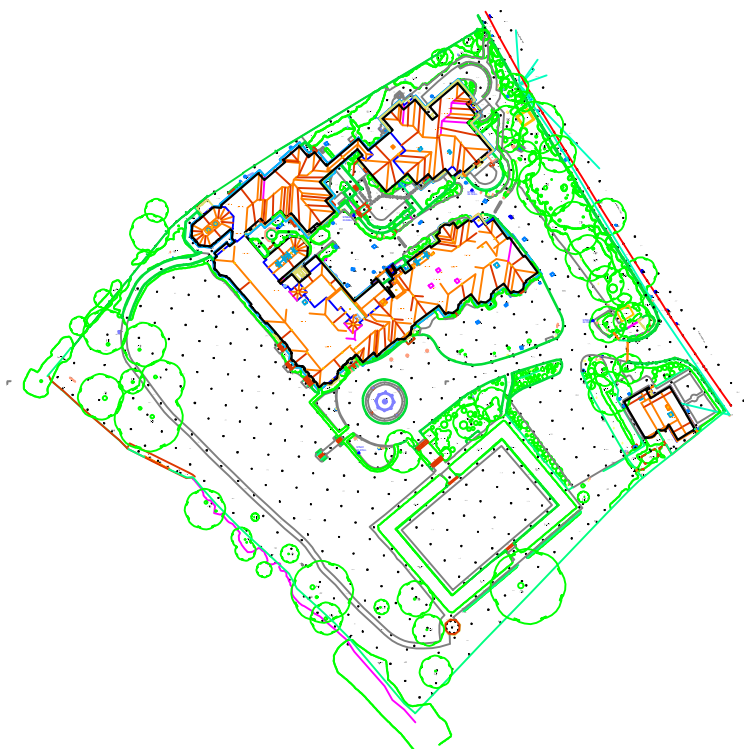
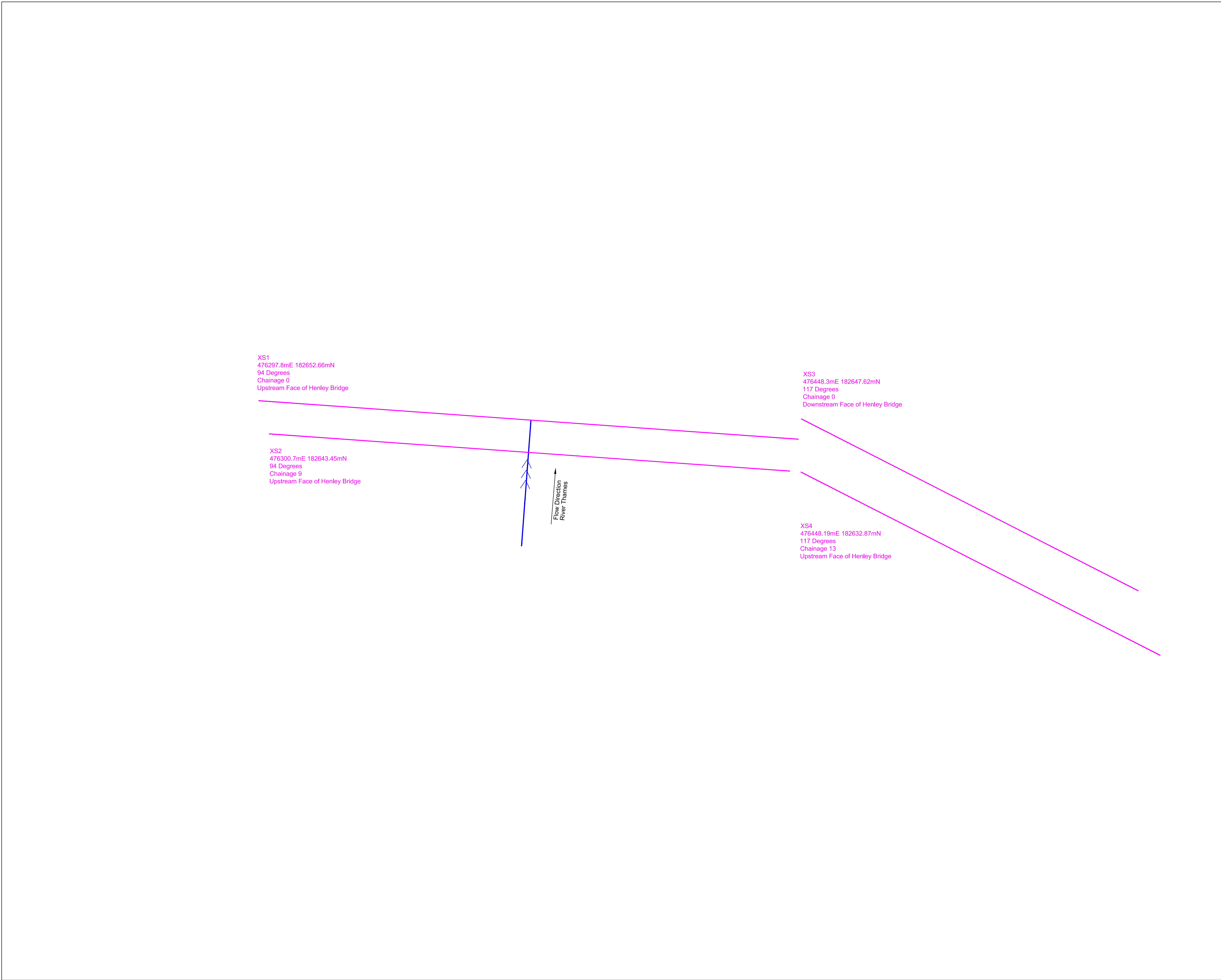




B Appendix B – Survey of Henley Bridge



Notes

This survey should only be relied upon for its original purpose. Grantham Coates Surveys Limited accepts no responsibility for use of this plan outside of the original remit, or by use of any party other than the original client.

Whilst every effort has been made to identify all above ground details, it should be noted that some items may have been obscured at time of survey.

Below ground drainage information as been visually inspected from the surface and should therefore be treated as approximate only.

Where this survey has been carried out for the purpose of enabling trackside drainage design. The position of any running rail has been surveyed in line with a general topographic survey and should not be used for the purpose of track design.

All dimensions to be checked on site prior to design and construction.

Legend			
AIR VALVE	AV	WATER TAP	TAP
BOLLARD	BD	TEMPORARY BENCH MARK	TBM
BORER HOLE	BHL	TELEPHONE CALL BOX	TCB
BUS STOP	BS	TELEPHONE POST	TEL
BT INSPECTION COVER	BT	THRESHOLD LEVEL	THL
BT BOX	BTB	TRAFFIC LIGHT	TL
CABLE TV INSPECTION COVER	CTV	TOP OF WALL	TOW
COVER LEVEL	CL	TELEGRAPH POLE	TP
DOWN PIPE	DP	UNABLE TO LIFT	UTL
DROPPED KERB	DK	VENT PIPE	VP
ELECTRICITY CONTROL BOX	ECB	RAIL WELD	WE
EAVES HEIGHT	EH	WATER METER	WM
ELECTRICITY MANHOLE	EM	WASHOUT	WO
ELECTRICITY POLE	EP		
EARTH ROD	ER		
FINISHED FLOOR LEVEL	FFL		
FIRE HYDRANT	FH	SURVEY STATION	GCS1
FOUL WATER	FW		
GULLY	GV		
GATE POST	GP	BUSHES	
GAS VALVE	GV		
INSULATED BLOCK JOINT	IBJ		
INSPECTION COVER	IC	HEDGES	
INVERT LEVEL	IL		
KERB OUTLET	KO		
LAMPPOST	LP	TREES	Height Species (Spread to scale)
LITTER BIN	LB		
MARKER POST	MK		
MILE POST	MP		
POST	PO		
RODDING EYE	RE	GATE	
RIDGE HEIGHT	RH		
ROAD NAMEPLATE	RN		
ROAD SIGN	RS	SECURITY FENCE	
STUMP	SP	FENCE	
SOFFIT LEVEL	SF	OVERHEAD CABLES	
SIGNAL POST	SIG	FOUL WATER	
RAIL SLEEPER LEVEL	SLP	GAS MAIN	
SIGNALS AND TELECOMS BOX	STB	UG POWER LINE	
SIGNALS AND TELECOMS CABLE	STC	STORM WATER	
SIGNALS AND TELECOMS POST	STP	UG TELEPHONE	
SIGN POST	SN	WATER MAIN	
STOP TAP	ST		
STOP VALVE	SV		
STAY	SY		
STORM WATER	SW		

Control Table				
Station	Description	Eastings	Northings	Height

Grid and Datum

Grid: OS National Grid **Datum: Ordnance Datum Newlyn**

Survey related to Ordnance Survey National Grid (OSGB36) via GPS and the OS Active Network.

A National Grid (OSGB36) coordinate has been established on site via Transformation OSTN15 and Geoid Model OSGM15, a further OS coordinate was used to orientate the survey to Ordnance Grid.

No scale factor has been applied to the survey

Title:

**WATERCOURSE SURVEY AT
Henley Bridge
(Key Plan)**

Client:

JBA CONSULTING
The Library
St. Philip's Courtyard
Coleshill
Warwickshire B46 3AD

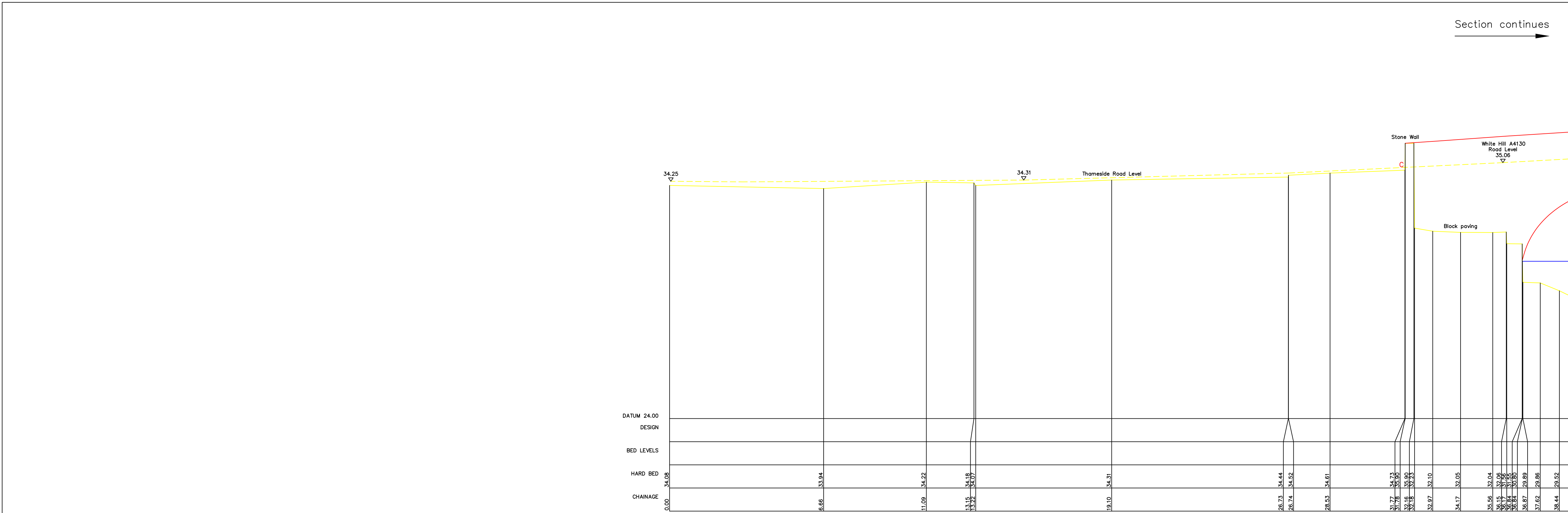
**Grantham Coates
Surveys Ltd**

Land - Engineering - Building Surveyors

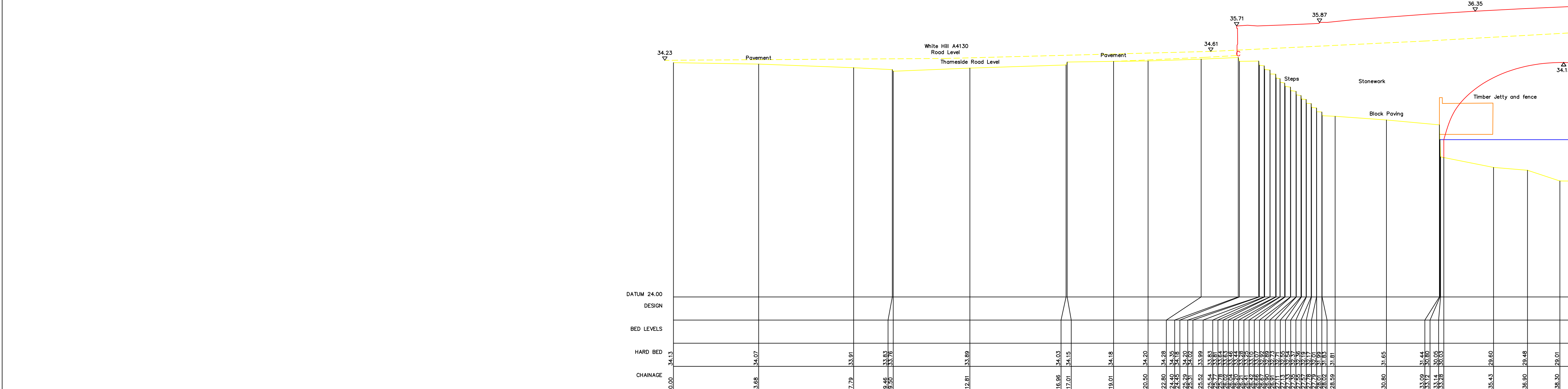
2 Arden Court, Arden Road, Alcester
Warwickshire, B49 6HN

Tel: 01789 764420
E-Mail: info@gcsurveys.co.uk
Web Site: www.gcsurveys.co.uk

Drawing No:		Rev:	
GCS/JBA/Henley Bridge/1		-	
Date:	Notes:	Name:	Rev:
Drawn:	Checked:	Scale:	Date:
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XS1
476297.8mE 182652.66mN Brg 94
Chainage 0
Upstream Face of Henley Bridge



XS2
476300.7mE 182643.45mN Brg 94
Chainage 9
Upstream Face of Henley Bridge

Notes

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Legend

AIR VALVE	AV	WATER TAP	TAP
BOLLARD	BD	TEMPORARY BENCH MARK	TBM
BORE HOLE	BHL	TELEPHONE CALL BOX	TCB
BUS STOP	BS	TELEPHONE POST	TEL
BT INSPECTION COVER	BT	THRESHOLD LEVEL	THL
BT BOX	BTB	TRAFFIC LIGHT	TL
CABLE TV INSPECTION COVER	CTV	TOP OF WALL	TOW
COVER LEVEL	CL	TELEGRAPH POLE	TP
DOWN PIPE	DP	UNABLE TO LIFT	UTL
DROPPED KERB	DK	VENT PIPE	VP
ELECTRICITY CONTROL BOX	ECB	RAIL WELD	WE
EAVES HEIGHT	EH	WATER METER	WM
ELECTRICITY MANHOLE	EM	WASHOUT	WO
ELECTRICITY POLE	EP		
EARTH ROD	ER		
FINISHED FLOOR LEVEL	FFL		
FIRE HYDRANT	FH	SURVEY STATION	△ GCS1
FOUL WATER	FW		
GULLY	GV		
GATE POST	GP	BUSHES	
GAS VALVE	GV		
INSULATED BLOCK JOINT	IBJ		
INSPECTION COVER	IC	HEDGES	
INVERT LEVEL	IL		
KERB OUTLET	KO		
LAMPPOST	LP	TREES	
LITTER BIN	LB	Height	
MARKER POST	MK	Species	
POST	PO	(Spread to scale)	
RODDING EYE	RE		
RIDGE HEIGHT	RH	GATE	
ROAD NAMEPLATE	RN		
ROAD SIGN	RS	SECURITY FENCE	
STUMP	SP	FENCE	
SOFFIT LEVEL	SL	OVERHEAD CABLES	
SIGNAL POST	SP	FOUL WATER	
RAIL SLEEPER LEVEL	SLP	GAS MAIN	
SIGNALS AND TELECOMS BOX	STB	UIG POWER LINE	
SIGNALS AND TELECOMS CABLE	STC	STORM WATER	
SIGN POST	SN	UIG TELEPHONE	
STOP TAP	ST		
STOP VALVE	SV		
STAY	SV		
STORM WATER	SW		

Control Table

Station	Description	Eastings	Northings	Height

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Datum: Ordnance Datum Newlyn

Survey related to Ordnance Survey National Grid (OSGB36) via GPS and the OS Active Network.

A National Grid (OSGB36) coordinate has been established on site via Transformation OSTN15 and Geoid Model OSGM15, a further OS coordinate was used to orientate the survey to Ordnance Grid.

No scale factor has been applied to the survey

Title:

WATERCOURSE SURVEY AT
Henley Bridge
(Cross Sections)

Client:

JBA CONSULTING
The Library
St. Philip's Courtyard
Coleshill
Warwickshire B46 3AD

Grantham Coates
Surveys Ltd

Land - Engineering - Building Surveyors

2 Arden Court, Arden Road, Alcester
Warwickshire, B49 6HN

Tel: 01789 764420

E-Mail: info@gcsurveys.co.uk

Web Site: www.gcsurveys.co.uk

Drawing No:

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95 Whilst every effort has been made to identify all above ground details, it should
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Below ground drainage information has been visually inspected from the surface and should therefore be treated as approximate only.

Where this survey has been carried out for the purpose of enabling trackside drainage design. The position of any running rail has been surveyed in line with a general topographic survey and should not be used for the purpose of track design.

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WATERCOURSE SURVEY AT
Henley Bridge



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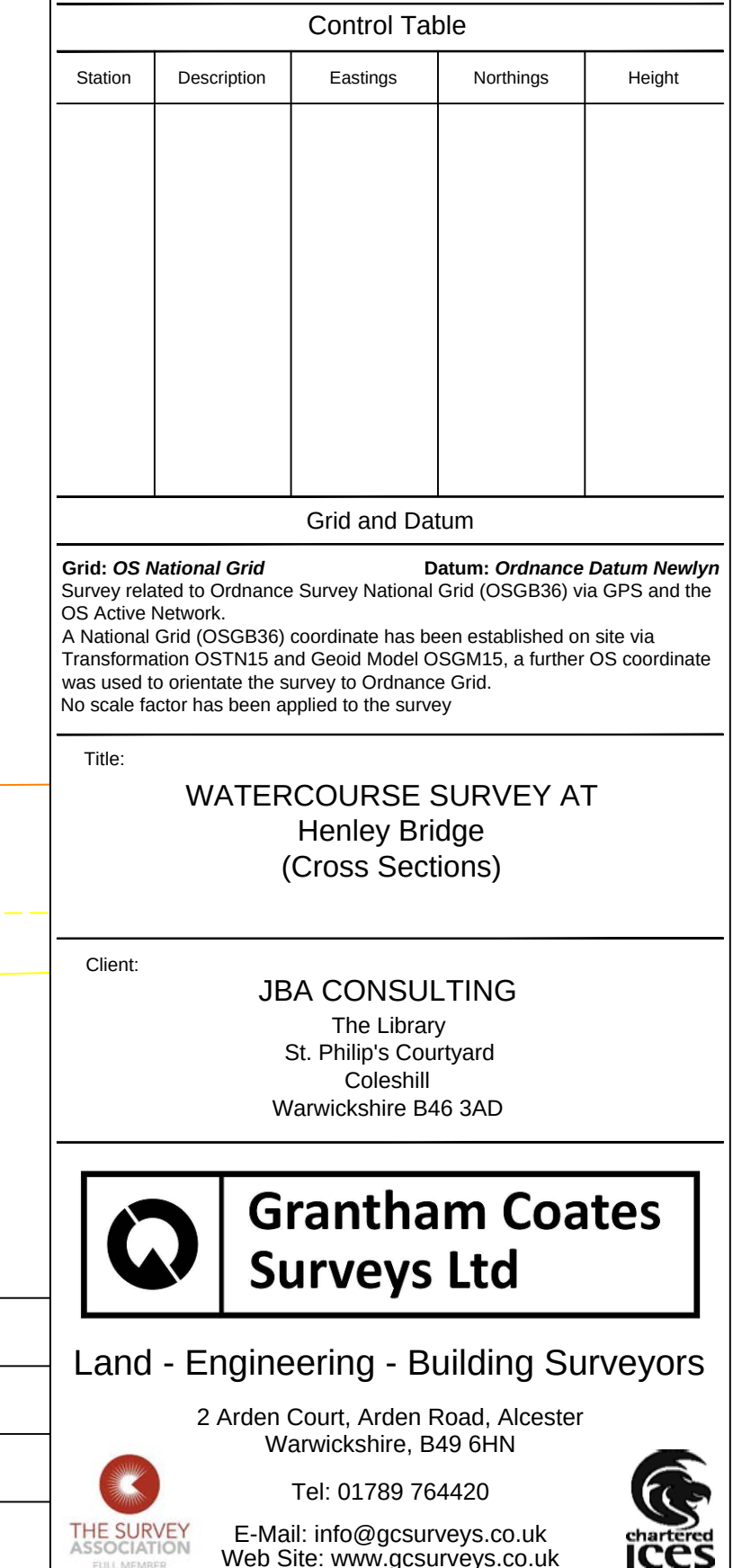
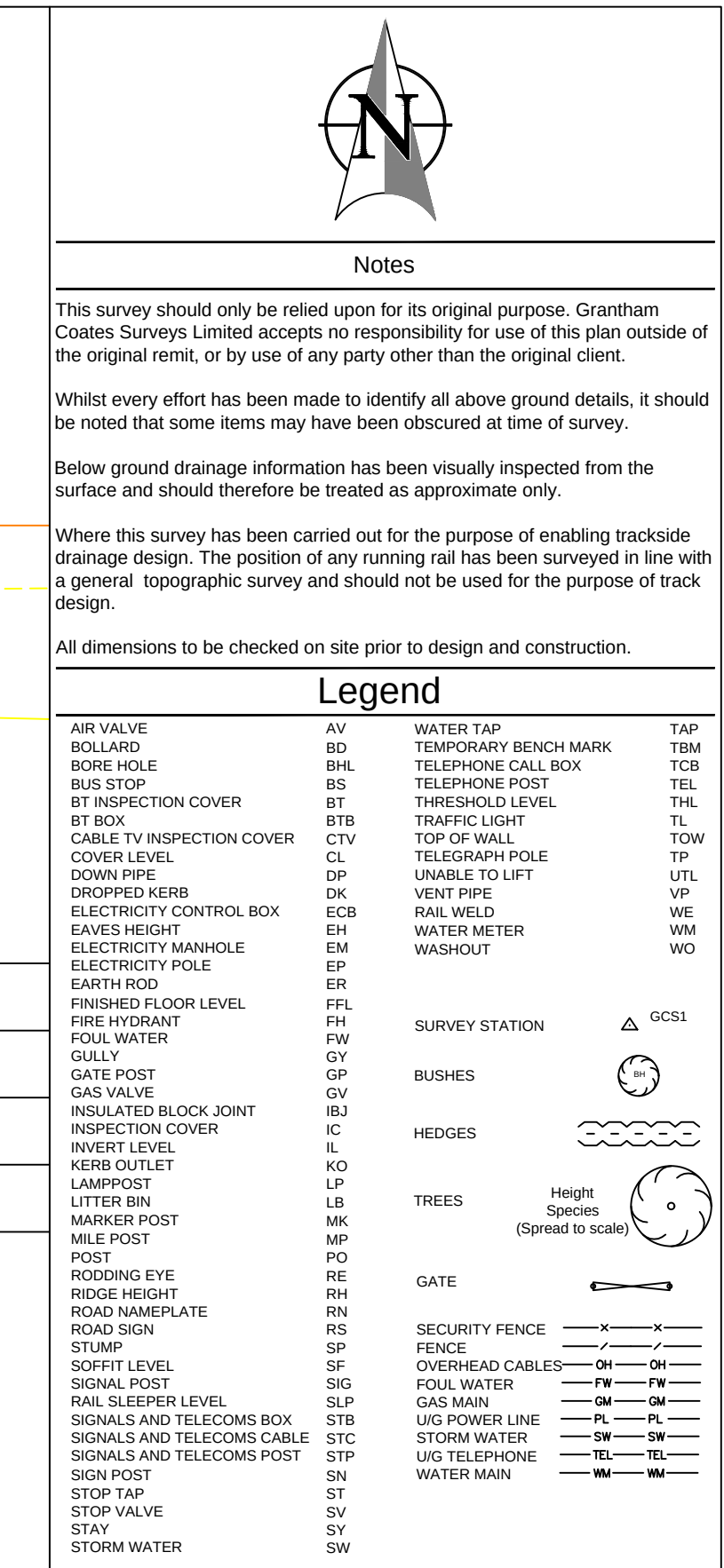
THE SUBMITTER'S NAME AND ADDRESS

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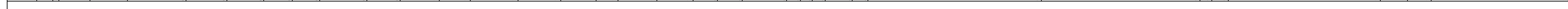
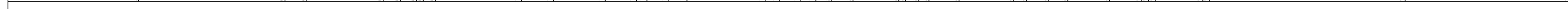
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AV	WATER T
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WATER QUALITY SURVEY (1994)

Henley Bridge

JBA CONSULTING



© 2006 The Authors
Journal compilation © 2006 Blackwell Publishing Ltd

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000 50/1 Cheney Bridge 1		
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C Appendix C – Sensitivity analysis

The hydraulic model was tested for sensitivity to key model parameters which might impact flood risk at the proposed development site. This included the following scenarios:

- Increasing flows by 20%
- Increasing the Manning's n values by 20%. This both in the Flood Modeller 1D channel and in the 2D TUFLOW domain.
- Increasing the downstream boundary water levels by 250mm

The following sections discuss the impacts of these sensitivity scenarios.

C.1 Sensitivity to flow

Figure E-4-1 shows the changes in peak water level compared to the baseline 100-year event when an increase of 20% is applied to all inflows.

Figure E-4-1: Sensitivity analysis for +20 % inflows

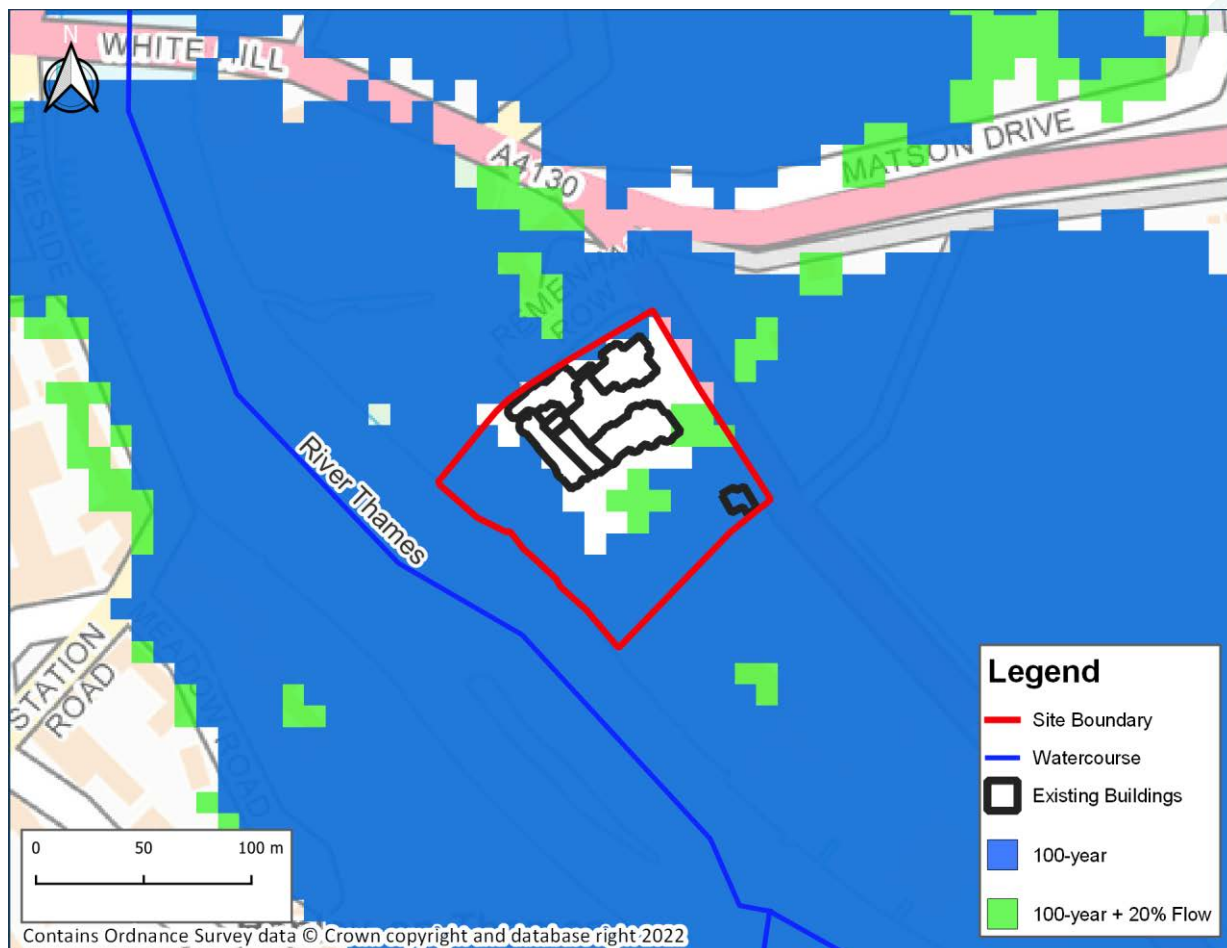


Figure E-4-1 indicates there that there are minimal changes in the peak water level results when increasing the flow with 20%. As a result, the model is considered to be insensitive to increases in flow.

C.2 Sensitivity to flow

Figure E-4-2 shows the changes in peak water level compared to the baseline 100-year event when an increase of 20% is applied to all inflows.

Figure E-4-2: Sensitivity analysis for +20 % inflows

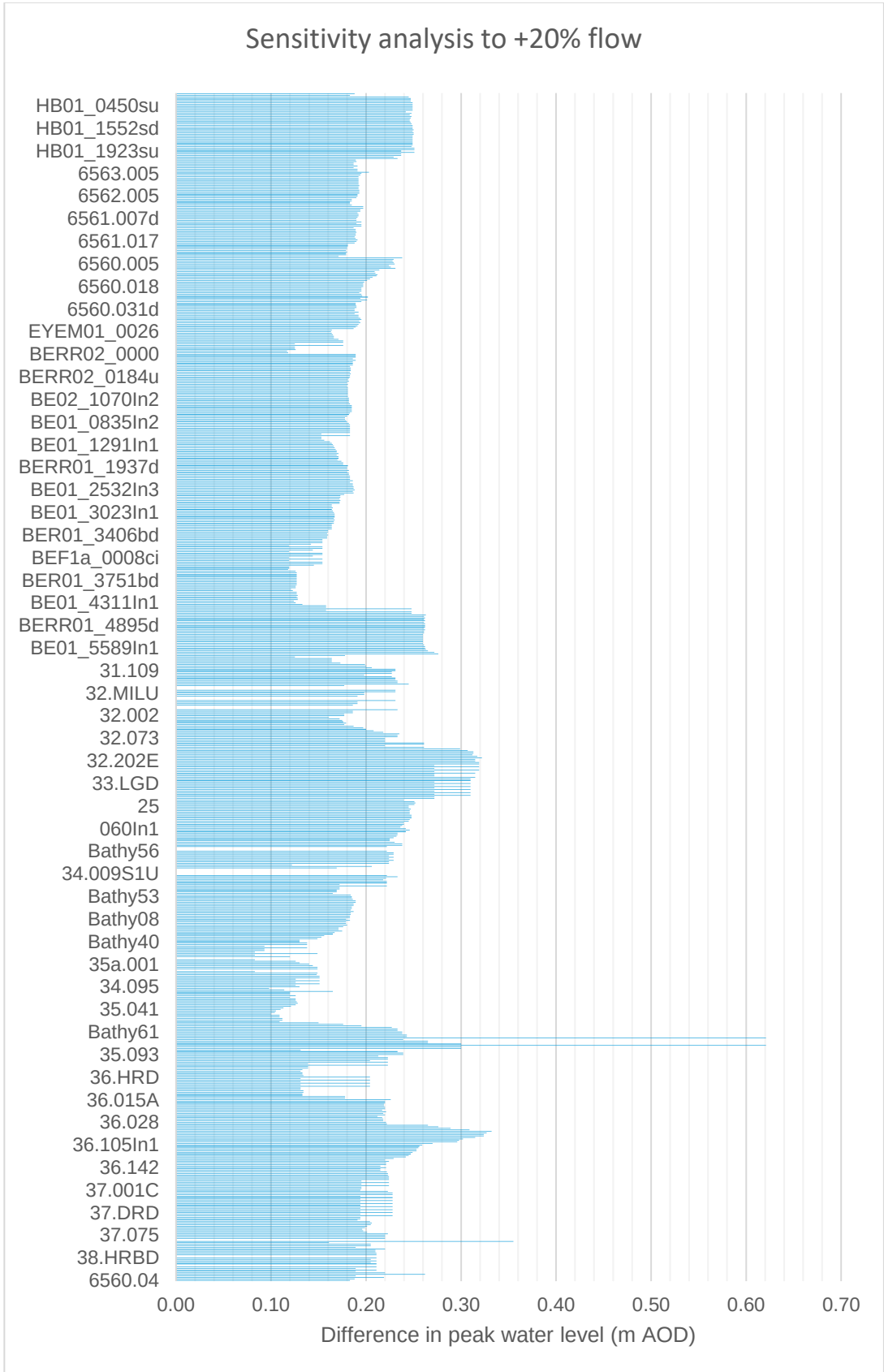


Figure E-4-2 indicates there is a maximum increase in peak water level of 0.62m around 36b.001 and Bathy58 cross sections, both located approximately 16km upstream of the site and is unlikely to affect the water levels at the site location. The results show that the model is considered insensitive to increases in flow.

C.3 Sensitivity to roughness

Figure E-4-3 shows the changes in peak water level compared to the baseline 100-year event when a change of +20% is applied Manning's 'n' in both the 1D and 2D domains.

Figure E-4-3: Sensitivity to changes of +20% in roughness

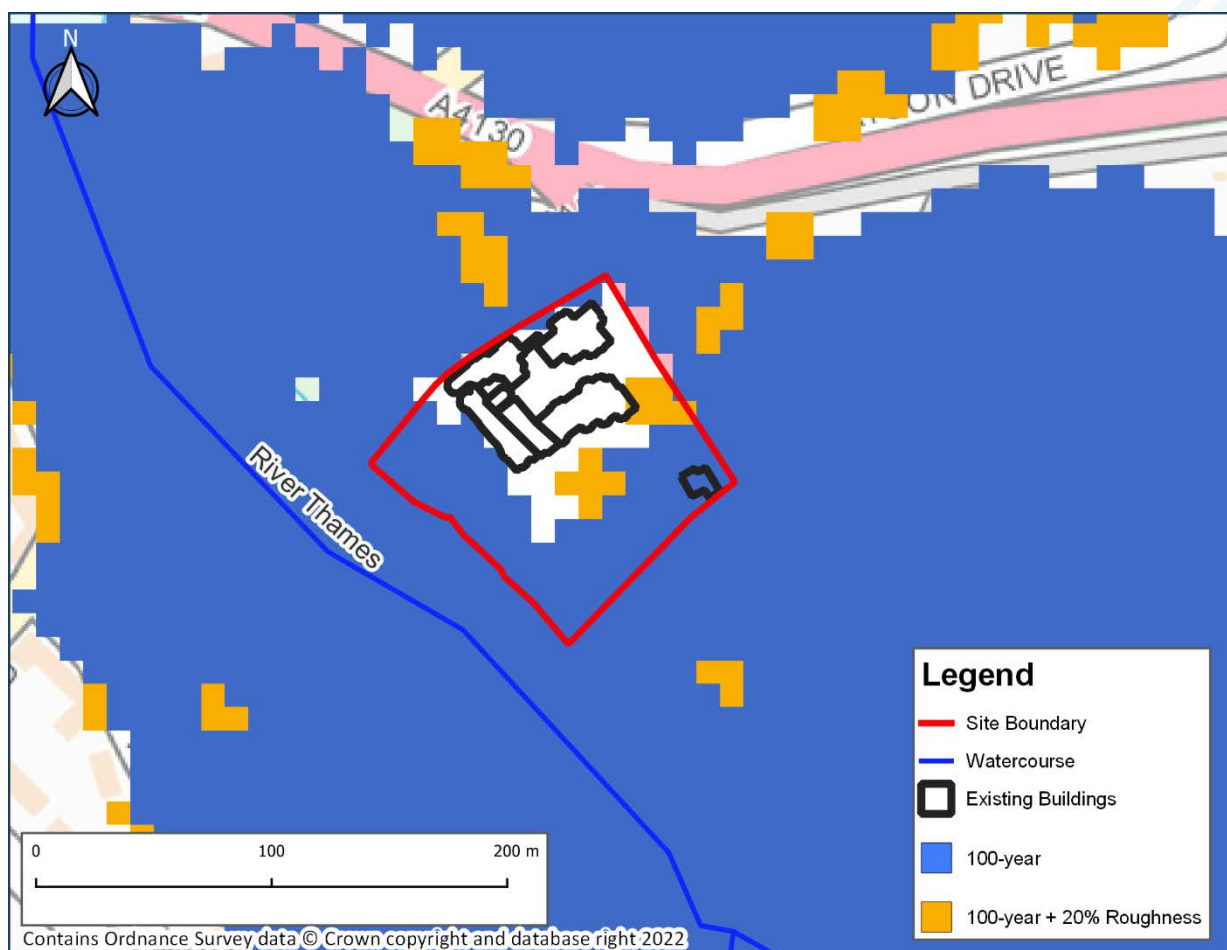


Figure E-4-3 indicates that, the model is relatively insensitive to the roughness values applied to the 1D and 2D domains within the site boundary, with minor changes in the peak flood extents predicted to occur within the south-eastern edge of the site boundary when roughness is increased by +20%.

C.4 Sensitivity to roughness

Figure E-4-4 shows the changes in peak water level compared to the baseline 100-year event when a change of +20% is applied Manning's 'n' in both the 1D and 2D domains.

Figure E-4-4: Sensitivity to changes of +20 % in roughness

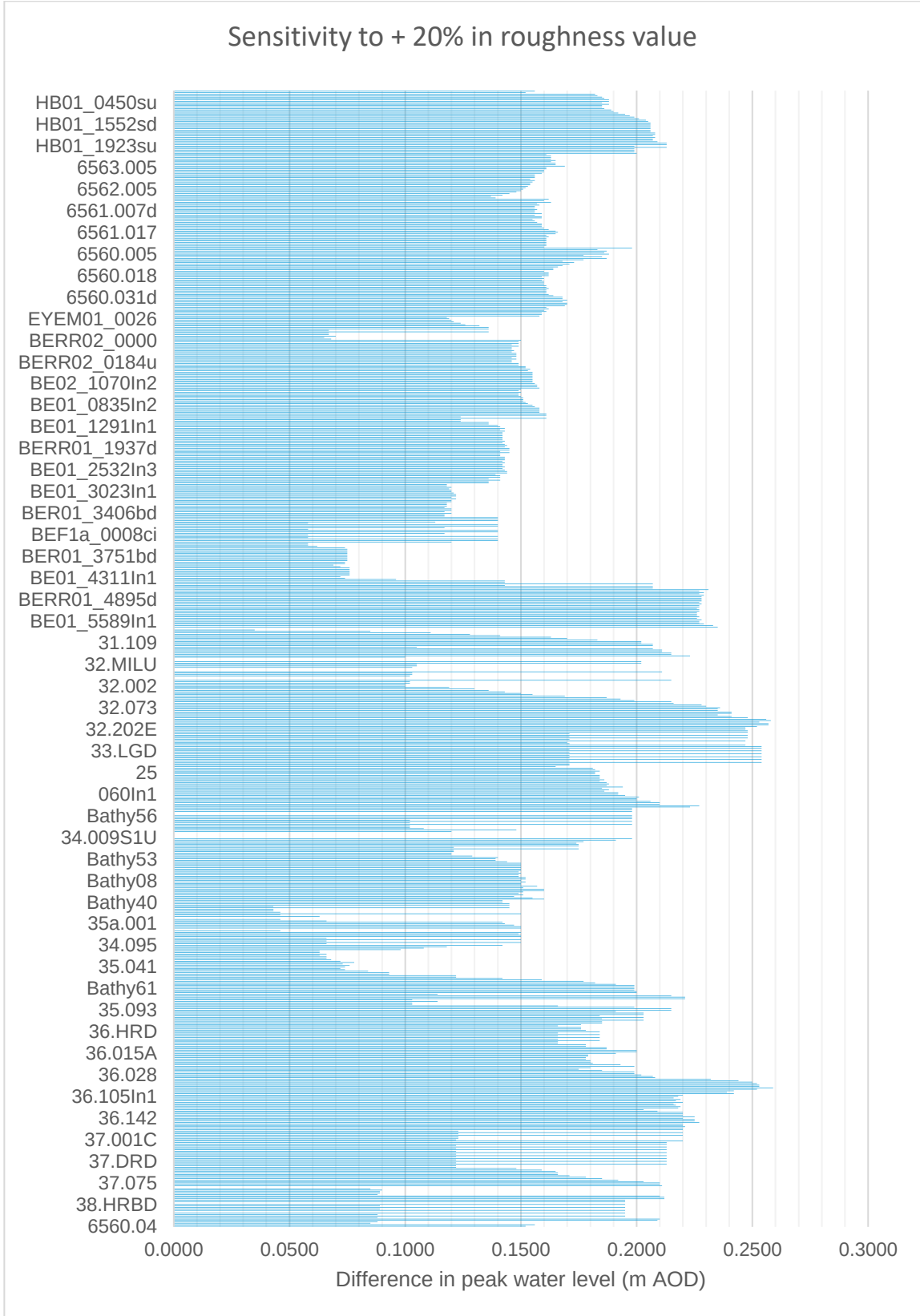


Figure E-4-4 indicates there is a maximum increase in peak water level of 0.26m around 36.071A cross section, which is located approximately 17km upstream of the site and is unlikely to affect the water levels at the site location. The results show that the model is relatively insensitive to increases in roughness values.

C.5 Sensitivity to downstream boundary conditions

Figure E-4-5 shows the changes in peak water levels compared to the baseline 100-year event when an increase of 250mm in water level is applied to the downstream model boundary condition.

Figure E-4-5: Sensitivity analysis for +250mm in water level at downstream boundary

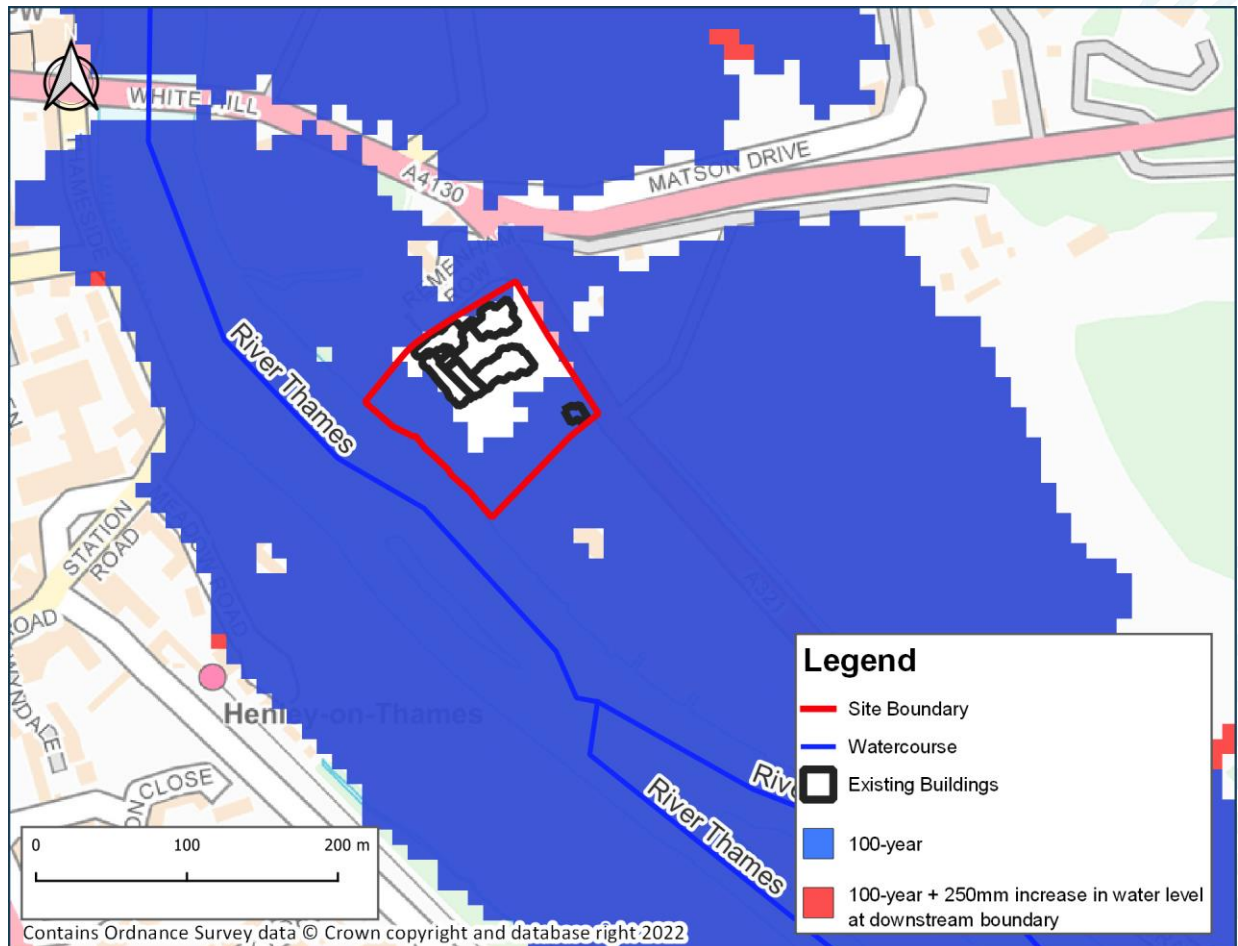


Figure E-4-5 indicates that minimal change can be seen due to the increase in water level at the downstream boundary. As a result, the model is insensitive to changes in downstream boundary condition within the site.

C.6 Sensitivity to downstream boundary conditions

Figure E-4-6 shows the changes in peak water levels compared to the baseline 100-year event when an increase of 250mm in water level is applied to the downstream model boundary condition.

Figure E-4-6: Sensitivity analysis for +250mm in water level at downstream boundary

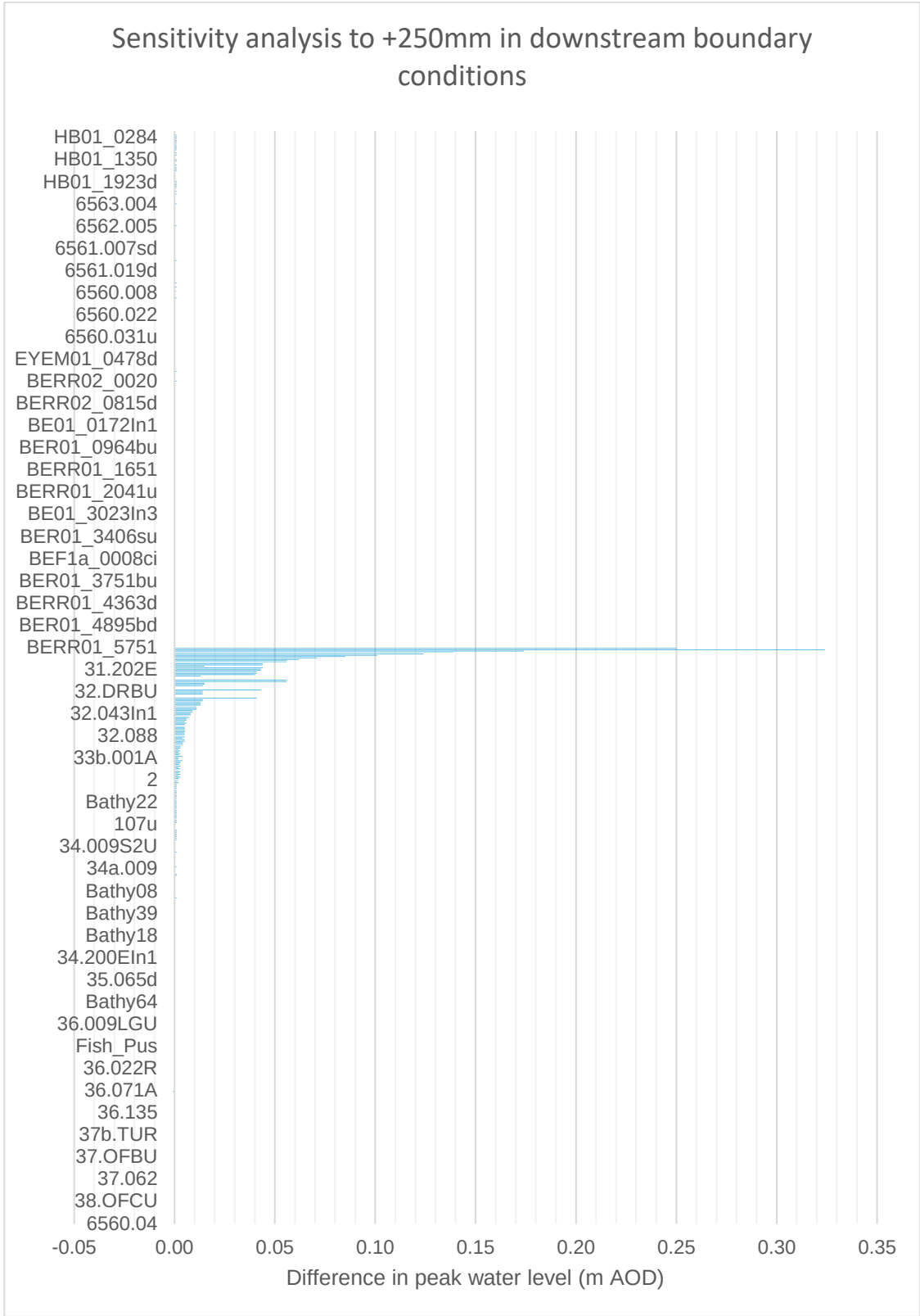


Figure E-4-6 indicates that the maximum increase in peak water level at the downstream boundary is 0.32m at cross section 31.055 located at the downstream extent of the model. The model is considered insensitive to changes in downstream boundary condition within the site.

D Appendix D – Flood Estimation Report

Flood estimation report

Introduction

This report template is based on a supporting document to the Environment Agency's flood estimation guidelines (Version 5, 2015). It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

1	Method statement	1
2	Locations where flood estimates required	24
3	Statistical method	27
4	Discussion and summary of results	33
5	Annex	38

Revision history

Revision ref / date issued	Amendments	Issued to
V1 / 17 May 2017	None. Discusses the proposed methods and results of exploratory analyses.	Caroline Drewett
V2 / 21 July 2017	Changes as per EA comments from method statement and completion of Chapter 2 onwards.	Caroline Drewett
V3 / 29 August 2017	Clarifications added following an external review, mostly regarding assumptions used in the analysis	Caroline Drewett

Approval

	Name and qualifications	Date
Method statement prepared by:	James Molloy BE(Hons) MEngSc / Duncan Faulkner MA MSc FCIWEM CSci	20 April 2017
Method statement reviewed by:	Ben Gibson BSc MSc MCIWEM C.WEM / Rachel Huitson-Little MSc MCIWEM C.WEM CEnv	17 May 2017
Calculations prepared by:	James Molloy BE(Hons) MEngSc	20 July 2017
Calculations reviewed by:	Duncan Faulkner MA MSc FCIWEM CSci	21 July 2017

Abbreviations

AM.....	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE.....	Council for the Protection of Rural England
FARL.....	FEH index of flood attenuation due to reservoirs and lakes
FEH.....	Flood Estimation Handbook
FSR.....	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT.....	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR.....	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

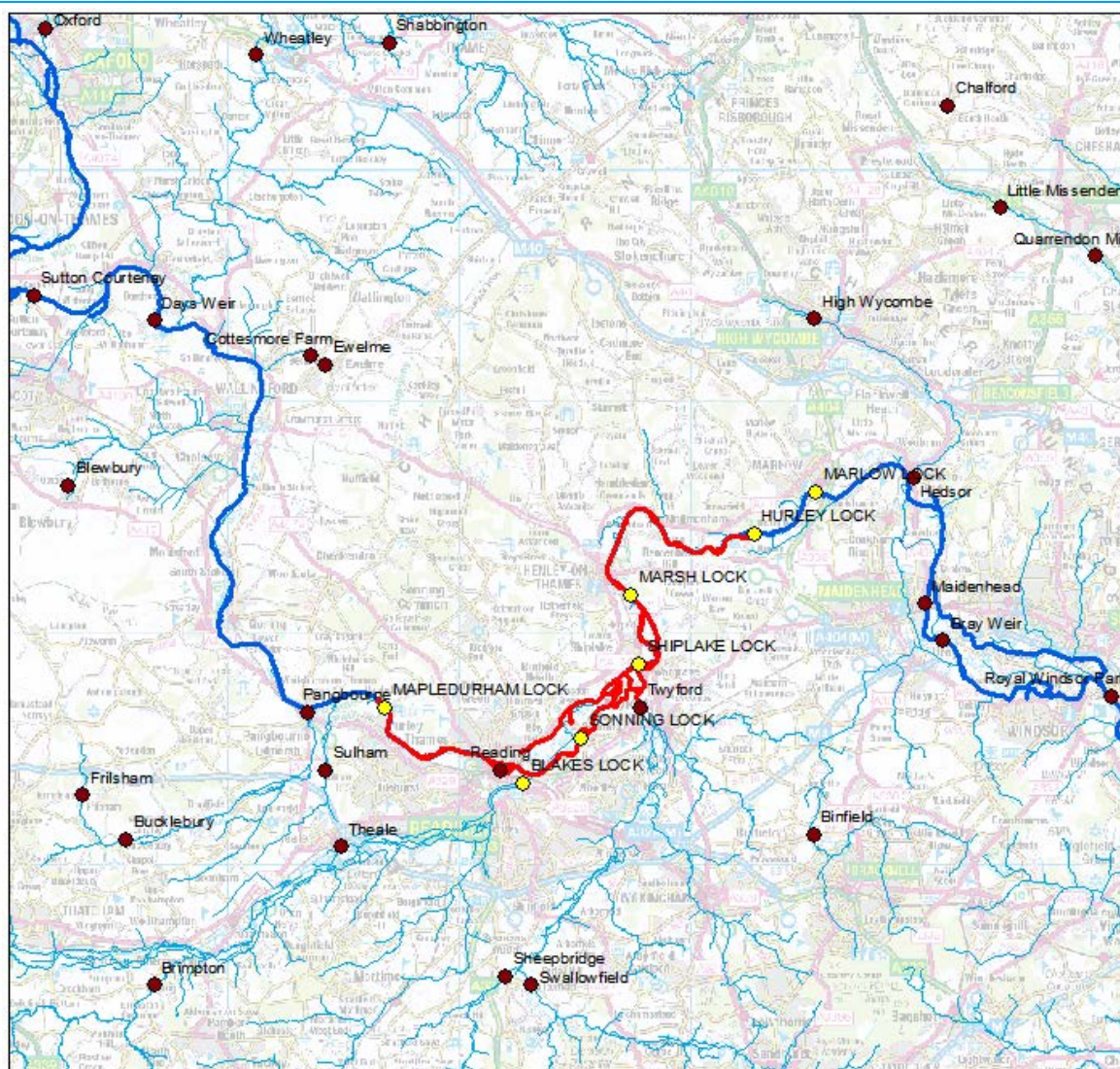
1 Method statement

1.1 Requirements for flood estimates

Overview • Purpose of study • Peak flows or hydrographs? • Range of return periods and locations	The aim of the project is to improve the quality of flood modelling from upstream of the Reading area down to Hurley and to provide improved flood mapping. As well as the Thames, the model is to include the River Loddon below the A4, along with the Borough Lake Stream and the St Patrick's Stream. Future use of the model outputs may also be required for flood alleviation modelling, in areas of flood risk including Caversham, Charvil and Hurley. The scope states that inflows to the models are to be obtained from the Thames at Mapledurham from the Thames (Sandford to Tilehurst) 2016 model and outflows from the model are to match the design inflow to the lower Thames 2016 model at Hurley. We will review whether or not these requirements are hydrologically sensible given that design floods are not usually expected to occur during the same event along the entire length of a river. The model is to be hydrodynamic so hydrographs will be needed. The project scope requires results for annual exceedance probabilities (AEPs) of 50%, 20%, 10%, 5%, 3.33%, 2%, 1.33%, 1%, 0.5%, 0.2% and 0.1%. For the 1% AEP event, three climate change scenarios are required, with flows increased by 25%, 35% and 70%. Note that these requirements were amended from those in the original scope (email from the Environment Agency on 20 February 2017). A brief review of a previous report on the hydrology of the study reach (Jacobs, 2011) is provided in Section 1.3.
---	--

1.2 The catchment

Map of study reach and broader context showing surrounding gauging stations



Legend

- Flow gauge on NRFA
- Other flow/level gauges in study area
- Rivers to be modelled
- River Thames
- Other watercourses

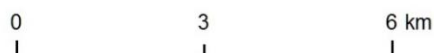
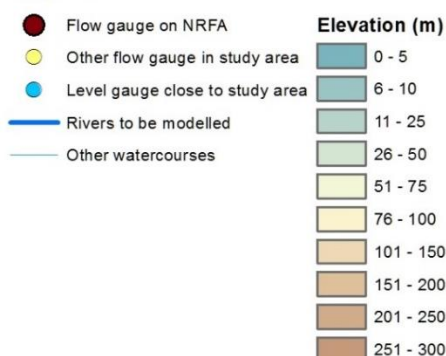
0 5 10 20 km

Contains OS data © Crown copyright and database right 2016

More detailed map of study reach



Legend



Contains OS data © Crown copyright and database right 2016

Description	Please refer to previous reports such as Jacobs (2011) for a description of the Thames catchment. The Redgrave Pinsent Rowing Lake between Caversham and Sonning Eye was created from Caversham Lakes (former gravel pits) and was completed in 2006. It is a significant conveyor of flood flows. The River Kennet joins the Thames in the eastern part of Reading. It drains a large catchment, which at this point forms 20% of the Thames catchment. The Kennet drains rural Chalk downs and so is a largely permeable catchment, with BFIHOST equal to 0.74. The River Loddon inflows enter the Thames both above and below Shiplake Lock. The Loddon adds 11% to the area of the Thames catchment at this point. It drains a moderately permeable catchment (BFIHOST 0.59) with some urbanisation (URBEXT2000 0.12). The Berry Brook rises in the eastern part of Lower Caversham and flows along the edge of the Thames floodplain, eventually joining the Thames via a network of
-------------	--

channels near Shiplake. Its catchment area at the upstream limit of the model reach is very small, less than 1km ² . By the time it joins the Thames it is draining an area of some 10km ² , largely rural and with moderately high permeability (BFIHOST 0.68).
--

1.3 Review of previous reports

1.3.1 Context

The scope requires a review of the hydrology report on the River Thames (Mapledurham to Sonning), 2011. This is provided below. It also calls for familiarisation with the hydrology reports for the Whitchurch to Henley model (2000) and Henley to Hurley model (2002). The reports provided did not quite match either description; a report was provided on the Whitchurch to Hurley flood mapping study (1998) and this referred back to the 1991 Caversham Lakes flood hydrology report for the estimation of design floods.

There has been a large volume of work carried out relating to flood studies on the Thames. Selected reports have been reviewed to develop an understanding of the runoff characteristics of the River Thames and to inform on issues such as data quality and reliability of gauging sites in the study reach. This list includes but is not limited to:

- Beran and Field (Institute of Hydrology, 1988), Maidenhead, Windsor and Eton Flood Study Stage 2 Hydrology Report.
- PBA (1991), Caversham Lakes Development Flood Hydrology Analysis. Report to NRA.
- Crooks (1994), Changing flood peak levels on the River Thames, Proc. Inst. Civil Engrs.
- Dunsmore (1997), River Thames Flood Hydrology Design Curves. J. CIWEM (11).
- Jacobs (2005), Lower Thames FRM Project Hydrology Report Issue No. 6.0.
- Jacobs (2011), Reading Complex Change Project Final Mapping Stage. Hydraulic modelling report.
- Marsh and Harvey (2012), The Thames flood series: a lack of trend in flood magnitude and a decline in maximum levels, Hydrology Research **43**(3).
- JBA Consulting (2014) Lower River Thames Flood Modelling Study, Hydrology Report.

1.3.2 Review of 2011 hydrology

The Reading Complex Change Project was also known as the Mapledurham to Sonning project and this is the one referred to in the scope. It was carried out by Jacobs and the revised draft hydrology report, Reading Flow Gauge Flood Frequency Analysis, is dated March 2011. An earlier draft from September 2010 was peer reviewed by JBA in February 2011 and so the comments below do not attempt to repeat that detailed critique. Our 2011 review concluded that the results in the draft report were suitable for use in the initial development of the Reading Flood Alleviation Scheme and for the ongoing flood mapping study, but the method described in a supplementary note for estimation of the 1000-year flow was not suitable and needed significant revision.

To estimate design flows, a flood peak series for the Reading area was extended back to 1892 using data on tailwater levels at locks, which was converted to flow using high flow rating curves derived from flow data at Reading, Windsor and Days Weir in conjunction with tailwater levels at Goring, Whitchurch and Mapledurham Locks. These locks were chosen in preference of those downstream of the confluence with the River Kennett. This analysis relies on the assumption of an unchanging stage-discharge curve over the period from 1892 to date. The report mentions that there has been little dredging or gravel extraction over the relevant reach.

The analysis also incorporated historical data in the form of flood levels at Whitchurch from 1768, converted to approximate flows. The flood growth curve was adjusted informally to incorporate these data, an approach which can be improved on using the maximum likelihood method. As a result, design flows were increased for return periods longer than 50 years.

The resulting estimate of the 1% AEP flood at Reading was 375 m³/s. The 2003 flood would have had an AEP between 4.0% and 2.0% according to the results of the flood frequency analysis. The March 1947 flood peak had an AEP between 1.33% and 1.00% (using the best estimates for the event peak from Jacobs 2011).

The method used to estimate design flood hydrographs was similar to that employed on a previous project, the Lower Thames Flood Study (2005). The hydrograph shape at Reading was set to that of the 2003 flood. Inflows to the Thames between Reading and Bray/Windsor i.e. from the Kennet, Loddon, Wye and Cut, were set in order to match the flood frequency curve on the Thames at Bray/Windsor.

The hydraulic modelling report also provides some brief information on the hydrological analysis. Flow data for calibration of the model was obtained from gauges. Routing models were used to check that the inflow hydrographs when routed through the system sum to match the hydrographs gauged downstream at Windsor. Inflows were adjusted as necessary to account for ungauged portions of the catchment. This adjusted inputs give an acceptable match with the gauged flows at Windsor.

1.4 Source of flood peak data

Source	NRFA peak flows dataset, Version 5, April 2017. This contains data up to water year 2014-15 for England, Wales and Northern Ireland and 28 gauges in Scotland and up to water year 2005-6 for the remaining gauges in Scotland.
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1.5 Gauging stations (flow or level)

(at or very near to the sites of flood estimates)

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start of record and end if station closed
Thames	Sutton Courtenay	1800	39046	3,425	Ultrasonic	1974 -
Thames	Days Weir	1900	39002	3,480	Rated	1938-
Thames	Maple-durham Lock	2199	n/a		Level and rating for flood flows	Late 1800s-
Thames	Reading	2200	39130	4,634	Ultrasonic	1992-
Thames	Caversham Lock		n/a		Level	Late 1800s-
Thames	Sonning Lock	2301	n/a		Level	Late 1800s-
Thames	Shiplake Lock	2302	n/a		Level	Late 1800s-
Thames	Marsh Lock	2495	n/a		Level	Late 1800s-
Thames	Hurley Lock	2497	n/a		Level	Late 1800s-
Thames	Maidenhead	2604	n/a	6,910	Ultrasonic	2003-
Thames	Taplow	2603	n/a	6,910	Ultrasonic	2003-
Thames	Windsor	2700	39072	7,124	Ultrasonic	1979-
Thames	Kingston / Teddington	3400	39001	9,948	Mixed	1882-
Kennet	Theale	2290	39016	1,033	Rated	1961-
Loddon	Twyford	2490	39138	751	Mixed	1994-

1.6 Data available at each flow gauging station in Table 1.5

Note: Comments on the Thames gauges are based on those in the Lower Thames draft hydrology report (JBA Consulting, 2014), with additions from the Environment Agency's Review of Flow Derivation Method documents.

Station name	Start and end of NRFA flood peak record	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality
Sutton Courtenay	None	Yes	n/s	n/s	No	See discussion of the nearby Days Weir gauge below
Days Weir	1938-2014	Yes	Yes	Yes	No	See below.
The Days Weir gauge is found in the NRFA peak flows database whereas the nearby Sutton Courtenay gauge is not. Comments provided by the Environment Agency Hydrometry team state that there is a higher level of confidence in flood flow measurements at the latter gauge however. The NFFS rating at Sutton Courtenay is also considered more reliable in flood conditions compared to the ultrasonic flow records (D Rylands, comments received 02 June 2017). The catchment areas of the two gauges are within 1% of each other. Sutton Courtenay was intended to be a replacement for Days Weir. Days Weir was built in 1885, modified in 1938 (when flow recording started) and rebuilt in 1968-9. It currently has 15 radial gates and a moveable thin plate weir. When the gates are fully opened the bankfull limit is about 140 m³/s (just below QMED); at higher flows there is a large amount of overspill and the weir is bypassed. Flows have been recorded at Sutton Courtenay using ultrasonic equipment since the start of the record in 1974. In 1982 the original single-path gauge was replaced by a multi-path device. A rating curve (calibrated from spot gaugings) is used to convert river levels to flows at Days Weir. In high flows, the rating curve calculates flows solely from the tailwater level. The location of the Days Weir gauge is not favourable, located on a meander and also potentially affected by backwater effects from the confluence with the River Thame 2km downstream. JBA (2014) compared flows at Days Weir from the rating with the limited number of spot gaugings available and found no bias at high flows. There were few spot gaugings available in the high flow range, with insufficient data to draw conclusions for the performance of the gauging site for flows larger than QMED. The reason given in the NRFA for Days Weir being suitable for pooling is that "Calculated flows are within 5% of measured flows, though this can increase to 10% over 100 m³/s." The highest flow recorded since the weir was replaced in 1969 is about 240 m³/s. The highest check gauging is at 140 m³/s. Given the amount of extrapolation of the rating and the potential for bypassing it is suggested that the rating would benefit from extension using a hydraulic model and until this happens the largest flood peak data at Days Weir should be treated with caution. Jacobs (2011) state that two hydraulic modelling studies have both indicated that the 1947 recorded flow figure at Days Weir is overestimated by approximately 60 m³/s.						
Maple-durham	None	n/a	n/a	n/a	Yes	See comments on Reading gauge.
Reading	None	n/a	n/a	n/a	Yes; see below.	See below.

Station name	Start and end of NRFA flood peak record	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality
The maximum reliable flow for Reading is estimated at 240m³/s according to the Gauging Station Data Quality (GSDQ) reports. This limit has been exceeded by just one or two floods since records began in 1992. The gauge is classed as good for high flow derivation by GSDQ in a two-page summary document for the gauge provided by the EA, but the "Review of flow derivation method" EA report and Jacobs (2011) state the GSDQ score is instead classed as "Fair". According to Jacobs (2011) this is due to a low relative height of the top-most ultrasonic path at the gauge. Comments received from the Environment Agency state that there is moderate underestimation at high flows due to bypassing. The flood forecasting model originally accounted for this bypassing using a high flow rating based on levels recorded at Reading gauge, but these are affected by gate movements just downstream at Caversham weir and sometimes by inflows from the Kennet, and also by the changes to the rowing course area further downstream. For these reasons since 2014 the forecast model has used the NFFS rating at Mapledurham instead during high flow conditions (developed by Capita, "Hydraulic Models for Forecasting, 2014 Improvements"). During this period, up to February 2017, there have been no major floods. This NFFS rating can be applied to the historic tailwater level record at Mapledurham, as an alternative to using the flow record at Reading. This gives an advantage of a much longer period of record at Mapledurham, available from the Lock Keeper POT records, as well as less sensitivity in levels than at Reading from the issues discussed above. Caution would need to be applied due to the step-change in Thames levels which occurred after the 1947 flood after the Thames was dredged. Gaps in the Lock Keeper record at Mapledurham in years where the AMAX flow was relatively low could be infilled from calculating a relationship between flows at Days Weir/Sutton Courtenay and Reading (with caution, as the Thame catchment enters the Thames between these gauges). It is recommended to review the NFFS Mapledurham rating, as flow gauging at this point is key to the flood-frequency calculations for this project (see the discussion of Rating Equations below) Notes from the Environment Agency state that there were problems with the ultrasonic flow gauge over the winter 2013-14 period due to debris affecting the measuring equipment at the gauging site. JBA (2014) compared the flows measured by the ultrasonic gauge with spot gaugings and concluded that the gauge performed moderately well, apart from in February 2014 as noted above. It was not possible to comment on the performance of the gauge during out-of-bank conditions (flows above 240m³/s), due to a lack of spot gaugings in this range. Hence, it was decided that an AMAX record derived from this gauge will give a representative QMED value and could potentially also be used to estimate design flows for short return periods.						
Maidenhead and Taplow	None	n/a	n/a	n/a	No	See below.
The Maidenhead and Taplow gauges are located just downstream of the point where the Jubilee River extracts flow from the Lower Thames, using ultrasonic equipment to measure channel flows. Flow diversion from the River Thames occurs for incoming flows above 180m³/s. For the purposes of the Lower Thames modelling study, the flow records were added at these two sites to provide a composite record, referred to as 'Maidlow'. These gauging sites were opened in 2002 to monitor flows after the construction of the Jubilee River flood alleviation scheme. Flows at both sites are measured using multi-path ultrasonic gauges. The gauges captured the January 2003 event on the Thames, but were not in place for a sufficient length of time to allow for an adequate calibration. Hence records of the January 2003 flood are less reliable at this site. The GSDQ reports for these sites give a "Good" quality flag for high flow measurements at both sites. Notes provided by S. Everitt and L. Lovell state that the upper range of reliability of these gauges is unknown, but likely to be above 230m³/s and 160m³/s for the Maidenhead and Taplow gauges respectively, which were the peak flows observed in February 2014. Hence the combined upper reliable limit for 'Maidlow' is of the order of 400m³/s. . These notes also state that the Taplow gauge did not perform well during the peak of the January 2014 peak, but appeared satisfactory for the February 2014 event. There are also reported problems with shifting bed levels over time at both sites and with turbulence in the measurement channel caused by an island upstream of the Maidenhead gauge.						
Windsor	1979-2014	No	Yes	No	No	Ultrasonic data have been used to measure flows from 1979. Data quality reviewed in detail in the JBA 2013 Lower Thames study. Past studies have attempted to extend the flow record here using nearby lock keeper records. There are concerns that the high-flow data quality at this gauge are lower quality due to the gauge location on a bend, and possible bypassing in extreme floods. The EA report a reliable upper limit of 330m³/s.

Station name	Start and end of NRFA flood peak record	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality
Kingston	1882-2014	No	Yes	Yes	No	Ultrasonic equipment has been used at Kingston to record flows since 1974. However, sub-daily resolution data are available here from 1984 onwards only. A much longer daily-resolution record is available from the Teddington site (located 2km downstream of Kingston), where flow was recorded twice-daily at low tide via a complex combination of weirs, gates and sluices. This earlier period of record extends back to the late 1800s.
Theale	1961-2014	Yes	Yes	Yes	Yes	There are two rating curves available at this site (WISKI and NFFS), giving significantly different flows in flood conditions. Following discussions with the EA, it was decided to apply the NFFS rating in this study. See further discussion below.
Twyford	None	n/a	n/a	n/a	No	Two side-looking ADCP devices, installed since 2010, located within two rectangular road bridge culverts. These replaced an ultrasonic gauge shortly downstream which was shut down following persistent mechanical and in-channel issues with the lower paths of the ultrasonic caused by a build-up of silts and weeds, resulting in dropouts and suspicious readings in the data. Substantial gaps in the flow data supplied from the ultrasonic gauge for the period 2006-10. A velocity index rating was developed from numerous flow gaugings. In November 2016 corrections were made to the calculation of flow and stage. GSDQ classes this gauge as "Caution" for high flow derivation.

1.7 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Comments and link to any rating reviews
Days Weir	Theoretical, checked with gaugings.	No; outside study area	Non-standard weir calculation for peak flows that is specific to this site. Rating formulae based upon gaugings - tailwater calibration applies for flows > 70 m ³ /s; above 100 m ³ /s overspill occurs.
Mapledurham	Empirical	Yes (see details of review below)	Rating derived by regression of tailwater level at Mapledurham on flow from the ultrasonic gauge at Reading. Currently used in the NFFS to estimate peak flows at Reading. Rating was derived by Capita (2014), recommending that Mapledurham tail levels are less sensitive to downstream effects from the Kennet and downstream rowing lakes, compared to the Reading gauge. A review of the Mapledurham NFFS rating is provided below.
Theale	Theoretical, checked.	No	There is an alternative rating used in NFFS which can give very different flows from the rating applied in WISKI. Peak flows from the former are considered more accurate in flood conditions, hence it is proposed to use the NFFS rated flows in preference to the WISKI rating at Theale in this study, as agreed following a conversation with EA hydrometry staff (pers. comm with D Rylands, 18/07/2017). It is noted that neither rating accounts for possible bypassing and storage through nearby gravel pits. Comparisons of flow hydrographs for an available period of overlapping data (2010 – 2016) show that the NFFS rating gives a close match to flows at the relatively new Blakes Lock gauge near the Thames confluence downstream, indicating that this issue is less critical if using the NFFS rating. This also indicates that adjustments for the additional drainage area downstream of the Theale gauge to the Thames confluence are not necessary when representing the entire Kennet contribution to flows in the Thames. The Kennet modelling study, being carried out in parallel to this study, also proposes to use the NFFS rating at Theale.
Marsh Lock	Not currently rated	Yes (see details below)	Moderately long tail water level record available (22 years of 15-min data, plus the long historic POT series of water levels), located downstream of the confluence of the River Loddon. Some issues with frequent spikes and gaps in the telemetry however. See below for a discussion of development of a rating curve at this site.

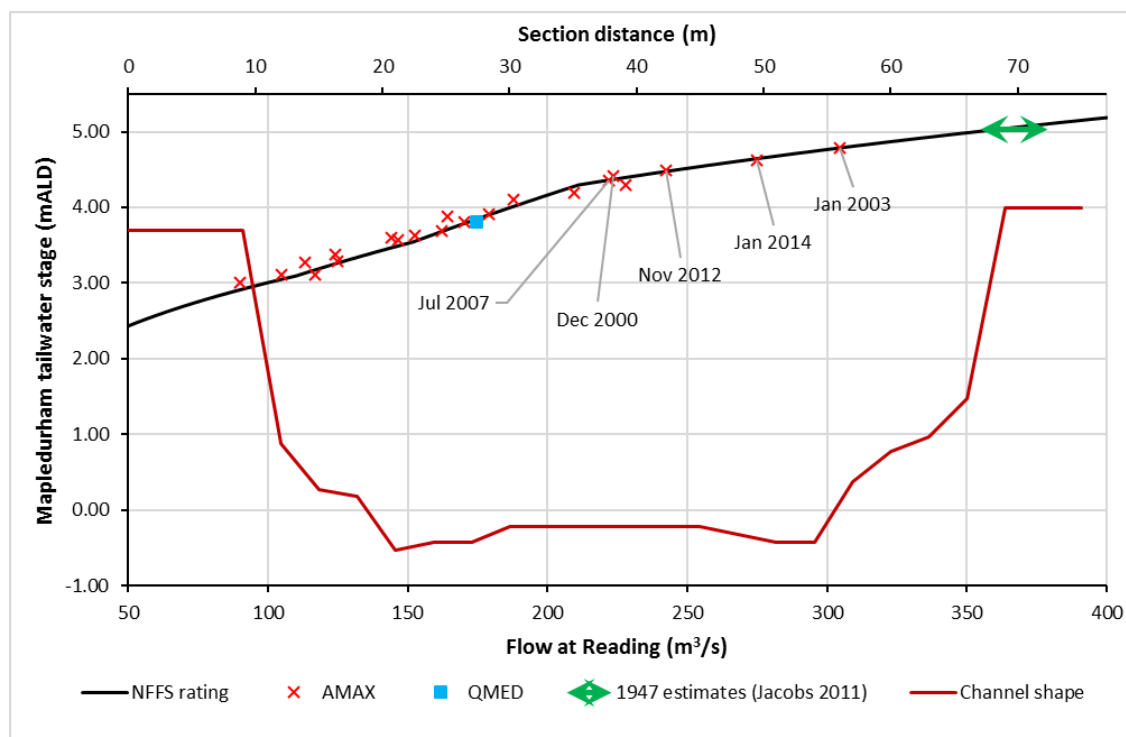
1.7.1 Analysis of Mapledurham existing NFFS rating

The existing NFFS rating curve for flows at Reading related to tailwater levels at Mapledurham is as follows, where $Q = C * (h - A)^B$ (previously reported by Capita, 2014):

Limb	C	A	B	SGmax
1	2.6493	0.0	3.2934	3.10
2	7.3968	0.0	2.3859	3.55
3	17.3902	0.0	1.7112	4.30
4	1.4628	0.0	3.4084	7.00

This rating is not applicable for levels at the downstream Mapledurham gauge below 2.44mALD.

The NFFS rating was checked by plotting pairs of AMAX flows from Reading against the corresponding peak levels at Mapledurham (1995 – 2016 water years). The best available range for the peak flow of the 1947 event, taken from Jacobs (2011) is also plotted.

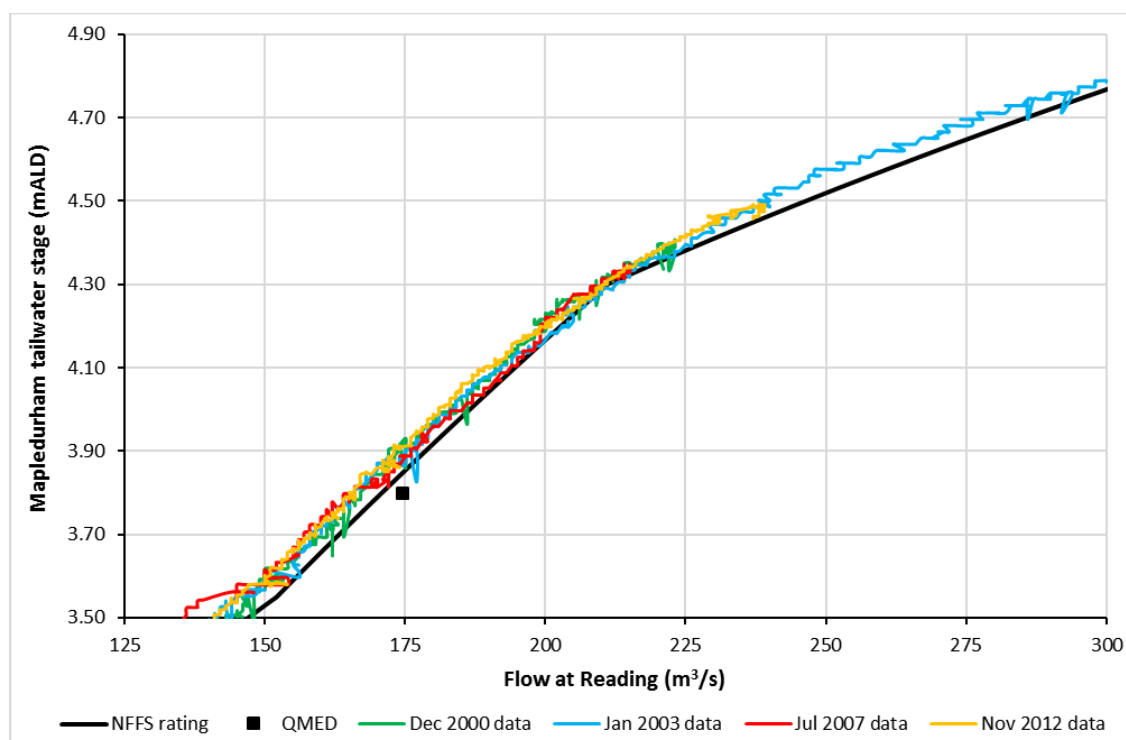


The comparison above shows that:

- The rating curve parameters appear sensible. The limb break positions also appear sensible, for example between limbs 2 and 3 a break occurs slightly above bank-full conditions.
- Flows are contained in-bank up to QMED only.
- The Mapledurham NFFS rating over-estimates flows less than QMED, however the error is not significantly large and would have little effect on overall flood-frequency calculations of higher return period peak flows.
- At and above QMED, the rating appears to perform well, matching well to peaks of large events.
- The rating was mainly derived using measured flows at the Reading ultrasonic gauge combined with levels at Mapledurham. The peak spot gauging at Reading is 240m³/s. The Capita 2014 study also used model output to estimate the rating shape for very large events, for example the March 1947 flood.

A similar comparison was carried out using the rising limb of four large event hydrographs at Reading & Mapledurham as follows (two before and two after the changes at the rowing lake):

- December 2000
- January 2003
- July 2007
- November 2012



This more detailed comparison shows that:

- The NFFS rating at first appears to slightly over-estimate flows by 5 - 10m³/s at Reading for extreme events. However it is known that there is a minor bypassing route of the Reading gauge (Jacobs, 2011) in large floods which accounts for this apparent small discrepancy, which the NFFS rating takes into account.
- A similar issue for smaller flows less than QMED as noted above is also apparent in this comparison.
- There appears to be no change in the stage-discharge relationship using the Mapledurham stage data before and after construction of the rowing lake, which confirms the assumption that the NFFS rating is insensitive to this issue.
- Above QMED, up to a stage of 4.40mAOD, there is an excellent match with the gauged data.

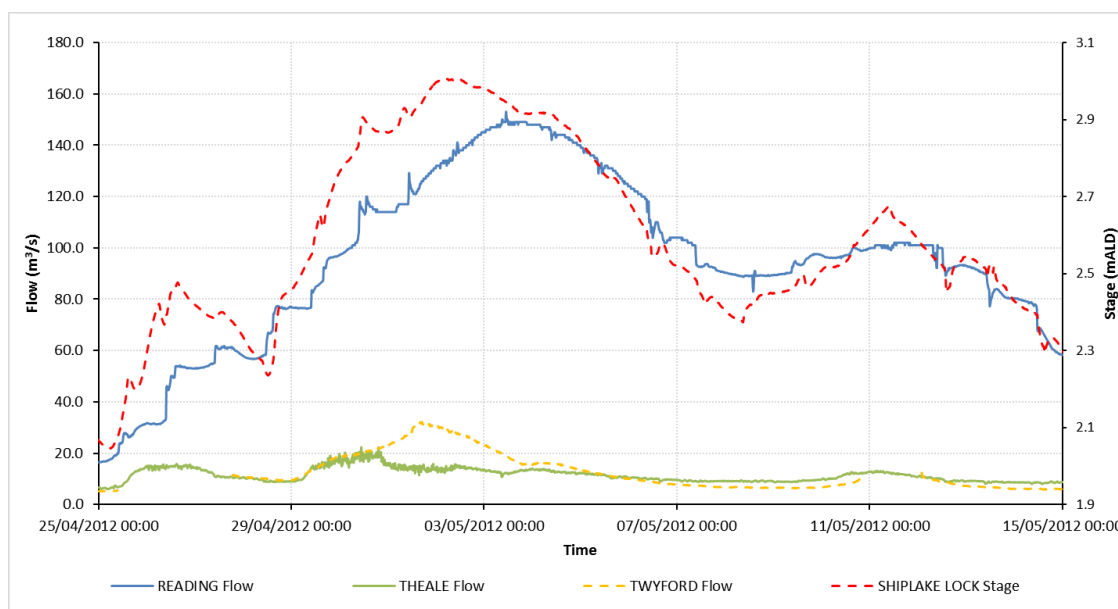
Following a discussion with EA staff (pers. comm with D Rylands, 18/07/2017), it was recommended that the ultrasonic record at Reading is reliable up to bankfull, but the NFFS Mapledurham rating is considered more reliable above this. Using the plots above and comparing the two flow datasets, it was decided here to apply a cutoff flow of 180m³/s (roughly corresponding to QMED at this site). Flows below this threshold are taken from the Reading ultrasonic gauge in this study, above this limit flows are taken from the Mapledurham NFFS rating.

1.7.2 Rating development at Shiplake / Marsh Lock

A separate report for the new Marsh/Shiplake Lock rating described below is beyond the agreed scope of this study. All relevant details for these calculations are provided below,

Flows downstream of the Loddon confluence could be estimated by creating a “virtual” flow gauge, using a sum of flows from Reading, Theale and Twyford. However the quality and presence of numerous gaps in the Twyford record limits the accuracy of this method. The Loddon adds a considerable area of over 500km² to the drainage area of the Thames downstream, so represents a significant inflow to the system. Alternate possibilities include using higher quality gauges further upstream in the Loddon catchment or downstream on the Thames. The significant flow accretion between these more distant gauges would require the use of simplifying assumptions when recreating the virtual flow series however. (for instance, there is over 200km² of drainage area between the Sheepbridge/Swallowfield gauges and the Twyford gauge on the Loddon).

As an alternative to the above, it was decided to estimate a rating curve at a downstream lock gauge on the Thames, where there are good quality continuous level records. Development of a rating curve is beneficial downstream of the Loddon confluence as it would help quantify the behaviour of the Thames and how flows might be affected by the Loddon inflow. This would also be useful at the model downstream boundary, as the overall increase in catchment area from here to Hurley Lock is relatively small. It appears that levels at Shiplake Lock are affected by inflows from the Loddon as shown in the example plot below (the plot shows an early peak in the Shiplake levels that cannot be attributed to flows from Reading or Theale):

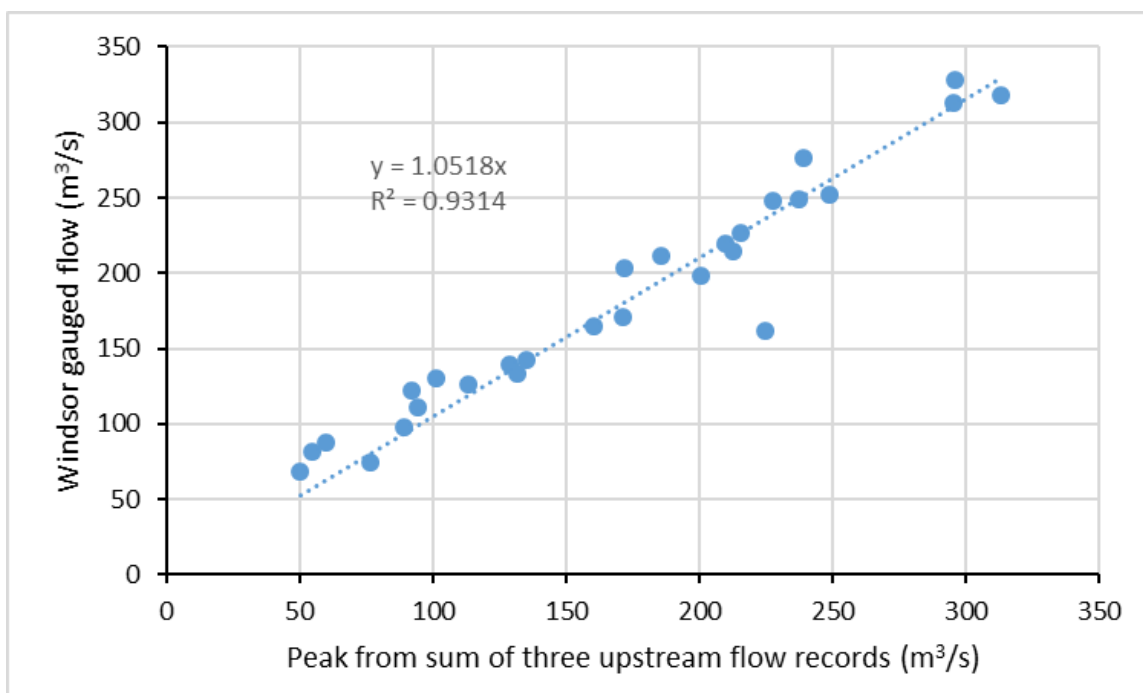


Two candidate lock levels sites were identified for development of a new rating:

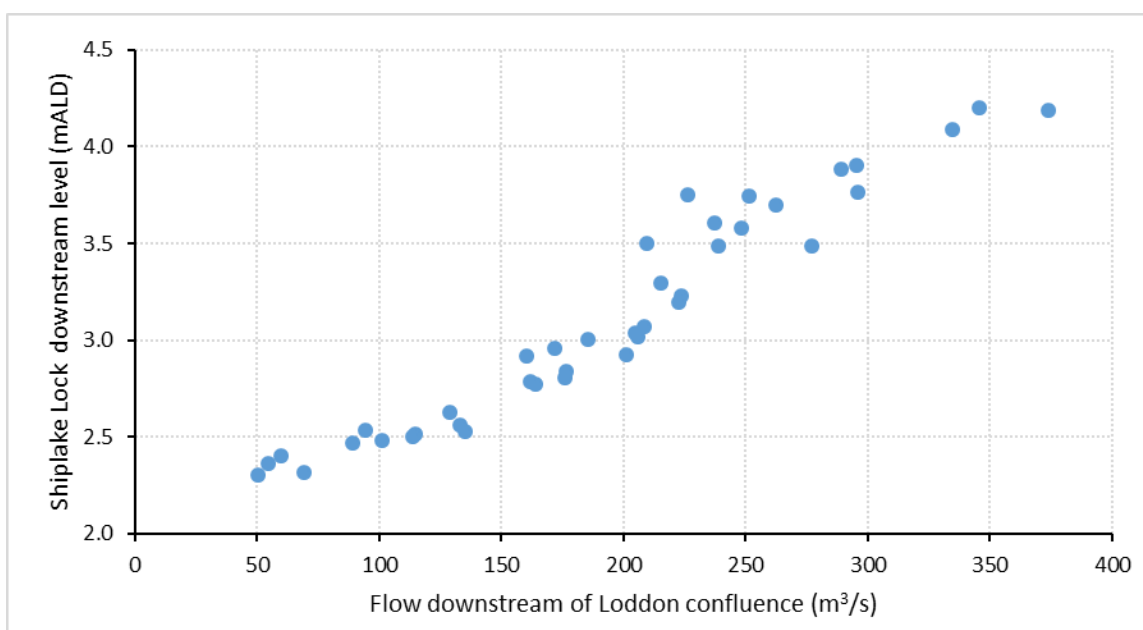
- Shiplake Lock (downstream gauge) (41 events extracted)
- Marsh Lock (downstream gauge) (46 events extracted)

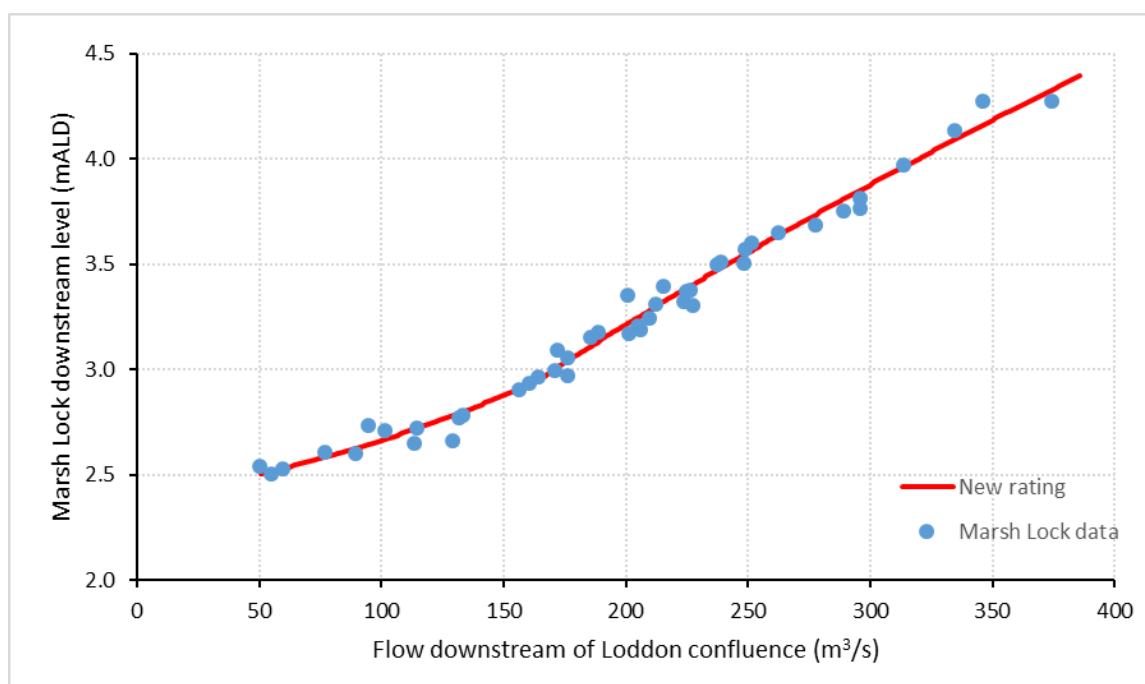
Numerous event peak levels at both locks were extracted from 15-minute telemetry. Corresponding peak flows for these peak levels were obtained from one of the following sources:

- Preferably, using the peak flow from a sum of event flow hydrographs from Reading (either the ultrasonic or NFFS rating, depending on the magnitude as discussed in Section 1.7.1), Theale (NFFS rating), and Twyford gauges. Summing the full hydrographs allows for possible variations in the arrival times of peaks from the three rivers.
- Often the above calculation was hindered by gaps or low quality data in the Twyford gauge. In these cases the event peak flow was instead extracted from the Windsor gauge further downstream, reduced by 5% based on a comparison of event peak flows from Windsor against the sum method above (effectively accounting for the small increase in drainage area between the Loddon confluence and the Windsor gauge). See the comparison of peak flows at Windsor against the sum from the upstream gauges in the plot below.



Once stage-discharge pairs were collected for both Shiplake and Marsh Lock as described above the data were plotted and examined. There was a moderate degree of scatter found in the Shiplake Lock stage-discharge plot. The Marsh Lock plot on the other hand gives a more linear relationship with significantly less scatter. This greater degree of scatter at Shiplake Lock is likely due to the complex interactions between various inter-connected channels around the Loddon confluence. It was therefore decided to carry the Marsh Lock dataset forward for development of a rating equation for estimation of flows downstream of the Loddon confluence.





The following rating equation was fitted to the Marsh Lock data (red line in the above plot), where $Q = C * (h - A)^B$

C	A	B	SGmin	SGmax
249.708	2.422	0.646	2.500	2.931
71.275	1.168	1.442	2.931	4.400

Combining this new rating curve with the full 15-minute available period of level record at Marsh Lock (November 1995 to present) allows abstraction of a 21-year AMAX peak flow dataset. This method gives a more robust estimate of QMED or other low return-period flows compared to a flow record created by summing upstream gauged flows, which are significantly affected by data quality and drop-out issues at the Twyford gauge.

Hydrological checks on a rating can sometimes be carried out to ensure the overall volume predicted by the rating is realistic. Given the size of the upstream catchment and the number of rainfall datasets required to give a reliable estimate of the catchment average rainfall, it was decided that this check was beyond the scope of this analysis. Instead, the comparison of peak flows from this new rating against the Windsor flow record downstream is considered a simpler and more robust method for this purpose. As the analysis above shows a realistic 5% increase in flows between the Loddon confluence and the Windsor gauge, it is concluded that the rating above is robust between the range of flows indicated in the rating curve plot above.

Future studies could refine the above rating curve further using hydraulic modelling, helping increase the reliability of the rating even further, or to extend it for extreme flood conditions for flows above 300m³/s.

1.8 Other data available and how it has been obtained

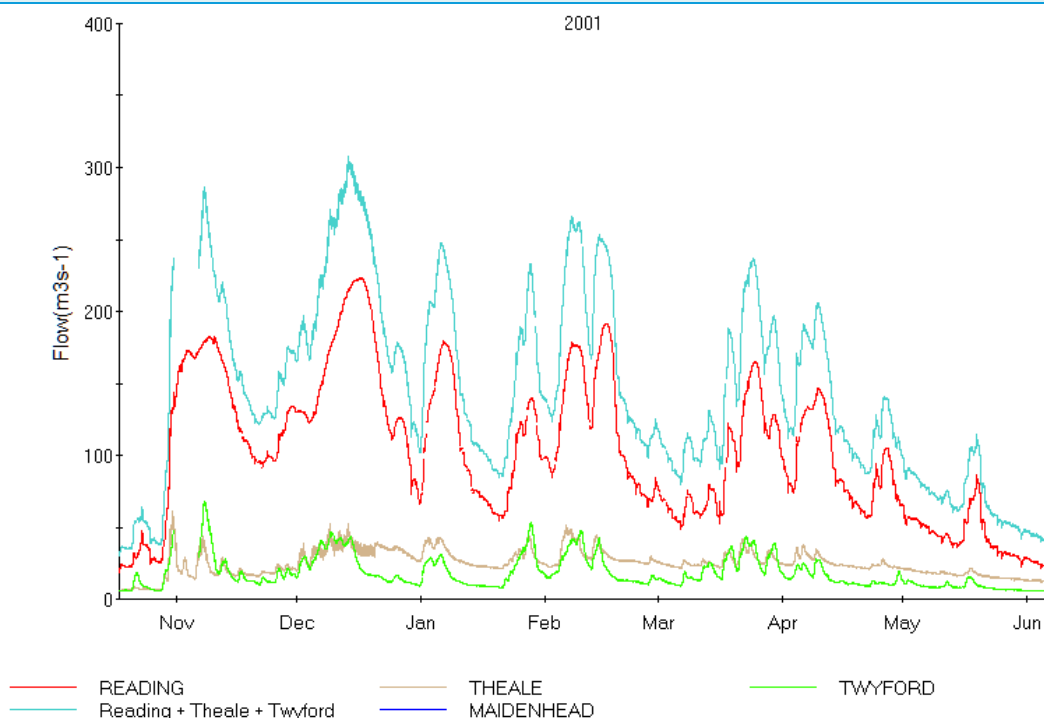
Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Check flow gaugings (if planned to review ratings)	Yes	Yes	EA	Data already incorporated in adjustments of flood peak series for Reading, as part of Lower Thames study.
Historic flood data	Yes	Yes	EA	Historic Lock Keeper POT series of water levels, provided to JBA previously as part of the Lower Thames (2013s7653) project.
			Jacobs (2011)	Figure 4.4 of the Jacobs (2011) hydrology report gives historic event flood peaks relative to the recent record upstream of Reading.
			PBA (2002), Whitchurch to Hurley Weir, Flood History Database	This report cannot be located by the Environment Agency. It is mentioned in Jacobs (2011).
			Other	Scope excludes collection of flood history data from sources apart from EA. There are other potential sources of information such as peak levels at Long Wittenham for floods back to 1768 in Volume 4 of the Flood Studies Report.
Flow or river level data for events	Yes	Yes	EA	Full records of flow provided for Days Weir, Reading and Theale. Full records of level provided for Reading, Theale and headwater & tailwater at locks in the study reach.
Rainfall data for events	No	n/a	n/a	Scope calls for rainfall-runoff model parameterisation using hydrometric data but rainfall-runoff modelling is unlikely to be a preferred method of design flood estimation.
Potential evaporation data	No	n/a	n/a	
Results from previous studies	Yes	Yes	EA	Discussed in section 1.3.
Other data or information	Yes	Yes	EA	The EA hold information of a spot gauging used to estimate flow entering the rowing lakes downstream of Reading, taken in January 2014.

1.9 Hydrological understanding of catchment

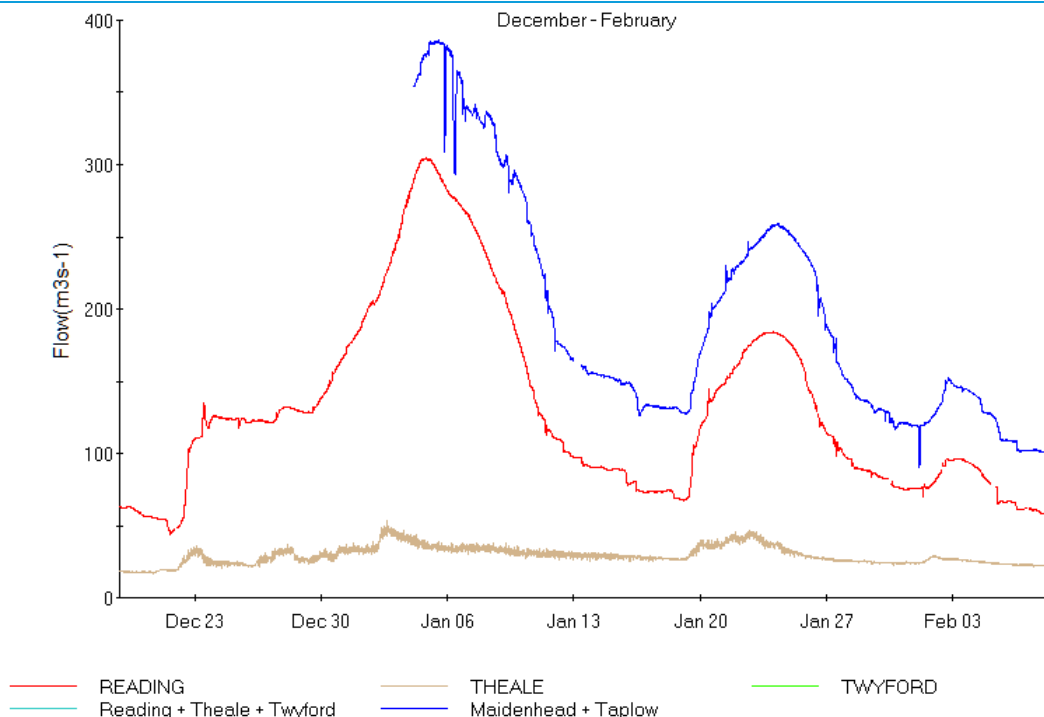
The flood event plots below include flow measured at gauges and also two summed flow series; one that combines Reading, Theale and Twyford, so approximating flow in the model reach downstream of Wargrave. The other adds the Thames at Maidenhead and the Jubilee River at Taplow, thus representing the combined flow on the Thames around Maidenhead, downstream of the present model reach.

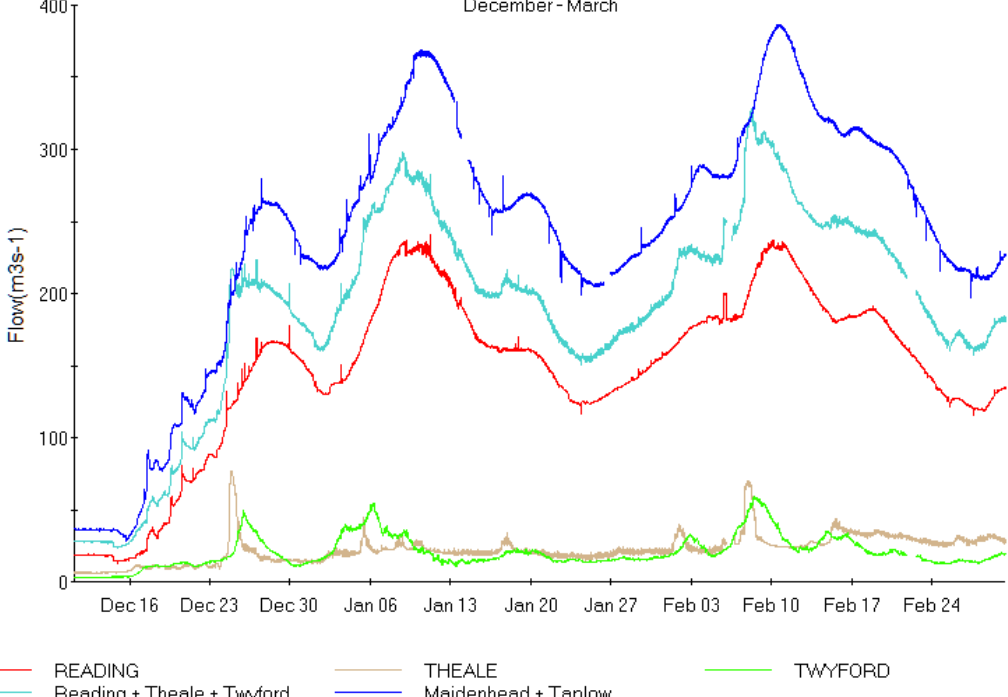
Note that the plots below use the WISKI rating at Reading and Theale and are intended to give a qualitative assessment of flow conditions only.

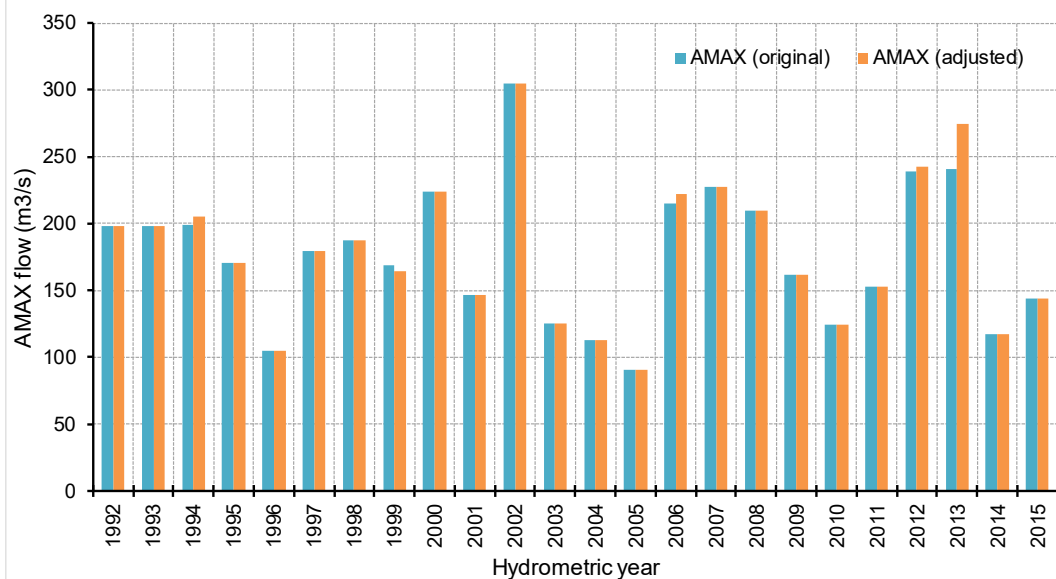
Winter 2000-2001 floods



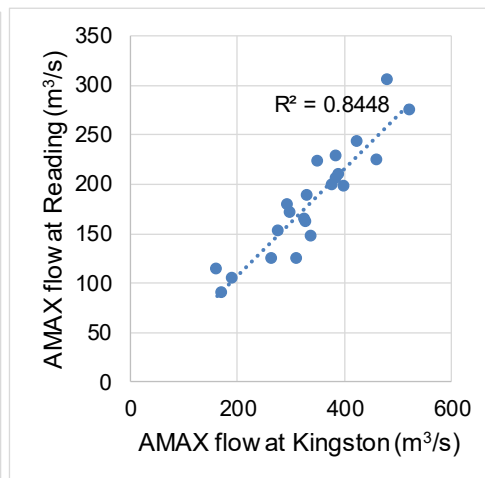
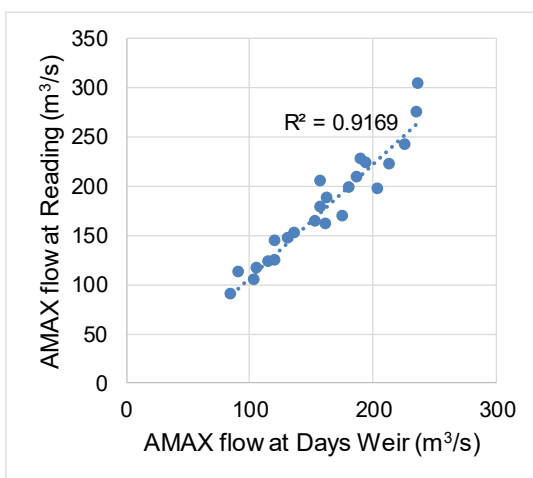
Jan 2003 flood (data is missing at several gauges)



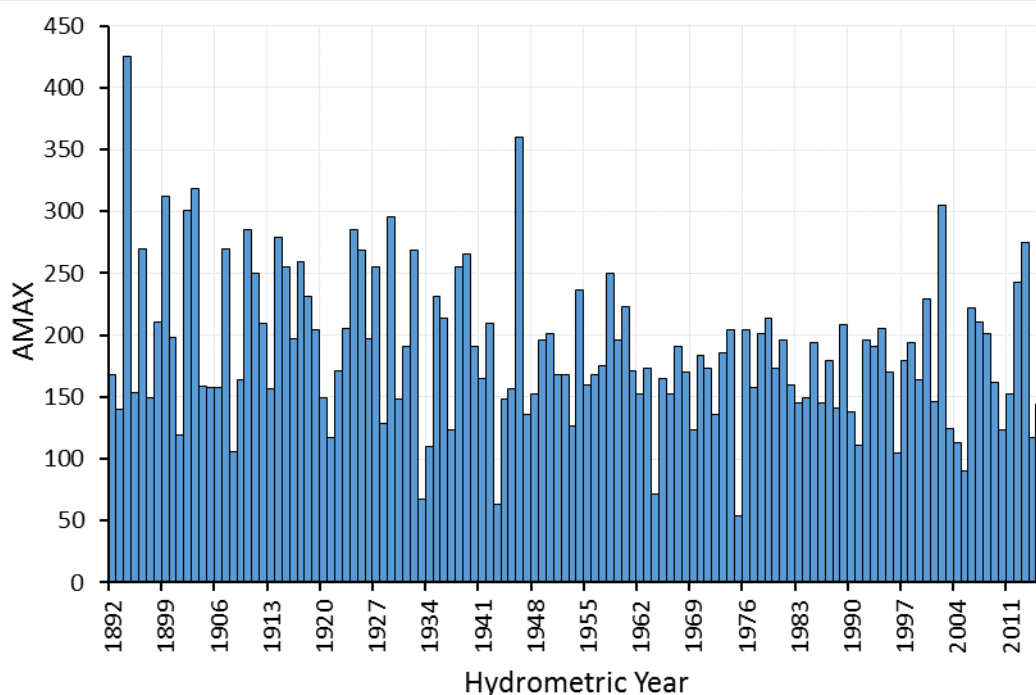
Winter 2013-14 floods	December - March  Note that the peak flow at Reading (from the ultrasonic flow series) was probably underestimated during this event: spot gaugings show a peak of about 260m³/s on 10 February 2014.
Hydrological interpretation	Floods on the Thames tend to occur in the winter in response to prolonged rainfall and/or snowmelt. They tend to be characterised by sequences of peaks, continuing weeks or months in total. High flows at Reading are typically sustained for 1-2 weeks. Flow tends to take several days to rise, or longer in some events. Inflows from the Kennet and Loddon tend to peak before the flood on the main Thames. Flood hydrographs for the Kennet show a rapid peaky response despite the dominant Chalk geology; this can be attributed to rapid runoff from Tertiary clay deposits in the lower catchment, drained by the River Enborne (where gauged flow data reveals a responsive regime) and other tributaries of the Kennet such as the Foudry Brook. Some events show multiple peaks from the Kennet and Loddon occurring during a single-peaked attenuated hydrograph on the Thames at Reading; in these circumstances it is possible for the peak flows on the tributaries to occur while the flow in the Thames is close to its maximum, reinforcing the potential for flooding downstream of Wargrave, for example at Henley. This occurred on 7-8 November 2000 and in early 2001. Depending on the relative magnitude of flows from the upper Thames and from the Kennet and Loddon, it is possible for the peak flow on the Thames downstream of Wargrave to occur either earlier or later than the peak at Reading.
Plots of flood peak data	JBA (2014) describe how AMAX flows from Reading gauge were adjusted when spot gaugings were available close to the time of the peak flow. The original and adjusted AMAX series, updated to include the two most recent years, are shown below.



The plots below illustrate the correlation between annual maximum flows at Reading and those at longer-record gauges on the Thames: upstream at Days Weir and downstream at Kingston.



It is possible to significantly extend the AMAX record at Reading, using the NFFS rating in conjunction with the Lock Keeper record at Mapledurham. Jacobs (2011) carried out a similar procedure, taking an average result from three upstream lock records, but the Mapledurham NFFS rating was not available at the time of their analysis. Data were extracted from multiple sources here, giving a complete AMAX record from 1892 to present at Reading, with data sources described in further detail in the Annex. See the AMAX plot below.



Hydrological interpretation

There are 23 years of flood peak data in the recent Reading ultrasonic dataset. In that period the January 2003 flood is the largest, with February 2014 ranking second. In the longer term there have been considerably more severe floods on the Thames, such as March 1947 and November 1894.

The scatter plots above show that annual maximum flows at Reading are closely correlated with those at Days Weir (where the catchment area is 25% smaller) and less closely with Kingston, where the catchment is a little over twice as large as at Reading.

Previous studies have considered in great detail the relationships between peak flows on the Thames and peak levels at locks, in particular relating flow at Windsor with level at Bray, Hurley, Temple and Marlow locks and flow at Reading with three upstream locks. Jacobs (2011) found that an extended flow dataset at Reading, from 1892, gave a flood frequency curve extremely similar to that estimated from single-site analysis. This result could be due to the short ultrasonic record at Reading (17 years) available at the time of the Jacobs 2011 analysis however. Similarly, JBA (2014) found that extension of the Windsor dataset using the long record of water level from Marlow Lock gave a flood frequency curve very similar to that fitted solely to annual maximum flows at Kingston.

Inclusion of historical level records from locks needs care because of the potential for the relationship between level and flow to have changed since the last 19th century as a result of changes in the conveyance of the river channel and/or floodplain. This can be seen in the Reading AMAX plot above, where there is a visible increase in the frequency of large flood events in the first half of the record. Formal trend testing confirms this pattern, indicating a statistically significant decreasing trend in the extended Reading AMAX series above. This issue was discussed with EA staff (pers. comm. with D Rylands, 18/07/2017), and was also acknowledged in the previous Jacobs (2011) study. Previous CEH studies of this issue have concluded that the trend can be attributed to more frequent flood events in the first half of the 20th century, rather than being caused by changes in conveyance of the Thames. Including the larger AMAX from the extended dataset also leads to larger design flows when carrying out flood-frequency analysis at Reading. As a result, the EA have recommended including the full dataset in this study.

Outline the conceptual model and note any unusual catchment features	As a large lowland catchment the Thames floods in response to prolonged rainfall and/or snowmelt. The size of the catchment changes considerably along the model reach, with the Kennet adding 20% to the catchment area and the Loddon another 11%. As noted above, the magnitude and timing of flow on the Thames downstream of these tributaries can be quite sensitive to the nature of the inflows, with potential for peak flows to occur at similar times. Flood duration is an important consideration given the potential for flooding from the Thames to disrupt transport networks and economic activity. The model reach also includes Berry Brook which is a heavily urbanised and low-lying catchment, with potential storage in gravel pits. Flood levels on at least part of the brook are likely to be closely linked to those on the Thames, with which it flows in parallel.
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1.10 Initial choice of approach

Is FEH appropriate?	Yes, with suitable choice of methods to account for unusual nature of catchment and wealth of data available.
Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	The FEH statistical method will form the basis of flood estimation in this study (the Thames catchment is too large for the ReFH rainfall-runoff method to be applicable). Flow estimation points (FEPs) Over the modelled reach, the hydrological behaviour of the Thames only significantly changes at the following locations: • Significant increase in flows at the Kennet confluence • Significant increase in flows at the Loddon confluence • Minor uniform lateral flow accretion downstream of the Loddon confluence as far as the model downstream limit at Hurley Lock. The above schematisation requires four flow estimation points on the River Thames as follows • Upstream model limit at Mapledurham (flows derived directly from the Reading gauge). FEP is labelled as “Upstream” in the below chapters. • Downstream of the Kennet confluence. FEP is labelled as “DS Kennet” in the below chapters. • Downstream of the Loddon confluence. FEP is labelled as “DS Loddon” in the below chapters. • Downstream model limit at Hurley Lock. FEP is labelled as “Downstream” in the below chapters. In each case, the additional point inflows from the Kennet and Loddon tributaries, and the minor lateral inflow between the Loddon and downstream limit, will be calculated by subtraction of the design event hydrographs at upstream-downstream pairs of the above flow estimation points. This procedure helps to conserve the volume of the T-year design flood hydrograph on the Thames. Growth curve estimation Given the dominance of the River Thames compared to the Kennet and Loddon, a single flood-frequency curve is derived from the extended Reading dataset and applied over the entire model reach. A comparison of growth curves is discussed further in the Annex. The final Reading flood-frequency curve is derived using the extended AMAX dataset described above, modified further with historic data using a Maximum Likelihood fitting procedure (see Annex). The growth curve at Reading will also be compared against an Enhanced Single Site analysis, and the previous Jacobs (2011) growth curve. Fig 9-14 in the Lower Thames report (JBA, 2014) showed the higher AMAX flows at

Reading plotting below the 95% confidence limits of the adopted growth curve. This is likely due to the influence of the Wey, Colne and Mole catchments, and indicates that the flood frequency curve previously derived at Kingston is not applicable as far upstream as Reading. However given the very long and high quality record at Kingston, transferring the growth curve from Kingston may still be useful for estimating flood flows for AEPs below 0.5%.

Peak flow estimation

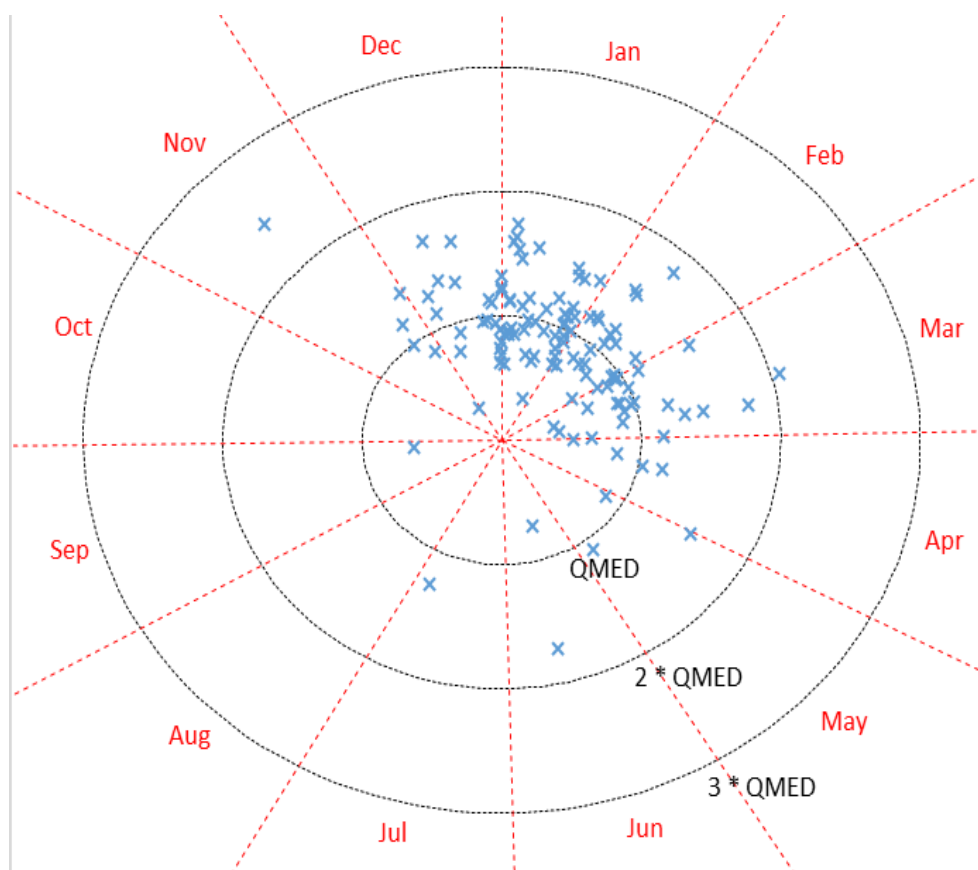
Peak flows at the upstream model limit at Mapledurham will be derived from a direct analysis of the Reading AMAX record as described in Section 1.9.

It is possible to create a “virtual” flow gauge downstream of the Kennet confluence, by adding the flow series at Reading and Theale gauges (latter from the NFFS rating as recommended by the EA). An AMAX series can then be compiled from this new dataset, allowing robust estimation of QMED and other low return-period peak flows. Using the new Marsh Lock rating curve as discussed in Section 1.7.2 allows estimation of another AMAX series downstream of the Loddon confluence. This will similarly be used to directly estimate QMED and other low return-period peak flows downstream of the Loddon confluence.

QMED at the model downstream limit at Hurley Lock will be estimated using the FEH QMED donor procedure, transferring data from the Marsh Lock dataset above (AKA “DS Loddon”) and Windsor further downstream.

Flood seasonality

A flood seasonality plot was created (see below) using the extended Reading AMAX record. Given the large catchment area and relatively permeable characteristics, as expected the majority of AMAX flood events at Reading occur in the winter/early spring season, with very few summer floods in comparison. This shows that flood events on the Thames are usually dominated by winter events.

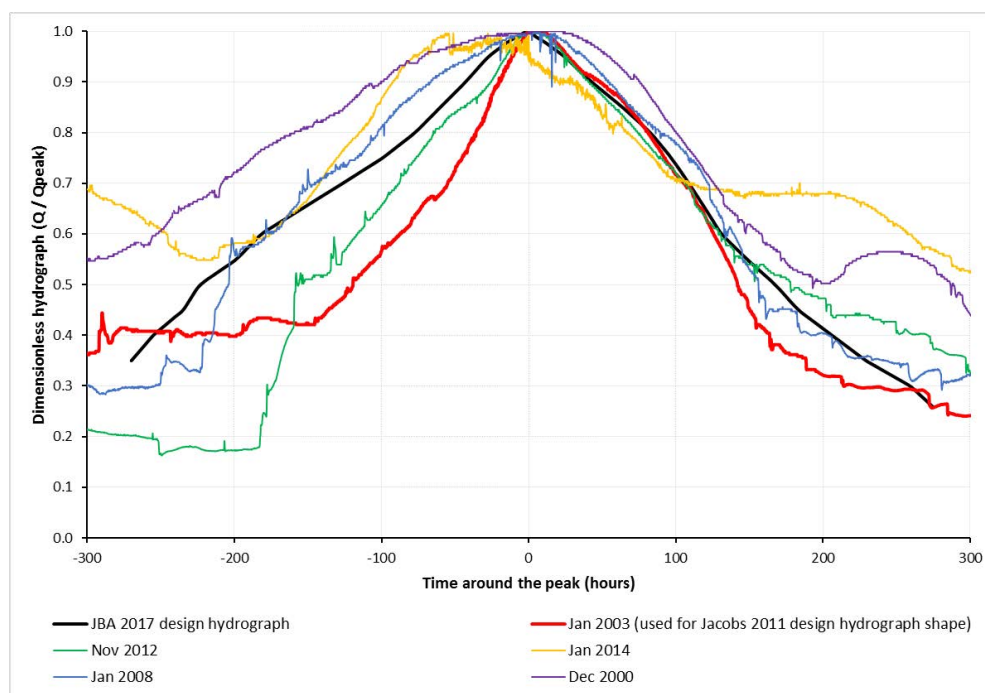


Estimation of hydrograph shapes

The Jacobs (2011) hydrological study adopted the January 2003 flow hydrograph shape for design events in their analysis. A similar approach is applied here, but instead uses an averaged hydrograph shape calculated from multiple events (taken from the previous JBA 2013 Lower Thames study, calculated using the “Hydrograph Width Analysis” technique as developed recently in the Irish Flood Studies Update programme). A comparison plot is given below, also plotting the top five flood events, all scaled by their own peak flow.

The following events were used to calculate an event-average hydrograph shape at Reading from the JBA 2013 analysis:

- December 1992
- January 1993
- January 1994
- February 1995
- January 1999
- November 2000
- December 2000
- January 2001
- February 2001
- January 2003
- March 2007
- July 2007
- January 2008
- February 2009
- November 2012
- December 2012
- January 2013
- January 2014
- February 2014

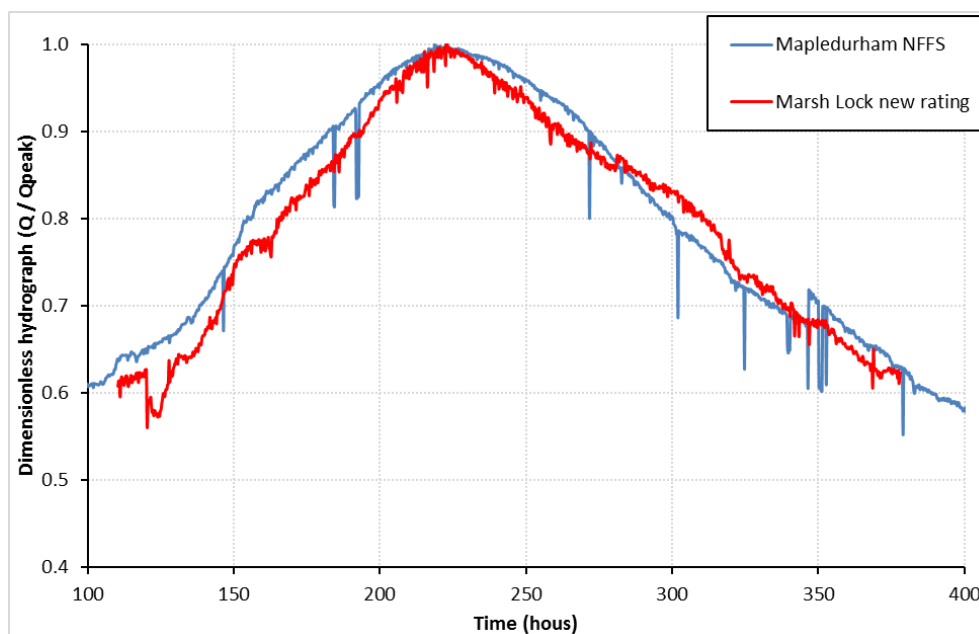


The averaged design hydrograph shape has a similar falling limb to the January 2003 event shape used in the Jacobs 2011 study, but contains a greater volume on the rising limb. The comparison against other gauged hydrographs at Reading shows that there is moderate inter-event variation on flood event volume on the rising limb. However in most cases there is a good match across events on the falling limb.

A check was carried out to ensure this hydrograph shape is also applicable downstream of the Kennet and Loddon tributaries. The analysis above was repeated, but on this occasion averaging hydrographs from the following flow series:

- Using the Mapledurham NFFS rating at Reading
- Using the new Marsh Lock rating downstream of the Loddon confluence

An average hydrograph shape was calculated from both flow series above, using the same nine flood events across both calculations (peak flows at Reading ranging between 150m³/s to 300m³/s, hence covering a wide range of flow conditions). This gives the following averaged hydrograph shapes.



Ignoring the telemetry spikes in the above plots, there appears to be a very good match in hydrograph shapes between these locations. There is no evidence of a significant change in the shape of the rising limb from an early response from the Kennet or Loddon in the Marsh Lock plot. Therefore it appears that a constant hydrograph shape along this reach of the Thames (scaling for increasing peak flows moving downstream) is a robust assumption.

Berry Brook

Inclusion of Berry Brook from a hydrological perspective is not within the scope of the project. In the context of the River Thames flood hydrology, the Berry Brook (catchment area <10km²) is insignificant, although it is noted that in a local context it could prove influential to flooding by providing an alternate flow route in extreme conditions. The response of this catchment is likely to differ notably from that of the River Thames (tending towards flooding in shorter duration intense rainfall events), although elevated water levels on the River Thames could influence flooding on Berry Brook.

No design estimate hydrology will be prepared for Berry Brook, and hydraulic simulations focused on critical durations for this watercourse will not be completed. However, it was discussed during the site visit held January 2017, that inclusion of part of the watercourse, towards the confluence of the River Thames, may be beneficial for modelling backwater effects from the River Thames, but also as a conveyance route for flood flows close to Sonning. This is discussed in the model review document prepared for this commission.

Software to be used FEH CD-ROM v3.0¹ / WINFAP-FEH v3.0.003²

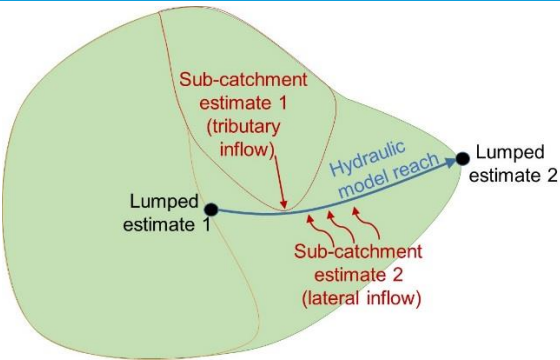
¹ FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

² WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

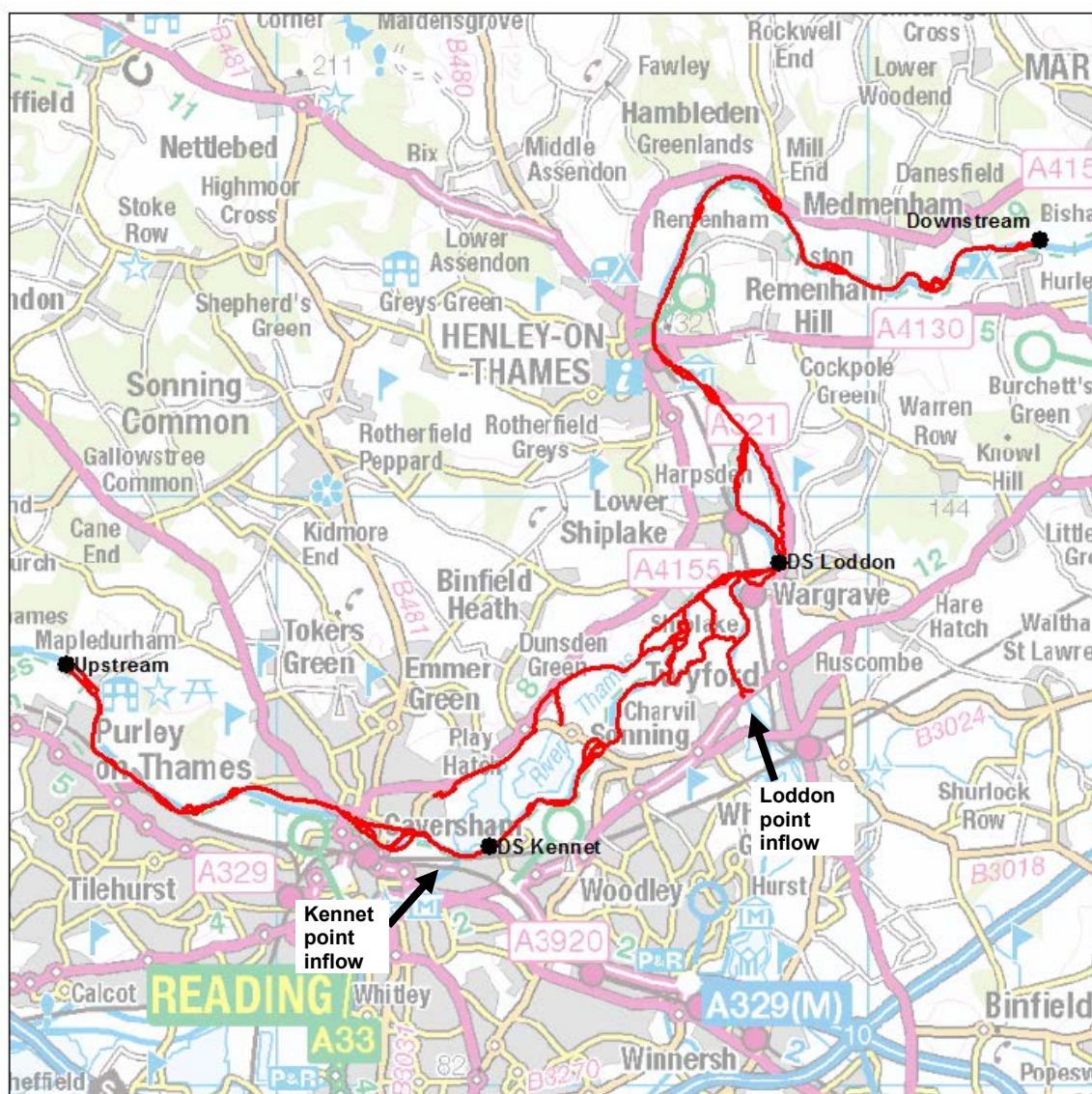
2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	River	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised AREA if altered
Upstream	L	Thames	Upstream model extent at Mapledurham Lock	466500	177200	4575.68	
DS Kennet	L	Thames	Immediately downstream of the Kennet confluence	473100	173900	5781.35	
DS Loddon	L	Thames	Downstream of the various flow splits at the Loddon confluence	477900	178700	6497.97	
Downstream	L	Thames	Downstream model extent at Hurley Lock	482700	184450	6697.66	
Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required. Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced. The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.							

Inflows to the model using the above flow estimation points (FEPs) will be calculated as follows:

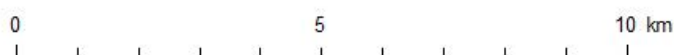
- A point inflow will be applied to the upstream limit of the model, upstream of the Mapledurham Lock site, using the flow calculated from the “Upstream” FEP.
- A second point inflow representing the River Kennet inflow is calculated by subtracting the “Upstream” and “DS Kennet” design flood hydrographs.
- A third point inflow representing the River Loddon inflow is calculated by subtracting the “DS Kennet” and “DS Loddon” design flood hydrographs.
- A final lateral inflow hydrograph representing the minor flow accretion between the Loddon confluence and the downstream model limit is calculated by subtracting the “Downstream” and “DS Loddon” design flood hydrographs (it is intended to apply this inflow uniformly between these two points).

This method aims to conserve the volume of the design flood event moving downstream. The minor lateral flow accretion between the upstream limit, Kennet confluence and Loddon confluence are ignored here, essentially lumped into the point inflows to be applied to the model as described above. A map displaying the locations of each FEP and inflow locations is given below.



Legend

- Flow Estimation Points
- River Thames



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2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000*	FPEXT
Upstream	0.961	0.31	0.642	96.71	37.9	680	0.030	0.1694
DS Kennet	0.961	0.31	0.664	94.84	40.7	694	0.032	0.1543
DS Loddon	0.955	0.31	0.656	95.20	39.4	695	0.042	0.1544
Downstream	0.956	0.31	0.660	108.56	40.6	696	0.042	0.1517
URBEXT2000 updated to 2017 conditions using the CPRE formula from 2006 CEH report on URBEXT2000								

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (add maps if needed)	The catchment boundary was checked qualitatively against LIDAR. No discrepancies were found. Comparing the nominal and FEH CD-ROM catchment area values at gauged locations also showed no obvious errors.
Record how other catchment descriptors were checked and describe any changes. Include before/after table if necessary.	Qualitative check on FARL, SAAR, BFIHOST and URBEXT shows no obvious discrepancies: - Given that there are no major reservoirs in the Thames catchment, a FARL value of 0.95 from descriptors appears realistic. - The catchment SAAR value of just under 700mm/year is realistic for the southern region of England. Using the long-term mean annual flow for Reading as reported by the NRFA database of 38.5m³/s, the ratio of rainfall to annual runoff volume is just below 0.4, which appears realistic. - The geology of the Thames catchment consists of a mixture of chalk, limestone, sandstone and mudstone upstream of Reading. BFIHOST values around 0.6 – 0.7 appear realistic for this type of geology. - According to the NRFA database, the overall urban landcover proportion of the Thames catchment upstream of Reading is 7.3%. URBEXT2000 values around 0.03 appear realistic for this fraction.
Source of URBEXT	URBEXT2000
Method for updating of URBEXT	CPRE formula from 2006 CEH report on URBEXT2000

3 Statistical method

3.1 Overview of estimation of QMED at each subject site

Site code	QMED from CDs (m ³ /s)	Final method	Data transfer						Final estimate of QMED (m ³ /s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Power term, a	Moderate d QMED adjustment factor, (A/B) ^a	If more than one donor		
							Weight	Weighted ave. adjustment	
Upstream	180.2	AM*							174.2
DS Kennet	214.6	AM							192.0
DS Loddon	245.8	AM							219.6
Downstream	250.1	DT	DS Loddon	0.98	1.0	0.894	0.5	0.89	222.8
			39072	2.68	1.0	0.889	0.5		
Are the values of QMED spatially consistent?						Yes, QMED increase in a sensible pattern moving downstream. Ratio with catchment descriptor QMED also appears consistent around 0.9 across the reach.			
Notes Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details). When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added below. The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) ^a times the initial estimate from catchment descriptors. If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column. Important note on urban adjustment The method used to adjust QMED for urbanisation, for both subject sites and donor sites, is that published in Kjeldsen (2010) ³ in which PRUAF is calculated from BFIHOST. The result will differ from that of WINFAP-FEH v3.0.003 which does not correctly implement the urban adjustment of Kjeldsen (2010). Significant differences will occur only on urban catchments that are highly permeable. For the QMED adjustment at the Downstream estimation point, given that the donors are in close proximity on the same river, it was decided to over-write the “a” parameter used in the adjustment procedure to 1.0. Further discussion of the sensitivity of results to this adjustment is given below. *The full extended AMAX series (1892 – present) is used to estimate QMED at the “Upstream” flow estimation point. Using the ultrasonic gauged period alone (1995 – present) gives a slightly lower QMED estimate of 167.3m ³ /s.									

Given the close proximity of flow gauges to the FEPs in this study, it was decided that the “a” term in the FEH QMED is not applicable here. The “a” term was introduced in the updated FEH guidelines when using more distant flow gauges to adjust an ungauged QMED estimate. In that research, it was found that the donor adjustment should reduce for donor sites that are further away from a target site, as there is greater uncertainty in the regional bias in the FEH QMED model over large distances.

³ Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

In this study, all donor gauges are located on the same river, where the bias in the FEH QMED model is expected to be consistent. This was checked by calculating the ratio of actual vs regression model QMED at the FEPs above, which gives the following values:

- 0.96 at the Reading gauge.
- 0.89 at DS Kennet.
- 0.89 at DS Loddon.
- 0.89 at the Windsor gauge.

The Thames catchment area is also quite large compared to the range of catchment areas in the dataset used in the updated FEH research to calibrate the “a” parameter. The adjustment is generally intended for smaller catchment where QMED donor information is not available on the same watercourse.

3.2 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	It is possible to estimate QMED directly at three of the FEPs: • Directly from the extended Reading AMAX dataset • From the virtual flow series downstream of the Kennet confluence • From the newly-rated Marsh Lock site downstream of the Loddon. The remaining FEP at the downstream model limit at Hurley Lock required data transfer procedures to estimate QMED. Given the proximity to the Marsh Lock rated site and the Ultrasonic Windsor gauge downstream, these two sites alone were considered suitable as QMED donors. All AMAX series mentioned above are tabulated in the Annex.
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3.3 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)*	Adjustment ratio (A/B)
DS Loddon	Located a short distance upstream of the flow estimation point. AMAX series available from the newly rated Marsh Lock.	AM	n/a	219.6	223.4	0.894
39072	Located a short distance downstream of the flow estimation point. Data quality previously assessed in the JBA 2013 Lower Thames study and considered OK for QMED estimation.	AM	n/a	235	236.8	0.889

*The catchment descriptor value here excludes the Urban Adjustment Factor (UAF) for QMED. This is accounted for in the QMED adjustment procedure at a later stage however (the UAF values are 1.10 and 1.12 for DS Loddon and 39072 respectively)

3.4 Derivation of pooling groups

Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
Upstream	39130	Yes	None, apart from use of the extended AMAX record at the Reading gauge based on the calculations given in Section 1.9. (Pooling group tabulated in the Annex). A review of the pooling group, looking at record lengths, catchment properties, and data quality was carried out. This did not reveal issues with the default pooling group, hence it was retained without modification.	LCV = 0.177 LSKEW = 0.133
Notes Pooling groups were derived using the procedures from Science Report SC050050 (2008).				

It was decided to derive the pooling group using the Reading gauge as a target site, given the advantage of a very long AMAX record at this site (1892 to present) calculated from the Mapledurham NFFS rating. This gives a much more robust resulting flood-frequency curve using the ESS pooling method, as opposed to a pooling group derived elsewhere on the Thames where AMAX records are typically much shorter.

On larger catchments, it is generally more difficult to estimate representative pooling groups, due to the smaller number of large catchments available in the NRFA database. A pooling group derived at a downstream location on the Thames for instance would likely only change the order of sites in the original pooling group, rather than giving a better representation of the downstream sites' flood frequency curve. Further discussion of this point is given in Section 3.7.

3.5 Derivation of flood growth curves at subject sites

In this case the fully extended AMAX series at Reading (1892 – present) is used in these calculations. The single-site (SS) and historic-adjusted single-site (SSH) calculation below are not standardised by QMED, the final row (ESS) is standardised by QMED.

The Generalised Logistic frequency model was selected for consistency across all methods considered below, based on current FEH guidance to use this model unless there is strong evidence to the contrary. The GEV model is acceptable in some circumstances but can tend to give flood-frequency curves that are bounded-above.

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (Error! Referenc e source not found.)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape after adjustments)	Growth factor for 100-year return period
Upstream	SS	n/a	GLO, best fit from visual assessment of flood-frequency plot and comparison on theoretical and sample L- moment ratio plot	None	Location = 180.3 Scale = 32.6 Shape = -0.124	2.12
	SS (gauged period only 1995 – present)	n/a	GLO, for consistency in comparison below	None	Location = 169.9 Scale = 31.8 Shape = -0.119	2.15
	SSH	n/a	As above	None	Location = 180.7 Scale = 33.2 Shape = -0.137	2.18
	ESS	Upstream	GLO, result from WINFAP goodness of fit test (ZGLO value of 1.0, ZGEV also acceptable with value of -1.5)	No, catchment is classed as essentially rural (URBEXT2000 < 0.03)	Location = 1.0 Scale = 0.179 Shape = - 0.133	2.13

Notes

Methods: SS – Single site; SSH – Single site with historic adjustment, P – Pooled; ESS – Enhanced single site; J – Joint analysis
A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites.
Each site may have a different urban adjustment, and therefore different growth curve parameters.
Urban adjustments are all carried out using the v3 method: Kjeldsen (2010).
Growth curves were derived using the procedures from Science Report SC050050 (2008).

3.6 Growth curves from the statistical method

Site code	Flood peak (m ³ /s) for the following Annual Exceedance Probabilities										
	50%	20%	10%	5%	3.3%	2%	1.3%	1%	0.5%	0.2%	0.1%
Upstream (SS)	180.3	229.6	262.6	296.1	316.5	343.4	365.7	382.2	424.3	485.6	536.8
Upstream (SS gauged only)	169.9	217.9	249.8	282.2	301.8	327.5	348.9	364.7	404.8	463.0	511.3
Upstream (SSH)	180.7	231.3	265.8	301.1	322.7	351.3	375.3	393.1	438.7	505.8	562.4
Upstream (ESS)	174.5	222.1	254.2	287.1	307.2	333.7	355.9	372.4	414.5	476.2	528.1

The above results are discussed and compared graphically in Section 3.7.

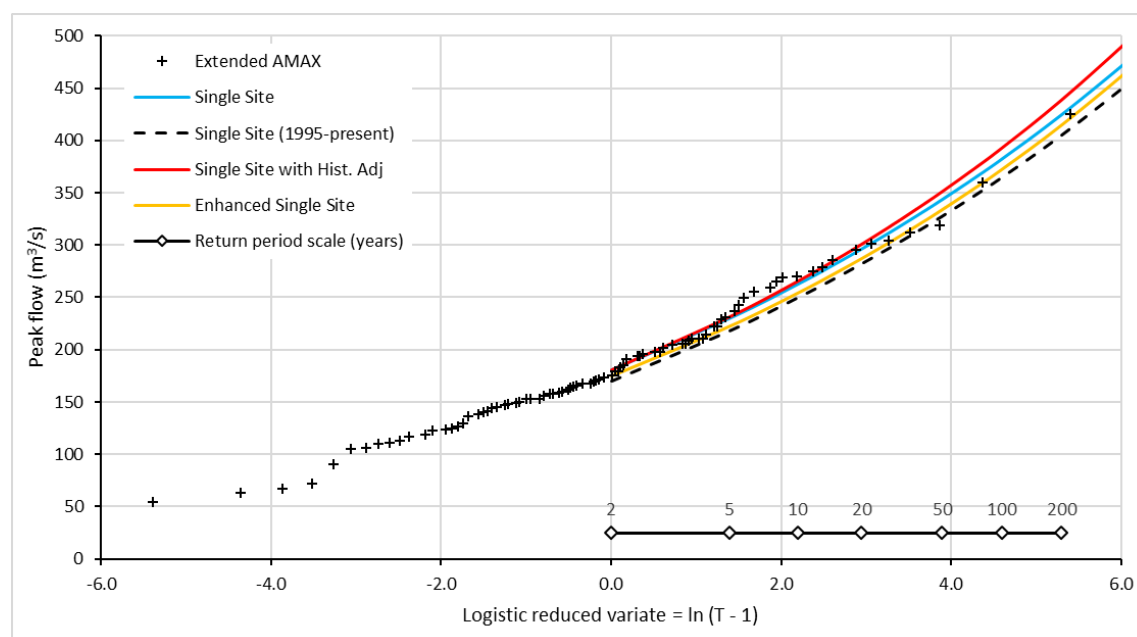
3.7 Discussion of results

3.7.1 Selection of the final flood frequency curve at Reading

Extension of the Reading AMAX series to 1892 (see Annex) gives a 124-year continuous record. These were initially used in a single-site analysis as summarised above. This calculation was then modified using further historic information for floods before 1892 (labelled as “SSH” above). This procedure uses a Maximum Likelihood fitting procedure, as outlined in the recent FEH Local research project. Information from Figure 4.4 of the Jacobs 2011 hydrology report shows that there were 4 events recorded at the Whitchurch Lock gauge that exceeded the 1947 flood (1768, 1770, 1774 and 1809). Following recommendations from the FEH Local project, it was decided to set the start of the historic period to 1700, based on average time gaps between events in the historic dataset and the start of the extended AMAX record in 1892. This resulted in a slightly steeper growth curve.

An enhanced single site approach was also applied for comparative purposes. This was built with the extended Reading AMAX series at the top of its own pooling group. This calculation resulted in a similar growth curve to the previous two calculations above, but was found to be less steep than the calculations above.

The dashed black line in the plot below shows the results of a single-site analysis at Reading if only the ultrasonic period of record is used (see second row in the table in Section 3.6). This frequency curve plots slightly below the other options analysed here, showing the effect of the inclusion of historic data in the frequency calculation (blue and red lines in the plot below). It should also be kept in mind that this ultrasonic record is relatively short (22 years) and is therefore robust for short return periods only.



It was decided to adopt the historic-adjusted single-site calculation for the dimensionless growth curve in this study, given the use of data before 1892 (standardised by the at-site QMED value of $174.5\text{m}^3/\text{s}$). The 1,000-year growth factor from this curve is 3.11. Current flood estimation procedures recommend a check against a hybrid rainfall-runoff procedure for estimation of this figure, but in this case given the size of the Thames catchment, it was decided that application of a rainfall-runoff procedure in this case is not suitable.

3.7.2 Spatial checks

Gauging stations on large streams are usually well established and hence have relatively long flow records, giving a much more robust picture of the flood-frequency relationship compared to the FEH pooling procedure. Using the AMAX series for the DS Kennet and DS Loddon FEPs derived in this study, it is possible to compare the final flood-frequency curve derived at Reading to single-site flood frequency estimates at these locations. This gives a useful spatial check on the applicability of the selected flood frequency curve across the reach of the Thames being modelled. This is a more robust spatial comparison method compared to the FEH pooling method, for the reasons given above.

The 5% AEP growth factor for the final flood-frequency curve is 1.67. Similar values of 1.58 and 1.63 are obtained from single-site analyses of the AMAX records at DS Kennet and DS Loddon respectively. Unfortunately, this method is only robust up to approximately the 5% AEP event, limited by the number of AMAX events that can be derived for the DS Kennet and DS Loddon sites. Extrapolation above this would add uncertainty to the comparison, but for moderately large floods up to the 5% AEP the comparison shows that the flood-frequency behaviour along this reach of the River Thames is similar to the result derived at Reading.

4 Discussion and summary of results

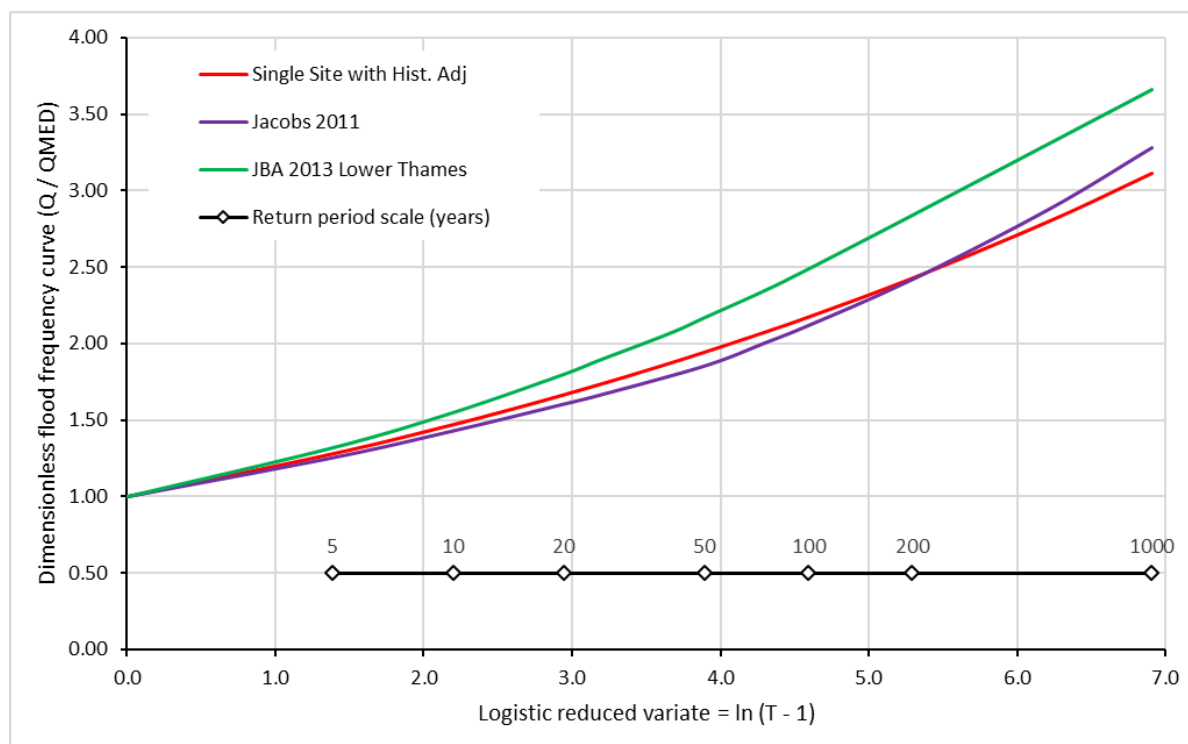
4.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Comparison against previous results			
	Return period 2 years		Return period 100 years	
	This study	Jacobs 2011	This study	Jacobs 2011
Upstream	174.2	177.0	379.0	375.0
DS Kennet	192.0	197.0 – 199.0	417.7	420.0 – 438.0
DS Loddon	219.6	201.0 – 204.0	477.8	431.0 – 452.0
Downstream	222.8	Not reported	484.9	Not reported

The Jacobs 2011 hydraulic modelling report (Table 2.3) quotes upper and lower ranges for design inflows, dependent on assumptions for the design hydrograph applied at Windsor.

A further comparison was carried out between growth curves on this reach of the Thames, that used in the Jacobs 2011 study, and the curve derived from Kingston used in the JBA Lower Thames study (2013). These curves are plotted below.



The Reading growth curve from this study (red line) gives an excellent match with the Jacobs 2011 result (purple line). This is to be expected, as the methods used to derive these curves are broadly similar. However, the Kingston growth curve (green line) is significantly steeper than the others. This indicates that it is not suitable to apply the Lower Thames growth curve on this reach of the Thames around Reading. There are numerous other significant tributaries including the Wey, Mole and Colne that enter the Thames downstream of this reach, which influence the flood-frequency behaviour on the lower reach.

4.2 Final choice of method

Choice of method and reasons	A single growth curve is applied across the entire model reach, derived from the extended AMAX series at Reading, adjusted with historic data. QMED is estimated at key locations, through a combination of “virtual” gauges (sums of upstream gauged flows), development of new ratings at existing gauged level sites, or using the FEH QMED transfer procedure. The abundance of gauged data in this case has greatly aided the accuracy of the calculations.
How will the flows be applied to a hydraulic model?	Point inflows representing the major tributaries are calculated by subtracting upstream-downstream pairs of design event hydrographs as follows: River Kennet point inflow: DS Kennet – Upstream River Loddon point inflow: DS Loddon – DS Kennet Downstream lateral inflow: Downstream – DS Loddon (to be applied uniformly from the Loddon confluence to the model downstream limit) Routing of these resulting hydrographs through a hydraulic model may lead to modelled peak flows that are less than the intended design event peak flows at the FEPs at DS Kennet, DS Loddon and Downstream. Iteration of the above model inflows may therefore be required to reach the required design event peak flow as summarised in the table in Section 4.5.

Assumptions, limitations and uncertainty	1) Addition of the gauged flow series at Reading (either WISKI or NFFS as appropriate) with the Theale (NFFS rated) is assumed to give a good approximation for flows in the Thames downstream of the Kennet confluence. 2) It is assumed the NFFS rating at Theale gives a good approximation of the total flow generated by the Kennet catchment. It is also assumed that this rating is less heavily affected by storage in nearby gravel pits compared to the WISKI rating. 3) There are gaps in the extended AMAX series at Reading where the lock keeper POT series at Mapledurham does not have a large event in a given AMAX year. In these cases, low-flow water year AMAX are instead copied from the Jacobs 2011 AMAX series to infill these gaps. These are all events significantly less than QMED and are assumed not to adversely affect the flood-frequency calculation. 4) The newly-derived rating at Marsh Lock is assumed to give a good representation of flood flows, at least up to QMED. Further hydraulic modelling of the rating at that location could be used to possibly extend the rating. The stage-discharge pairs used to derive the Marsh Lock rating contain an assumption of good quality flow data at Reading, Theale and Twyford. 5) The noted trend in the extended Reading AMAX series is assumed to be due to genuine climatic behaviour in the first half of the 20th century, as summarised by past research carried out by CEH. The inclusion of these older data at Reading lead to a larger (hence more conservative) flood-frequency analysis (the design flows would likely reduce if these older data are omitted). It is also assumed that there is no significant change to the stage-discharge relationship at Mapledurham over the 20th century. 6) It is assumed that all large events from 1700 to 1891 are accounted for in the historic adjustment procedure when adjusting the Reading flood-frequency curve. 7) It is known that the Kennet and Loddon flows tend to peak before the main Thames peak arrives during flood events, This may have a small effect on the shape of the rising limb of flood hydrograph downstream of these confluences. However in large floods the Thames flow is significantly larger than the flows from these streams. Checks described in Section 1.10 have shown that there is no overall change on average between hydrograph shapes at Reading and downstream of the Kennet. It is therefore assumed in this study that the same
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	hydrograph shape is applicable across the reach of the Thames being modelled here.
Discuss any particular limitations,	The inflows derived from subtraction of upstream-downstream pairs of event hydrographs are intended to maintain the shape/volume of the design flood event on the River Thames. These should not be viewed as corresponding T-year flood hydrographs for the individual tributaries. Iteration may be required with model inflows derived here to maintain the required design peak flow on the Thames, due to attenuation in the hydraulic model. It is recommended to use the peak flows in Section 4.5 as target peak flows.
Give what information you can on uncertainty in the results,	67% and 95% confidence intervals have been estimated for the Reading flood-frequency curve, using an in-house Monte-Carlo calculation tool. These have been calculated for a single-site analysis of the extended Reading AMAX dataset; while not matching precisely with the historic-adjusted flood-frequency method adopted in this study, given the very long AMAX record the results below are broadly indicative of the uncertainty in the historic-adjusted flood-frequency curve. A 67% confidence interval of the 100-year peak flow at Reading is within $\pm 10\%$ of the calculated value. This increases to $\pm 18\%$ for a 95% confidence interval. For typical record lengths available in the UK, these confidence intervals are usually much wider, showing the value in adding historic data.
Comment on the suitability of the results for future studies.	The new rating derived at Marsh Lock (downstream side of the lock) could be useful in future studies, or perhaps improved upon using hydraulic modelling. This might help to more accurately predict flows in the Thames, affecting downstream communities in Marlow or Henley. A longer AMAX series could be derived using the new rating at Marsh Lock using the historic Lock Keeper record (use of the recent 15-minute record was sufficient for estimating QMED in this study). This might be a useful check on the flood-frequency behaviour of the Thames downstream of the Loddon confluence. Future use of the outputs from this study can inform flood alleviation modelling on this reach of the Thames. Given the use of 1) an extended AMAX series from the Reading gauge, 2) a “virtual” AMAX series downstream of the Kennet confluence and 3) a new data-based rating at Marsh Lock used to estimate AMAX flows downstream of the Loddon confluence, the results from this study can be used to

	inform these types of analyses. In future studies, it may be a useful exercise to derive a formal modelled rating curve at Hurley Lock, or use modelling to improve the Marsh Lock rating initially derived in this study, helping to improve design flow estimates at these locations even further.
Give any other comments on the study.	It is intended to use the flow estimation points indicated in this report to check the calibration of the model, as well as at level telemetry locations at the locks and gauging stations. For example, flow hydrographs will be extracted from the model and compared to design flows / event flows from gauges. Detailed discussion of the calibration strategy is beyond the scope of this report, provided in more detail in the hydraulic modelling phase of this study.

4.3 Checks

Are the results consistent, for example at confluences?	Yes. All design peak flows increase sensibly moving downstream. Comparing the Reading growth curve with single-site growth curves derived using the AMAX series at DS Kennet and DS Loddon gives the following results: <table><tr><th>AEP</th><th>Reading growth curve</th><th>DS Kennet SS growth curve</th><th>DS Loddon SS growth curve</th></tr><tr><td>20%</td><td>1.28</td><td>1.26</td><td>1.27</td></tr><tr><td>10%</td><td>1.47</td><td>1.42</td><td>1.44</td></tr><tr><td>5.0%</td><td>1.67</td><td>1.58</td><td>1.61</td></tr><tr><td>3.3%</td><td>1.79</td><td>1.67</td><td>1.71</td></tr></table> Only short return periods can be compared here due to the length of the AMAX records at DS Kennet and DS Loddon (24 and 21 years respectively). Even so, for short return periods there appears to be a moderately good match in the shape of the growth curve.	AEP	Reading growth curve	DS Kennet SS growth curve	DS Loddon SS growth curve	20%	1.28	1.26	1.27	10%	1.47	1.42	1.44	5.0%	1.67	1.58	1.61	3.3%	1.79	1.67	1.71
AEP	Reading growth curve	DS Kennet SS growth curve	DS Loddon SS growth curve																		
20%	1.28	1.26	1.27																		
10%	1.47	1.42	1.44																		
5.0%	1.67	1.58	1.61																		
3.3%	1.79	1.67	1.71																		
What do the results imply regarding the return periods of floods during the period of record?	At Reading, the adopted growth curve implies the following return periods for floods in the period of record: November 1894 – 200-year March 1947 – 75-year January 2003 – 30-year.																				
What is the range of 100-year growth factors? Is this realistic?	2.18. This appears realistic given the size of the upstream catchment and climate in southern England.																				
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.43																				
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	The growth curve compares very well with that derived previously by Jacobs (2011). This is likely due to the similarities in the methods applied. There are differences in the design inflows for the Kennet and Loddon however, due to differences in how the downstream design hydrograph was derived at Windsor in the Jacobs 2011 analysis. The data extension at Windsor used in the Jacobs 2011 study has since been shown to be possibly affected by non-stationary conveyance behaviour of the Thames over time and should hence be treated with caution.																				
Are the results compatible with the longer-term flood history?	Yes, the return periods for the three largest events on record above appear sensible.																				
Describe any other checks on the results																					

4.4 Final results

Site code	Flood peak (m ³ /s) for the following Annual Exceedance Probabilities										
	50%	20%	10%	5%	3.3%	2%	1.3%	1%	0.5%	0.2%	0.1%
Upstream	174.2	223.1	256.3	290.3	311.1	338.7	361.9	379.0	423.0	487.7	542.3
DS Kennet	192.0	245.9	282.4	320.0	342.9	373.4	398.9	417.7	466.2	537.6	597.7
DS Lonnon	219.6	281.2	323.1	365.9	392.2	427.0	456.2	477.8	533.3	614.9	683.6
Downstream	222.8	285.4	327.8	371.4	398.0	433.3	462.9	484.8	541.1	623.9	693.7

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below)

Spreadsheet titled "Design event inflows" provides peak flows and results of the subtraction method described in Section 4.2.

5 Annex

5.1 AMAX data

5.1.1 Extended Reading AMAX dataset

Water Year	Date	AMAX	Source
1892	01/03/1893	167.9	Lock Keeper POT record, using Mapledurham NFFS rating
1893	19/02/1894	140	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1894	16/11/1894	425.4	Lock Keeper POT record, using Mapledurham NFFS rating
1895	23/03/1896	153	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1896	08/02/1897	269.9	Lock Keeper POT record, using Mapledurham NFFS rating
1897	01/01/1898	149	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1898	12/02/1899	210.3	Lock Keeper POT record, using Mapledurham NFFS rating
1899	20/02/1900	311.8	Lock Keeper POT record, using Mapledurham NFFS rating
1900	03/01/1901	197.9	Lock Keeper POT record, using Mapledurham NFFS rating
1901	31/12/1901	119	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1902	18/06/1903	300.9	Lock Keeper POT record, using Mapledurham NFFS rating
1903	12/02/1904	318.5	Lock Keeper POT record, using Mapledurham NFFS rating
1904	17/03/1905	159	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1905	10/01/1906	158.1	Lock Keeper POT record, using Mapledurham NFFS rating
1906	04/01/1907	158.1	Lock Keeper POT record, using Mapledurham NFFS rating
1907	01/05/1908	269.9	Lock Keeper POT record, using Mapledurham NFFS rating
1908	02/01/1909	106	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1909	27/02/1910	163.8	Lock Keeper POT record, using Mapledurham NFFS rating
1910	18/12/1910	285.3	Lock Keeper POT record, using Mapledurham NFFS rating
1911	25/01/1912	249.7	Lock Keeper POT record, using Mapledurham NFFS rating
1912	31/12/1912	210	Lock Keeper POT record, using Mapledurham NFFS rating
1913	13/03/1914	156.3	Lock Keeper POT record, using Mapledurham NFFS rating
1914	03/01/1915	279.2	Lock Keeper POT record, using Mapledurham NFFS rating
1915	23/03/1916	255.4	Lock Keeper POT record, using Mapledurham NFFS rating
1916	26/12/1916	197.6	Lock Keeper POT record, using Mapledurham NFFS rating
1917	22/01/1918	259.3	Lock Keeper POT record, using Mapledurham NFFS rating
1918	23/03/1919	231.4	Lock Keeper POT record, using Mapledurham NFFS rating
1919	13/04/1920	204.2	Lock Keeper POT record, using Mapledurham NFFS rating
1920	06/01/1921	149.8	Lock Keeper POT record, using Mapledurham NFFS rating
1921	09/03/1922	117	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1922	11/01/1923	171.4	Lock Keeper POT record, using Mapledurham NFFS rating
1923	26/01/1924	205.8	Lock Keeper POT record, using Mapledurham NFFS rating
1924	04/01/1925	285.3	Lock Keeper POT record, using Mapledurham NFFS rating
1925	05/01/1926	269.1	Lock Keeper POT record, using Mapledurham NFFS rating
1926	02/03/1927	197.6	Lock Keeper POT record, using Mapledurham NFFS rating

Water Year	Date	AMAX	Source
1927	06/01/1928	255.4	Lock Keeper POT record, using Mapledurham NFFS rating
1928	30/12/1928	129	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1929	11/12/1929	295.8	Lock Keeper POT record, using Mapledurham NFFS rating
1930	03/01/1931	148	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1931	25/05/1932	191.1	Lock Keeper POT record, using Mapledurham NFFS rating
1932	02/03/1933	269.1	Lock Keeper POT record, using Mapledurham NFFS rating
1933	16/03/1934	67	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1934	30/12/1934	110	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1935	31/12/1935	231.4	Lock Keeper POT record, using Mapledurham NFFS rating
1936	19/03/1937	214	Lock Keeper POT record, using Mapledurham NFFS rating
1937	14/01/1938	123	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1938	29/01/1939	255.4	Lock Keeper POT record, using Mapledurham NFFS rating
1939	09/02/1940	265.1	Lock Keeper POT record, using Mapledurham NFFS rating
1940	26/01/1941	191.1	Lock Keeper POT record, using Mapledurham NFFS rating
1941	28/01/1942	165.3	Lock Keeper POT record, using Mapledurham NFFS rating
1942	04/02/1943	210	Lock Keeper POT record, using Mapledurham NFFS rating
1943	25/01/1944	63	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1944	14/02/1945	148	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1945	30/12/1945	156.3	Lock Keeper POT record, using Mapledurham NFFS rating
1946	17/03/1947	359.6	Lock Keeper POT record, using Mapledurham NFFS rating
1947	30/01/1948	136	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1948	03/01/1949	152.6	Lock Keeper POT record, using Mapledurham NFFS rating
1949	16/02/1950	196	Lock Keeper POT record, using Mapledurham NFFS rating
1950	10/01/1951	201.7	Lock Keeper POT record, using Mapledurham NFFS rating
1951	27/02/1952	167.6	Lock Keeper POT record, using Mapledurham NFFS rating
1952	23/12/1952	167.6	Lock Keeper POT record, using Mapledurham NFFS rating
1953	14/06/1954	127	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1954	11/12/1954	236.8	Lock Keeper POT record, using Mapledurham NFFS rating
1955	25/01/1956	160	Lock Keeper POT record, using Mapledurham NFFS rating
1956	11/02/1957	167.6	Lock Keeper POT record, using Mapledurham NFFS rating
1957	30/01/1958	175.3	Lock Keeper POT record, using Mapledurham NFFS rating
1958	23/01/1959	249.7	Lock Keeper POT record, using Mapledurham NFFS rating
1959	28/01/1960	196	Lock Keeper POT record, using Mapledurham NFFS rating
1960	06/12/1960	222.6	Lock Keeper POT record, using Mapledurham NFFS rating
1961	14/01/1962	171.4	Lock Keeper POT record, using Mapledurham NFFS rating
1962	12/03/1963	152.6	Lock Keeper POT record, using Mapledurham NFFS rating
1963	21/11/1963	173.7	Lock Keeper POT record, using Mapledurham NFFS rating
1964	22/03/1965	72	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1965	01/03/1966	165.3	Lock Keeper POT record, using Mapledurham NFFS rating
1966	02/03/1967	152.6	Lock Keeper POT record, using Mapledurham NFFS rating

Water Year	Date	AMAX	Source
1967	17/01/1968	191.1	Lock Keeper POT record, using Mapledurham NFFS rating
1968	15/03/1969	169.9	Lock Keeper POT record, using Mapledurham NFFS rating
1969	31/01/1970	123	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1970	26/01/1971	183.1	Lock Keeper POT record, using Mapledurham NFFS rating
1971	07/03/1972	173.7	Lock Keeper POT record, using Mapledurham NFFS rating
1972	08/12/1972	136	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1973	13/02/1974	185.5	Lock Keeper POT record, using Mapledurham NFFS rating
1974	23/11/1974	204.2	Lock Keeper POT record, using Mapledurham NFFS rating
1975	29/11/1975	54	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1976	25/02/1977	204.2	Lock Keeper POT record, using Mapledurham NFFS rating
1977	30/01/1978	157.8	Lock Keeper POT record, using Mapledurham NFFS rating
1978	31/03/1979	201.7	Lock Keeper POT record, using Mapledurham NFFS rating
1979	31/12/1979	214	Lock Keeper POT record, using Mapledurham NFFS rating
1980	14/03/1981	173.7	Lock Keeper POT record, using Mapledurham NFFS rating
1981	03/01/1982	196	Lock Keeper POT record, using Mapledurham NFFS rating
1982	12/12/1982	160	Lock Keeper POT record, using Mapledurham NFFS rating
1983	28/01/1984	145	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1984	27/11/1984	149.8	Lock Keeper POT record, using Mapledurham NFFS rating
1985	27/12/1985	193.5	Lock Keeper POT record, using Mapledurham NFFS rating
1986	09/04/1987	145	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1987	26/01/1988	179.2	Lock Keeper POT record, using Mapledurham NFFS rating
1988	28/02/1989	141	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1989	05/02/1990	208.1	Lock Keeper POT record, using Mapledurham NFFS rating
1990	31/12/1990	138	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1991	26/09/1992	111	Jacobs 2011 Table 3.3 (no AMAX level from Mapledurham available)
1992	06/12/1992	196	Lock Keeper POT record, using Mapledurham NFFS rating
1993	08/01/1994	191.1	Lock Keeper POT record, using Mapledurham NFFS rating
1994	02/02/1995	205.6	From JBA Lower Thames 2013 analysis (Reading ultrasonic adjusted with spot gaugings)
1995	25/12/1995	170.3	Reading ultrasonic gauge
1996	26/02/1997	104.8	Reading ultrasonic gauge
1997	13/04/1998	179	Reading ultrasonic gauge
1998	24/01/1999	194.3	Mapledurham NFFS rating (considered more reliable than ultrasonic above 180m ³ /s)
1999	28/12/1999	164.2	From JBA Lower Thames 2013 analysis (Reading ultrasonic adjusted with spot gaugings)
2000	16/12/2000	229.4	Mapledurham NFFS rating (considered more reliable than ultrasonic above 180m ³ /s)
2001	07/02/2002	146.7	Reading ultrasonic gauge
2002	04/01/2003	304.6	Mapledurham NFFS rating (considered more reliable than ultrasonic above 180m ³ /s)
2003	03/02/2004	124.8	Reading ultrasonic gauge
2004	31/03/2005	113.1	Reading ultrasonic gauge

Water Year	Date	AMAX	Source
2005	01/04/2006	90.1	Reading ultrasonic gauge
2006	26/07/2007	222	From JBA Lower Thames 2013 analysis (Reading ultrasonic adjusted with spot gaugings)
2007	20/01/2008	210.8	Mapledurham NFFS rating (considered more reliable than ultrasonic above 180m ³ /s)
2008	12/02/2009	201.7	Mapledurham NFFS rating (considered more reliable than ultrasonic above 180m ³ /s)
2009	19/01/2010	162	Reading ultrasonic gauge
2010	19/01/2011	123.9	Reading ultrasonic gauge
2011	03/05/2012	152.5	Reading ultrasonic gauge
2012	29/11/2012	242.4	From JBA Lower Thames 2013 analysis (Reading ultrasonic adjusted with spot gaugings)
2013	10/01/2014	274.9	From JBA Lower Thames 2013 analysis (Reading ultrasonic adjusted with spot gaugings)
2014	18/01/2015	117	Reading ultrasonic gauge
2015	12/02/2016	144	Reading ultrasonic gauge

5.1.2 DS Kennet AMAX dataset

Each AMAX event here was calculated by first adding the Reading and Theale gauged flow series, then calculating the maximum from the added series for each water year.

Water Year	Date	AMAX	Notes
1992	07/12/1992 20:45	232.36	Using Reading Ultrasonic (no data from Mapledurham for NFFS rating)
1993	10/01/1994 13:15	229.04	Using Reading Ultrasonic (no data from Mapledurham for NFFS rating)
1994	02/02/1995 17:00	241.58	Using Reading Ultrasonic adjusted using spot gaugings from Lower Thames study (no data from Mapledurham for NFFS rating)
1995	23/12/1995 11:45	189.64	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
1996	27/02/1997 09:15	114.83	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
1997	13/04/1998 18:30	192.52	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
1998	24/01/1999 10:00	224.63	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
1999	25/12/1999 15:30	191.42	Using Reading Ultrasonic adjusted using spot gaugings from Lower Thames study
2000	13/12/2000 22:15	272.5	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
2001	05/02/2002 15:00	185.17	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2002	04/01/2003 10:00	350.32	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
2003	07/02/2004 15:00	139.91	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2004	31/03/2005 13:45	125.28	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2005	01/04/2006 11:45	98.53	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)

Water Year	Date	AMAX	Notes
2006	27/07/2007 00:15	238.54	Using Reading Ultrasonic adjusted using spot gaugings from Lower Thames study
2007	20/01/2008 08:30	242.41	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
2008	12/02/2009 17:30	233.31	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
2009	19/01/2010 10:30	178.15	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2010	19/01/2011 13:00	145.43	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2011	03/05/2012 11:00	165.43	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2012	27/12/2012 13:15	266.56	Using Reading Ultrasonic adjusted using spot gaugings from Lower Thames study
2013	10/01/2014 06:15	319.66	Using Mapledurham NFFS at Reading (above cutoff where ultrasonic is considered less reliable)
2014	16/01/2015 12:00	151.92	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)
2015	29/03/2016 11:30	177.82	Using Reading Ultrasonic (Below cutoff point for NFFS Mapledurham rating)

5.1.3 Marsh Lock (AKA DS Loddon) AMAX dataset

The Marsh Lock (downstream) level series contains some gaps, and periods where there are frequent and severe telemetry spikes. This prevents the use of automated methods for extracting an AMAX level series. Instead this process was carried out manually, comparing the Marsh Lock level telemetry against the gauged flow series from Reading to help identify each AMAX event.

Year	Date	Stage (mALD)	AMAX flow from new rating	Notes
1995	24/12/1995 11:45	3.309	213.6	
1996	26/02/1997 13:00	2.812	135.9	
1997	13/04/1998 20:00	3.35	219.6	
1998	22/01/1999 01:45	3.465	236.4	
1999	27/12/1999 00:30	3.572	252.5	
2000	14/12/2000 18:45	3.972	315.2	
2001	06/02/2002 11:30	3.397	226.4	
2002	04/01/2003 10:00	4.274	365.3	
2003	03/02/2004 00:15	2.933	161.7	
2004				Missing data over the peak. Likely less than QMED judging from the Reading dataset
2005	01/04/2006 11:15	2.655	97.4	
2006	26/07/2007 04:45	3.647	263.9	
2007	17/01/2008 19:30	3.687	270.1	
2008	12/02/2009 16:00	3.755	280.7	
2009				Missing data for most of the WY. Would have been slightly below QMED judging from other datasets
2010	19/01/2011 17:00	3.093	183.3	
2011	02/05/2012 04:15	3.153	191.6	

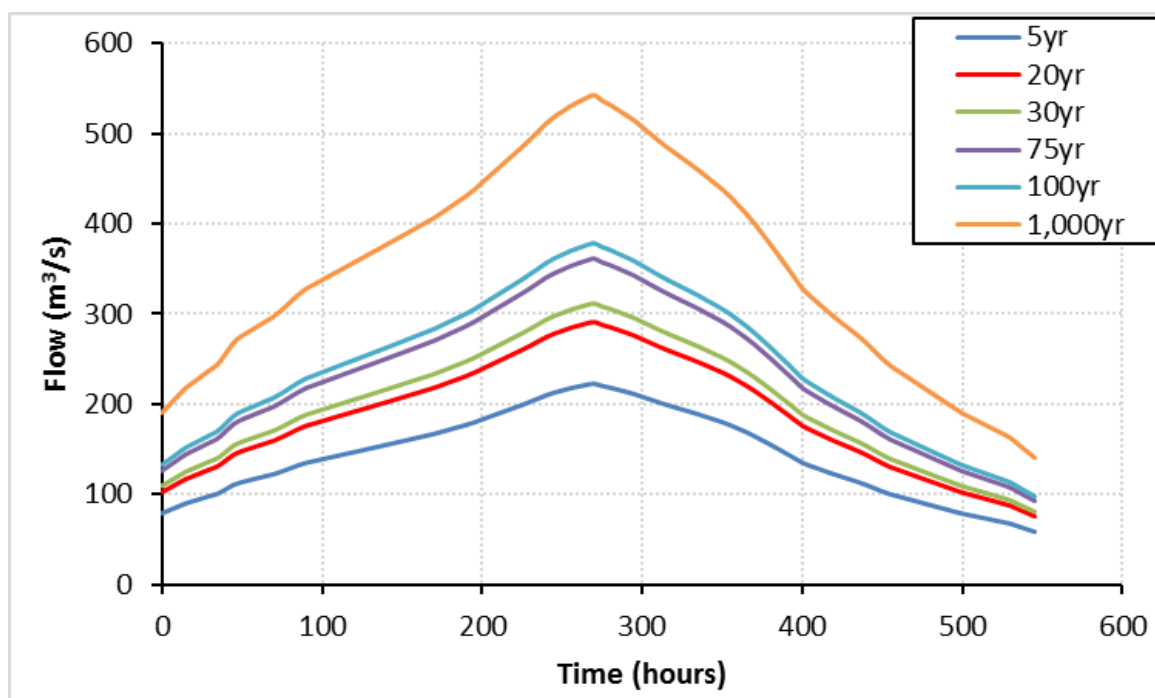
Year	Date	Stage (mALD)	AMAX flow from new rating	Notes
2012	27/12/2012 10:00	3.812	289.6	
2013	09/02/2014 02:45	4.275	365.5	Truncated hydrograph, true peak is probably even higher
2014	16/01/2015 16:45	3.128	188.1	
2015	13/01/2016 03:15	3.279	209.3	
2016	02/02/2017 11:45	2.655	97.4	

5.2 Reading ESS pooling group

Station	SDM	n	QMED	LCV	LSKEW	Disc	Area	SAAR	FPEXT	FARL
39130 (Thames @ Reading)	0	124	174.5	0.179	0.124	0.148	4599	680	0.17	0.961
39002 (Thames @ Days Weir)	0.4	77	149.6	0.195	0.096	1.316	3480	690	0.176	0.953
27009 (Ouse @ Skelton)	0.815	129	322.0	0.137	0.116	0.769	3301	899	0.136	0.983
54001 (Severn @ Bewdley)	0.919	92	336.0	0.134	0.131	0.729	4330	912	0.106	0.973
27041 (Derwent @ Buttercrambe)	1.546	42	70.7	0.139	0.321	1.648	1594	765	0.141	0.994
21021 (Tweed @ Sprouston)	1.646	36	816.9	0.188	0.127	1.391	3346	1014	0.046	0.978

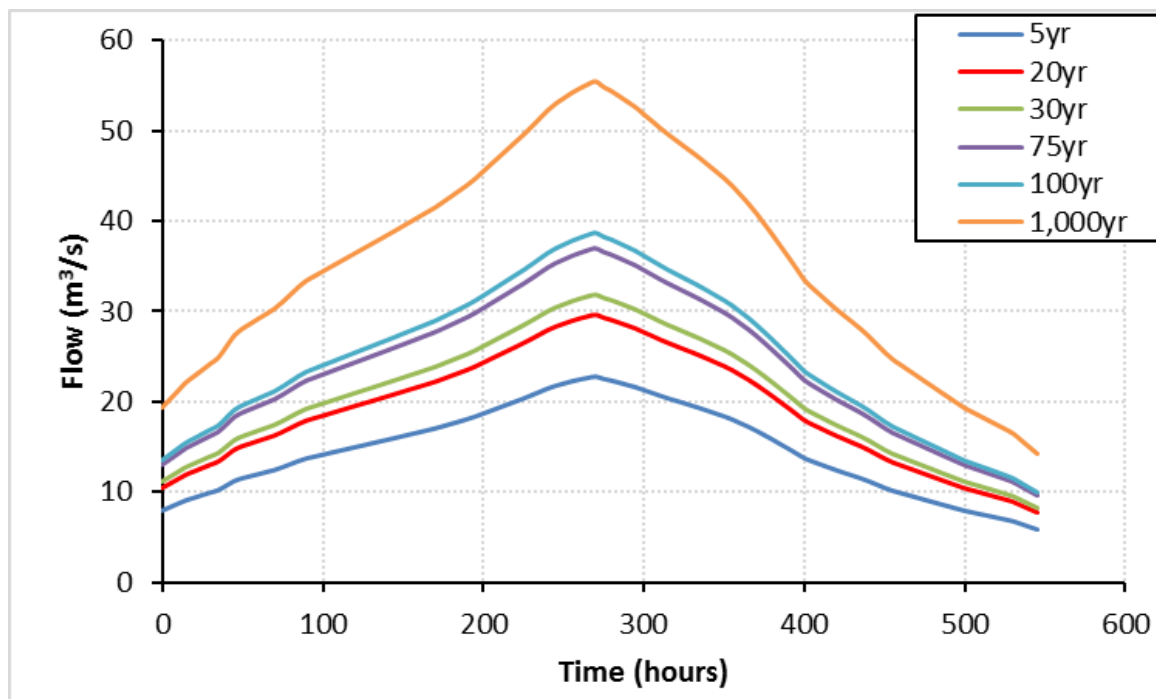
5.3 Inflow hydrographs

5.3.1 Upstream inflows



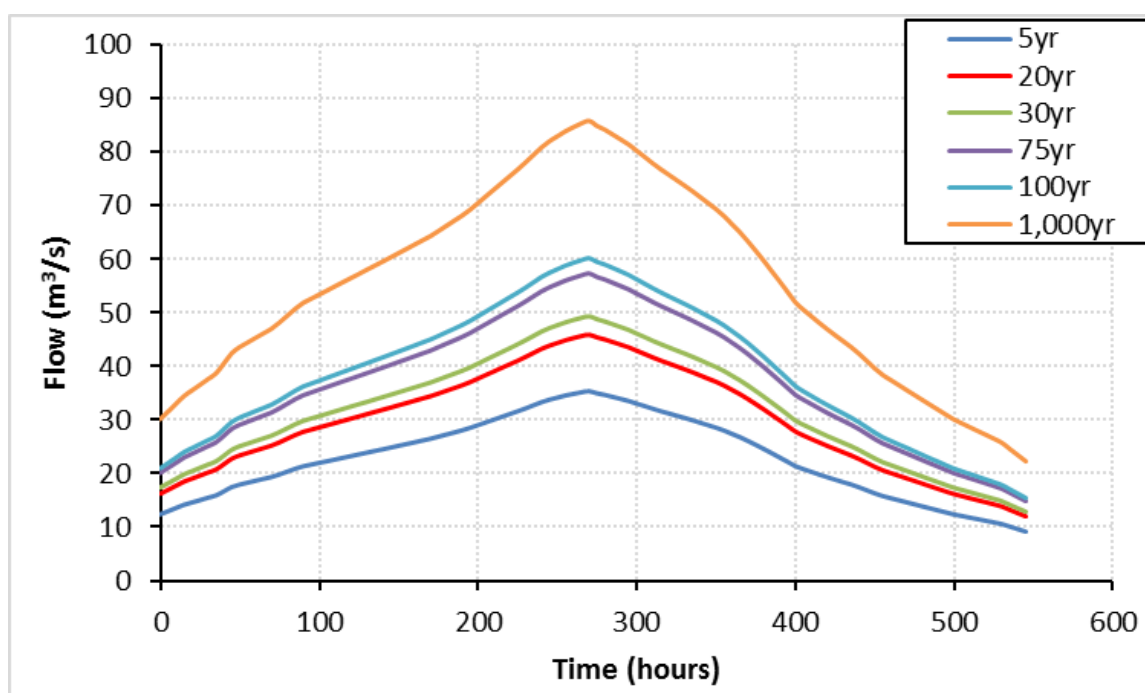
5.3.2 Kennet inflows

Calculated by subtracting design flow hydrographs at Upstream and DS Kennet



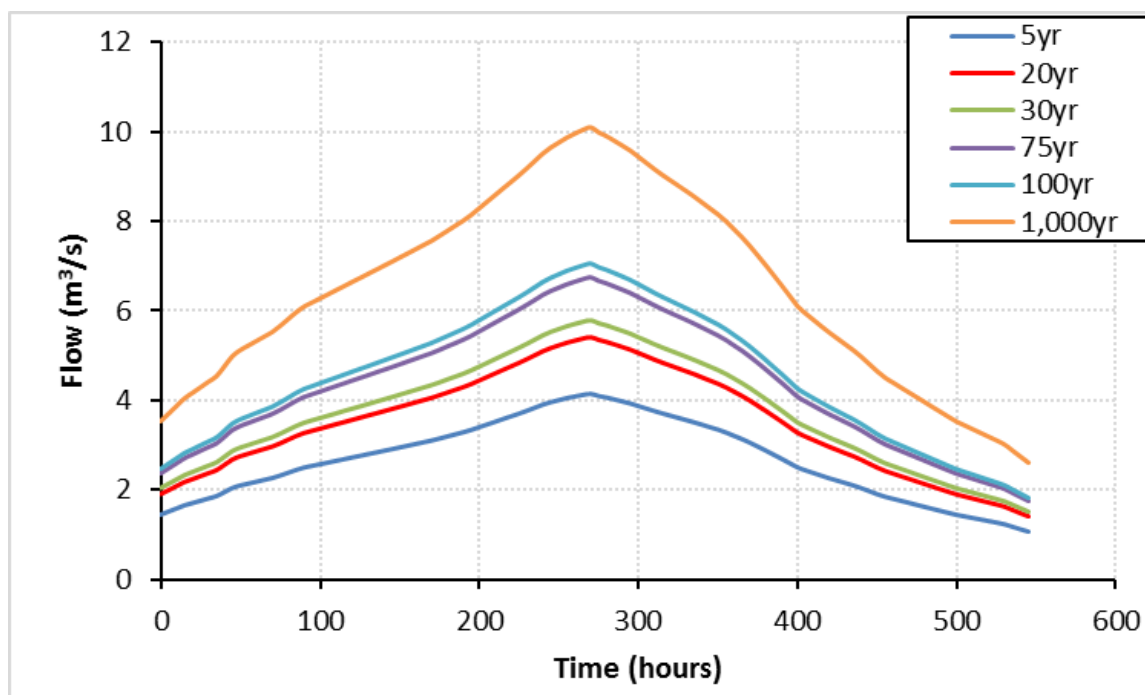
5.3.3 Loddon inflows

Calculated by subtracting design flow hydrographs at DS Kennet and DS Loddon



5.3.4 Downstream lateral inflow

Calculated by subtracting design flow hydrographs at DS Loddon and Downstream



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E EA Approval Letter

Emelie Persson
J B A
The Library Church Hill
Coleshill
BIRMINGHAM
B46 3AD

Our ref: WA/2022/129911/02-L01
ENVPAC/1/THM/00685

Date: 10 February 2023

Dear Ms Persson

Review Of Flood Modelling

Thames Field Retirement Villages

I'm pleased to confirm that we now deem the modelling fit for intended use.

Please see our more detailed review comments sent separately via email on 10 February 2023.

Yours sincerely,

Mr Jack Moeran
Planning Specialist

Direct dial 02030259655
Direct e-mail planning-wallington@environment-agency.gov.uk

Disclaimer

Please note that the views expressed in this report by the Environment Agency, is a response to a pre-application enquiry only and **does not represent our final view in relation to any future statutory consultations made in relation to this site**. We reserve the right to change our position in relation to any such application. You should seek your own expert advice in relation to technical matters relevant to any conditions before submission.

End

F Landscape Strategy

Thamesfield Village

Henley-on-Thames, Oxfordshire

December 2023



Landscape Strategy

Turley Design were commissioned by Retirement Villages Group (RVG) to provide landscape proposals to support a full application for the part demolition of existing building and replacement with a three-storey extension to provide extra-care units (Use Class C2), with associated soft and hard landscaping works; provision of additional vehicle parking, bin stores and ancillary structures; and alterations to existing basement at Thamesfield Retirement Village, Henley-on-Thames.

Objectives

The landscape proposals have been informed and shaped by RVG's Landscape Design Code and Vision. The overarching themes of the Vision is to create a sense of place, promote physical and mental well-being, and implement climate resilience. These themes will be achieved within the landscape proposals by meeting the following objectives:

- Integrate with the existing surrounding landscape setting, including cultural, social and historical characteristics;
- Provide an inspiring and inviting first impression to visitors by aiming to uplift the quality of the public realm;
- Identify opportunities for the enhancement of biodiversity and participation by residents in caring for the planet;
- Encourage residents and staff to exercise and experience the outdoors;
- Promote locally sourced, organic fruit and vegetables for healthy eating options;

- Provide a safe and secure environment for a community to live, work and play, reducing anxiety levels and stress;
- Providing means and spaces for social interaction between residents;
- Implement spaces for a wide range of intellectually stimulating processes, such as bird watching or bee keeping;
- Make spaces and settings for rest and relaxation, promoting physical well-being;
- Provide habitat enhancements by connecting planted systems, integrating with adjacent habitats, and maximising green spaces; and
- Maximise daylight gain in winter, shade in summer and wind protection throughout the year by strategically placing trees.

Proposals

The adjacent Illustrative Landscape Masterplan sets out the landscape proposals for Thamesfield Village. Alongside the redevelopment of extra care units, the courtyard will undergo a transformation to create a high-quality communal outdoor space which has the potential to become the heart of the village.

The courtyard will be a scenic walk between destinations with interest along the route. The courtyard will be fully accessible for all users.

The design creates outdoor rooms within the courtyard, separated by a flowering pergola, which residents would journey through. A Kitchen Garden to one end and a Residents Garden to the other. This series of social spaces would promote impromptu conversations and meetings as well as organised activities which promote mental and physical well-being.

The courtyard will be a vibrant, stimulating, inclusive and beautiful place for residents, staff and their visitors to enjoy.

The western boundary woodland walk will connect the courtyard with the wider outdoor facilities whilst providing ecological enhancements to support wildlife.

The proposals support resident engagement and participation in outdoor activities. Residents will be able to help make decisions on the gardens and be involved in it's evolution, help with gardening, grow their own food , fruit veg and herbs and share their produce from the garden as well as organise events in the gardens. This will promote a sense of ownership and encouraging participation serves to promote wellness and a healthy sociable community.

The courtyard proposals have been designed to accommodate fire vehicle access and turning. Fire vehicles will be able to overrun the hard surfaced areas as well as the grassed areas which will be reinforced with pavers to accommodate their loading capacity requirements. There are no raised kerbs or built elements, ensuring a flush surface for the extent of the turning head.



- 1 Resin bound gravel
- 2 Raised beds
- 3 Allotment beds
- 4 Greenhouse
- 5 Garden shed
- 6 Bin store (inc. fence screen)
- 7 Circular tree bench
- 8 Benches, tables and chairs
- 9 Freestanding planters
- 10 Steps to basement
- 11 Patio over basement
- 12 Private balcony/ garden
- 13 Existing trees
- 14 Proposed trees
- 15 Ornamental shrub planting
- 16 Garden mix planting
- 17 Hedgerow planting
- 18 Meadow mix planting
- 19 Native shrub mix planting
- 20 Mown grass with protection mesh for fire vehicle access
- 21 Vertical bike shed

Kitchen Garden

- Provision for growing fruit, vegetables and herbs. Raised, robust allotment beds which are sufficiently spaced for comfortable access for all to use.
- Research in environmental psychology and horticulture demonstrates that the act of gardening has a positive psychological and therapeutic effect on people. Horticulture therapy for those with dementia focuses on positive reminiscence, re-connecting with others and gentle appropriate physical exercise and stimulation of a great number of cognitive processes which reduces the anxiety of living with dementia.
- A community Kitchen Garden Team consisting of interested residents and restaurant/ RVG management staff will ensure a thriving, productive kitchen garden. A Kitchen Garden Annual Management Plan will define activities and responsibilities throughout the year.
- Enabling equipment would be required – a greenhouse (to broaden the growing season/plant propagation) and a shed (for equipment storage) as well as outdoor taps, rainwater harvesting tank, electricity points and composting bins.



Resident's Garden

- The proposed terrace will offer a vibrant space for social interaction between residents. Dementia patients with a lower mental capacity enjoy emotional participation - they take interest in their social surroundings, observe people, are friendly and talk to others but do not have the strength to actively take part or integrate in busy social situation. Dementia patients appreciate a sense of concealment and protection, yet open views of their surrounding environment.
- The Resident's Garden will offer an attractive and inviting space to linger where residents will feel encouraged to spend time outdoors, feel safe and relaxed without it being overstimulated.
- A central feature would create a focal point, this may be a large ornamental tree, a water sculpture or a piece of art.
- Seating with back and arm rests have been arranged strategically to offer sunshine and shade opportunities throughout the day.
- Planting will incorporate species of flowering and sensory interest, providing seasonal variety and change throughout the year.



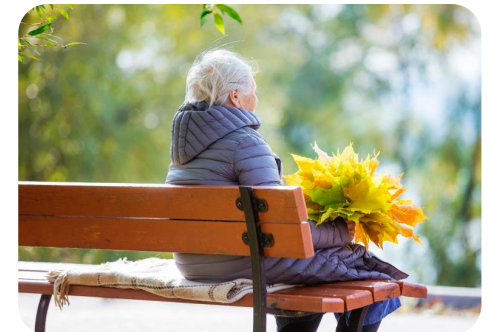
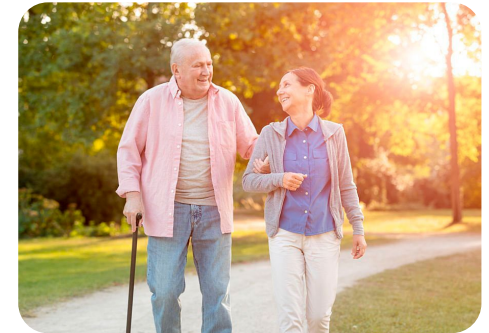
Private Outdoor Space

- Patio terraces to ground floor apartments. Extending 2m from the building and providing residents with c.16-20sqm of private amenity space. Paved spaces which provide residents an outdoor place they can make their own and personalise.
- To offer a degree of separation and enclosure between ground level private amenity space and the public courtyard, a 1.1m high balustrade would define their patio with hedgerow planting for greening and visual screening. Where space permits, further planting to the communal space would separate private boundaries from communal routes.



Woodland Walk

- Ecological enhancements to boundary vegetation will establish a wildlife corridor including supplementary tree and native shrub planting. Bird and bat boxes will provide nesting and roosting opportunities, whereas bird feeders will allow residents to bird watch from their apartments.
- Provision of a continuous and looped footpath network, set entirely outdoors, to offer diverse and interesting routes to explore and promote physical well-being. This will be informal surfacing of self-binding aggregate to enhance parkland setting, avoiding steps where possible.
- Structured locations of fixed furnishings create destinations, landmarks and circulation cues that encourage movement into and through the garden. Seating will be strategically located to provide places to rest.
- Movable furnishings allow an adaptable environment, creating places for both social interaction and also private contemplation for those not wishing to be sociable at that time.

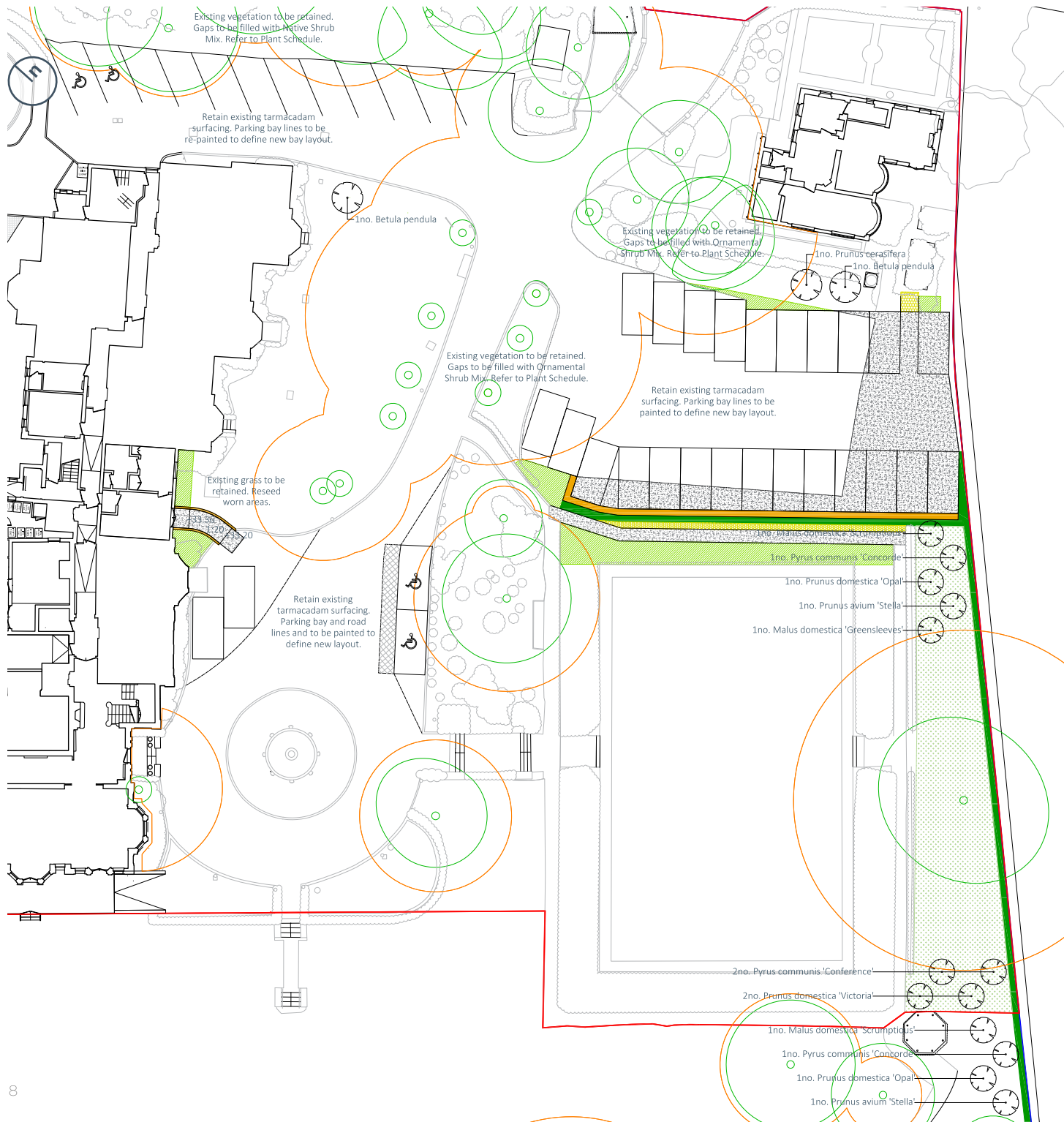




-  Application boundary
-  Ownership boundary
-  Resin Bound Gravel
Buff Colour. Permeable. Installed to product specification. Setts edging to courtyard. Aluminum edging to paths beyond courtyard and patio.
-  Setts
Single row of 100 x 100mm setts. Buff Colour. Laid flush to adjacent surfaces. Installation to engineers specification.
-  Suregreen PP40 Porous Paver Grass Finish
Or similar approved, suitable for Fire Engine overrun. Laid flush to adjacent hard surfaces. Installed to product specification.
-  Raised Beds
Height 60cm inc coping. Brick finish same as bricks to new building.
-  Allotment Beds
Height 60cm inc coping. Brick finish same as bricks to new building. To be filled with a soil/compost mix.
-  Retaining wall
Height min 1.1m above step level inc coping. Brick finish same as bricks to new building.
-  Greenhouse
6ft x 8ft. Timber or aluminum frame, apex. Concrete base. RVG product choice.
-  Garden Shed
6ft x 8ft. Pressure treated timber, tongue and groove, apex. Concrete base. RVG product choice.
-  Garden Bench
Hardwood timber. With back and arm rests. Freestanding. RVG product choice.
-  Circular Tree Bench
D.2m approx. Hardwood timber. With back rest. RVG product choice.
-  Table and Chairs
Freestanding. RVG product choice.
-  Large Planters
Freestanding. RVG product choice.
-  Small Planters
Freestanding. RVG product choice.
-  Vertical Bike Locker
Galvanised steel. RVG product choice. Installed to manufacturers specifications.
-  Fence Screen to Bin Store
6ft horizontal double slatted panels (slats mounted alternately on the front and back of the panel). Pressure treated timber. Timber or concrete posts.
-  Balustrade to patio
To match balustrades to terrace or to balconies.
-  Existing tree retained
-  Combined root protection area

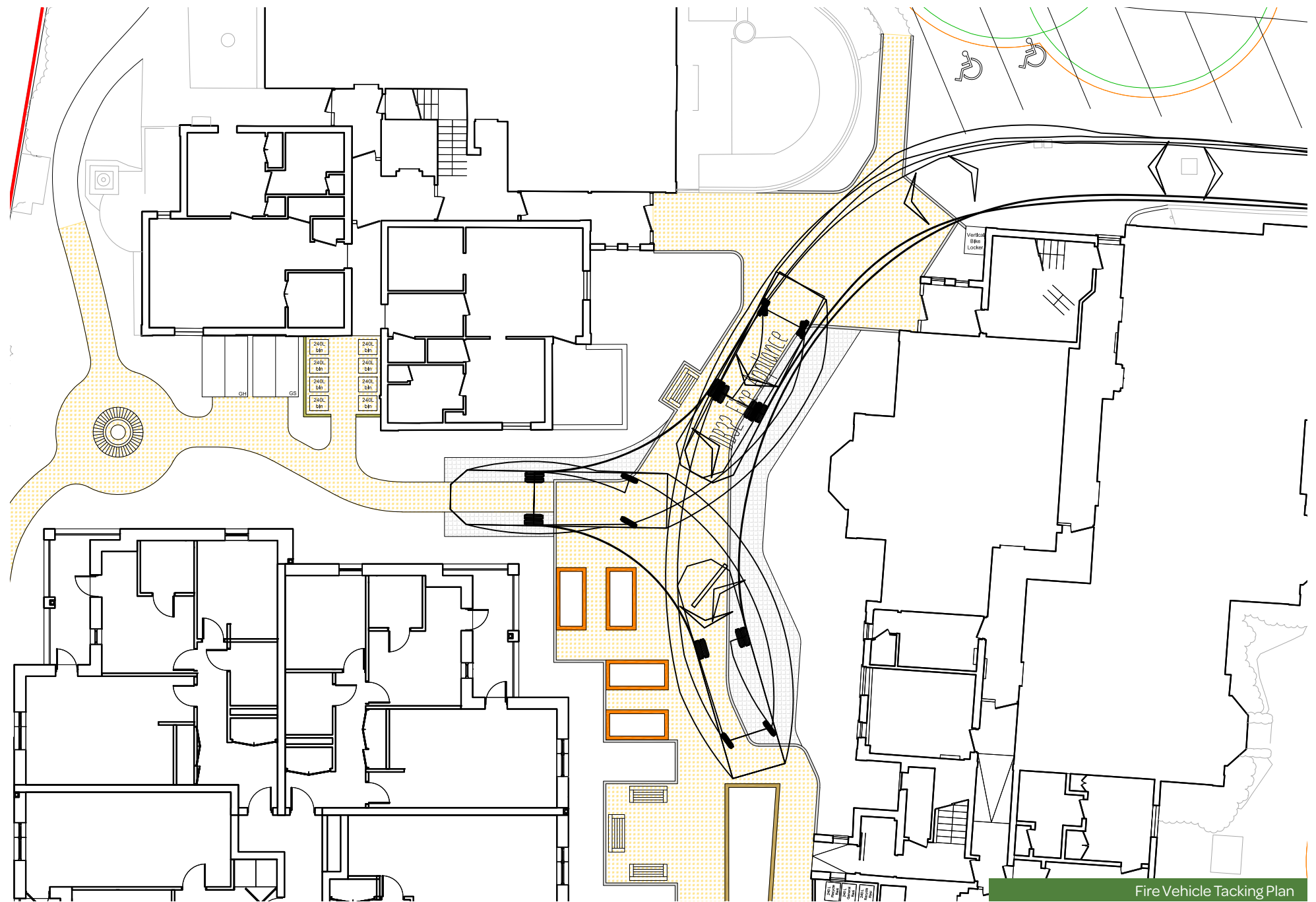


- Application boundary
- Ownership boundary
- Existing tree retained
- Combined root protection area
- Proposed tree
- Ornamental hedgerow
Planted in a single row, at 3no. plants per linear metre
- Garden Mix 1
Interspersed with Infills and Bedding Mix
- Garden Mix 2
Interspersed with Infills and Bedding Mix
- Garden Mix 3
Interspersed with Infills and Bedding Mix
- Infills and Bedding Mix
- Ornamental Shrub Mix
Interspersed with Infills and Bedding Mix
- Native Shrub Mix
Retain existing vegetation where possible and add additional plants where needed.
- Meadow Mix
- Close Mown Grass
- Close Mown Grass with Suregreen
PP40 Porous Paver Grass Finish
Product: Suregreen PP40 Pourous Pavers or similar approved. Installed to product specification.
- Allotment Bed
To be filled with a soil/compost mix. Planted contents to be decided by residents and Kitchen Garden Team.



- Application boundary
- Ownership boundary
- Tarmacadam
Continuation of existing surface materials.
Installed to product specification.
- Extent of existing tarmacadam to be retained
- Relocated garden path
New area of path to use the same or similar approved product as existing garden paths.
Installed to engineers specification.
- Retaining wall
Height min.50cm above floor level of car park inc coping. Brick finish same as bricks to new building.
- Existing tree retained
- Combined root protection area
- Proposed tree
- Native hedgerow
Planted in a double staggered row, 400mm between rows, at 5no. plants per linear metre
- Ornamental shrub mix
In areas of existing vegetation, retain existing vegetation where possible and add additional plants where needed.
- Meadow mix
- Infill and bedding mix

Hard and Soft Car Park Landscape Plan



Hard Materials

Hard materials across the proposals will look to complement or match the proposed new architecture. Colours look to be soft and neutral to create a calming environment, allowing the natural colouring of plants to animate the spaces.

High-quality surface materials have been chosen for their suitability for elderly residents. Surfaces will be smooth yet with anti-slip properties and there will be no loose stone or uneven surfaces. Small kerbs have not been used to avoid trip hazards.

Furniture with back and arm-rests for this will be provided to reflect the resident demographic. High quality, robust hardwood timber will be used to maximise lifespan and reduce maintenance costs. All timber to be FSC certified and sustainably sourced.

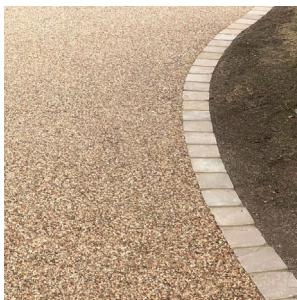
Surface Materials



Resin bound gravel



Aluminium edging to resin bound gravel



Setts edging to resin bound gravel



SureGreen PP40 Lawn Protection Mesh

Built Elements



Raised beds and allotments



Balustrade to patio



Fence screen to bin store

Furniture



Benches



Circular Bench



Tables and Chairs



Greenhouse



Shed



Vertical bike shed

Plant Schedule

This Planting Schedule sets out an indicative species list for the garden mixes, climbers, infill and bedding plants, wildflower grassland areas, hedgerows and trees.

Plant species have been chosen for their suitability to site conditions, in particular partial shade due to the courtyard setting, and for their seasonal interest and sensory properties. Colour, form and scent have all been important considerations as well as using more traditional varieties which residents will recognise. A mix of both evergreen and deciduous species have been chosen alongside species which are pollinators and bee-friendly or have other wildlife-benefitting properties.

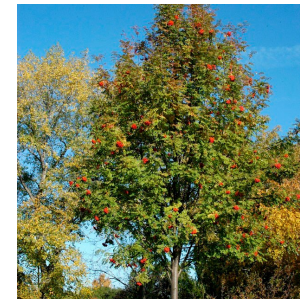
Orchard & Car Park Trees	
Rootballed or container grown. Select Standard.	
Tree pit size: 900 x 900 x 750mm, backfilled with topsoil.	
Underground tree anchoring system. 0.6m dia. bark surface to pits.	
10-12cm stem girth. 3-3.5m height. Min 2m clear stem.	
Species	Common Name
<i>Betula pendula</i>	Silver Birch
<i>Malus domestica</i> 'Scrumptious'	Apple 'Scrumptious'
<i>Malus domestica</i> 'Greensleeves'	Apple 'Greensleeves'
<i>Pyrus communis</i> 'Concorde'	Pear 'Concord'
<i>Pyrus communis</i> 'Conference'	Pear 'Conference'
<i>Prunus domestica</i> 'Opal'	Plum 'Opal'
<i>Prunus domestica</i> 'Victoria'	Plum 'Victoria'
<i>Prunus avium</i> 'Stella'	Cherry 'Stella'
<i>Prunus cerasifera</i>	Cherry Plum

Courtyard Trees	
Rootballed or container grown. Select Standard.	
Tree pit size: 900 x 900 x 750mm, backfilled with topsoil.	
Underground tree anchoring system. 0.6m dia. bark surface to pits.	
10-12cm stem girth. 3-3.5m height. Min 2m clear stem.	
Species	Common Name
<i>Acer griseum</i>	Paperbark Maple
<i>Acer platanoides</i> 'Emerald Queen'	Norway Maple
<i>Betula utilis</i> var. <i>Jacquemontii</i>	Himalayan Birch 'Jacquemontii' (multi-stem)
<i>Prunus</i> 'Amanogawa'	Cherry 'Amanogawa'
<i>Prunus</i> 'Royal Burgandy'	Cherry 'Royal Burgandy'
<i>Sorbus aucuparia</i>	Rowan
<i>Sorbus aria</i> 'Lutescens'	Whitebeam

Trees



Acer griseum (Paperbark Maple)



Sorbus aucuparia (Rowan)



Betula utilis var. *Jacquemontii* (Birch)



Malus domestica 'Scrumptious' (Apple)



Prunus avium 'Stella' (Cherry)



Pyrus communis 'Conference' (Pear)

Ornamental Plant Mixes		
Garden Mix 1		
Planted at 4/m ² , except specimens planted as individuals		
Species marked * to be located to the front of beds		
groups of 3, 5 and 7no.		
Species	Stock	Size
Choisya 'Aztec Pearl' (Specimen)	C10L	40-50cm
Hebe 'White Gem'*	C5L	30-40cm
Hauchera micrantha 'Palace Purple'*	C3L	-
Kniphofia 'Royal Standard'	C3L	30-40cm
Lavandula angustifolium 'Hidcote'	C2L	20-30cm
Lobelia cardinalis 'Queen Victoria'	C3L	30-40cm
Pittosporum tenifolium 'Tom Thumb'*	C3L	20-30cm
Santolina virens*	C3L	20-30cm
Salvia officinalis 'Purpurascens'	C5L	-
Spiraea japonica 'Gold Mound'*	C3L	30-40cm
Stipa tenuissima	C2L	-

Garden Mix 2		
Planted at 4/m ² , except specimens planted as individuals		
Species marked * to be located to the front of beds		
To be planted in single species staggered informal groups of 3, 5 and 7no.		
Species	Stock	Size
Artemisia ludoviciana 'Valerie Finnis'	C2L	40-60cm
Bergenia cordifolia 'Purpurea'	C2L	20-30cm
Hebe 'White Gem'*	C5L	30-40cm
Choisya 'Aztec Pearl'	C3L	30-40cm
Philadelphus 'Belle Etoile'	C10L	Specimen
Phormium tenax 'Purpureum'	C10L	Specimen
Polystichum setiferum	C2L	30-40cm
Rosmarinus 'Miss Jessop's Upright'	C2L	40-60cm
Salvia verticillata 'Purple Rain'	C3L	30-40cm
Skimmia 'Kew Green'*	C3L	30-40cm
Spiraea japonica 'Firelight'	C3L	30-40cm

Garden Mix 3		
To be planted at 3/m ² and in single species groups of 3, 5 and 7no.		
Species marked * to be located to the front of beds		
In small beds, select species marked **, specimens as groups of 1, 3 or 5no.		
Species	Stock	Size
Bergenia cordifolia 'Purpurea'	C2L	20-30cm
Calamagrostis x acutiflora 'Karl Forester'	C10L	Specimen
Cornus alba 'Sibirica'	C10L	Specimen
Euonymus fortunei 'Emerald Gaiety'	C2L	20-30cm
Geranium macrorrhizum 'Johnson's Blue'	C2L	20-30cm
Hebe 'Champagne'	C2L	20-30cm
Hebe 'White Gem'**	C5L	30-40cm
Hydrangea macrophylla 'Lanarth's White'	C3L	30-40cm
Lavandula angustifolium	C2L	20-30cm
Perovskia 'Blue Spire'	C; 9cm	-
Stipa gigantea	C10L	Specimen
Vinca minor 'Atropurpurea'	C3L	30-40cm

Garden Mixes



Kniphofia 'Royal Standard'



Lavandula angustifolium 'Hidcote'



Artemisia ludoviciana 'Valerie Finnis'



Phormium tenax 'Purpureum'



Stipa gigantea



Euonymus fortunei 'Emerald Gaiety'