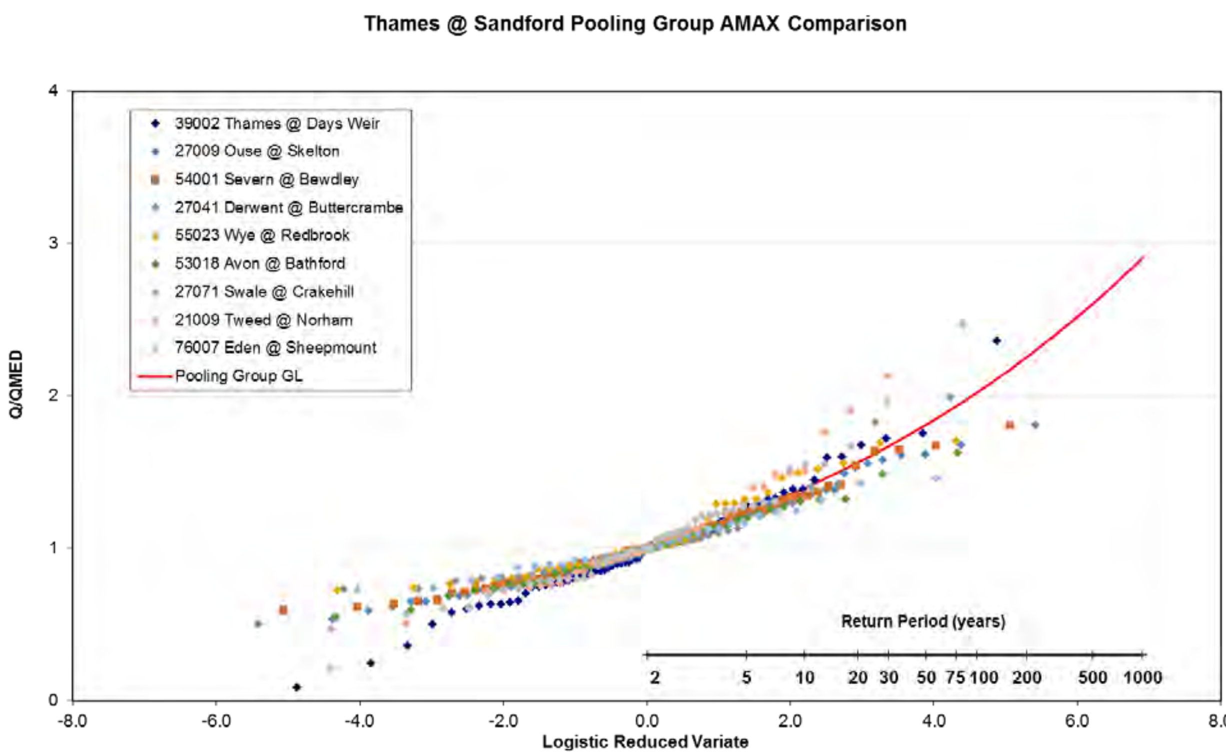

Figure 2-21 Thames @ Sandford Comparison of AMAX components of pooling group

As to be expected when using a flow record of greater than 100 years, there is a good consistency in all estimates. On considering Figure 2-20 it appears that the single site analyses provide higher flow estimates for the 3 – 20 year return period estimates, than those estimated using pooling group approaches. Comparisons were made with earlier flood frequency estimates made at Sandford and are shown below.

Table 2-15 Comparison of Sandford Flood Frequency Estimates
Peak flow (m^3/s)

Return Period Year	B&V Oxford Flood Risk Management Strategy	Oxford Hydrology Update, JBA 2013	CH2M ESS single site	CH2M Pooling Group
2	142	140	140	140
5	183	184	181	173
20	228	228	231	219
75	268	259	281	270
100	278	264	292	283
1,000	348	299	390	407

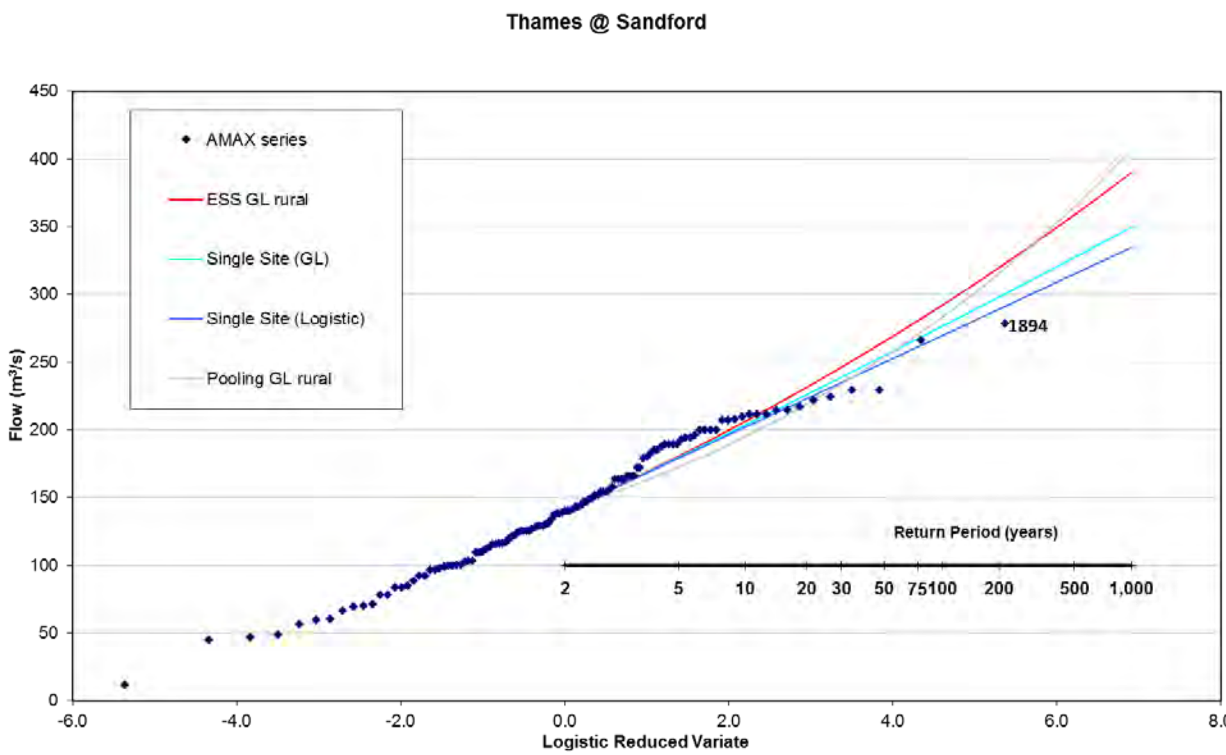

Figure 2-22 Thames @ Sandford Comparison of Flood Frequency Estimates

In comparing the peak flow estimates, all studies have generated similar results, apart from the 1,000 year estimate. The Oxford Hydrology Update, JBA 2013 1,000 year estimate does appear to be low when plotted against the observed data. Using this estimate suggests the 1894 flood event has a return period of > 200 year, whereas the historical consensus prefers a 100 year return period approximation for this event.

This study's pooling group estimate has the steepest growth curve, which on inspection is likely to be overly conservative on such a large catchment. Therefore our preferred flood frequency estimate at Sandford Lock is that derived using the Enhanced Single Site approach.

Table 2-16 Comparison of Sandford Flood Frequency Estimates
Peak flow (m^3/s)

Return Period (years)	ESS GL	Single Site (GL)	Single Site (L)	Pooling GL
2	140.00	140.00	140.00	140.00
5	180.51	179.76	179.06	172.52
10	206.19	203.56	201.88	195.23
20	231.26	225.82	222.88	218.97
30	246.07	238.70	234.78	233.75
50	265.09	254.66	249.62	253.55
75	280.56	267.26	261.24	270.34
100	291.77	276.22	269.36	282.89
200	319.67	298.06	289.10	315.53
500	358.66	327.18	315.00	364.57
1000	389.90	349.58	334.60	406.77

2.10 Summary

As with any flood frequency there are large uncertainties with flood frequency estimates. Whilst this study benefits from a number of records with long or very long records, the derivation of the extended AMAX series has limitations including:

- Accuracy in the record and conversion of tackle sheet levels to tail water levels when AMAX records have been extended, in the case of Eynsham, Pinkhill and Sandford.
- Conversion of head water levels to tail water levels based on a regression equation where no tail water records exist
- A stage discharge relationship for the tail water level where no single structure exists
- Assumption that one rating can be applied to the whole record and that any channel modifications have not had an impact of the stage/discharge relationship.

As a result there is likely to be large uncertainty in the accuracy of each record, but there is likely to be a higher confidence in the relative magnitude of each of the AMAX peak and estimate of Qmed.

A comparison of the preferred growth curves is shown in Table 2-17. As expected the smaller catchments have the steeper growth curves, with the Eynsham growth curve being shallower than that estimated at Sandford.

Table 2-17 Comparison of preferred growth curves
Growth factors

Return Period (years)	Thames @ Sandford	Ray @ Islip	Evenlode @ Cassington	Cherwell @ Enslow Mill	Thames @ Eynsham*
2	1.00	1.00	1.00	1.00	1.00
5	1.29	1.34	1.37	1.37	1.23

Table 2-17 Comparison of preferred growth curves

Growth factors

Return Period (years)	Thames @ Sandford	Ray @ Islip	Evenlode @ Cassington	Cherwell @ Enslow Mill	Thames @ Eynsham*
10	1.47	1.57	1.62	1.62	1.38
20	1.65	1.79	1.89	1.88	1.54
30	1.76	1.92	2.05	2.04	1.64
50	1.89	2.10	2.26	2.25	1.77
75	2.00	2.24	2.44	2.42	1.87
100	2.08	2.34	2.57	2.56	1.95
200	2.28	2.61	2.91	2.89	2.16
500	2.56	2.99	3.41	3.39	2.45
1000	2.79	3.30	3.84	3.81	2.71

Note*: Eynsham growth factors preferred for upstream boundary over Pinkhill and Farmoor

The limitations of the flood frequency estimates will be mitigated by sense checking the flood extents of all design events against known flood events, and we will assess the impacts of varying the relative magnitude of tributary inflows on flood peaks at Sandford Lock. Additionally a series of sensitivity runs will be undertaken using the hydraulic model to assess the impact of assumptions and presented in the hydraulic modelling report.

Design Hydrograph Analysis

3.1 Archer's Method

The standard approach for deriving hydrological inflows is to use the FEH or ReFH rainfall runoff approach, where design rainfall is routed through a unit hydrograph to generate design flows. This approach assumes uniform design rainfall across the whole of the catchment, and is assumed valid for catchments up to 1,000km^2. The combined catchment area of Thames to Eynsham and Evenlode to Cassington is approximately 2,000km^2 so an alternative approach to derive design hydrographs is needed.

B&V 2009 also found in their review of previous studies, that those attempting to use the FSR/FEH rainfall-runoff model to estimate flood flows at Oxford encountered additional problems. These problems arose from the need to consider long storm durations, the occurrence of both summer and winter events, the influence of snowmelt in some of the largest recorded events, and the joint probability of flows in the Rivers Thames and Cherwell. There are similar challenges in applying the ReFH (Revitalised Flood Hydrograph) approach. In light of these issues B&V 2009 decided to derive design hydrographs from an alternative method, and a similar approach is used in this study.

The method used in here and in previous Oxford hydrology studies is Archer's method from Archer et al (2000)[6]. This has been used to derive average hydrograph shapes for each subcatchment. It takes a series of observed hydrographs and averages them to generate a design hydrograph which can then be scaled to the appropriate peak value.

In the B&V 2009 study, one hydrograph shape was derived at Sandford Lock and then scaled and used for all the upstream inflows. As part of our hydrology review and revision we investigate below deriving unique design hydrographs for each of the upstream inflow locations. This analysis will form the baseline for our hydrological inflow shapes, but sensitivity analysis will be undertaken on the relative time and magnitude of each of the tributary inflows.

In this study we have looked to derived design hydrographs at the following gauged locations.

- 39007 Thames@ Eynsham
- 39021 Cherwell at Enslow
- 39034 Evenlode at Cassington
- 39140 Ray at Islip

These gauging stations were selected as they are the closest gauged sites to the locations of the model inflows.

For each gauged location the 15 minute flow series, obtained from the Environment Agency was plotted. Initially, events on the AMAX series were inspected for suitability. Events were considered suitable if they met the following criteria:

- Full data record was available for the site
- Data contained no anomalies
- The hydrograph was dominated by a single peak – multi-peak events were excluded.

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6 David Archer, Miranda Foster, Duncan Faulkner & John Mawdsley, CIWEM/ICE Water Environment 2000: Flood Warning & Management, ICE, London

Once the AMAX series was reviewed, other large peaks from the flow series were visually inspected to identify any further events.

Details of the calculations undertaken for each sub-catchment are provided below.

3.1.1 39008 Thames at Eynsham

A 15 minute flow series from 1987 was inspected. The Eynsham record was chosen over the Pinkhill and Farmoor records, as for the period the data appears to the most complete, and there are uncertainties over the Pinkhill rating. The set of selected events is shown in Table 3-1. Due to data problems with some events at Eynsham (flow data around peaks was missing), data from Farmoor gauge has been used to infill some events, as the gauge only lies a short distance upstream. This allows for a greater number of events to be included in the analysis and the close proximity of these gauges means that data series from them are considered interchangeable for the purposes of Archer analysis. The fact that the hydrographs are non-dimensionalised in the analysis means that it is the shape of the hydrograph that is important to the analysis and not the absolute flows.

Table 3-1: Events used for Archer Analysis – 39008 Thames at Eynsham

Event	Name	Source	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m^3/s)
A*	Dec-92	AMAX	25/11/1992	31/12/1992	888	92.45
B*	Jan-93	Flow series inspection	10/01/1993	28/02/1993	1200	83.99
C	Apr-93	Flow series inspection	09/04/1993	28/04/1993	480	52.50
D	May-93	Flow series inspection	26/05/1993	09/06/1993	360	46.50
E*	Jan-94	AMAX	28/12/1993	01/02/1994	864	90.62
F*	Dec-95	AMAX	17/12/1995	31/12/1995	360	78.16
G*	Dec-99	AMAX	21/12/1999	31/01/2000	996	77.30
H	Nov-00	Flow series inspection	28/10/2000	21/11/2000	582	88.00
I	Dec-00	AMAX	02/12/2000	30/12/2000	696	110.00
J	Jul-07	AMAX	19/07/2007	14/08/2007	648	157.00
K	Oct-07	Flow series inspection	16/10/2007	05/11/2007	504	44.30
L	Jan-08	AMAX	04/01/2008	13/02/2008	984	98.10
M	Mar-08	Flow series inspection	15/03/2008	07/04/2008	576	75.40
N	Jun-08	Flow series inspection	03/06/2008	20/06/2008	432	57.80
O	Nov-08	Flow series inspection	09/11/2008	21/11/2008	312	48.70
P	Feb-09	AMAX	09/02/2009	01/03/2009	504	76.30

* Hydrograph from Thames at Farmoor used in absence of Eynsham data.

Events used for calculation of average hydrograph shapes at 39008 (Thames at Eynsham) are shown in Figure 3-1.

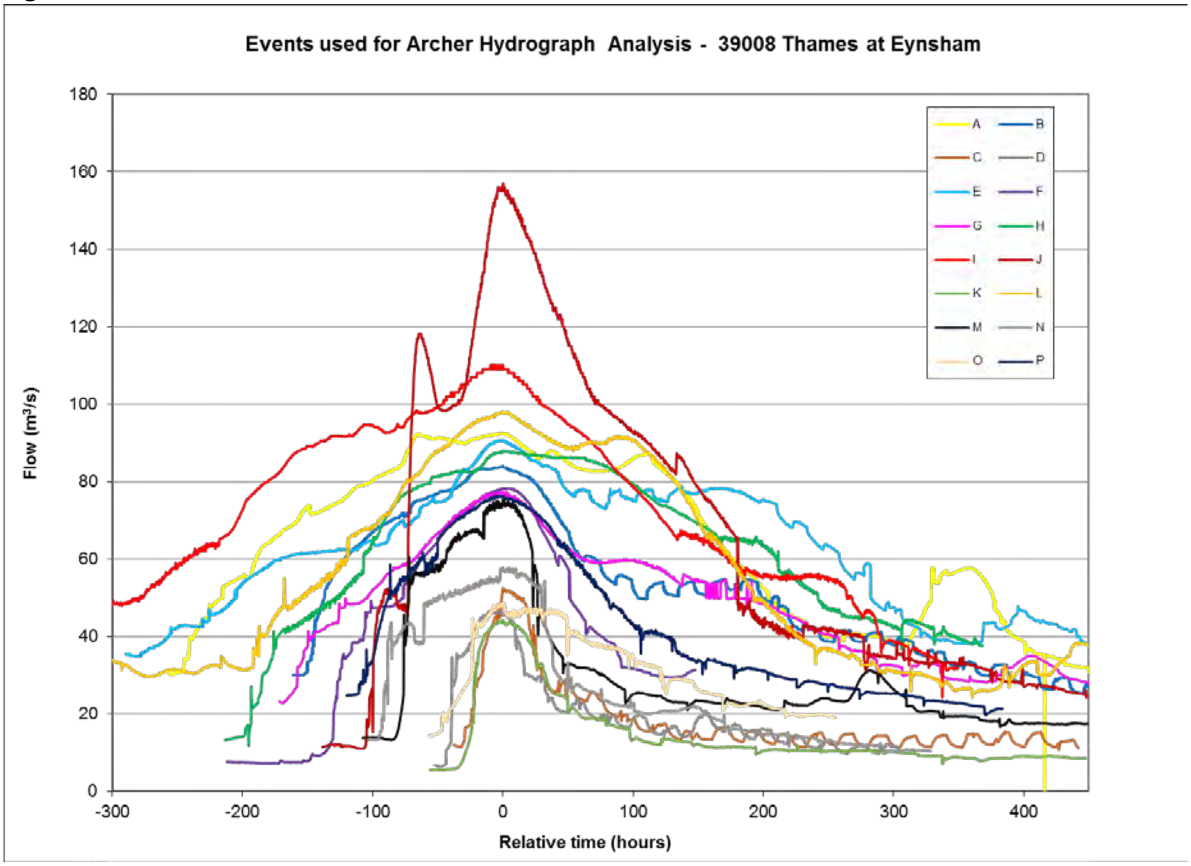

Figure 3-1: Event plots used for calculation of average hydrograph shape – 39008 (Thames at Eynsham)

The estimated average hydrograph shape analysis for 39008 Thames at Eynsham are provided in Table 3-2

Table 3-2: Hydrograph shape analysis 39008 (Thames at Eynsham)

Hydrograph

Time (hrs)	Relative time (hrs)	% of Peak Flow (%)	Time (hrs)	Relative time (hrs)	% of Peak Flow (%)
-132.57	0.0	20	37.20	169.8	90
-127.57*	5.0	30	69.88	202.4	80
-122.58*	10.0	40	93.97	226.5	70
-117.58	15.0	50	117.17	249.7	60
-102.47	30.1	60	150.78	283.4	50
-82.70	49.9	70	215.33	347.9	40
-61.78	70.8	80	275.48	408.1	30
-35.00	97.6	90	439.27	571.8	20
0.00	132.6	100			

Note: * Interpolated between 0 and 15 hours to avoid unusually shaped rising limb.

These results are plotted against inflows from the 2014 study in Figure 3-2

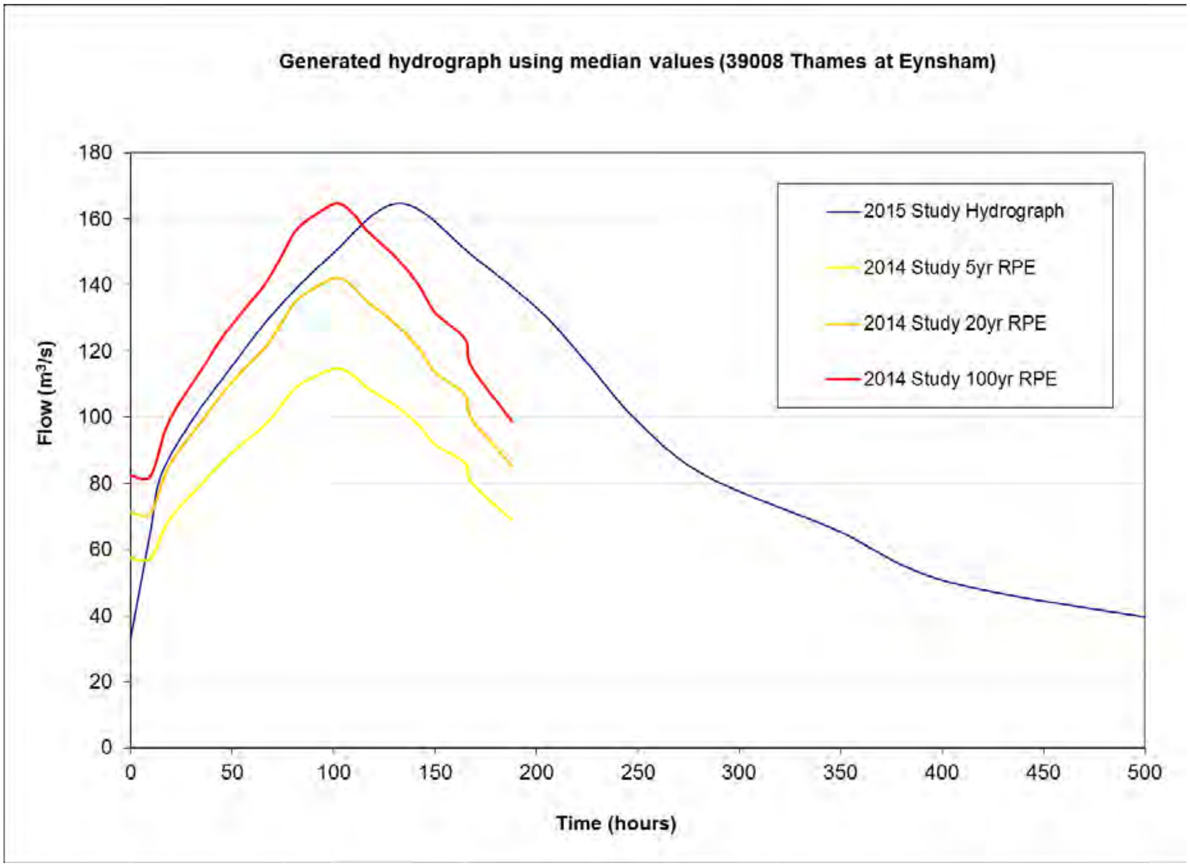

Figure 3-2 Generated hydrograph using median values (39008 Thames at Eynsham).

In comparing the updated hydrograph shape with that used in previous studies, the shape is as expected consistent with that derived at Sandford.

3.1.2 39021 Cherwell at Enslow Mill

A 15 minute flow series from the Environment Agency was used in this analysis. The set of selected events for analysis is shown in Table 3-3.

Table 3-3: Events used for Archer Analysis – 39021 Cherwell at Enslow Mill

Event	Name	Source	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m^3/s)
A	Jan-92	Flow series inspection	09/01/1992	25/01/1992	408	30.05
B	Sep-92	AMAX series	23/09/1992	03/10/1992	252	38.23
C	Apr-93	Flow series inspection	09/04/1993	23/04/1993	354	27.61
D	Apr-98	AMAX series	08/04/1998	23/04/1998	375	114.00
E	Dec-99	AMAX series	21/12/1999	12/01/2000	540	37.66
F	Apr-00	Flow series inspection	01/04/2000	11/04/2000	261	31.83
G	Jan-03	AMAX series	19/01/2003	01/02/2003	321	28.06

Table 3-3: Events used for Archer Analysis – 39021 Cherwell at Enslow Mill

Event	Name	Source	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m^3/s)
H	Jul-07	AMAX series	20/07/2007	13/08/2007	591	85.54
I	Dec-08	AMAX series	13/12/2008	30/12/2008	426	28.36

Events used for calculation of average hydrograph shapes at 39021 (Cherwell at Enslow Mill) are shown in Figure 3-3.

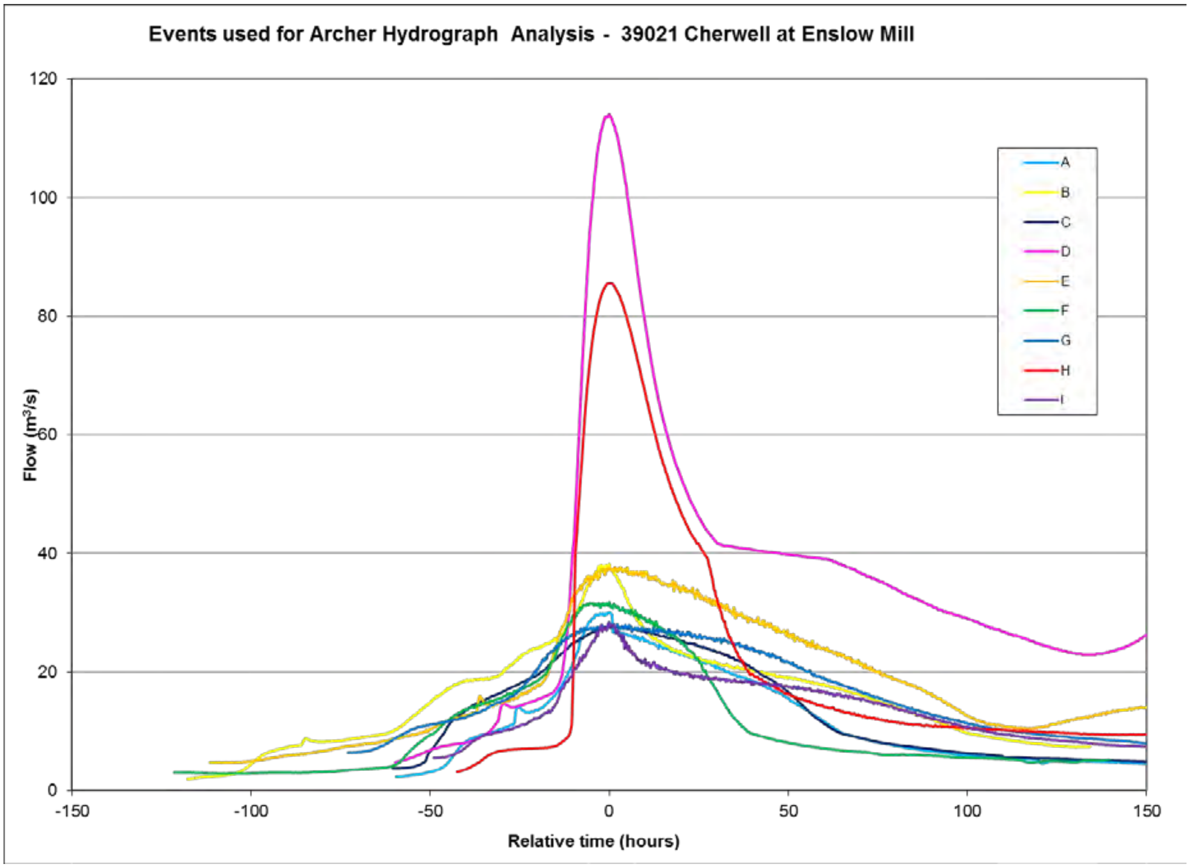

Figure 3-3: Event plots used for calculation of average hydrograph shape – 39021 (Cherwell at Enslow Mill)

Outputs of average hydrograph shape analysis for 39021 (Cherwell at Enslow Mill) are provided in Table 3-4.

Table 3-4: Hydrograph shape analysis 39021 Cherwell @ Enslow Mill

Hydrograph

Time (hrs)	Relative time (hrs)	% of Peak Flow (%)	Time (hrs)	Relative time (hrs)	% of Peak Flow (%)
-48.50	0.0	20	6.00	54.5	90
-46.75	1.8	30	13.50	62.0	80
-29.00	19.5	40	24.25	72.8	70

Table 3-4: Hydrograph shape analysis 39021 Cherwell @ Enslow Mill

Hydrograph

-18.00	30.5	50	42.00	90.5	60
-15.75	32.8	60	51.00	99.5	50
-12.75	35.8	70	60.50	109.0	40
-8.75	39.8	80	79.50	128.0	30
-7.00	41.5	90	123.50	172.0	20
0.00	48.5	100			

These results are plotted against inflows from the 2014 study in Figure 3-4

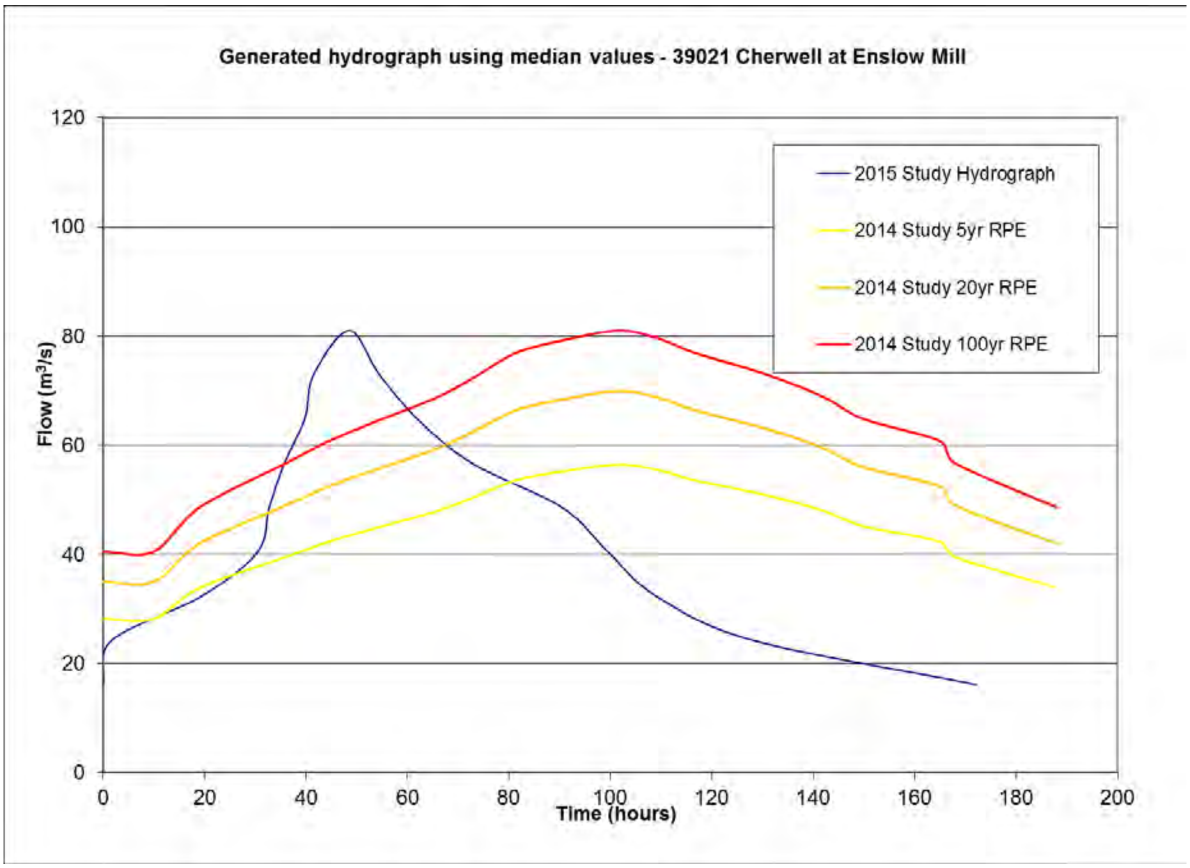

Figure 3-4: Generated hydrograph using median values (39021 Cherwell at Enslow Mill)

The hydrograph derived in the analysis, is as to be expected much peakier that the Sandford based hydrograph used in previous studies, and the updated hydrograph is considered to be more representative of recently observed events on the River Cherwell.

3.1.3 39034 Evenlode at Cassington

A 15 minute flow record from 1986 was used in this analysis. The set of selected events for inclusion in Archer's method analysis is shown in Table 3-5.

Table 3-5: Events used for Archer Analysis – 39034 Evenlode at Cassington

Event	Name	Source	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m^3/s)
A	Jan-88	Flow series inspection	22/01/1988	28/01/1988	150	24.72
B	Dec-89	Flow series inspection	13/12/1989	06/01/1990	588	27.82
C	Jan-93	AMAX series	10/01/1993	26/01/1993	402	32.56
D	Dec-93	Flow series inspection	12/12/1993	18/12/1993	163	17.63
E	Dec-95	AMAX series	20/12/1995	06/01/1996	432	24.43
F	Apr-98	AMAX series	09/04/1998	23/04/1998	342	28.37
G	Jan-99	Flow series inspection	15/01/1999	16/02/1999	780	31.71
H	Dec-99	AMAX series	21/12/1999	13/01/2000	546	27.93
I	Apr-00	Flow series inspection	02/04/2000	11/04/2000	216	21.96
J	Feb-01	AMAX series	12/02/2001	26/02/2001	348	26.85
K	Jan-03	Flow series inspection	29/12/2002	18/01/2003	498	23.22
L	Mar-07	Flow series inspection	04/03/2007	30/03/2007	642	22.76
M	Jul-07	AMAX series	20/07/2007	11/08/2007	543	75.46
N	Jan-08	AMAX series	11/01/2008	04/02/2008	570	27.60
O	Mar-08	Flow series inspection	15/03/2008	28/03/2008	303	24.24
P	Jun-08	Flow series inspection	03/06/2008	16/06/2008	330	19.83
Q	Dec-08	AMAX series	13/12/2008	11/01/2009	720	22.04

Events used for calculation of average hydrograph shapes at 39034 (Evenlode at Cassington) are shown in Figure 3-5.

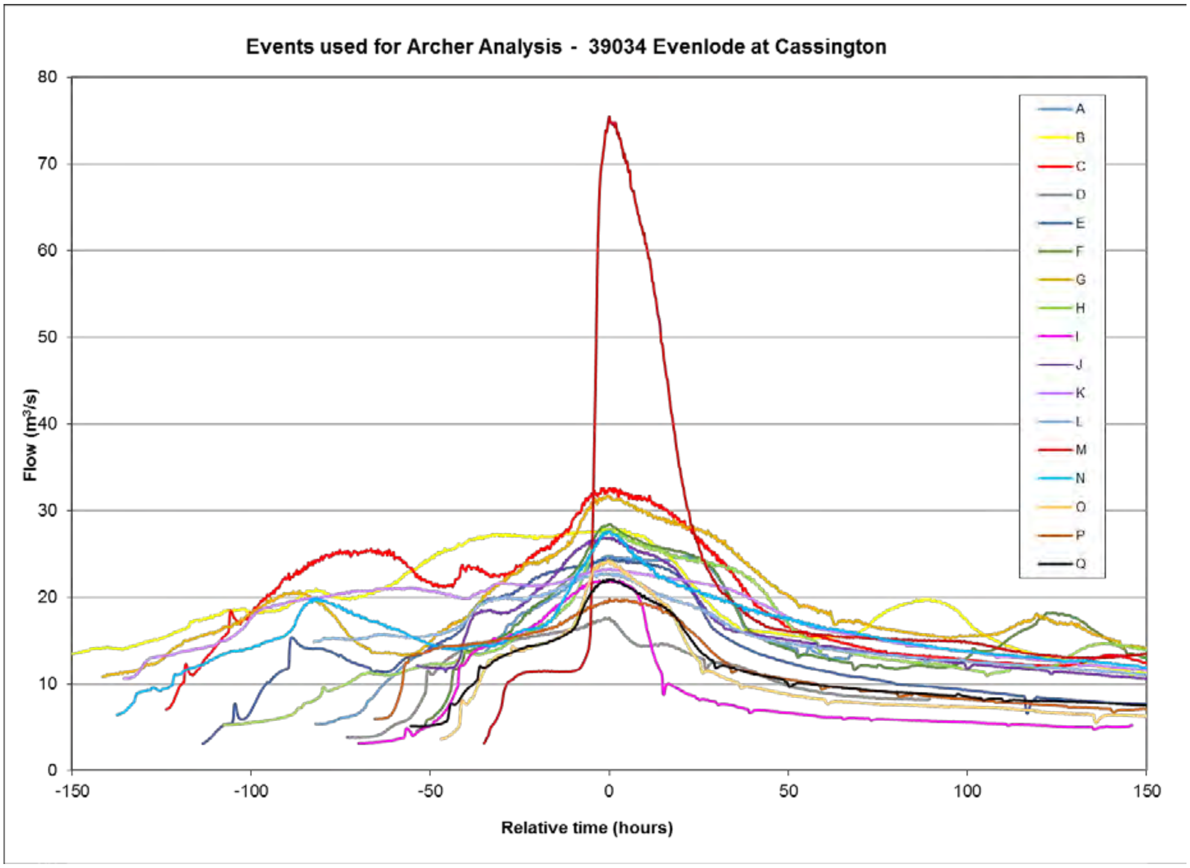

Figure 3-5: Event plots used for calculation of average hydrograph shape – 39034 (Evenlode @Cassington)

Outputs of average hydrograph shape analysis for 39034 (Evenlode at Cassington) are provided in Table 3-6.

Table 3-6: Hydrograph shape analysis 39034 (Evenlode at Cassington)

Hydrograph

Time (hrs)	Relative time (hrs)	% of Peak Flow (%)	Time (hrs)	Relative time (hrs)	% of Peak Flow (%)
-76.63	0.0	20	15.00	91.6	90
-68.25	8.4	30	23.50	100.1	80
-63.50	13.1	40	28.00	104.6	70
-49.88	26.8	50	37.25	113.9	60
-39.50	37.1	60	58.50	135.1	50
-28.75	47.9	70	106.25	182.9	40
-17.25	59.4	80	254.25	330.9	30
-9.50	67.1	90	318.25	394.9	20
0.00	76.6	100			

These results are plotted against inflows from the 2014 study in Figure 3-6.

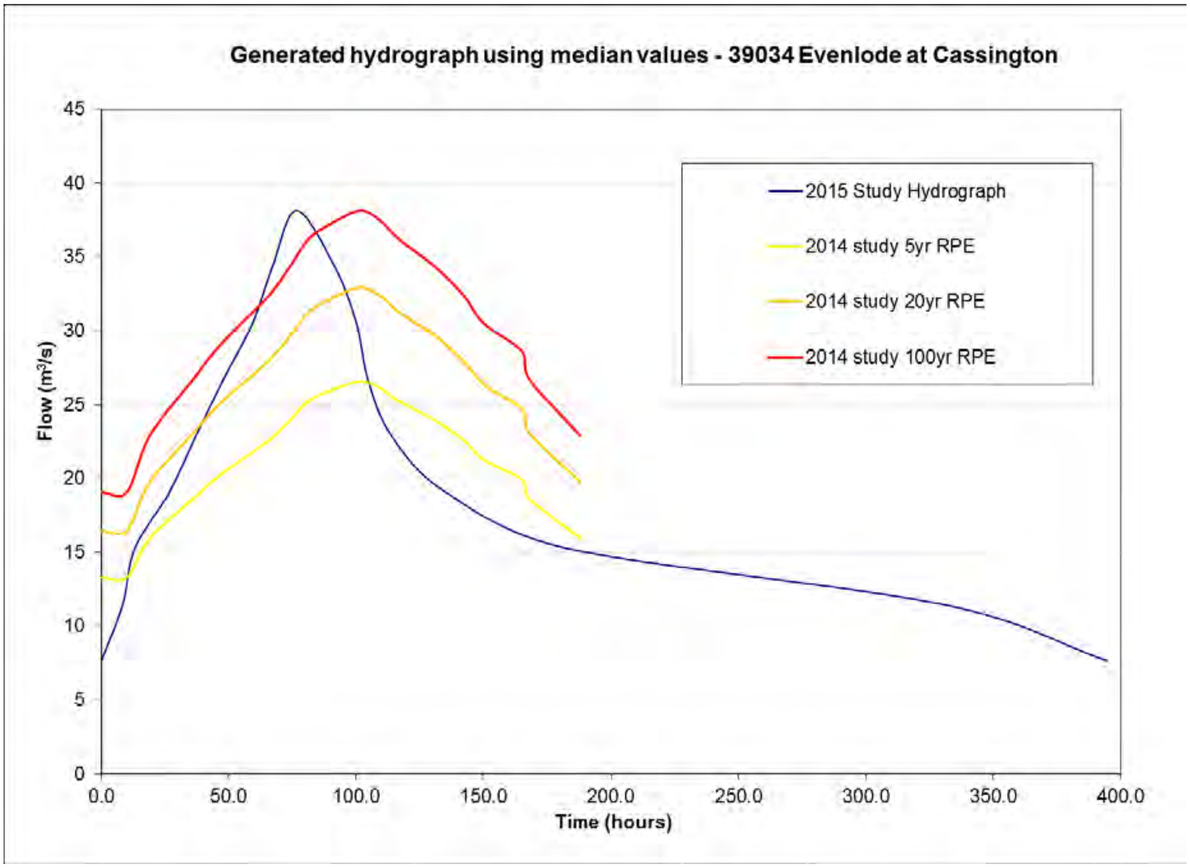

Figure 3-6: Generated hydrograph using median values (39034 Evenlode at Cassington).

It is noted that the generated hydrograph is shorter and more peaky than that used in the previous modelling study, and is considered to be more representative of flood flows on the River Evenlode. A sensitivity analysis was undertaken on the influence of the 1998 flood hydrograph on the final Archers estimate. Figure 3-6 shows that there is very little impact on excluding the 1998 event, apart from an increase in the time to peak.

3.1.4 39140 Ray at Islip

A 15 minute flow series from 1995 to the present was analysed. As it is known that the proximity of the gauge to the Cherwell confluence causes problems in larger events, the Cherwell series was inspected simultaneously, and only events on the Ray with relatively small events on the Cherwell were used. The set of events used in the analysis is shown in Table 3-7.

Table 3-7: Events used for Archer Analysis – 39140 Ray @ Islip

Event	Name	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m^3/s) on Islip
A	Feb-96	22/02/1996	01/03/1996	216	13.10
B	Apr-96 (1)	12/04/1996	21/04/1996	240	4.30
C	Apr-96 (2)	22/04/1996	30/04/1996	216	5.54
D	Jun-96	08/06/1996	18/06/1996	264	1.38

Table 3-7: Events used for Archer Analysis – 39140 Ray @ Islip

Event	Name	Data Start	Data End	Duration of event hydrograph (hrs) approx.	Peak flow (m³/s) on Islip
E	Feb-97	24/02/1997	07/03/1997	261	8.32
F	May-97	17/05/1997	31/05/1997	348	2.60
G	Feb-00	01/02/2000	04/02/2000	96	5.32
H	Apr-04	18/04/2004	27/04/2004	240	4.28
I	May-04	03/05/2004	12/05/2004	210	6.20
J	Aug-12	05/08/2012	14/08/2012	228	4.27
K	Mar-13	07/03/2013	15/03/2013	216	6.23
L	Apr-13	11/04/2013	23/04/2013	312	4.36

Events used for calculation of average hydrograph shapes at 39140 (Ray at Islip) are shown in Figure 3-7.

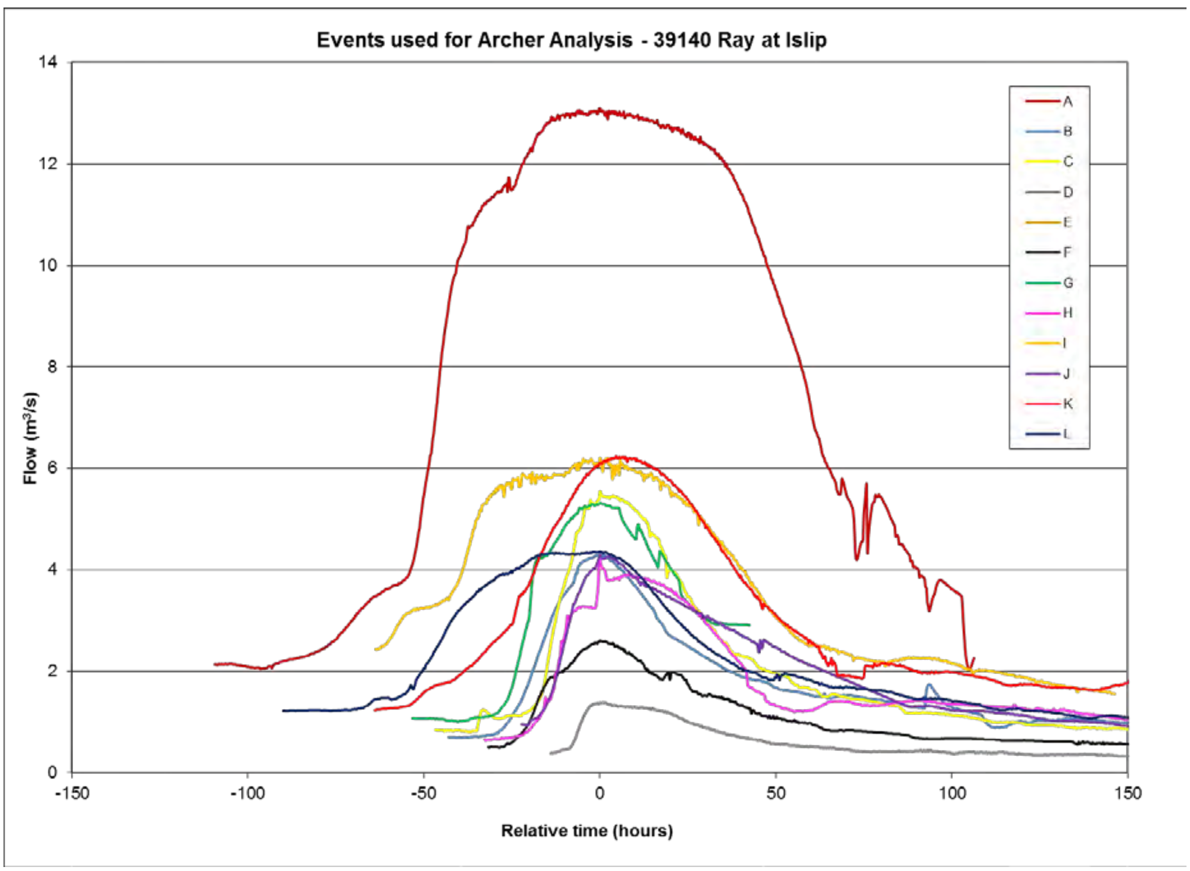

Figure 3-7: Event plots used for calculation of average hydrograph shape – 39140 (Ray at Islip)

Outputs of average hydrograph shape analysis for 39140 (Ray at Islip) are provided in Table 3-8.

Table 3-8: Hydrograph shape analysis 39140 (Ray at Islip)
Hydrograph

Time (hrs)	Relative time (hrs)	% of Peak Flow (%)	Time (hrs)	Relative time (hrs)	% of Peak Flow (%)
-27.75	0.0	20	11.25	39.0	90
-23.50	4.3	30	21.25	49.0	80
-22.00	5.8	40	27.88	55.6	70
-20.13	7.6	50	33.63	61.4	60
-18.38	9.4	60	41.63	69.4	50
-15.75	12.0	70	61.25	89.0	40
-11.38	16.4	80	85.00	112.8	30
-6.88	20.9	90	171.25	199.0	20
0.00	27.8	100			

These results are plotted in Figure 3-8

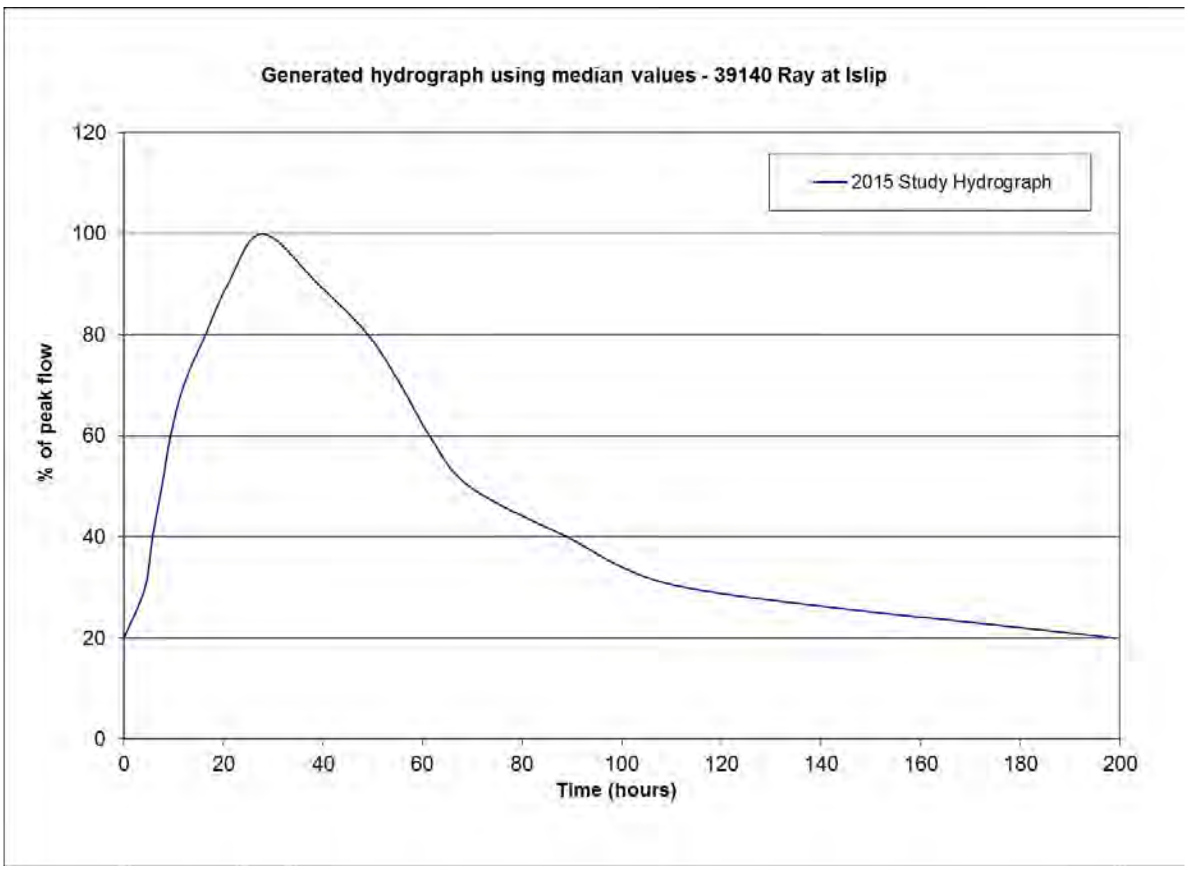

Figure 3-8: Generated hydrograph using median values (39140 Ray at Islip).

There is uncertainty in the shape of the hydrograph due to the influence of the River Cherwell on flow records at the Islip gauge. We have aimed to minimise this by analysing only those events which do not appear to correspond with high flows on the River Cherwell. By doing this we are considering uninfluenced hydrographs, but they may not be representative of larger flood flows in the catchment.

The Ray hydrograph is not input directly to the 1D-2D Oxford FAS hydraulic model. Instead, both the Ray and Cherwell inflows are routed using the Environment Agency's flood forecasting model to derive an inflow boundary at the River Cherwell under the A40. The relative timings of the Cherwell and Ray hydrograph peaks will be investigated to assess their impacts on flows in the River Thames.

3.1.5 Strengths and Weaknesses

This method benefits from using observed hydrographs to generate a design inflow for each of the main tributaries, when the limits relating to standard rainfall-runoff design hydrograph methods are exceeded. In practice as it is an average of observations; the resultant design inflow will never be as peaky as the most flashy observed event, or have a recession as long as the longest lasting flood event. The selected design hydrograph needs to be considered in the context of flood mechanisms within the catchment and if these are captured within it. (i.e., is rate of raise important or hydrograph volume).

3.2 Peak Timing Analysis

An assessment was undertaken to determine relative timings to be used for the various inflow hydrographs derived. For a range of events, the relative timings of recorded peak flows for each of the watercourses (Ray, Cherwell, Evenlode and Thames at Eynsham) were calculated. Initially, the events used for Archer's analysis for the various subcatchments were considered. Subsequent to this, the whole flow record was inspected to select additional events.

Details of the events used and the relative timings of hydrograph peaks for each analyses event can be found in Appendix D. A summary of the analysis is shown in Table 3-9.

Table 3-9: Summary of Relative Timing of Peaks Analysis
Relative to the first observed peak at each of the four gauging stations

		Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip
Number of events with identifiable peak		33	45	44	18
Time (hrs)	**Mean**	15.71	14.73	3.82	5.24
	Median	9.75	9.25	0.12	1.25
Relative time after first peak (hrs)	**Mean**	11.89	10.90	0.00	1.41
	Median	9.63	9.13	0.00	1.13

Based on Table 3-9, the following conclusions have been drawn. On average:

- Evenlode at Cassington is the first to peak
- Ray at Islip peaks approximately an hour after Evenlode at Cassington
- Thames at Eynsham peaks approximately ten hours after Evenlode at Cassington
- Cherwell at Enslow peaks approximately ten hours after Evenlode at Cassington

As a result, the preliminary design runs have been set up with the Evenlode peaking first, then the Ray, one hour later, with the Cherwell and Thames peaking a further nine hours later.

3.3 Intermediate Inflows

With the Oxford FAS model there are an additional four hydrological inflows to the ones discussed already in this section. These are Sanug, Iffug, 47.SL and HD07.023 which represent inflows from smaller catchments and inter station inflows. More details on each of the inflow can be found in Appendix C.

In earlier versions of the model, these inflows had the same hydrograph shape and the major tributaries, and were scaled to a factor of 0.9% of the total of all inflows (equivalent to 3.29% of the Cherwell inflow) in the 2014 study. This factor was based on the contributing catchment area from these smaller inflows.

In this analysis the Cherwell hydrograph shape has been selected, as it is the peakiest of all the inflow hydrographs, and will provide a more representative shape for these smaller catchments and urbanized contributions. In the absence of any additional hydrometric data the 3.29% scaling factor for each inflow has been retained.

3.4 Routed Flows

The majority of analysis discussed in the report has been carried out at gauged locations. The 1D-2D hydraulic model does not extend to the locations of the gauging stations, so to route the flows to generate the necessary boundaries the Environment Agency's Oxford Flood Forecasting model was used. The benefit of using the flood forecasting model is that it has a much shorter run time. Comparisons have been undertaken between the flood forecasting model and linked 1D-2D model and they have been shown to produce similar outflows at Sandford.

The results illustrated below are hydrographs derived at Sandford using the flood forecasting model (2015 FFM), the linked 1D-2D hydraulic model (2015 PAR) and are compared with the previous design hydrographs obtained from the Mott MacDonald analysis. The 5, 20 and 100 year return period events are presented, and peaks compared with those derived from the flood frequency analysis in Section 2.

In the FFM and PAR models, the preliminary X year return period scenario at Sandford is derived using the X year return period inflows for all inflows, using the hydrograph derived using Archers method and the offset timings identified in Section 3.2.

Overall there is a good consistency in the hydrograph shapes, with the CH2M derived hydrographs being longer and peaking later, as a result of the variation of inflow shapes and timings. The 5 year return period peak flows at Sandford agree well with the flood frequency estimate, though for the 20 and 100 year return period events, the models are over-estimating when compared to the flood frequency estimates. Further analysis has been undertaken, looking at the relative timings of inflows and the relative magnitudes, using the flood forecasting model, to assess the impact at Sandford (see section 3.5 and 3.6).

The focus is on ensuring representative design flows are modelled at Sandford, as it is the location where all flows are combined in the River Thames. When looking at locations between Eynsham and Sandford on the River Thames there is a complex network of distributaries which increases the challenges in accurately assessing flood frequency across the range of return periods and assessing the performance of the hydraulic model.

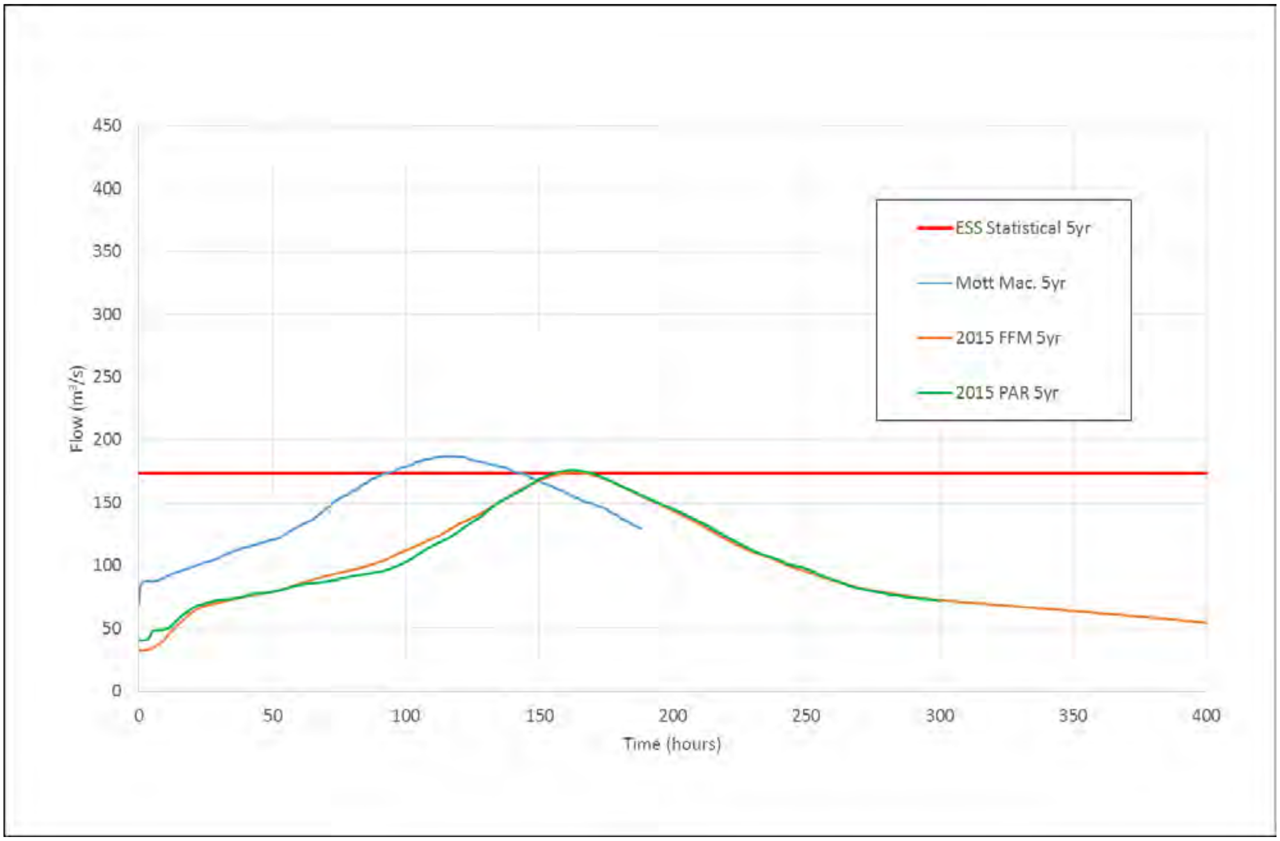

Figure 3-9: Comparison of 5 year return period modelled flows at Sandford

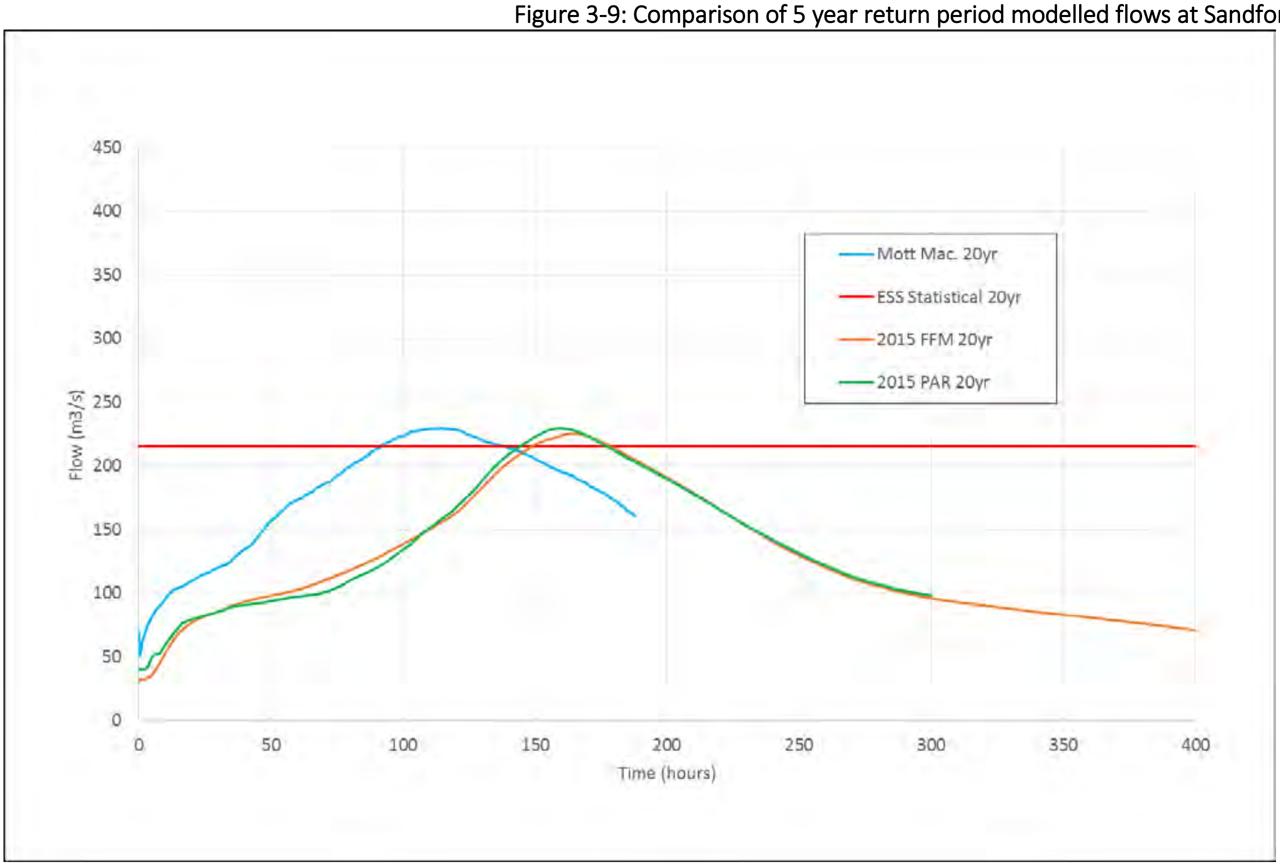

Figure 3-10: Comparison of 20 year return period modelled flows at Sandford

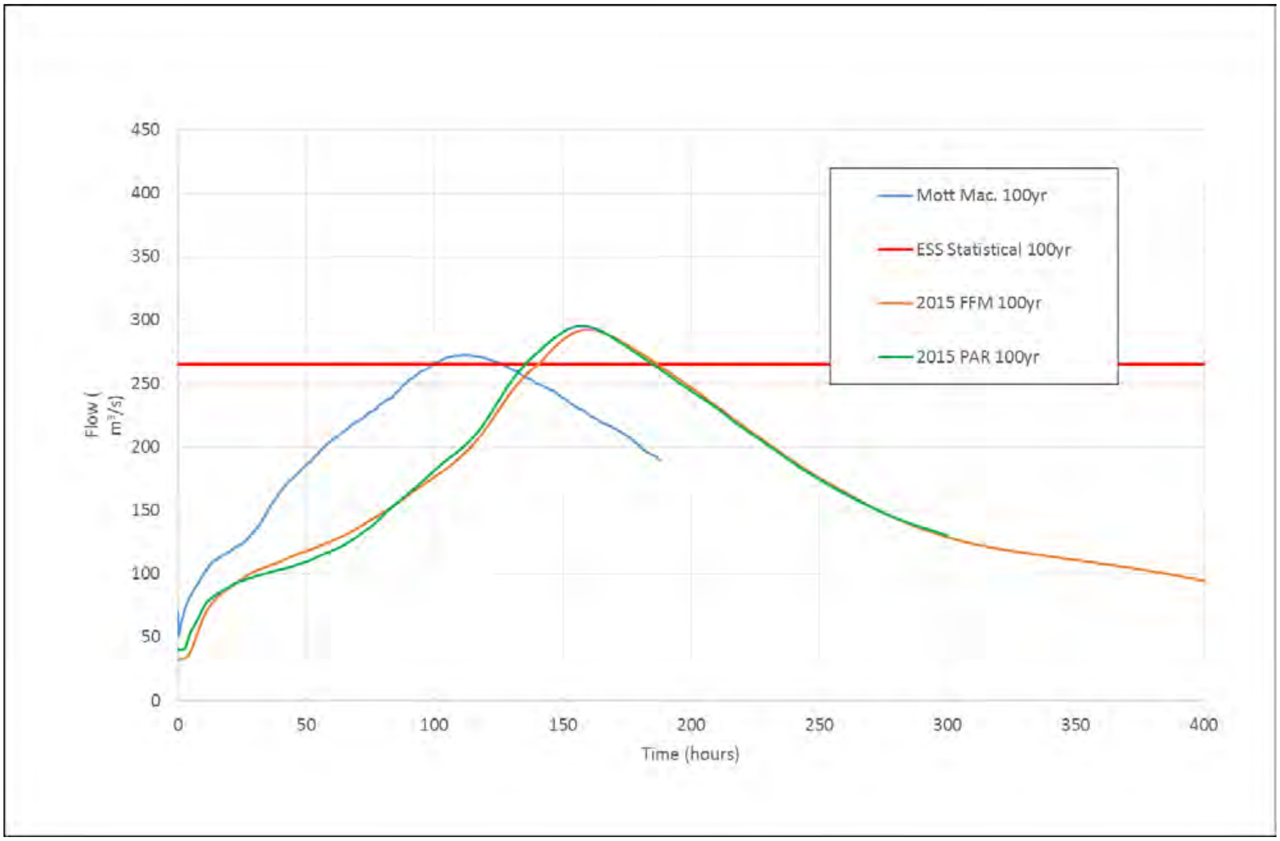

Figure 3-11: Comparison of 100 year return period modelled flows at Sandford

3.5 Hydrograph Timing Sensitivity

In this report so far, all comparisons have been made using an average of inflows. It has also been acknowledged that understanding of the sensitivity of inflow hydrograph assumptions will be key to understanding the benefits of any proposed flood alleviation scheme. In this section the impact of varying the relative timings of the inflow hydrographs is presented.

Three sensitivity tests were undertaken, these were based on peak flow timings from observed events. The three scenarios are:

- **Coincident peaks:** All tributary inflow peaks are adjusted so they join the River Thames as the Thames is in peak flow. This results in the largest flow at Sandford.
- **Early non-coincident peaks:** All tributary inflow peaks arrive at their confluence with the Thames at the earliest they have been observed relative to the Thames peak. This assumes a relative peak timings of:
  - Cherwell: 63.25 hours before the Thames peak
  - Evenlode: 70.5 hours before the Thames peak
  - Ray: 25.25 hours before the Thames peak
- **Late non-coincident peaks:** All tributary inflow peaks arrive at their confluence with the Thames at the latest they have been observed relative to the Thames peak. This assumes relative peak timings of:
  - Cherwell: 40 hours after the Thames peak
  - Evenlode: 27.75 hours after the Thames peak
  - Ray: 14 hours after the Thames peak

A summary of the variation in the inflow peaks and their timings for the 100 year return period event is shown in Figure 3-12

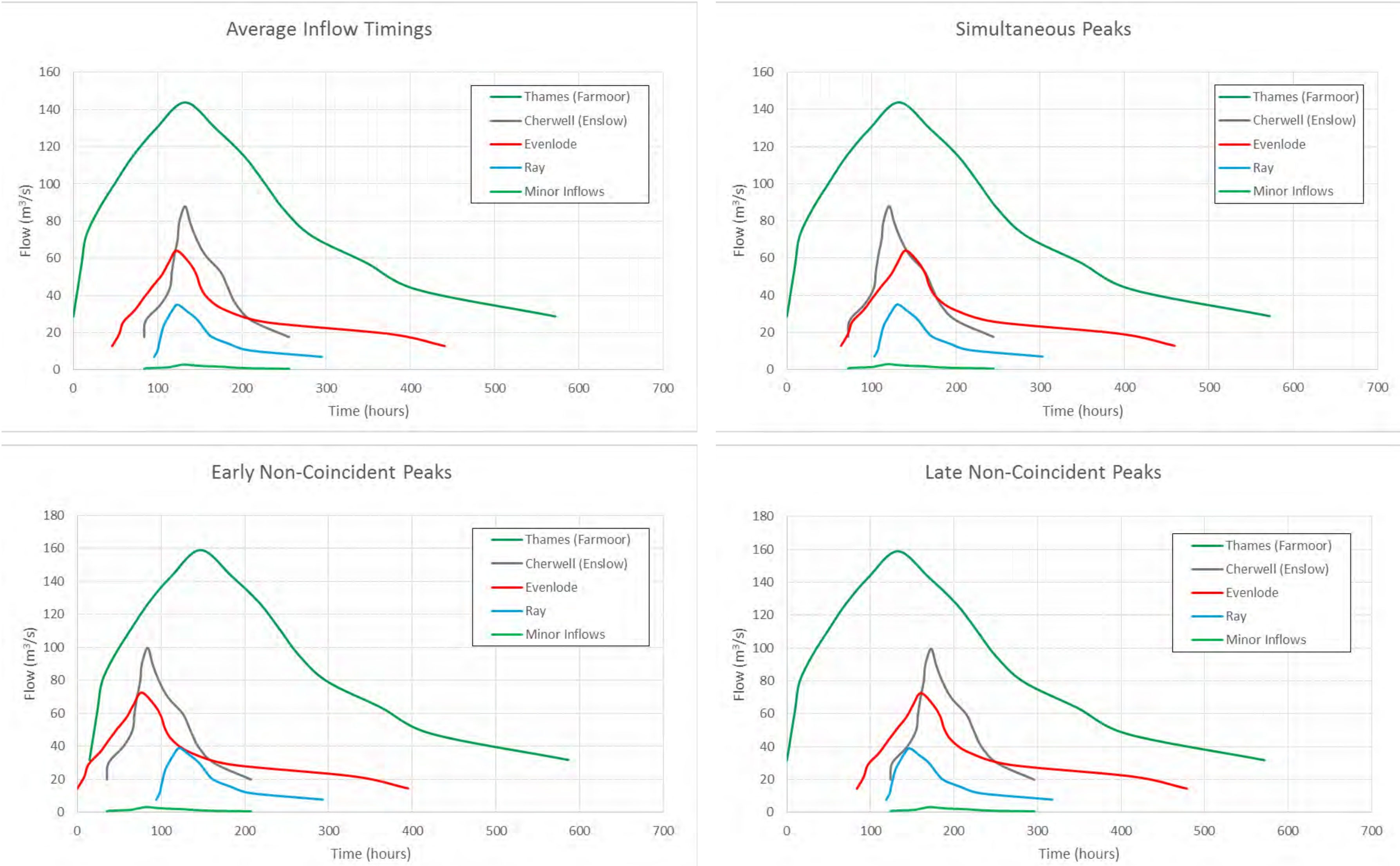

Figure 3-12: Hydrograph inflow timing scenarios

The impact of changing the inflow timings is shown for three return periods (2, 20 and 100 years) in Figure 3-13, Figure 3-14 and Figure 3-15. As expected there is a variation in hydrograph shape in Sandford, both in the timing and relative sizing of the peaks, though the overall flood volume remains the same. Due to the relative sizes of the inflows, Thames inflow at Eynsham will always dominate the hydrograph shape at Sandford.

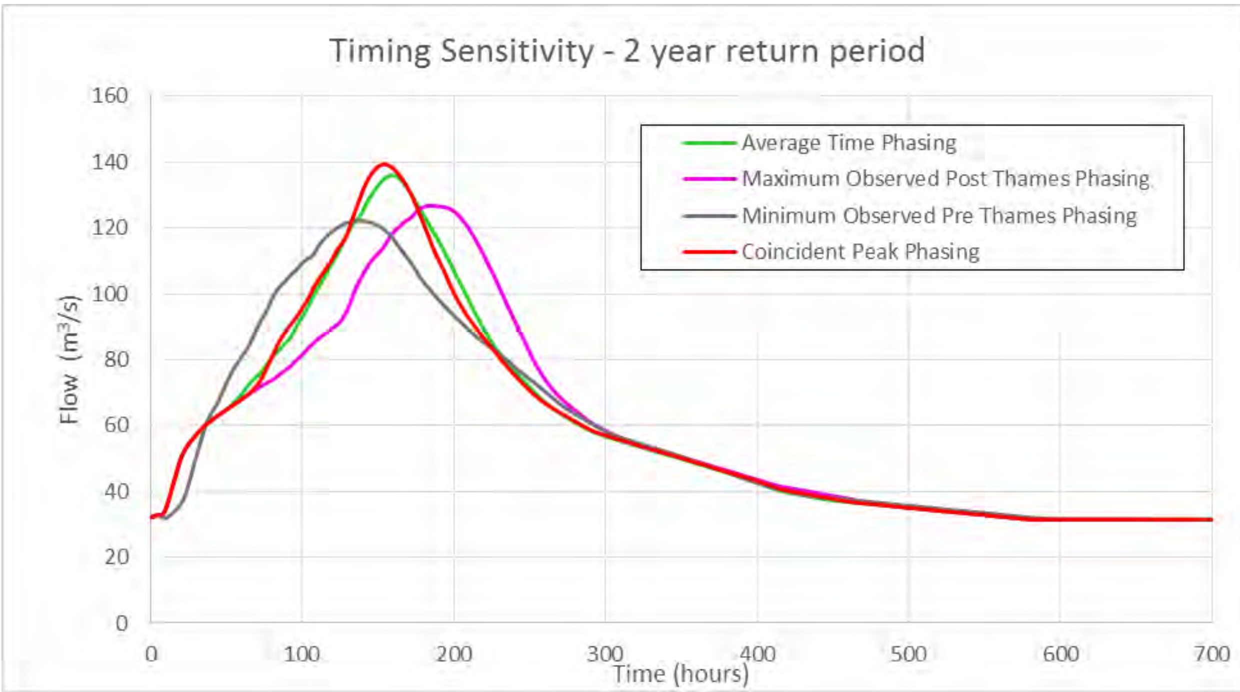

Figure 3-13: Impact of inflow timings on Sandford Hydrograph - 2 year return period

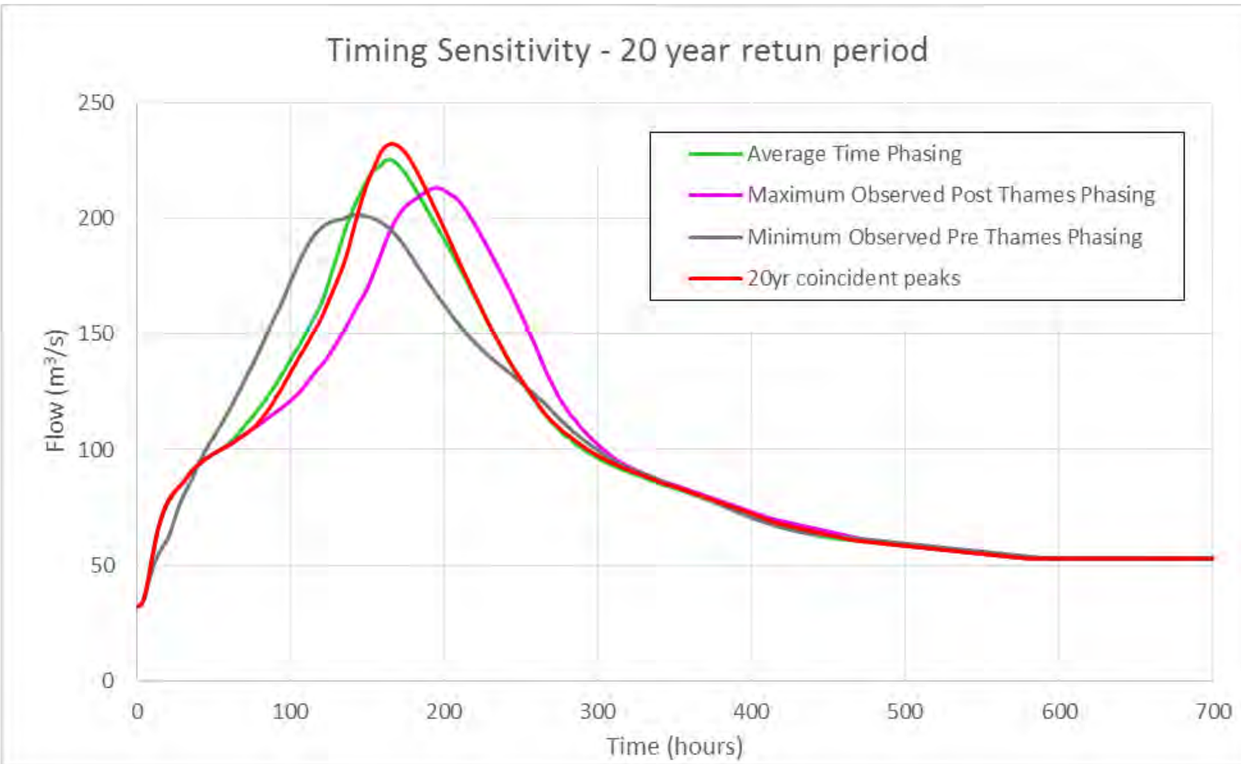

Figure 3-14: Impact of inflow timings on Sandford Hydrograph - 20 year return period

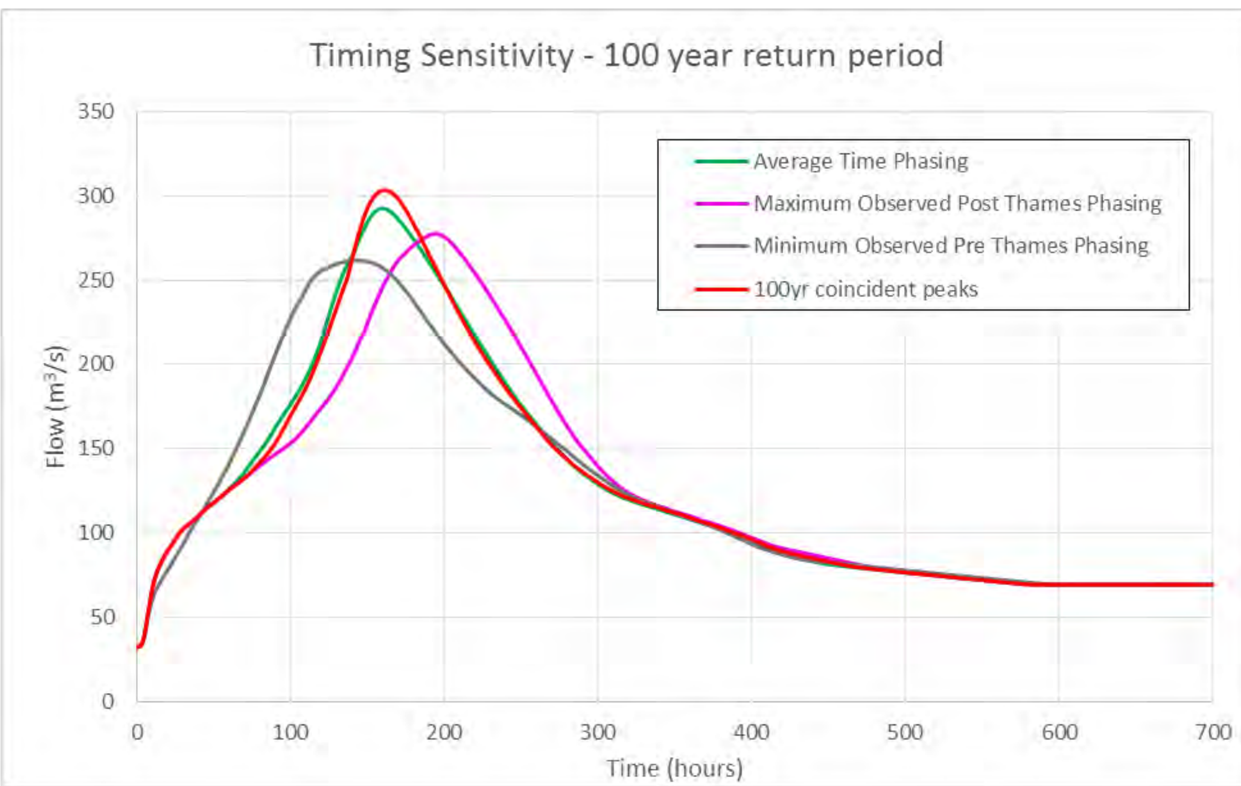

Figure 3-15: Impact of inflow timings on Sandford Hydrograph - 100year return period

3.6 Inflow peak sensitivity

An investigation was undertaken into the percentage of total peak flow at Sandford which each tributary contributes. The relative sizes of inflows at the gauging stations used to derive design flows are shown in Figure 3-16. Magnitude of total peak flow at all four gauges is represented on the x-axis, with relative percentages of each inflow on the y-axis. Magnitudes of peak flows for design events have been derived from statistical analysis at each station. Magnitudes of peak flows for observed events have been obtained from flow records at each station. For observed events, it has only been possible to show events for which gauged peak flows are available at all four stations during an event, as it is not possible to calculate a percentage of total flow when not all records are available. Figures are also presented in Table 3-10and Table 3-11.

As expected the River Thames in the majority of events, provides the largest element of flow (the exception is the Easter 1998 event). Thames provided a larger percentage of the total peak flow in observed events than was the case in design events. It was noted that the Thames provided an average of 55.29% of total peak flow in observed events, and 44.62% of total peak flow in design events.

Although the observed data shows a range of flow splits, as expected over a large catchment, it is noted that the design inflow assumptions for the tributaries demonstrate a consistency with the observed data. Though from reviewing the information in Figure 3-16 there is an opportunity to vary the relative contribution from each of the tributaries should the need arise.

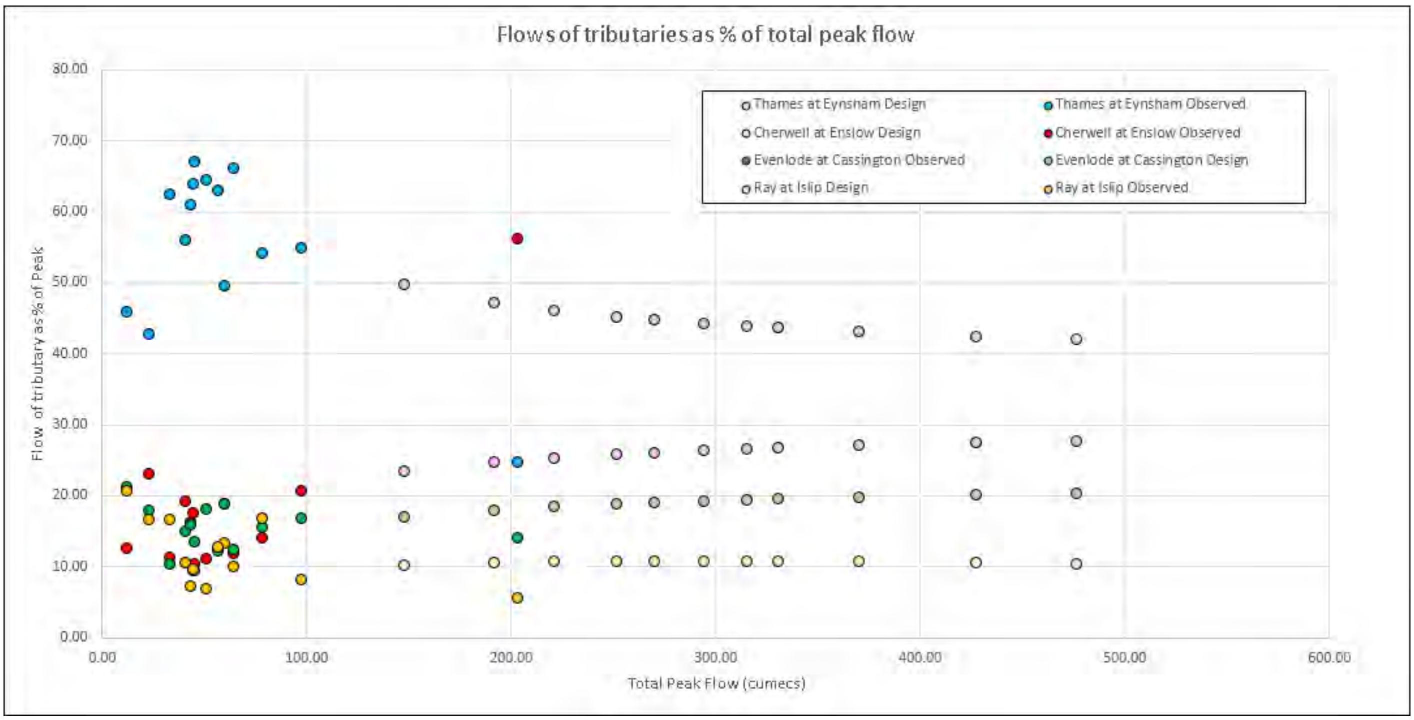

Figure 3-16: Relative sizes of inflows at the gauging stations used to derive design flows

Table 3-10 Tributary peak flow as % of Sandford Peak Flow - Observed Events.

		Peak Flow (m^3/s) at Stations:				TOTAL PEAK FLOW	% of Peak Flow (m^3/s) at Stations:			
		39008 Thames at Eynsham	39021 Cherwell at Enslow	39034 Evenlode at Cass.	39140 Ray at Islip		39008 Thames at Eynsham	39021 Cherwell at Enslow	39034 Evenlode at Cass.	39140 Ray at Islip
Event	**1996 02 (1)**	29.80	11.29	11.21	7.89	**60.19**	49.51	18.76	18.62	13.11
	1996 02 (2)	42.60	11.00	12.20	13.10	**78.89**	54.00	13.94	15.46	16.60
	1996 04 (1)	30.70	4.74	6.16	4.30	**45.90**	66.89	10.33	13.41	9.37
	1996 04 (2)	21.00	3.76	3.44	5.54	**33.74**	62.24	11.14	10.20	16.42
	1997 05	5.80	1.59	2.67	2.60	**12.65**	45.84	12.53	21.08	20.55
	1998 01	53.60	20.06	16.27	7.93	**97.86**	54.77	20.50	16.63	8.10
	1998 03	33.00	5.64	9.22	3.47	**51.33**	64.29	10.99	17.95	6.76
	1998 04	50.10	114.00	28.37	11.10	**203.57**	24.61	56.00	13.94	5.45
	1998 12 (1)	42.70	7.61	7.96	6.43	**64.70**	66.00	11.76	12.30	9.94
	1999 10	23.10	7.87	6.11	4.30	**41.38**	55.82	19.02	14.77	10.39
	1999 11	26.40	7.03	6.88	3.12	**43.43**	60.79	16.19	15.84	7.18
	2000 02	35.90	7.11	6.92	7.23	**57.17**	62.80	12.44	12.11	12.65
	2001 11	9.83	5.30	4.11	3.79	**23.03**	42.69	23.03	17.83	16.46
	2004 04	28.80	7.87	4.18	4.28	**45.13**	63.81	17.44	9.26	9.48
	Average	-					55.29	18.15	14.96	11.60

Table 3-11: Tributary peak flow as % of Sandford Peak Flow - Design Events

		Return Period Event (RPE)										Average
		2	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**200**	**1000**	
Eynsham	**Peak Flow (m^3/s)**	73.64	90.34	101.70	113.36	120.51	129.99	137.93	143.82	158.96	200.07	-
Enslow Mill		34.65	47.18	55.77	64.62	70.08	77.33	83.43	87.96	99.64	131.62	
Cassington		25.00	34.21	40.51	47.00	51.00	56.30	60.76	64.07	72.59	95.89	
Islip		14.94	20.05	23.39	26.72	28.72	31.32	33.46	35.03	38.99	49.28	
TOTAL PEAK FLOW		**148.23**	**191.77**	**221.36**	**251.70**	**270.30**	**294.93**	**315.58**	**330.88**	**370.17**	**476.86**	
Eynsham	**% Peak Flow**	49.68	47.11	45.94	45.04	44.58	44.07	43.71	43.47	42.94	41.96	44.62
Enslow Mill		23.38	24.60	25.19	25.68	25.93	26.22	26.44	26.58	26.92	27.60	25.99
Cassington		16.87	17.84	18.30	18.67	18.87	19.09	19.25	19.36	19.61	20.11	18.90
Islip		10.08	10.45	10.57	10.61	10.62	10.62	10.60	10.59	10.53	10.33	10.49

The flow splits shown above are comparable to those used by B&V in their study and reproduced in Table 3-12 below.

Table 3-12: B&V 2009 subdivision of design hydrographs
Reproduction of Table 6.2 from B&V 2009

Catchment	**Area (km²)**	**Percentage of total runoff volume at Sandford**
Thames at Pinkhill Lock	1608	56.0
Thames at Eynsham Lock	1627	56.6
Evenlode at Cassington	427	12.7
Cherwell at Oxford	908	27.0
Local runoff	124	3.7
Thames at Sandford	3086	100.0

Reviewing the observed data, it is clear that there is a variable contribution of tributary inflow for each event. A sensitivity test was therefore undertaken using the 1D flood forecasting model to determine the effect of modifying the percentage of peak flow that each tributary provided in design events on the design hydrograph at Sandford. As the River Thames is the dominant component of inflows it was decided to base the sensitivity of the contribution around the Thames inflow at Eynsham. Four scenarios were selected for Thames @ Eynsham contribution:

- 31.75% (minimum observed contribution)
- 43.5% (based on a similar figure to the average for design events)
- 55.25% (based on a similar figure to the average for observed events)
- 67% (maximum observed contribution)

Analysis was carried out for the 100 year return period event only. To derive the contribution from the other tributaries the following was carried out:

- Peak inflows for all tributaries was summed
- Thames peak flow derived using the scenario percentage
- For the remaining inflows peaks were scaled up/down, as required, in the same ratio with each other until the new tributary total peak flows matched the original value.

The results of this investigation are presented in Figure 3-16. It is noted that the effect on total flows at Sandford is small, though there is a noticeable variation in hydrograph volume.

It is recommended that a set of sensitivity runs are identified varying both the timing and relative inflow contributions in order to fully assess the performance of any proposed flood alleviation scheme for Oxford.

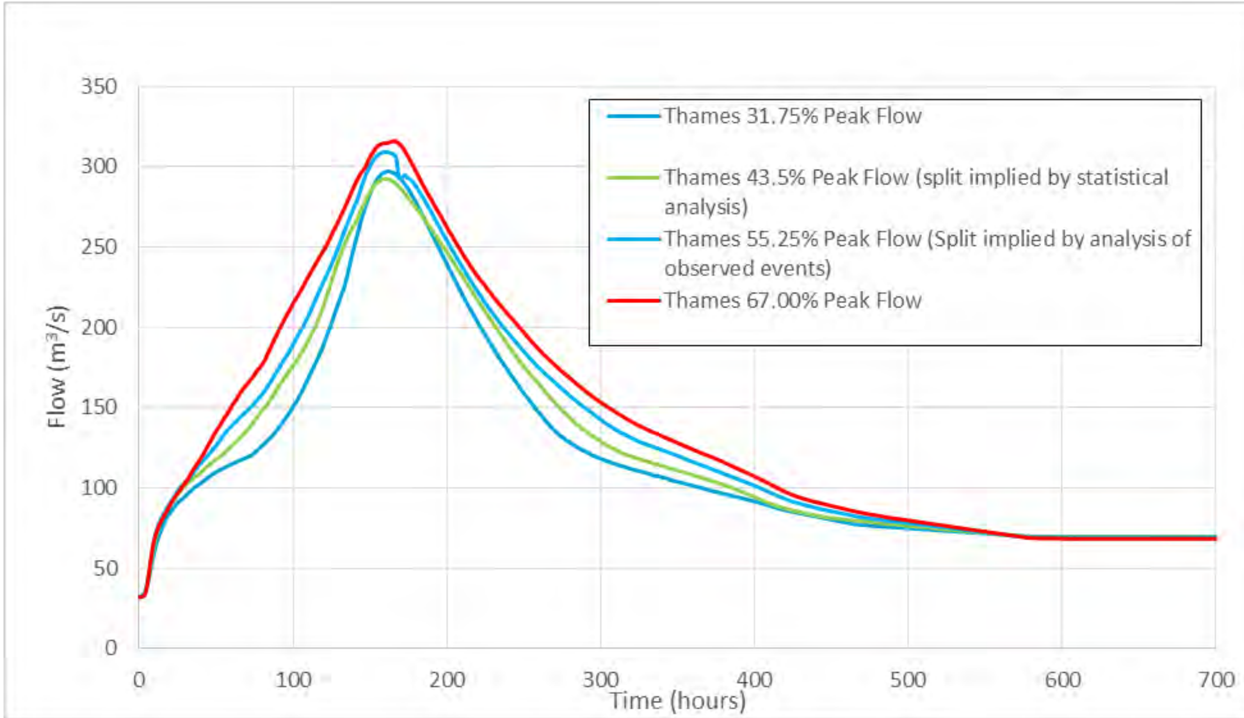

Figure 3-17: Impact of varying flow inflow contribution on the 100 year return period event at Sandford.

Conclusions and recommendations

4.1 Conclusions

The review and update of the hydrology for the Oxford FAS model has achieved the following:

- Increased confidence in the flood frequency analysis, by extending the statistical analysis to cover all of the main inflows. This has shown a logical pattern in flood growth factors and has helped to confirm the robustness of the flood estimates at Sandford, which are key to the study.
- Increased confidence in the inflow design hydrographs, by undertaking analysis of observed events at each station, instead of disaggregating a design hydrograph derived at Sandford. This is particularly important, given that the scheme will operate to improve conveyance of Thames flows (excluding the Cherwell) through the western floodplain. By undertaking our analysis, there is now greater confidence in the flood flows and overall volumes that will be routed through the hydraulic model at different points.
- Despite the additional work, there remains inherent uncertainty in the design flows. In particular, there is uncertainty associated with:
  - The magnitude of the peak flows estimated for each return period.
  - The coincident timing and magnitude of the assumed design flood adopted on each tributary for each return period (for example, many different combinations of inflows could provide a 1 in 100 year peak at Sandford).
- The design hydrograph flood volumes generated at Sandford have been compared with B&V 2009 detailed flood volume analysis to ensure consistency with observed events and the findings are presented in Appendix F. The flood volume estimates lie with a ±10% range across all scenarios, demonstrating a good consistency in estimates, and showing that the design flood volumes are representative of events observed in the River Thames through Oxford.

4.2 Recommendations

A few areas for further investigation have been listed in this report. The main recommendations for additional work are:

- Further investigation into the sensitivity of the proposed scheme to:
  - Changes in the baseline assumptions regarding relative timings of the various inflow tributaries
  - Scaling of one or more on the inflow peaks, whilst remaining within the bounds of observations
  - Uncertainties in the flood frequency estimates, especially at extremes (i.e. > 1 in 100 year)
  - Impact of varying flood volumes on the preferred flood alleviation scheme
- The flood volume analysis was carried out using the flood forecasting mode, this should be revisited once outputs from the 1D-2D hydraulic model are available, to confirm the volume estimates remain consistent.

The results of the sensitivity analysis will be presented in the Final Hydraulic Modelling Report.

Appendix A
Summary of Previous Studies

Previous Oxford Studies and Investigations

Study Stage	Year	Main Actions
Peter Brett Associates (PBA) Studies	1992	PBA develop an initial hydraulic modelling to identify potential flooding problems to proposed Oxford Science Park development at South Hinksey.
	1994-1995	PBA make model improvements - “comprehensive” flood alleviation scheme, including flow transfer from the Thames into the Seacourt Stream at Wolvercote and localised flood defence works elsewhere might be viable.
	1997	PBA confirms that the benefit-cost ratio of a “comprehensive scheme” should be greater than one, but recommend that further investigations need to be carried out.
	1998	PBA produce two reports which: 1. Confirms the feasibility of a localised flood alleviation scheme at the Lover Wolvercote. 2. Further investigations into the feasibility of flood alleviation measures at New Botley, Osney and Hinksey. Apart from South Hinksey, flood alleviation measures were considered to be cost beneficial.
	Dec 2000	PBA undertake further works to check feasibility of flow transfer options for flood alleviation in Botley and Osney.
Inception Stage	Dec 2001	Binnie, Black and Veatch and Lewin, Fryer & Partners review requirement for a Strategy and the works PBA have understand since 1992.
	Jan 2002	PBA hydrology review concludes that improved flow transfer from the Thames to the existing west bank channels not beneficial. The hydraulic model needs to be refined before used in detailed feasibility study into localised flood defence works at New Botley, Osney and New Hinksey.
	Feb 2002	Binnie, Black and Veatch and Lewin, Fryer & Partners appointed to carry out the work
	May 2002	Inception report produced by Binnie, Black and Veatch and Lewin, Fryer & Partners. It confirms the need for Strategic approach.
	May – Oct 2002	Over 100 possible measures/options were proposed by the project team. All these measures were considered and reviewed within a series of three workshops.
	Oct 2002	1st Workshop - included internal/external consultees. 57 measures/options were considered on their environmental, technical and economic feasibility/viability. 45 measures/options were taken forward.
	Feb – Mar 2003	2nd Workshop - further assessment was undertaken, including a questionnaire survey sent out to 3664 people, 461 responses were received. 40 measures/options were taken forward.
	Dec 2003	3rd Workshop. A short-list of options of were produced: Do nothing, Maintenance options, Improved conveyance options, Coping with existing flood levels and Damage limitation options

APPENDIX A

Previous Oxford Studies and Investigations

Study Stage	Year	Main Actions
Strategy Plan	Dec 2003	Strategy Plan produced and SEA Public Consultation
Strategy	2004 - 2005	Strategy recommended for approval by NRG, but it was n0t signed off Strategy recommended further investigation into: conveyance options, upstream storage and other strategic options. Some options were not recommended for further consideration. SEA/Strategy recommended that 'additional' and 'shortterm' management responses be included in final option.
	2005 - 2006	Feasibility commenced in 2 Stage approach Agreed Do Nothing and Do Minimum assumptions Stage 1 - assessment of 18 Western Conveyance options Preferred alignment agreed with internal consultees. Submission of revised Strategy based on update of 2004 Strategy Towles Mill Sluice option PAR
	Aug 2006 – Mar 2007	Submission of Form G2 to NRG to continue development of Strategy.
	2007	Towles Mill Sluice constructed Approval of Form G2 Commenced accelerated programme
	2008	Reviewed and consulted on the full range of flood risk management responses as detailed in the Flood Foresight Report. Additional review of Upstream Storage. Short Term Measures PAR Implementation of Demountable defences
	Dec 2009	Oxford Flood Risk Management Strategy published
Updated Modelling	2013 - 2014	Mott MacDonald and JBA undertake and review and update of hydrological analysis and hydraulic model of the Oxford Strategy model.
Funding	July 2014	Funding approved for Oxford Flood Alleviation Scheme
Design	May 2015	Halcrow (A CH2M Company) commissioned by the Environment Agency to undertake the detailed design of the Flood Alleviation. Includes further review and updates to Oxford hydraulic model and hydrology.

Table based on Appendix A.1 from Oxford Flood Mapping Study, Technical Report, 2009

Appendix B
AMAX data

APPENDIX B

AMAX records

Peak flow (m^3/s)

Water Year	Thames @ Eynsham	Thames @ Farmoor	Cherwell @ Enslow Mill	Evenlode @ Cassington	Ray @ Islip	Thames @ Sandford	Thames @ Pinkhill
1891							97.9
1892							95.2
1983							91.3
1894	136.20					278.7	152.8
1895	56.11					66.2	84.7
1896	72.12					200.1	113.6
1897	64.65					99.2	91.3
1898	74.55					163.8	102
1899	90.42					221.8	121.4
1900	78.74					189.2	106.2
1901	59.45					70	67.8
1902	153.21					229.3	156.7
1903	92.32					217.3	124.6
1904	57.35					78.4	72.4
1905	66.65					111.8	86.4
1906	63.76					109.7	80.5
1907	90.42					189.2	116.7
1908	61.59					71.6	78
1909	77.05					129.4	95.2
1910	95.22					214.4	116.7
1911	85.79					189.2	109.1
1912	83.10					172.4	106.2
1913	64.65					102.6	86.4
1914	97.19					211.5	121.4
1915	87.62					200.1	113.6
1916	78.74					154.3	97.9
1917	90.42					207.2	113.6
1918	87.62					178.7	109.1
1919	90.42					182.6	121.4
1920	68.18					117	86.4
1921	62.45					92.6	84.7

AMAX records
Peak flow (m^3/s)

Water Year	Thames @ Eynsham	Thames @ Farmoor	Cherwell @ Enslow Mill	Evenlode @ Cassington	Ray @ Islip	Thames @ Sandford	Thames @ Pinkhill
1922	72.12					140	95.2
1923	90.42					163.8	129.6
1924	97.19					200.1	129.6
1925	95.22					210	124.6
1926	81.33					144.3	97.9
1927	97.19					200.1	116.7
1928	61.33					97.8	97.9
1929	100.96					229.3	124.6
1930	66.96					119.3	91.3
1931	57.10					152	96.5
1932	95.61					214.4	118.2
1933	85.25					56.8	20
1934						60.6	72.4
1935						185.2	113.6
1936	80.81					166.2	103.4
1937	51.06					59.6	40
1938	85.25					196	110.6
1939	85.25					207.2	110.6
1940	70.84					148.6	87.3
1941	72.44					140	87.3
1942	80.81					172.4	96.5
1943						46.8	20
1944	62.63					115.5	80.5
1945	61.33					127	78.8
1946	121.51					266.6	138.2
1947	51.06					92.6	50
1948	59.20					125.4	72.4
1949	80.81					157.8	92.6
1950	80.81					163.8	99.2
1951	62.63					125.4	80.5
1952	55.05					125.4	70.9

APPENDIX B

AMAX records

Peak flow (m^3/s)

Water Year	Thames @ Eynsham	Thames @ Farmoor	Cherwell @ Enslow Mill	Evenlode @ Cassington	Ray @ Islip	Thames @ Sandford	Thames @ Pinkhill
1953						100.5	51
1954	87.99					189.2	106.2
1955	53.03					109.7	67.1
1956	63.50					131	84.7
1957	57.10					129.4	83
1958	92.70					193.3	110.6
1959	85.25					166.2	99.2
1960	97.59					185.2	126.2
1961	66.96					137.5	87.3
1962	53.03					113.3	70.9
1963	83.45					141.7	99.2
1964			11.9			48.4	23.5
1965	76.54		35.3			139.2	99.2
1966	64.82		33.2			115.5	96.5
1967	76.54		43.8			166.2	96.5
1968	59.20		40.5			125.4	76.4
1969	51.06		35.3			96.5	62.2
1970	79.08		36.5	34.6		154.3	103.4
1971	66.96		41.9	34.9		129.4	87.3
1972	49.89		39.0	27.2		88.5	56.8
1973	79.08		41.0	34.3		149.8	96.5
1974	61.33		46.6	36.6		127.8	68.6
1975	6.50		2.7	2.5		11.9	6.5
1976	79.08		35.3	33.8		154.3	96.5
1977	56.28		40.7	26.9		110.4	70.9
1978	72.44		43.9	34.6		155.5	84.7
1979	85.25		51.4	43.2		180	99.2
1980	61.33		39.6	21.6		130.2	76.4
1981	79.08		39.3	30.8		146.8	90
1982	55.05		35.3	17.7		103.3	61.4
1983	55.05		35.3	17.7		99.9	62.3

AMAX records
Peak flow (m^3/s)

Water Year	Thames @ Eynsham	Thames @ Farmoor	Cherwell @ Enslow Mill	Evenlode @ Cassington	Ray @ Islip	Thames @ Sandford	Thames @ Pinkhill
1984	63.50		28.7	25		122.3	68.6
1985	74.88		30.2	21		138.4	90
1986	54.00		24.1	21.3		99.9	57.5
1987	68.49		39.3	26.9		134.2	83
1988	54.00		17.9	16.1		103.3	55
1989	76.54		34.7	30.1		152	86.4
1990	48.80		19.8	15.9		83.8	48.8
1991	39.00	**76.906**	38.2	23.5		78.3	39
1992	85.25	**92.445**	36.2	32.6		163.8	103.4
1993	79.08	**90.624**	27.9	25.7		143.4	92.6
1994	80.81	**93.464**	25.1	23.9		143.4	96.5
1995	74.88	78.163	18.6	24.4	13.85	121	76.2
1996	40.40	61.724	9.7	13.9	8.32	45.1	48.2
1997	68.41	78.096	114.0	28.4	11.258	194.6	72.4
1998	85.43	98.529	33.9	31.7	19.67	146.8	86.4
1999	70.37	77.302	37.7	27.9	14.78	140	74
2000	104.17	110.774	34.6	26.9	15.56	194.6	102
2001	62.50	68.676	18.8	18.2	20.92	116.3	66.3
2002	104.17	109.798	32.8	23.2	20.9	211.5	99.2
2003	54.80	61.849	23.2	15.5	9.76	96.5	54.8
2004	50.90	66.886	21.7	13.4	6.03	85	48.6
2005	49.00	66.272	7.8	12.5	9.16	69.3	50.3
2006	136.61	167.046	85.5	75.5	15.19	224.8	138.2
2007	109.14	102.751	25.9	27.6	18.03	187.9	88.6
2008	76.29	80.022	28.4	22.0	23.85	138.4	76.6
2009	66.73	64.340	19.4	22.9	15.1	124.1	61.7
2010	47.26	62.516	14.7	12.6	11.51	83.7	48.5
2011	59.15	63.720	18.1	14.9	9.31	116.3	56.9
2012	97.99	103.391	48.5	31.7	19.77	207.7	96.2
2013	105.97	116.576	34.6	26.9	19.07	211.4	96.5
2014	55.95	61.640	16.8	16.6	12.9	100.0	54.1

APPENDIX B

AMAX records

Peak flow (m^3/s)

Water Year	Thames @ Eynsham	Thames @ Farmoor	Cherwell @ Enslow Mill	Evenlode @ Cassington	Ray @ Islip	Thames @ Sandford	Thames @ Pinkhill
Qmed	74.55	71.60	34.6	25.0	**14.94**	140.0	90.0

Appendix C
FEH Pooling Group Reviews

39008 Thames @ Eynsham

Enhanced Single Site Analysis

39008 Thames @ Eynsham Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39008 (Thames @ Eynsham)	0.000	115	74.55	0.143	0.139	0.029
39998 (Thames @ Pinkhill Lock)	0.024	124	90.01	0.170	-0.062	1.103
39129 (Thames @ Farmoor)	0.024	24	78.13	0.153	0.288	0.660
27858 (Derwent @ Malton A64 Road Bridge)	0.649	11	68.58	0.100	0.018	2.176
27041 (Derwent @ Buttercrambe)	0.656	39	71.52	0.128	0.313	1.418
27015 (Derwent @ Stamford Bridge)	0.657	15	85.71	0.170	0.261	1.145
39999 (Thames @ Sandford)	0.932	121	140.00	0.201	0.020	1.160
27071 (Swale @ Crakehill)	0.943	32	161.70	0.101	0.126	0.890
54012 (Tern @ Walcot)	0.973	53	35.58	0.154	-0.003	0.419
Total		534				
Weighted means				0.144	0.095	

During the pooling group review the following changes were made:

Station	Reason for change
39129 Thames @ Farmoor	Removed as located immediately upstream and will have the same flood record
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as will record same floods a 27041 Derwent @ Buttercrambe, and this is the shorter of the two records.
39999 Thames @ Sandford	Removed as in same catchment as subject site
39998 (Thames @ Pinkhill Lock)	Removed as in same catchment as subject site
53018 Avon @ Bathford	Added to ensure pooling group has minimum of 500 station years
43007 Stour @ Throop	Added to ensure pooling group has minimum of 500 station years
33034 Little Ouse @ Abbey Heath	Added to ensure pooling group has minimum of 500 station years
27009 Ouse @ Skelton	Added to ensure pooling group has minimum of 500 station years

Station	Reason for change
55003 Lugg @ Lugwardine	Added to ensure pooling group has minimum of 500 station years

39008 Thames @ Eynsham Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39008 (Thames @ Eynsham)	0.000	115	74.55	0.143	0.139	0.364
27041 (Derwent @ Buttercrambe)	0.656	39	71.52	0.128	0.313	1.833
27071 (Swale @ Crakehill)	0.943	32	161.70	0.101	0.126	0.472
54012 (Tern @ Walcot)	0.973	53	35.58	0.154	-0.003	1.196
53018 (Avon @ Bathford)	1.125	43	167.22	0.130	0.053	0.579
43007 (Stour @ Throop)	1.149	39	102.78	0.190	0.103	0.40
33034 (Little Ouse @ Abbey Heath)	1.261	43	17.00	0.235	-0.003	1.911
27009 (Ouse @ Skelton)	1.262	126	322.00	0.138	0.118	0.034
55003 (Lugg @ Lugwardine)	1.329	42	40.70	0.059	0.025	2.211
Total		532				
Weighted means				0.143	0.120	

Standard Pooling Group Analysis

39008 Thames @ Eynsham Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39998 (Thames @ Pinkhill Lock)	0.024	124	90.01	0.17	-0.062	0.890
39129 (Thames @ Farmoor)	0.024	24	78.13	0.153	0.288	0.795
27858 (Derwent @ Malton A64 Road Bridge)	0.649	11	68.58	0.100	0.018	2.161
27041 (Derwent @ Buttercrambe)	0.656	39	71.52	0.128	0.313	1.580
27015 (Derwent @ Stamford Bridge)	0.657	15	85.71	0.170	0.261	1.289
39999 (Thames @ Sandford)	0.932	121	140.00	0.201	0.02	1.060
27071 (Swale @ Crakehill)	0.943	32	161.70	0.101	0.126	0.896
54012 (Tern @ Walcot)	0.973	53	35.58	0.154	-0.003	0.324
39002 (Thames @ Days Weir)	1.085	74	148.01	0.192	0.091	0.710
53018 (Avon @ Bathford)	1.125	43	167.22	0.130	0.053	0.295
Total		536				
Weighted means				0.154	0.059	

During the pooling group review the following changes were made:

Station	Reason for change
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as will record same floods a 27041 Derwent @ Buttercrambe, and this is the shorter of the two records.
39999 Thames @ Sandford	Removed as in same catchment as subject site
39998 Thames @ Pinkhill	Removed as in same catchment as subject site
39002 (Thames @ Days Weir)	Removed as in same catchment as subject site
43007 Stour @ Throop	Added to ensure pooling group has minimum of 500 station years
33034 Little Ouse @ Abbey Heath	Added to ensure pooling group has minimum of 500 station years
27009 Ouse @ Skelton	Added to ensure pooling group has minimum of 500 station years
55003 Lugg @ Lugwardine	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

Station	Reason for change
68001 Weaver @ Ashbrook	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

39008 Thames @ Eynsham Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39129 (Thames @ Farmoor)	0.024	24	78.13	0.153	0.288	1.868
27041 (Derwent @ Buttercrambe)	0.656	39	71.52	0.128	0.313	1.719
27071 (Swale @ Crakehill)	0.943	32	161.7	0.101	0.126	0.513
54012 (Tern @ Walcot)	0.973	53	35.576	0.154	-0.003	0.651
53018 (Avon @ Bathford)	1.125	43	167.223	0.13	0.053	0.364
43007 (Stour @ Throop)	1.149	39	102.775	0.19	0.103	0.401
33034 (Little Ouse @ Abbey Heath)	1.261	43	16.995	0.235	-0.003	1.598
27009 (Ouse @ Skelton)	1.262	126	322	0.138	0.118	0.03
55003 (Lugg @ Lugwardine)	1.329	42	40.702	0.059	0.025	2.228
68001 (Weaver @ Ashbrook)	1.401	75	48.627	0.201	0.19	0.628
Total		516				
Weighted means				0.149	0.135	

39129 Thames @ Farmoor

Enhanced Single Site Analysis

39129 Thames @ Farmoor Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39129 (Thames @ Farmoor)	0.000	24	78.13	0.153	0.288	0.830
39008 (Thames @ Eynsham)	0.024	109	76.29	0.135	0.160	0.073
27858 (Derwent @ Malton A64 Road Bridge)	0.627	11	68.58	0.100	0.018	2.129
27041 (Derwent @ Buttercrambe)	0.638	39	71.52	0.128	0.313	1.462
27015 (Derwent @ Stamford Bridge)	0.641	15	85.71	0.170	0.261	1.366
27071 (Swale @ Crakehill)	0.923	32	161.70	0.101	0.126	0.823
39999 (Thames @ Sandford)	0.945	121	140.00	0.201	0.020	1.286
54012 (Tern @ Walcot)	0.952	53	35.576	0.154	-0.003	0.644
39002 (Thames @ Days Weir)	1.099	74	148.01	0.192	0.091	0.983
53018 (Avon @ Bathford)	1.110	43	167.22	0.130	0.053	0.403
Total		521				
Weighted means				0.150	0.153	

During the pooling group review the following changes were made:

Station	Reason for change
39008 Thames @ Eynsham	Removed as immediately downstream of subject site and will have a very similar flood record.
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as will record same floods a 27041 Derwent @ Buttercrambe, and this is the shorter of the two records.
39999 Thames @ Sandford	Removed as in same catchment as subject site
39002 Thames @ Days Weir	Removed as in same catchment as subject site
43007 Stour @ Throop	Added to ensure pooling group has minimum of 500 station years
33034 Little Ouse @ Abbey Heath	Added to ensure pooling group has minimum of 500 station years
27009 Ouse @ Skelton	Added to ensure pooling group has minimum of 500 station years
68001 Weaver @ Ashbrook	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

Station	Reason for change
55003 Lugg @ Lugwardine	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

39129 Thames @ Farmoor Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39129 (Thames @ Farmoor)	0.000	24	78.13	0.153	0.288	1.868
27041 (Derwent @ Buttercrambe)	0.638	39	71.52	0.128	0.313	1.719
27071 (Swale @ Crakehill)	0.923	32	161.70	0.101	0.126	0.513
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.651
53018 (Avon @ Bathford)	1.110	43	167.22	0.130	0.053	0.364
43007 (Stour @ Throop)	1.127	39	102.78	0.190	0.103	0.401
33034 (Little Ouse @ Abbey Heath)	1.242	43	17.00	0.235	-0.003	1.598
27009 (Ouse @ Skelton)	1.265	126	322.00	0.138	0.118	0.030
55003 (Lugg @ Lugwardine)	1.306	42	40.70	0.059	0.025	2.228
68001 (Weaver @ Ashbrook)	1.381	75	48.63	0.201	0.190	0.628
Total		516				
Weighted means				0.151	0.140	

39129 Thames @ Farmoor Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39008 (Thames @ Eynsham)	0.024	109	76.29	0.135	0.160	0.124
27858 (Derwent @ Malton A64 Road Bridge)	0.627	11	68.58	0.100	0.018	2.051
27041 (Derwent @ Buttercrambe)	0.638	39	71.52	0.128	0.313	1.680
27015 (Derwent @ Stamford Bridge)	0.641	15	85.71	0.170	0.261	2.101
27071 (Swale @ Crakehill)	0.923	32	161.70	0.101	0.126	0.820
39999 (Thames @ Sandford)	0.945	121	140.00	0.201	0.020	1.049
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.611
39002 (Thames @ Days Weir)	1.099	74	148.01	0.192	0.091	0.660
53018 (Avon @ Bathford)	1.110	43	167.22	0.130	0.053	0.400
43007 (Stour @ Throop)	1.127	39	102.78	0.190	0.103	0.504
Total		536				
Weighted means				0.148	0.128	

During the pooling group review the following changes were made:

Station	Reason for change
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as will record same floods a 27041 Derwent @ Buttercrambe, and this is the shorter of the two records.
39999 Thames @ Sandford	Removed as in same catchment as subject site
39002 Thames @ Days Weir	Removed as in same catchment as subject site
33034 Little Ouse @ Abbey Heath	Added to ensure pooling group has minimum of 500 station years.
27009 Ouse @ Skelton	Added to ensure pooling group has minimum of 500 station years.
55003 Lugg @ Lugwardine	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

39129 Thames @ Farmoor Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39008 (Thames @ Eynsham)	0.024	109	76.29	0.135	0.160	0.488
27041 (Derwent @ Buttercrambe)	0.638	39	71.52	0.128	0.313	1.753
27071 (Swale @ Crakehill)	0.923	32	161.70	0.101	0.126	0.471
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	1.159
53018 (Avon @ Bathford)	1.110	43	167.22	0.130	0.053	0.572
43007 (Stour @ Throop)	1.127	39	102.78	0.190	0.103	0.410
33034 (Little Ouse @ Abbey Heath)	1.242	43	17.00	0.235	-0.003	1.952
27009 (Ouse @ Skelton)	1.265	126	322.00	0.138	0.118	0.026
55003 (Lugg @ Lugwardine)	1.306	42	40.70	0.059	0.025	2.170
Total		526				
Weighted means				0.140	0.121	

39021 Cherwell @ Enslow Mill

Enhanced Single Site Analysis

39021 Cherwell @ Enslow Mill Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39021 (Cherwell @ Enslow Mill)	0	50	34.65	0.251	0.137	0.327
36006 (Stour @ Langham)	0.283	49	27.81	0.229	0.095	0.408
36015 (Stour @ Lamarsh)	0.375	39	29.56	0.172	-0.231	1.937
31005 (Welland @ Tixover)	0.404	50	37.42	0.292	0.248	0.900
28024 (Wreake @ Syston Mill)	0.440	42	34.39	0.307	0.393	1.48
39034 (Evenlode @ Cassington Mill)	0.479	45	25.00	0.219	0.123	0.166
31004 (Welland @ Tallington Total)	0.485	45	35.72	0.280	0.196	0.736
34004 (Wensum @ Costessey Mill)	0.495	37	15.89	0.166	0.141	2.11
27014 (Rye @ Little Habton)	0.517	15	84.72	0.192	0.025	0.268
33005 (Bedford Ouse @ Thornborough Mill)	0.538	28	21.80	0.178	-0.112	0.910
21031 (Till @ Etal)	0.559	28	82.90	0.273	0.282	0.775
33037 (Bedford Ouse @ Newport Pagnell Total)	0.567	43	59.75	0.225	-0.009	0.891
21806 (Till @ Heaton Mill)	0.568	10	151.60	0.341	0.312	2.307
43009 (Stour @ Hammoon)	0.584	44	111.29	0.188	0.063	0.785
Total		525				
Weighted means				0.246	0.119	

During the pooling group review the following changes were made:

Station	Reason for change
36015 (Stour @ Lamarsh)	Removed as located in the same catchment as the higher ranked 36006 (Stour @ Langham)
34004 Wensum @ Costessey Mill	Removed as unsuitable for pooling and Qmed
33037 Bedford Ouse @ Newport Pagnall Total	Removed as unsuitable for pooling and Qmed
31004 Welland @ Tallington	Removed as 31005 (Welland @ Tixover) located is the same catchment and higher ranked.
21806 Till @ Heaton Mill	Removed as 21031 (Till @ Etal) located is the same catchment and higher ranked.

Station	Reason for change
41014 Arun @ Pallingham	Added to ensure pooling group has minimum of 500 station years
21022 Whiteadder Water @ Hutton Castle	Added to ensure pooling group has minimum of 500 station years
10003 Ythan @ Ellon	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments
39006 Windrush @ Newbridge	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments

39021 Cherwell @ Enslow Mill Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39021 (Cherwell @ Enslow Mill)	0.000	50	34.65	0.250	0.134	0.980
36006 (Stour @ Langham)	0.283	49	27.81	0.229	0.095	0.058
31005 (Welland @ Tixover)	0.404	50	37.42	0.292	0.248	0.539
28024 (Wreake @ Syston Mill)	0.440	42	34.39	0.307	0.393	2.094
39034 (Evenlode @ Cassington Mill)	0.479	45	25.00	0.219	0.123	0.070
27014 (Rye @ Little Habton)	0.517	15	84.72	0.192	0.025	0.661
21031 (Till @ Etal)	0.559	28	82.90	0.273	0.282	0.606
33037 (Bedford Ouse @ Newport Pagnell Total)	0.567	43	59.75	0.225	-0.009	0.877
43009 (Stour @ Hammoon)	0.584	44	111.29	0.188	0.063	0.766
41014 (Arun @ Pallingham)	0.656	38	77.43	0.176	0.079	0.796
21022 (Whiteadder Water @ Hutton Castle)	0.671	36	118.59	0.307	0.126	2.035
10003 (Ythan @ Ellon)	0.684	23	57.70	0.232	0.035	1.279
39006 (Windrush @ Newbridge)	0.691	62	11.05	0.194	0.241	2.240
Total		525				
Weighted means				0.247	0.144	

Standard Pooling Group Analysis

39021 Cherwell @ Enslow Mill Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
36006 (Stour @ Langham)	0.283	49	27.81	0.229	0.095	0.346
36015 (Stour @ Lamarsh)	0.375	39	29.56	0.172	-0.231	1.991
31005 (Welland @ Tixover)	0.404	50	37.42	0.292	0.248	0.895
28024 (Wreake @ Syston Mill)	0.440	42	34.39	0.307	0.393	1.630
39034 (Evenlode @ Cassington Mill)	0.479	45	25.00	0.219	0.123	0.083
31004 (Welland @ Tallington Total)	0.485	45	35.72	0.280	0.196	0.732
34004 (Wensum @ Costessey Mill)	0.495	37	15.89	0.166	0.141	1.642
27014 (Rye @ Little Habton)	0.517	15	84.72	0.192	0.025	0.219
33005 (Bedford Ouse @ Thornborough Mill)	0.538	28	21.80	0.178	-0.112	0.980
21031 (Till @ Etal)	0.559	28	82.90	0.273	0.282	0.708
33037 (Bedford Ouse @ Newport Pagnell Total)	0.567	43	59.75	0.225	-0.009	0.881
21806 (Till @ Heaton Mill)	0.568	10	151.60	0.341	0.312	2.396
43009 (Stour @ Hammoon)	0.584	44	111.29	0.188	0.063	0.759
41014 (Arun @ Pallingham)	0.656	38	77.43	0.176	0.079	0.737
Total		513				
Weighted means				0.230	0.110	

During the pooling group review the following changes were made:

Station	Reason for change
36015 (Stour @ Lamarsh)	Removed as located in the same catchment as the higher ranked 36006 (Stour @ Langham)
34004 Wensum @ Costessey Mill	Removed as unsuitable for pooling and Qmed
33037 Bedford Ouse @ Newport Pagnall Total	Removed as unsuitable for pooling and Qmed
31004 Welland @ Tallington	Removed as 31005 (Welland @ Tixover) located is the same catchment and higher ranked.
21806 Till @ Heaton Mill	Removed as 21031 (Till @ Etal) located is the same catchment and higher ranked.
41014 Arun @ Pallingham	Added to ensure pooling group has minimum of 500 station years

Station	Reason for change
21022 Whiteadder Water @ Hutton Castle	Added to ensure pooling group has minimum of 500 station years
10003 Ythan @ Ellon	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments
39006 Windrush @ Newbridge	Added to ensure pooling group has minimum of 500 station years. Although identified as unsuitable for pooling are included are preferred over less similar catchments
43008 Wylye @ South Newton	Added to ensure pooling group has minimum of 500 station years

39021 Cherwell @ Enslow Mill Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
36006 (Stour @ Langham)	0.283	49	27.81	0.229	0.095	0.037
31005 (Welland @ Tixover)	0.404	50	37.42	0.292	0.248	0.557
28024 (Wreake @ Syston Mill)	0.44	42	34.39	0.307	0.393	2.348
39034 (Evenlode @ Cassington Mill)	0.479	45	25.00	0.219	0.123	0.052
27014 (Rye @ Little Habton)	0.517	15	84.72	0.192	0.025	0.431
33005 (Bedford Ouse @ Thornborough Mill)	0.538	28	21.80	0.178	-0.112	2.081
21031 (Till @ Etal)	0.559	28	82.90	0.273	0.282	0.477
43009 (Stour @ Hammoon)	0.584	44	111.29	0.188	0.063	0.574
41014 (Arun @ Pallingham)	0.656	38	77.43	0.176	0.079	0.789
21022 (Whiteadder Water @ Hutton Castle)	0.671	36	118.59	0.307	0.126	2.009
10003 (Ythan @ Ellon)	0.684	23	57.70	0.232	0.035	1.353
39006 (Windrush @ Newbridge)	0.691	62	11.05	0.194	0.241	2.189
43008 (Wylye @ South Newton)	0.705	41	12.35	0.254	0.137	0.103
Total		501				
Weighted means				0.235	0.141	

39034 Evenlode @ Cassington

Enhanced Single Site Analysis

39034 Evenlode @ Cassington Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39034 (Evenlode @ Cassington Mill)	0.000	45	25.00	0.219	0.123	0.065
28024 (Wreake @ Syston Mill)	0.292	42	34.39	0.307	0.393	2.150
39006 (Windrush @ Newbridge)	0.296	62	11.05	0.194	0.241	1.488
31005 (Welland @ Tixover)	0.372	50	37.42	0.292	0.248	0.366
41014 (Arun @ Pallingham)	0.382	38	77.43	0.176	0.079	0.787
36015 (Stour @ Lamarsh)	0.405	39	29.56	0.172	-0.231	2.774
43008 (Wylye @ South Newton)	0.407	41	12.35	0.254	0.137	0.095
43005 (Avon @ Amesbury)	0.459	47	10.78	0.245	0.193	0.038
21022 (Whiteadder Water @ Hutton Castle)	0.464	36	118.59	0.307	0.126	2.185
39021 (Cherwell @ Enslow Mill)	0.479	50	34.65	0.251	0.137	0.776
10001 (Ythan @ Ardlethen)	0.489	46	50.18	0.179	0.116	0.681
10002 (Ugie @ Inverugie)	0.509	35	45.87	0.291	0.243	0.595
Total		531				
Weighted means				0.226	0.149	

During the pooling group review the following changes were made:

Station	Reason for change
43008 Wylye @ South Newton	Removed as an extremely permeable catchment and dissimilar to the subject site
43005 Avon @ Amesbury	Removed as an extremely permeable catchment and dissimilar to the subject site
33005 Bedford Ouse @ Thornbury	Added to ensure pooling group has minimum of 500 station years
20001 Tyne @ East Linton	Added to ensure pooling group has minimum of 500 station years

39034 Evenlode @ Cassington Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39034 (Evenlode @ Cassington Mill)	0.000	45	25.00	0.219	0.123	0.070
28024 (Wreake @ Syston Mill)	0.292	42	34.39	0.307	0.393	2.221
39006 (Windrush @ Newbridge)	0.296	62	11.05	0.194	0.241	1.538
31005 (Welland @ Tixover)	0.372	50	37.42	0.292	0.248	0.309
41014 (Arun @ Pallingham)	0.382	38	77.43	0.176	0.079	0.794
36015 (Stour @ Lamarsh)	0.405	39	29.56	0.172	-0.231	1.884
21022 (Whiteadder Water @ Hutton Castle)	0.464	36	118.59	0.307	0.126	1.580
39021 (Cherwell @ Enslow Mill)	0.479	50	34.65	0.251	0.137	0.675
10001 (Ythan @ Ardlethen)	0.489	46	50.18	0.179	0.116	0.617
10002 (Ugie @ Inverugie)	0.509	35	45.87	0.291	0.243	0.423
33005 (Bedford Ouse @ Thornborough Mill)	0.518	28	21.80	0.178	-0.112	0.926
20001 (Tyne @ East Linton)	0.523	47	57.80	0.320	0.193	0.961
Total		518				
Weighted means				0.226	0.135	

Standard Pooling Group Analysis

39034 Evenlode @ Cassington Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
28024 (Wreake @ Syston Mill)	0.292	42	34.39	0.307	0.393	2.161
39006 (Windrush @ Newbridge)	0.296	62	11.05	0.194	0.241	1.545
31005 (Welland @ Tixover)	0.372	50	37.42	0.292	0.248	0.376
41014 (Arun @ Pallingham)	0.382	38	77.43	0.176	0.079	0.815
36015 (Stour @ Lamarsh)	0.405	39	29.56	0.172	-0.231	1.890
43008 (Wylye @ South Newton)	0.407	41	12.35	0.254	0.137	0.101
43005 (Avon @ Amesbury)	0.459	47	10.78	0.245	0.193	0.062
21022 (Whiteadder Water @ Hutton Castle)	0.464	36	118.59	0.307	0.126	2.180
39021 (Cherwell @ Enslow Mill)	0.479	50	34.65	0.251	0.137	0.660
10001 (Ythan @ Ardlethen)	0.489	46	50.18	0.179	0.116	0.685
10002 (Ugie @ Inverugie)	0.509	35	45.87	0.291	0.243	0.505
33005 (Bedford Ouse @ Thornborough Mill)	0.518	28	21.80	0.178	-0.112	0.945
Total		514				
Weighted means				0.238	0.139	

During the pooling group review the following changes were made:

Station	Reason for change
43008 Wylye @ South Newton	Removed as an extremely permeable catchment and dissimilar to the subject site
43005 Avon @ Amesbury	Removed as an extremely permeable catchment and dissimilar to the subject site
20001 Tyne @ East Linton	Added to ensure pooling group has minimum of 500 station years
66001 Clwyd @ Pont-y-cambwll	Added to ensure pooling group has minimum of 500 station years

39034 Evenlode @ Cassington Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
28024 (Wreake @ Syston Mill)	0.292	42	34.39	0.307	0.393	2.127
39006 (Windrush @ Newbridge)	0.296	62	11.05	0.194	0.241	0.872
31005 (Welland @ Tixover)	0.372	50	37.42	0.292	0.248	0.323
41014 (Arun @ Pallingham)	0.382	38	77.43	0.176	0.079	0.422
36015 (Stour @ Lamarsh)	0.405	39	29.56	0.172	-0.231	1.879
21022 (Whiteadder Water @ Hutton Castle)	0.464	36	118.59	0.307	0.126	1.562
39021 (Cherwell @ Enslow Mill)	0.479	50	34.65	0.251	0.137	0.628
10001 (Ythan @ Ardlethen)	0.489	46	50.18	0.179	0.116	0.457
10002 (Ugie @ Inverugie)	0.509	35	45.87	0.291	0.243	0.396
33005 (Bedford Ouse @ Thornborough Mill)	0.518	28	21.80	0.178	-0.112	0.961
20001 (Tyne @ East Linton)	0.523	47	57.80	0.320	0.193	0.964
66001 (Clwyd @ Pont-y-cambwll)	0.574	39	47.11	0.168	0.166	1.410
Total		512				
Weighted means				0.237	0.141	

39140 Ray @ Islip

Enhanced Single Site Analysis

39140 Ray @ Islip Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39140 (Ray @ Islip)	0.000	20	14.94	0.198	0.012	1.123
28017 (Devon @ Cotham)	0.430	18	26.81	0.227	-0.15	0.641
54016 (Roden @ Rodington)	0.731	51	14.08	0.173	0.042	0.367
39018 (Ock @ Abingdon)	0.955	16	10.45	0.229	-0.212	2.296
39081 (Ock @ Abingdon)	0.955	33	10.53	0.239	0.272	1.380
33044 (Thet @ Bridgham)	0.980	45	7.81	0.243	0.068	0.210
33019 (Thet @ Melford Bridge)	1.097	52	7.83	0.265	0.126	0.594
40005 (Beult @ Stilebridge)	1.126	42	42.10	0.227	0.218	1.439
33021 (Rhee @ Burnt Mill)	1.204	50	8.27	0.264	-0.13	0.685
34006 (Waveney @ Needham Mill)	1.212	48	22.67	0.355	0.236	1.226
54020 (Perry @ Yeaton)	1.257	49	10.57	0.157	-0.016	0.482
27087 (Derwent @ Low Marishes)	1.315	23	14.70	0.149	0.260	1.610
33046 (Thet @ Redbridge)	1.353	45	8.31	0.257	-0.036	0.240
34010 (Waveney @ Billingford Bridge)	1.449	44	14.14	0.387	0.275	1.832
68005 (Weaver @ Audlem)	1.513	43	13.86	0.196	0.189	1.271
33027 (Rhee @ Wimpole)	1.519	47	5.53	0.272	-0.058	0.372
34007 (Dove @ Oakley Park)	1.549	46	13.57	0.352	0.073	1.162
68007 (Wincham Brook @ Lostock Gralam)	1.578	50	20.33	0.123	-0.099	1.070
Total		722				
Weighted means				0.218	0.061	

During the pooling group review the following changes were made:

Station	Reason for change
28017 Devon @ Cotham	Removed as data record only extend to 1983
39018 Ock @ Abingdon	Removed as station closed in 1977
33044 Thet @ Bridgham	Removed as unsuitable for pooling and Thet @ Melford Bridge is located immediately below in pooling group

Station	Reason for change
33046 Thet @ Redbridge	Removed as unsuitable for pooling and Thet @ Melford Bridge is located in pooling group
34010 Waveney @ Billingford Bridge	Removed as unsuitable for pooling and 34006 (Waveney @ Needham Mill) is in the pooling group
34007 Dove@ Oakly Park	Removed as unsuitable for pooling and Qmed.

39140 Ray @ Islip Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39140 (Ray @ Islip)	0.000	20	14.94	0.198	0.012	0.931
54016 (Roden @ Rodington)	0.731	51	14.08	0.173	0.042	0.273
39081 (Ock @ Abingdon)	0.955	33	10.53	0.239	0.272	1.016
33019 (Thet @ Melford Bridge)	1.097	52	7.83	0.265	0.126	0.735
40005 (Beult @ Stilebridge)	1.126	42	42.10	0.227	0.218	1.536
33021 (Rhee @ Burnt Mill)	1.204	50	8.27	0.264	-0.130	1.276
34006 (Waveney @ Needham Mill)	1.212	48	22.67	0.355	0.236	1.769
54020 (Perry @ Yeaton)	1.257	49	10.57	0.157	-0.016	0.433
27087 (Derwent @ Low Marishes)	1.315	23	14.70	0.149	0.260	1.167
68005 (Weaver @ Audlem)	1.513	43	13.86	0.196	0.189	0.904
33027 (Rhee @ Wimpole)	1.519	47	5.53	0.272	-0.058	0.840
68007 (Wincham Brook @ Lostock Gralam)	1.578	50	20.33	0.123	-0.099	1.121
Total		508				
Weighted means				0.208	0.078	

Standard Pooling Group Analysis

39140 Ray @ Islip Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
28017 (Devon @ Cotham)	0.430	18	26.81	0.227	-0.150	0.620
54016 (Roden @ Rodington)	0.731	51	14.08	0.173	0.042	0.346
39018 (Ock @ Abingdon)	0.955	16	10.45	0.229	-0.212	2.234
39081 (Ock @ Abingdon)	0.955	33	10.53	0.239	0.272	1.350
33044 (Thet @ Bridgham)	0.980	45	7.81	0.243	0.068	0.305
33019 (Thet @ Melford Bridge)	1.097	52	7.83	0.265	0.126	0.732
40005 (Beult @ Stilebridge)	1.126	42	42.10	0.227	0.218	1.697
33021 (Rhee @ Burnt Mill)	1.204	50	8.27	0.264	-0.130	0.646
34006 (Waveney @ Needham Mill)	1.212	48	22.67	0.355	0.236	1.173
54020 (Perry @ Yeaton)	1.257	49	10.57	0.157	-0.016	0.506
27087 (Derwent @ Low Marishes)	1.315	23	14.70	0.149	0.260	1.525
33046 (Thet @ Redbridge)	1.353	45	8.31	0.257	-0.036	0.268
34010 (Waveney @ Billingford Bridge)	1.449	44	14.14	0.387	0.275	1.751
68005 (Weaver @ Audlem)	1.513	43	13.86	0.196	0.189	1.227
33027 (Rhee @ Wimpole)	1.519	47	5.53	0.272	-0.058	0.341
34007 (Dove @ Oakley Park)	1.549	46	13.57	0.352	0.073	1.139
68007 (Wincham Brook @ Lostock Gralam)	1.578	50	20.33	0.123	-0.099	1.140
Total		702				
Weighted means				0.241	0.066	

During the pooling group review the following changes were made:

Station	Reason for change
28017 Devon @ Cotham	Removed as data record only extend to 1983
39018 Ock @ Abingdon	Removed as station closed in 1977
33044 Thet @ Bridgham	Removed as unsuitable for pooling and Thet @ Melford Bridge is located immediately below in pooling group

Station	Reason for change
33046 Thet @ Redbridge	Removed as unsuitable for pooling and Thet @ Melford Bridge is located in pooling group
34010 Waveney @ Billingford Bridge	Removed as unsuitable for pooling and 34006 (Waveney @ Needham Mill) is in the pooling group
34007 Dove@ Oakly Park	Removed as unsuitable for pooling and Qmed.
34001 Yare @ Colney	Added to ensure pooling group had 500 station years.

39140 Ray @ Islip Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
54016 (Roden @ Rodington)	0.731	51	14.08	0.173	0.042	0.275
39081 (Ock @ Abingdon)	0.955	33	10.53	0.239	0.272	1.109
33019 (Thet @ Melford Bridge)	1.097	52	7.83	0.265	0.126	0.621
40005 (Beult @ Stilebridge)	1.126	42	42.10	0.227	0.218	1.527
33021 (Rhee @ Burnt Mill)	1.204	50	8.27	0.264	-0.130	1.290
34006 (Waveney @ Needham Mill)	1.212	48	22.67	0.355	0.236	1.519
54020 (Perry @ Yeaton)	1.257	49	10.57	0.157	-0.016	0.487
27087 (Derwent @ Low Marishes)	1.315	23	14.70	0.149	0.260	1.180
68005 (Weaver @ Audlem)	1.513	43	13.86	0.196	0.189	0.950
33027 (Rhee @ Wimpole)	1.519	47	5.53	0.272	-0.058	0.825
68007 (Wincham Brook @ Lostock Gralam)	1.578	50	20.33	0.123	-0.099	1.219
34001 (Yare @ Colney)	1.652	54	11.63	0.312	0.195	0.999
Total		542				
Weighted means				0.228	0.098	

Thames @ Sandford

Enhanced Single Site Analysis

Thames @ Sandford Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39999 (Thames @ Sandford)	0.000	121	140.00	0.201	0.020	1.000
39002 (Thames @ Days Weir)	0.179	74	148.01	0.192	0.091	1.411
27009 (Ouse @ Skelton)	0.655	126	322.00	0.138	0.118	0.984
39008 (Thames @ Eynsham)	0.932	29	70.60	0.195	0.165	0.535
39129 (Thames @ Farmoor)	0.945	25	78.10	0.151	0.298	0.612
27015 (Derwent @ Stamford Bridge)	0.991	15	85.71	0.170	0.261	1.069
54001 (Severn @ Bewdley)	1.019	89	335.08	0.134	0.135	0.852
27041 (Derwent @ Buttercrambe)	1.025	39	71.52	0.128	0.313	1.538
Total		518				
Weighted means				0.197	0.080	

During the pooling group review the following changes were made:

Station	Reason for change
39002 Thames@ Days Weir	Removed as located in same catchment as subject site
39008 Thames @ Eynsham	Removed as located in same catchment as subject site
39129 Thames@ Farmoor	Removed as located in same catchment as subject site
27015 Derwent at Stamford Bridge	Removed as unsuitable for pooling and Qmed
55023 Wye @ Redbrook	Added to ensure pooling group had 500 station years.
53018 Avon @ Bathford	Added to ensure pooling group had 500 station years.
27071 Swale @ Crakehill	Added to ensure pooling group had 500 station years.
21009 Tweed @ Norham	Added to ensure pooling group had 500 station years.

Thames @ Sandford Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39999 (Thames @ Sandford)	0.000	121	140.00	0.201	0.020	1.441
27009 (Ouse @ Skelton)	0.655	126	322.00	0.138	0.118	0.079
54001 (Severn @ Bewdley)	1.019	89	335.08	0.134	0.135	0.124
27041 (Derwent @ Buttercrambe)	1.025	39	71.52	0.128	0.313	1.337
55023 (Wye @ Redbrook)	1.282	42	529.68	0.138	0.225	2.076
53018 (Avon @ Bathford)	1.312	43	167.22	0.130	0.053	0.711
27071 (Swale @ Crakehill)	1.354	32	161.70	0.101	0.126	0.716
21009 (Tweed @ Norham)	1.529	46	791.68	0.204	0.202	1.515
Total		538				
Weighted means				0.195	0.074	

APPENDIX B

Standard Pooling Group Analysis

Thames @ Sandford Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39002 (Thames @ Days Weir)	0.179	74	148.01	0.192	0.091	1.786
27009 (Ouse @ Skelton)	0.655	126	322.00	0.138	0.118	0.192
39008 (Thames @ Eynsham)	0.932	29	70.60	0.195	0.165	1.277
39129 (Thames @ Farmoor)	0.945	25	78.10	0.151	0.298	0.744
27015 (Derwent @ Stamford Bridge)	0.991	15	85.71	0.170	0.261	1.210
54001 (Severn @ Bewdley)	1.019	89	335.08	0.134	0.135	0.301
27041 (Derwent @ Buttercrambe)	1.025	39	71.52	0.128	0.313	1.741
27858 (Derwent @ Malton A64 Road Bridge)	1.200	11	68.58	0.100	0.018	2.471
55023 (Wye @ Redbrook)	1.282	42	529.68	0.138	0.225	0.286
55001 (Wye @ Cadora)	1.288	33	558.18	0.128	0.179	0.230
53018 (Avon @ Bathford)	1.312	43	167.22	0.130	0.053	0.761
Total		526				
Weighted means				0.150	0.162	

During the pooling group review the following changes were made:

Station	Reason for change
39008 Thames @ Eynsham	Removed as located in same catchment as subject site
27015 Derwent at Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @Malton A64 Road Bridge	Removed as 27041 (Derwent @ Buttercrambe) already in pooling group
55001 Wye @ Cadora	Removed as unsuitable for pooling and Qmed
54005 Severn @ Mountford	Removed as 54001 (Severn @ Bewdley)already in pooling group
67020 Dee @ Chester Weir	Removed as unsuitable for pooling and Qmed
27071 Swale @ Crakehill	Added to make pooling group have 500 station years
21009 Tweed @ Norham	Added to make pooling group have 500 station years

Thames @ Sandford Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39002 (Thames @ Days Weir)	0.179	74	148.01	0.192	0.091	1.130
27009 (Ouse @ Skelton)	0.655	126	322.00	0.138	0.118	0.199
39129 (Thames @ Farmoor)	0.945	25	78.10	0.151	0.298	1.309
54001 (Severn @ Bewdley)	1.019	89	335.08	0.134	0.135	0.139
27041 (Derwent @ Buttercrambe)	1.025	39	71.52	0.128	0.313	2.273
55023 (Wye @ Redbrook)	1.282	42	529.68	0.138	0.225	1.053
53018 (Avon @ Bathford)	1.312	43	167.22	0.130	0.053	0.734
27071 (Swale @ Crakehill)	1.354	32	161.70	0.101	0.126	0.877
21009 (Tweed @ Norham)	1.529	46	791.68	0.204	0.192	0.482
Total		537				
Weighted means				0.153	0.154	

Thames @ Pinkhill Lock

Enhanced Single Site Analysis

Thames @ Pinkhill Lock Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39998 (Thames @ Pinkhill Lock)	0.000	124	90.01	0.170	-0.062	1.060
39129 (Thames @ Farmoor)	0.001	23	69.439	0.161	0.286	0.759
39008 (Thames @ Eynsham)	0.024	28	73.64	0.164	0.070	0.196
27858 (Derwent @ Malton A64 Road Bridge)	0.628	11	68.58	0.100	0.018	2.046
27041 (Derwent @ Buttercrambe)	0.639	39	71.52	0.128	0.313	1.332
27015 (Derwent @ Stamford Bridge)	0.642	15	85.71	0.170	0.261	1.589
27071 (Swale @ Crakehill)	0.924	32	161.70	0.101	0.126	1.078
39999 (Thames @ Sandford)	0.945	121	140.00	0.201	0.020	0.928
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.412
39002 (Thames @ Days Weir)	1.099	74	148.01	0.192	0.091	0.599
Total		520				
Weighted means				0.168	0.031	

During the pooling group review the following changes were made:

Station	Reason for change
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as same flood as Buttercrambe, but has a shorter record
39129 Thames@ Farmoor	Removed as located in same river as subject site
39008 Thames @ Eynsham	Removed as located in same river as subject site
39999 Thames @ Sandford	Removed as located in same river as subject site
39002 Thames @ Days Weir	Removed as located in same river as subject site
53018 (Avon @ Bathford)	Added to make pooling group have 500 station years
43007 (Stour @ Throop)	Added to make pooling group have 500 station years
27009 (Ouse @ Skelton)	Added to make pooling group have 500 station years

Thames @ Pinkhill Lock Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39998 (Thames @ Pinkhill Lock)	0.000	124	90.01	0.170	-0.062	1.556
27041 (Derwent @ Buttercrambe)	0.639	39	71.52	0.128	0.313	1.822
27071 (Swale @ Crakehill)	0.924	32	161.70	0.101	0.126	1.035
39999 (Thames @ Sandford)	0.945	121	140.00	0.201	0.020	1.807
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.279
53018 (Avon @ Bathford)	1.111	43	167.22	0.130	0.053	0.317
43007 (Stour @ Throop)	1.128	39	102.78	0.190	0.103	0.882
27009 (Ouse @ Skelton)	1.266	126	322.00	0.138	0.118	0.302
Total		577				
Weighted means				0.157	-0.002	

APPENDIX B

Standard Pooling Group Analysis

Thames @ Pinkhill Lock Initial Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39129 (Thames @ Farmoor)	0.001	23	69.43	0.161	0.286	0.926
39008 (Thames @ Eynsham)	0.024	28	73.64	0.164	0.070	0.176
27858 (Derwent @ Malton A64 Road Bridge)	0.628	11	68.58	0.100	0.018	2.306
27041 (Derwent @ Buttercrambe)	0.639	39	71.52	0.128	0.313	1.452
27015 (Derwent @ Stamford Bridge)	0.642	15	85.71	0.170	0.261	2.168
27071 (Swale @ Crakehill)	0.924	32	161.70	0.101	0.126	0.968
39999 (Thames @ Sandford)	0.945	121	140.00	0.201	0.020	0.565
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.678
39002 (Thames @ Days Weir)	1.099	74	148.01	0.192	0.091	0.506
53018 (Avon @ Bathford)	1.111	43	167.22	0.130	0.053	0.576
43007 (Stour @ Throop)	1.128	39	102.78	0.190	0.103	0.326
33034 (Little Ouse @ Abbey Heath)	1.243	43	17.00	0.235	-0.003	1.353
Total		521				
Weighted means				0.161	0.120	

During the pooling group review the following changes were made:

Station	Reason for change
39008 Thames @ Eynsham	Removed as located in same river as subject site
39999 Thames @ Sandford	Removed as located in same river as subject site
27041 Derwent @ Stamford Bridge	Removed as unsuitable for pooling and Qmed
27858 Derwent @ Malton A64 Road Bridge	Removed as same flood as Buttercrambe, but has a shorter record
27009 (Ouse @ Skelton)	Added to make pooling group have 500 station years
203010 Blackwater @ Maydown Bridge	Added to make pooling group have 500 station years
39016 Kennet @ Theale	Added to make pooling group have 500 station years
25009 Tees @ Low Moor	Added to make pooling group have 500 station years

Thames @ Pinkhill Lock Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
39129 (Thames @ Farmoor)	0.001	23	69.43	0.161	0.286	0.926
27041 (Derwent @ Buttercrambe)	0.639	39	71.52	0.128	0.313	1.452
27071 (Swale @ Crakehill)	0.924	32	161.7	0.101	0.126	0.968
54012 (Tern @ Walcot)	0.952	53	35.58	0.154	-0.003	0.678
53018 (Avon @ Bathford)	1.111	43	167.22	0.130	0.053	0.576
43007 (Stour @ Throop)	1.128	39	102.78	0.190	0.103	0.326
33034 (Little Ouse @ Abbey Heath)	1.243	43	17.00	0.235	-0.003	1.353
27009 (Ouse @ Skelton)	1.266	126	322.00	0.138	0.118	0.133
203010 (Blackwater @ Maydown Bridge)	1.396	21	135.93	0.080	0.207	1.116
39016 (Kennet @ Theale)	1.411	51	38.00	0.176	0.046	0.147
25009 (Tees @ Low Moor)	1.411	42	410.18	0.179	-0.04	2.561
Total		512				
Weighted Means				0.153	0.120	

Appendix D
Relative Timing of Peaks Analysis

APPENDIX D

Table 4-1: Relative Timing of Peaks Analysis

Event	Events used for Archers Method?				Date and Time of Peak				Time of Peak After First Peak (hours)			
	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip
1992 01		X			not used	11/01/1992 11:15	11/01/1992 10:45	no data		0.50	0.00	
1992 09		X			not used	27/09/1992 21:45	27/09/1992 12:45	no data		9.00	0.00	
1992 12	X				20/12/1992 13:00	20/12/1992 14:45	20/12/1992 07:45	no data	5.25	7.00	0.00	
1993 01	X		X		no data	15/09/1992 06:00	15/09/1992 07:30	no data		0.00	1.50	
1993 04	X	X			10/04/1993 13:45	11/04/1993 18:30	10/04/1993 17:30	no data	0.00	28.75	3.75	
1993 05	X				not used	not used	not used	not used				
1993 12			X		not used	15/12/1993 12:00	15/12/1993 05:00	no data		7.00	0.00	
1994 01	X				no data	06/01/1994 19:30	07/01/1994 00:15	no data		0.00	4.75	
1994 04					02/04/1994 08:30	02/04/1994 17:15	01/04/1994 17:00	no data	15.50	24.25	0.00	
1995 12	X		X		no data	24/12/1995 15:00	24/12/1995 16:00	no data		0.00	1.00	
1996 02 (1)				X	10/02/1996 14:30	12/02/1996 05:15	10/02/1996 08:45	10/02/1996 09:30	5.75	44.50	0.00	0.75
1996 02 (2)					26/02/1996 00:45	27/02/1996 07:15	25/02/1996 10:00	26/02/1996 13:30	14.75	45.25	0.00	27.50
1996 04 (1)				X	13/04/1996 17:15	14/04/1996 02:30	13/04/1996 18:15	13/04/1996 19:00	0.00	9.25	1.00	1.75
1996 04 (2)				X	24/04/1996 09:45	23/04/1996 22:45	24/04/1996 07:15	23/04/1996 22:45	11.00	0.00	8.50	0.00
1996 06				X	09/06/1996 10:30	no event	no event	08/06/1996 14:00	20.50			0.00
1997 02				X	no data	26/02/1997 13:30	26/02/1997 10:15	26/02/1997 21:00		3.25	0.00	10.75
1997 05				X	18/05/1997 17:15	18/05/1997 19:15	19/05/1997 04:15	18/05/1997 19:45	0.00	2.00	11.00	2.50

Event	Events used for Archers Method?				Date and Time of Peak				Time of Peak After First Peak (hours)			
	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip
1998 01					20/01/1998 10:15	21/01/1998 02:15	19/01/1998 08:45	19/01/1998 09:00	25.50	41.50	0.00	0.25
1998 03					04/03/1998 17:30	05/03/1998 02:45	05/03/1998 08:45	05/03/1998 03:00	0.00	9.25	15.25	9.50
1998 04		X	X		10/04/1998 08:45	10/04/1998 20:45	11/04/1998 11:30	10/04/1998 09:00	0.00	12.00	26.75	0.25
1998 12 (1)					19/12/1998 21:15	20/12/1998 11:00	19/12/1998 22:45	19/12/1998 21:15	0.00	13.75	1.50	0.00
1998 12 (2)					29/12/1998 11:15	28/12/1998 12:45	28/12/1998 00:15	not used	35.00	12.50	0.00	
1999 01			X		no data	21/01/1999 06:45	21/01/1999 09:00	not used		0.00	2.25	
1999 10					25/10/1999 18:15	26/10/1999 21:00	26/10/1999 04:15	25/10/1999 18:15	0.00	26.75	10.00	0.00
1999 11					07/11/1999 11:30	07/11/1999 08:00	06/11/1999 15:00	07/11/1999 00:45	20.50	17.00	0.00	9.75
1999 12	X	X	X		no data	26/12/1999 03:30	25/12/1999 23:45	not used		3.75	0.00	
2000 02				X	26/02/2000 00:00	26/02/2000 02:45	26/02/2000 00:30	26/02/2000 10:45	0.00	2.75	0.50	10.75
2000 04		X	X		04/04/2000 09:30	06/04/2000 01:30	05/04/2000 13:15	not used	0.00	40.00	27.75	
2000 11	X				no data	08/11/2000 11:45	08/11/2000 10:00	not used		1.75	0.00	
2000 12	X				16/12/2000 00:45	14/12/2000 12:15	14/12/2000 13:45	not used	36.50	0.00	1.50	
2001 02			X		14/02/2001 11:30	14/02/2001 01:45	14/02/2001 04:00	not used	9.75	0.00	2.25	
2001 11					10/11/2001 06:00	09/11/2001 02:15	09/11/2001 09:00	09/11/2001 08:45	27.75	0.00	6.75	6.50
2002 12			X		only one distinct peak - no comparison possible							
2003 02		X			12/02/2003 09:45	13/02/2003 01:30	12/02/2003 09:15	not used	0.50	16.25	0.00	
2004 04				X	20/04/2004 09:15	20/04/2004 00:30	19/04/2004 09:00	19/04/2004 08:45	24.50	15.75	0.25	0.00

Event	Events used for Archers Method?				Date and Time of Peak				Time of Peak After First Peak (hours)			
	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip	Thames at Eynsham	Cherwell at Enslow	Evenlode at Cassington	Ray at Islip
2004 05				X	05/05/2004 13:45	06/05/2004 13:30	not used	06/05/2004 03:45	0.00	23.75		14.00
2007 03			X		08/03/2007 01:30	06/03/2007 23:45	07/03/2007 14:30	not used	25.75	0.00	14.75	
2007 07	X	X	X		24/07/2007 18:30	22/07/2007 03:15	21/07/2007 20:00	not used	70.50	7.25	0.00	
2007 10	X				18/10/2007 07:45	19/10/2007 16:30	18/10/2007 09:30	not used	0.00	32.75	1.75	
2008 01	X		X		19/01/2008 09:30	17/01/2008 19:30	17/01/2008 02:00	not used	55.50	17.50	0.00	
2008 03	X		X		19/03/2008 11:45	17/03/2008 23:30	17/03/2008 19:30	not used	40.25	4.00	0.00	
2008 06	X		X		07/06/2008 07:15	06/06/2008 20:30	05/06/2008 23:30	not used	31.75	21.00	0.00	
2008 11	X				03/11/2008 17:00	05/11/2008 07:00	03/11/2008 07:15	not used	9.75	47.75	0.00	
2008 12		X	X		not used	15/12/2008 07:00	15/12/2008 06:45	not used		0.25	0.00	
2009 02	X				peaks not distinct enough							
2010 01			X		not used	18/01/2010 13:30	18/01/2010 03:45	not used		9.75	0.00	
2010 12					no data	01/01/2011 20:00	31/12/2010 20:00	31/12/2010 03:45		40.25	16.25	0.00
2012 08				X	peaks not distinct enough							
2013 03 (1)				X	17/03/2013 10:45	18/03/2013 22:00	17/03/2013 20:00	not used	0.00	35.25	9.25	
2013 03 (2)					25/03/2013 06:45	25/03/2013 04:00	23/03/2013 22:30	not used	32.25	29.50	0.00	
2013 04				X	only one distinct peak - no comparison possible							

Appendix E
Flood Forecasting Model Summary

Table 4-2: Summary of use of flood forecasting model to provide inflows for PAR model

Node Labels in original FFM	Changes from original FFM to updated FFM	Node Labels in updated FFM	Hydrograph produced for FFM?	Changes from updated FFM to PAR model	Node Label in PAR model
Farmoor	no change	Farmoor	Yes	Farmoor QTBDY not used due to reschematisation, flow from FFM node 50.078 used instead	50.078Q
Wharf	no change	Wharf	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
50.EVEN	no change	50.EVEN	Yes	no change	50.EVEN
50.078FR	no change	50.078FR	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
11.bdy	no change	11.bdy	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
01.023	no change	01.023	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
47m. SWEET	no change	47m. SWEET	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
Hinug	renamed to match node in PAR model	HD07.023	Yes	no change	HD07.023
Sanug	no change	Sanug	Yes	no change	Sanug
KB1_0645	no change	KB1_0645	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
Enslow	no change	Enslow	Yes	Enslow QTBDY not used due to reschematisation, CH.082d extracted from FFM and input to PAR model	NA
MC2.074R	no change	MC2.074R	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
Rayug	deleted with Ray arm of model	-	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
Ray1012	deleted with Ray arm of model	-	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
Cherug	no change	Cherug	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
45n.in	no change	45n.in	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
44f.in	no change	44f.in	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
44c.in	no change	44c.in	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
44.OCK	no change	44.OCK	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
cul3	no change	cul3	No - but left in model as required for stability	No corresponding inflow in PAR model	NA
-	Node added as present in PAR model	47.SL	Yes	no change	47.SL
-	Node added as present in PAR model	Iffug	Yes	no change	Iffug
-	Node added as present in PAR model	CHU.024	Yes	CHU.024 QTBDY not used due to reschematisation, CH.082d extracted from FFM and input to PAR model	NA
-	-	-	-	Node created and inflow made by extraction from node CH.082d in FFM	CHU.024

A summary of the methods used to calculate input hydrographs for the 1D Flood Forecasting Model and PAR model are provided in Table 4-3

Table 4-3: Summary of inflow calculation methods for 1D Flood Forecasting Model and PAR model

<table>
<tr><th colspan="5">Design Hydrograph Inputs to 1D Flood Forecasting Model</th><th colspan="5">Design Hydrograph Inputs to linked 1D-2D 2015 PAR model</th></tr>
<tr><th>Node Label</th><th>Watercourse</th><th>Hydrograph peak calculation method for input to 1D model</th><th>Hydrograph shape calculation method for input to 1D model</th><th>Relative Peak Time calculation method</th><th>Node Label</th><th>Watercourse</th><th>Hydrograph peak calculation method for input to linked 1D-2D model</th><th>Hydrograph shape calculation method for input to linked 1D-2D model</th><th>Relative Peak Time calculation method</th></tr>
<tr><td>FARMOOR</td><td>Thames</td><td>Statistical Analysis at Thames at Eynsham (39008)</td><td>Archer’s Method at Thames at Eynsham (39008)</td><td rowspan="4">Relative Peak Time analysis undertaken on observed events at 39008, 39034, 39021 and 39140</td><td>50.079</td><td>Thames</td><td colspan="2">Extracted from FFM at node 50.079</td><td>Relative peak timing implicit in use of hydrograph extracted from FFM which used timed hydrographs as inputs</td></tr>
<tr><td>50.EVEN</td><td>Evenlode</td><td>Statistical Analysis at Evenlode at Cassington (39034)</td><td>Archer’s Methods at Evenlode at Cassington (39034)</td><td>50.EVEN</td><td>Evenlode</td><td>Statistical Analysis</td><td>Archer’s Method</td><td>Relative Peak Time analysis undertaken on observed events at 39008, 39034, 39021 and 39140</td></tr>
<tr><td>MC2.076</td><td>Cherwell</td><td>Statistical Analysis at Cherwell at Enslow (39021)</td><td>Archer’s Method at Cherwell at Enslow (39021)</td><td rowspan="2">CH.082d</td><td rowspan="2">Cherwell (including Ray as tributary)</td><td rowspan="2" colspan="2">Extracted from FFM at node 50.079</td><td rowspan="2">Relative peak timing implicit in use of hydrograph extracted from FFM which used timed hydrographs as inputs</td></tr>
<tr><td>CHU.024</td><td>Ray</td><td>Statistical Analysis at Ray at Islip (39140)</td><td>Archer’s Method at Ray at Islip (39140)</td></tr>
<tr><td>Sanug</td><td>Unnamed watercourse</td><td rowspan="4">Each minor inflow was scaled to a factor of 0.9% of the total of all inflows (equivalent to 3.29% of the Cherwell inflow) in the 2014 study. Since the hydrograph shape and relative peak time from the Cherwell have been adopted for this study, the 3.29% scaling factor for each inflow has also been used.</td><td rowspan="4">Archers Method at Cherwell at Enslow (39021)</td><td rowspan="4">Lag time corresponding with Cherwell at Enslow for which hydrograph shape was also used</td><td>Sanug</td><td>Unnamed watercourse</td><td rowspan="4">Each minor inflow was scaled to a factor of 0.9% of the total of all inflows (equivalent to 3.29% of the Cherwell inflow) in the 2014 study. Since the hydrograph shape and relative peak time from the Cherwell have been adopted for this study, the 3.29% scaling factor for each inflow has also been used.</td><td rowspan="4">Archer’s Method at Cherwell at Enslow (39021)</td><td rowspan="4">Lag time corresponding with Cherwell at Enslow for which hydrograph shape was also used</td></tr>
<tr><td>Iffug</td><td>Unnamed watercourse</td><td>Iffug</td><td>Unnamed watercourse</td></tr>
<tr><td>47.SL</td><td>Unnamed watercourse</td><td>47.SL</td><td>Unnamed watercourse</td></tr>
<tr><td>HD07.023</td><td>Hinksey Brook</td><td>HD07.023</td><td>Hinksey Brook</td></tr>
</table>

Appendix F
Sandford Flood Volumes Technical Note