Uttlesford District Council

Flood Mapping Study of River Bourn in Ashdon

October 2008

FINAL REPORT

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CONTRACT

This report describes work commissioned by Uttlesford District Council under contract dated on 21-05-2008. Uttlesford District Council's representative for the contract was Phil Hunt. Balaji Angamuthu and Tony Green of JBA Consulting carried out the work.

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PURPOSE

This document has been prepared solely as a Flood Mapping Study of River Bourn in Ashdon for Uttlesford District Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

ACKNOWLEDGMENTS

JBA would like to thank all those who provided information and data for this project. Uttlesford District Council: Phil Hunt Ashdon Parish Council: David Green Environment Agency: Graham Verrier, Hannah Byron and Karen Paterson and MetOffice: Graham Hoare. We would also like to thank the local residents, who provided information through the Parish Council and allowed access to their land to carry out a survey.

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EXECUTIVE SUMMARY

Introduction

In March 2008, JBA Consulting was commissioned by the Uttlesford District Council to undertake a Flood Mapping Study of the River Bourn in Ashdon. The study included the River Bourn and its tributaries from the headwater area, through Ashdon village. The purpose of the study was to identify the areas at flood risk and to determine and evaluate the options for alleviating the flooding in Ashdon.

Background

Ashdon has a history of several flooding incidents, most significantly, four events in 1987 and more recently flood events in 2001 and 2007. It is clear that the village of Ashdon has suffered from flooding more frequently than would normally be expected. As a result, a study was needed to properly understand the flood behaviour and determine if there are feasible options for alleviation.

Study approach

A hydraulic model of the River Bourn from Water End through was built in ISISv3.0 based on the channel and floodplains survey conducted by the Storm Geomatics in April 2008. The hydraulic model was calibrated using flood level data from the June 2007 event. The calibrated model run for 2, 5, 10, 20, 50, 75, 100, 1000 year flows. The final models were tested to assess their sensitivity to flow, roughness and downstream boundary and for assessing a range of potential improvement measures.

Findings and Conclusions

The current standard of flood protection through Ashdon is approximately the 2-year return period flood. This is significantly below other locations in England and that which would normally be expected.

Mitigation measures were tested that included upstream storage, channel deepening, widening structures, annual maintenance, and channel improvements.

To achieve a high level of flood protection (such as above a 75-100 year return period) extensive works would be required using a combination of improvements but the cost of such a comprehensive scheme is unlikely to be justified on economic grounds.

However, local improvements and construction of a storage area above Water End would be economically viable to give protection of between 5 to 10 year level and it is recommended that further study is carried out to pre feasibility level. Whether such a scheme could fully meet the current standard of priority for national funding from Defra would also need to be considered further at this stage.

The rate of runoff of the Bourn is higher than would be expected and given the rural nature of the catchment this is likely to be determined primarily by agricultural practices. If the speed of runoff could be reduced then significant reductions in the frequency of flooding could be expected. Discussion with landowners and Defra on how this could be achieved is recommended.

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ABBREVIATIONS

ISIS	Hydrodynamic Modelling Software marketed by Halcrow
JFlow	2 Dimensional flood modelling tool
FEH	Flood Estimation Handbook
ReFH	Revitalised Flood Hydrograph model improving on FEH model
SFRA	Strategic Flood Risk Assessment
AEP	Annual Exceedance Probability
QMED	Mean Annual Flood
URBEXT	FEH catchment descriptor defining urban extent
SPRHOST	Standard Percentage Runoff (%) associated with each HOST soil class
NextMap	Digital Map Provider
OS	Ordinance Survey
SSSI	Site of Special Scientific Interest
SPA	Special Protection Areas
SAC	Special Areas of Conservation
RAMSAR	Natural areas of international importance
UDC	Uttlesford District Council
SAR	Side Aperture Radar – a type remote of ground survey
LiDAR	Light Detection and ranging – more accurate ground survey than SAR

1 INTRODUCTION

1.1 Background to study and project brief

The village of Ashdon in Essex has suffered flooding from the River Bourn over a number of years including a significant event that caused much property flooding and damage in 2007. The River Bourn is a classified as an ordinary watercourse and is thus Uttlesford District Council is the 'operating authority'.

The objective of this study is develop a hydraulic model of the River Bourn between Water End and Knox End for which new survey was carried out, to use this model to map flood outlines, advise on the current standard of protection and to identify any feasible measures to alleviate flooding. The project brief required the following key elements of work:

1. Survey of river sections, hydraulic structures and property thresholds
2. Construction of a hydraulic model verified by data of past events
3. Estimates of design event flood hydrographs and flood extents
4. Investigation of flood mitigation measures for known flooding problems including the potential for flood warning measures.

The study area is shown in Map 1.

1.2 Catchment description and model extents

The Bourn is a tributary of the Granta, which becomes a main river at Linton and confluences downstream with the Cam. Above the village, the stream is relatively steep falling 12m in 1.3km. Through the village the gradient slackens and there are culverts beneath the roads that may form a constriction. Ground levels are key to the frequency and location of flooding.

The study area includes some headwater areas of the River Bourn and its tributaries. The River Bourn flows through Water End, Ashdon, Rogers End and Knox End (the limit of the before it confluences with the River Granta at Bartlow.

The size of catchment at Knox End is 18.66 km^2. The River Bourn rises near Bourn Farm at Grigg's Grove, upstream of Water End**.** The catchment area is mostly rural with woods and farms. There are two fishponds along the River Bourn upstream of Water End. Bourn and its tributaries drain the farmland drains. The catchment is steep with elevation varying from 126m AOD at watershed to 57m AOD at Knox End within a distance of 6km.

Table 1-1 Model and survey extents

Watercourse	Upstream limit of Model	Downstream limit of model
River Bourn	Upstream of Water End	Road bridge at Knox End
Unnamed tributary 1	Burnt House Water End	Confluence with Bourn at Water End
Unnamed tributary 2	Kate's Lane	Confluence with Bourn at Ashdon
Unnamed tributary 3	Newnham Hall Farm	Confluence with Bourn at Knox End

2 SURVEY AND DATA COLLECTION

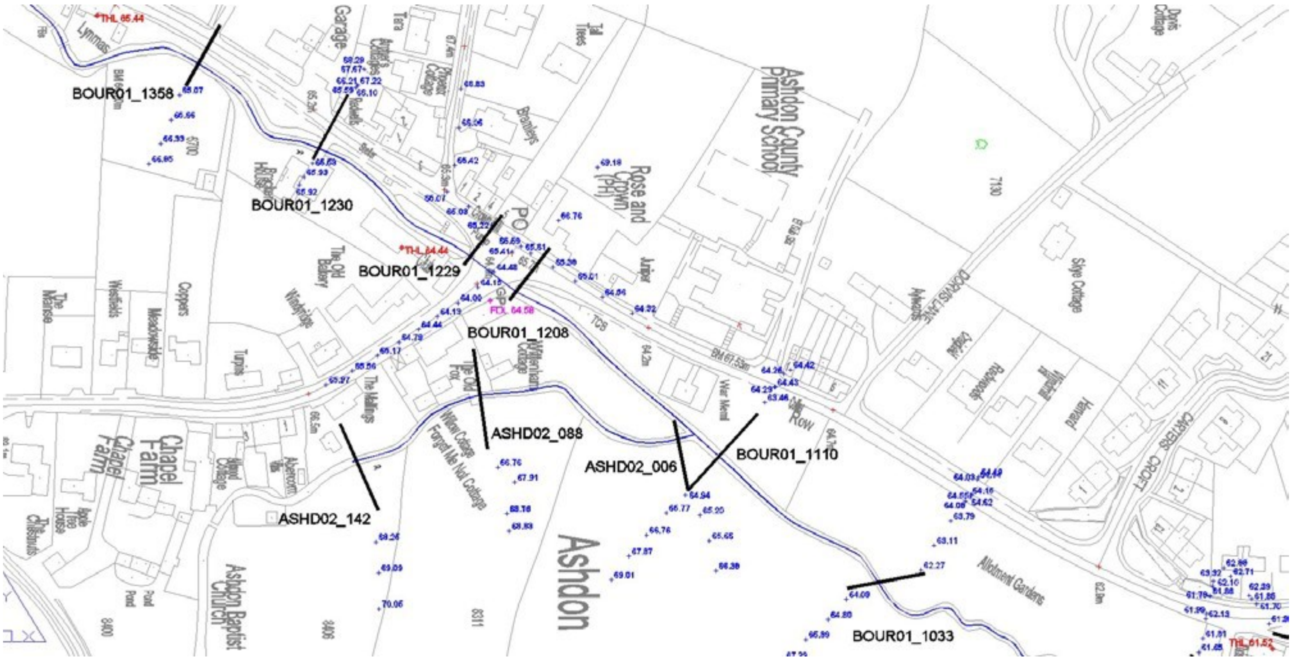
2.1 Topographical data

Storm Geomatics conducted a survey of rivers, hydraulic structures and property thresholds in April 2008 on behalf of JBA Consulting[1]. Extents of the river survey are the same as the modelled extents presented in Table 1-1. The survey work was carried out according to the Environment Agency (2005) National Standard Contract and Specification for Surveying Services v2.5. The results of the survey in terms of cross sections, are supplied on CD in autocad and model formats.

For flood mapping it is necessary to have ground data at more frequent intervals than surveyed or necessary for the modelling. The best ground information generally available is from remotely sensed LIDAR which is flown by the Environment Agency but in this case there are no LiDAR tiles available for Ashdon. An alternative source of less detailed ground survey (SAR data) was available from the Environment Agency and this is what was used for the National Flood Zone maps. The SAR data was therefore used in conjunction with recently surveyed levels for mapping of flood extents after checks on the agreement between surveys.

An extract of the survey drawing O8JB8146/14in the central part of the village is shown in Figure 2.1 below. Full details of the survey have been provided separately to UDC.

Figure 2.1 Extract from Survey Drawing Key Plan showing section locations and spot levels



[1]Storm Geomatics (April 2008). Survey of River Bourn in Ashdon, Essex.

Threshold levels of properties surveyed in April 2008 are presented in Table 2-1.

Table 2-1 Property threshold levels

Easting (m)	Northing (m)	Height (mAOD)	Type*	Address of property
558754.59	240768.63	73.67	THL	Bourn cottage
558769.54	240780.54	73.93	THL	White cottage
558541.54	241863.46	65.97	THL	Brook house, 7 church hill
558559.49	241881.34	65.57	THL	Village museum
558602.80	241968.66	65.61	THL	Jesters cottage
558602.97	241981.88	65.52	THL	Clayes cottage
558610.81	241983.32	65.44	THL	Lynmas
558697.55	242097.11	64.44	THL	Ashdon village hall
558847.25	242422.10	61.52	THL	Thristalls
558849.36	242432.51	60.87	FL	Brook cottage
558826.04	242472.53	62.01	THL	No.1 Bricklayers cottage
558822.59	242479.91	61.89	THL	No.2 Bricklayers cottage
558801.22	242526.94	60.53	THL	Bourn stream
558820.19	242492.57	61.86	THL	Watermead
558459.74	242930.28	56.77	THL	Knox end cottage
* THL – Threshold Level and FL – Floor Level				

A previous survey was conducted in 1987 by Anglian Water (Rivers Division), the cross sections from which were provided by Uttlesford District Council. This allowed the comparison of the levels in the 1987 with levels surveyed in April 2008. The cross sections show that there is no significant differences beyond normal variation of river surveys.

2.2 Flood defences and structures

There are no formal flood defences in place within Ashdon though a number of individual properties have installed flood gates and flood walls to protect themselves. There are several small bridge culverts crossing the Bourn and its tributaries. Details of these structures can be found in the deliverables of the survey carried out by Storm Geomatics in April 2008.

2.3 Rainfall data

The Environment Agency provided rainfall data recorded at Ashdon and Chesterford Park rain gauging stations. The interval and period of provided rainfall data are mentioned below in Table 2-2:

Table 2-2 Rainfall data

Gauging station	Frequency	Period of data
Ashdon	Daily	01-01-2001 to 30-09-2007
	15 minutes	01-01-2007 to 02-01-2008
Chesterford Park	Daily	01-01-2000 to 31-12-2000

Both daily data and 15 minute data was thus available for the 2007 event of June 2007 and is illustrated in Figure 2.2 and Figure 2.3. The 15 minute data for 2007 was used in the modelling for calibration purposes. The 2007 event peak of 5mm recorded in a 15 minute interval is high but not an exceptional total for drainage design.

Figure 2.2 Daily Rainfall Totals at Ashdon 2001, 2005-2007

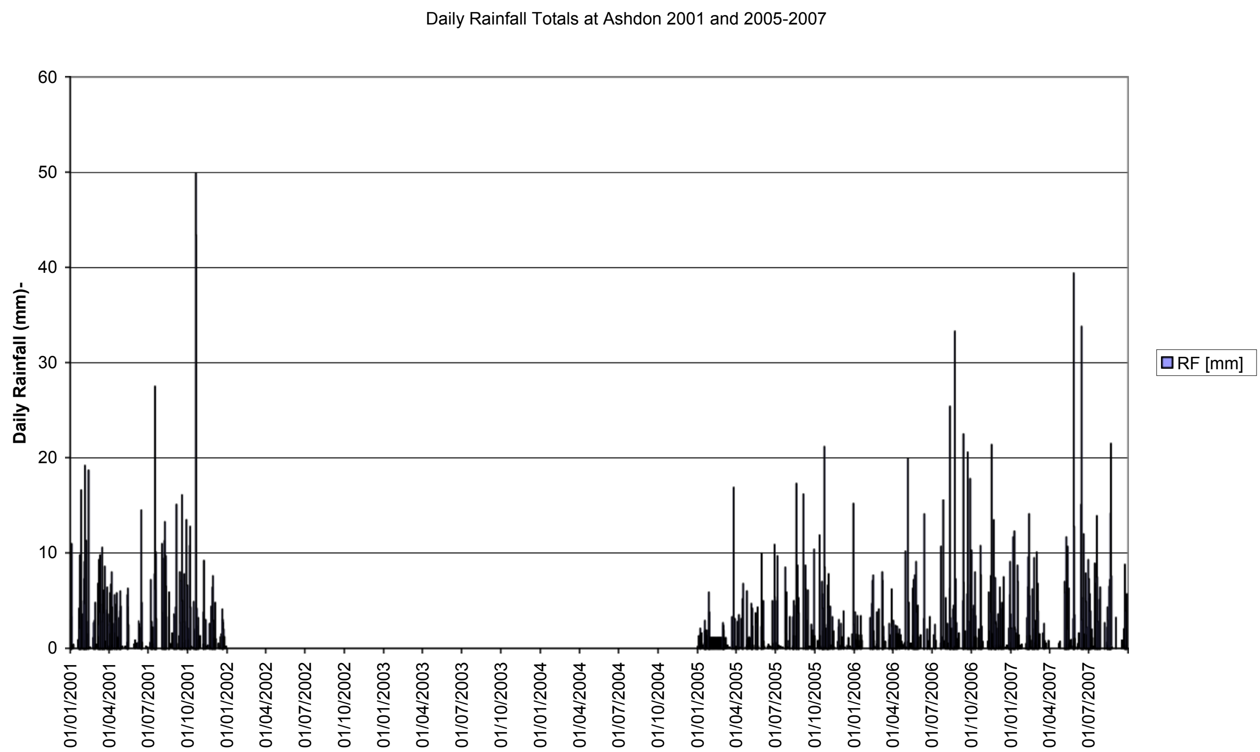
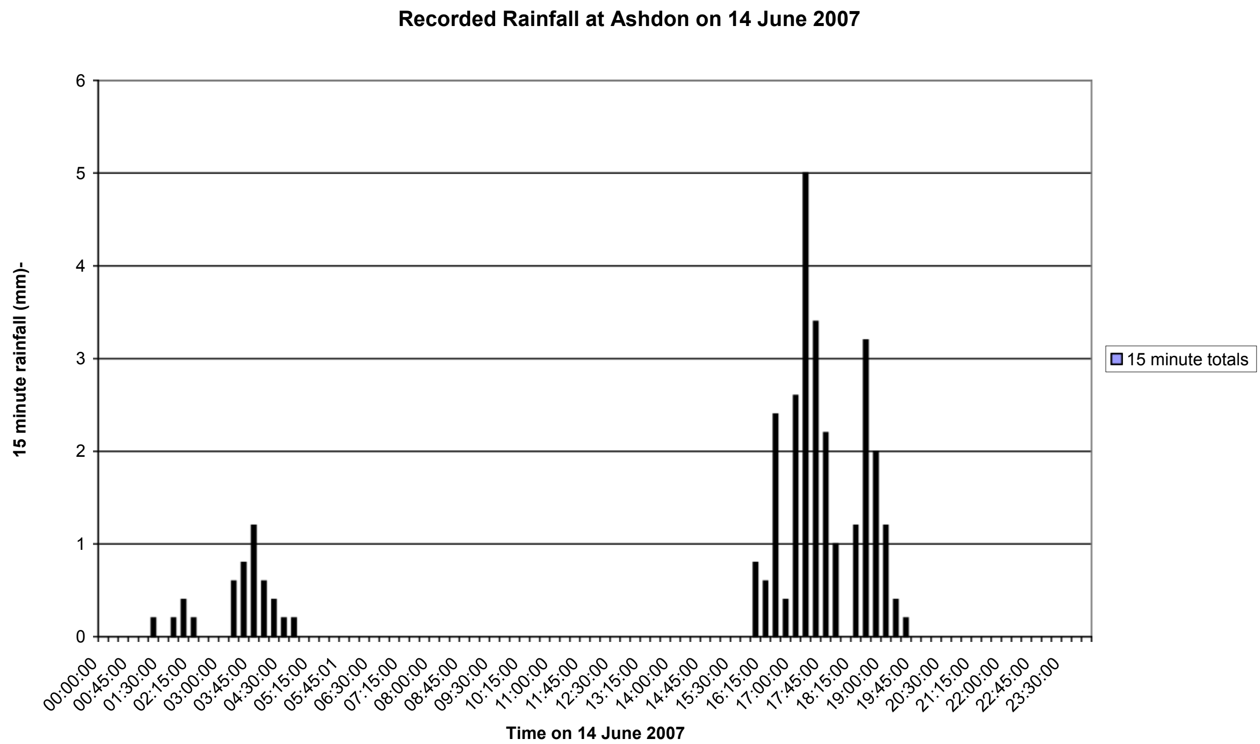


Figure 2.3 15 minute Rainfall Totals recorded at Ashdon June 2007



2.4 Gauge Data

There are no flow or level gauges on the River Bourn and the nearest flow measurement gauge on the Granta is of poor quality for flood flows. The Babraham Gauge on the Granta has a catchment area of 99km^2 so is significantly larger than the Bourn and thus also responds differently.

In the period 1977-2003, the highest recorded flow at Babraham was an estimated 20.4m3/s on 22 October 2001.

JBA carried out a study for the Environment Agency on the nearby Steeple Bumpstead Brook which also caused flooding including in 2007. Although in the River Stour catchment, the data availability for this stream is much better than for the River Bourn and the findings of the study were consulted and taken into account.

2.5 Other records obtained

Uttlesford District Council and Ashdon Parish Council provided information on flood events including records of rainfall and flooding compiled by Mr Christy of Bourn Cottage Water End and survey work done by Anglian Water (Rivers Division) in 1987 and a preliminary overview by the Environment Agency in 2008.

The consultant also visited the village and key structures on the River Bourn with parish and district council representatives.

Of particular help to the model development was the detailed record of the events of 2007 produced by the parish council giving times of the flood rise, onset of flooding and peak within the village.

David Green, Clerk to the parish council recorded for the 2007 event:

'I received a call at approximately 1900 to say the Village Hall had started to flood and that it was being bailed out. I rang the UDC Emergency response number at approx 1940 to request sand bags. The call was returned at approx 2000 by the Emergency Planning Officer. The police were also notified at this time about the flooding of the Ashdon/Radwinter Road. By this time it had stopped raining and the river was rising fast. It started to break its banks and cause serious flooding of the Village Hall at 2100 at which time the sand bags had arrived. The river continued to rise and completely surrounded the Village Hall, Crown Hill was severly flooded and was impassable. The village was completely cut off due to flooding at Bartlow, Steventon End, Plumtree Grove and the bridge at Ridgeons on the Ashdon Road. The water peaked and started to recede at approx 21:30.'

The houses at Water End were flooded to waist depth and at 6 Church Hill it is believed that water reached the highest level in 35 years.

2.6 History of flooding

A detailed history of recent flood events impacting Ashdown can be compiled from the available records and is presented in Table 2-3. The Environment Agency also provided information from a post flood survey undertaken after the October 2001 event. The table shows that 9 flood events were recorded in the last 20 years. This illustrates the severity and unusual frequency of flooding that has occurred in the village of Ashdon in the recent past.

Table 2-3 History of flood events

Date	Details of flood event
1947	No details available
1968	Was due to freak storm
1978	No details available
19-June- 1987	Heavy storm over 40mm in 1 hour. 22 properties including 9 residential properties flooded
29-July -1987	Heavy storm after prolonged rainfall. 17 properties including 8 residential properties flooded
25-August-1987	Persistent rainfall. 9 properties including 4 residential properties flooded
9-October -1987	40mm of rainfall in two days. 11 properties including 5 residential properties flooded. Road at Knox End flooded.
19-November-1987	Minor property flood
1993	No details available
2000	No details available
21-October- 2001	Post flood survey done by the Environment Agency. This event was 3 inches higher than previous highest recorded (June 1987) 93mm rainfall over two days 20/21.
14-June- 2007	76mm of rainfall in two days. 14 properties flooded and roads blocked. Severe disruption and more severe than recent past events.

2.7 Local Environmental considerations and Sites of Special Scientific Interest (SSSI)

An Internet search was carried out for SSSI, SAC, SPA and RAMSAR sites within the study catchment.

There are no SAC, SPA or RAMSAR site within the study area although 4 SSSI sites were found within the study catchment (http://www.naturalengland.org.uk/) as shown in Map 5.

The SSSI potentially most significant to the Bourn Study is Ashdon Meadows which has a small ponded area on a tributary above Water End. The bank for this pond is currently eroded by flood water after overtopping and water levels are lower than are desirable.

The village of Ashdon is a high quality environment and strong contender for the Essex best kept village award. The river is part of the character of the village and a valuable natural environment.

2.8 Other data

Uttlesford District Council gave permission to use digital Ordnance Survey (OS) 1:10,000 and 1:50,000 mapping, and provided OS Landline data.

2.9 Previous flood risk studies covering Ashdon

No flood mapping study has previously been conducted exclusively for Bourn through Ashdon. Jflow runs for 1 in 20 year return period and 100 year climate change scenario were made to produce flood zone maps during Uttlesford District Council SFRA study conducted by JBA Consulting in 2007 and similar results were found as shown on Environment Agency Flood Zone maps. Preliminary studies were carried out in 1987 by Anglian Water (Rivers Division) and Environment Agency in 2008 which give useful opinions on possible mitigation options.

3 FLOOD ESTIMATION

3.1 Introduction

Flood estimates were required for the 2, 5, 10, 20, 50, 75, 100 and 1,000-year return periods (equivalent to the 50%, 20%, 10%, 5%, 2%, 1.3%, 1% and 0.1% annual exceedance probability (AEP)), using Flood Estimation Handbook[2] (FEH) methods for the main stream and tributary inflows.

Their main purpose is to provide hydrographs for use in the hydraulic model, and to allow the flows throughout the model to be matched to the correct flow estimates for each return period and the consequent flood levels.

The peak flows estimated from uncalibrated hydrological models were tested in the hydraulic model but seriously under estimated the likelihood of flooding compared with the record of previous events. The detailed rainfall and observed times of flooding were therefore used to derive a joint hydraulic/hydrological calibration for the 2007 flood event which was carried forward to the design event calculation.

3.2 Approach

In accordance with 'Environment Agency policy', flood estimates have been derived using the Flood Estimation Handbook (FEH)[3] where applicable, following the Environment Agency's guidelines[4]. The Revitalised Flood Hydrograph (ReFH) method was also used. All calculations and decisions were documented as required by the Guidelines, and this calculation record is included as Appendix A. This chapter is a summary of the flood estimation process.

The FEH provides two basic approaches to flood estimation, the statistical and rainfall-runoff methods. The FEH rainfall-runoff method has now largely been superseded by ReFH. The approach to flood estimation must be informed by the nature of the catchment, the type of problem and the data available. At the start of the study, a Method Statement was prepared, in accordance with the Environment Agency's Guidelines[3].

The catchment areas to each flow estimation point vary from 1.63km^2 to 18.66km^2 downstream and at all points the catchment is classified as essentially rural by the FEH based on the catchment descriptor URBEXT2000. The catchment is also relatively impermeable. At all points along the study reach FEH methodologies can be considered appropriate.

3.3 Catchment descriptors

Catchment descriptors were extracted from the FEH CD-ROM (v2) at each flow estimation point. Checks were carried out on the data to ensure the catchment descriptors were appropriate and did not contain any errors. The checks included:

- Catchment boundaries were checked against NextMap data and contours on the OS 1:50,000 map. No discrepancies were found.
- SPRHOST values were checked against soil types from the Soil Map provided by the National Soil Resources Institute at Cranfield University[5]. No discrepancies were found.
- URBEXT was updated from 2000 to 2008 using the recommended method[6].

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[2] Institute of Hydrology (1999) *Flood Estimation Handbook (Volumes 1-5)*.

[3] Institute of Hydrology (1999) *Flood Estimation Handbook* – 5 volumes. Institute of Hydrology, Wallingford.

[4] Environment Agency (2000) *Flood Estimation Handbook Guidelines*.

[5] http://www.landis.org.uk/soilscapes/

[6] CEH (2006) *URBEXT2000 – A new FEH catchment descriptor: calculation, dissemination and application*. Defra/EA research project FD1919

3.4 Statistical method

The statistical method involves two steps: estimating the index flood, QMED, and estimating a flood growth curve. Details of application of the method are given in Appendix A. QMED has been estimated from catchment descriptors and refined using information from analogue gauged catchment found within 10km distance from the study catchment.

Growth curves were derived from pooling group analysis. 4 pooling groups were selected using WINFAP-FEH, version 2. Design flows were calculated with a spreadsheet.

3.5 Revitalised flood hydrograph (ReFH) method

The ReFH method is the result of a major research project[7], jointly funded by Defra and the Environment Agency, to "revitalise" the standard rainfall – runoff method within the FEH and go some way to reconcile the differences in flood estimates obtained from the two FEH methods. Full ReFH software, ISIS and an interim spreadsheet implementation of the ReFH method has been used to carry out the analysis in this study.

The time to peak used in the method influences the flood peaks derived. From the parish record and the detail rainfall data recorded at 15 minute intervals it was possible to adjust the hydrological models so that the timing of the predicted water levels in Ashdon matched the observed time. This required a faster response of the catchment than would be expected from standard catchment parameters.

Flow estimates from ReFH can be found in Table 4.3, Appendix A.

3.6 Peak flow estimates

Appendix A compares the statistical estimates to those from the ReFH method. The statistical method was found to be underestimating peak flow values when compared to the ReFH method following calibration to the timing of the 2007 event. There are large differences between the peak flow estimates from each of the methods.

As there are large differences between the methods, choice of approach is important. The ReFH method is preferred to statistical approaches for the estimation of peak flows, as the ReFH model parameters (Cmax and TPo) are calibrated to match the June 2007 flood levels and time to peak. The initial estimates of the design flows based on the catchment descriptors were input into the hydraulic model and found they need adjustments. These are detailed in section A.4.1 of Appendix A.

Flow estimates for the 1,000-year event would ordinarily be derived differently to the flows for the suite of return periods to 200-years. This is because it is not recommended to use the statistical method to estimate flows for return periods of this length. In fact no method is ideal for estimating flows for long return period events; however rainfall-runoff methods are generally preferable because rainfall frequency estimates are more certain than statistical flood frequency estimates for extreme events. ReFH rainfall results are considered valid for return periods up to at least 1,000 years. Because of this the estimates from the ReFH method were used.

A summary of the peak design flows used is given in Table 3-1.

[7] Kjeldsen *et al* (2005) Revitalisation of the FSR/FEH rainfall – runoff method. R&D Technical Report FD1913/TR

Table 3-1 Design flows for each location following calibration

Watercourse	Location	Flood peak (m^3/s) for the following return periods (years)							
		2	5	10	20	50	75	100	1000
Bourn	Upstream of Water End	5.69	7.56	9.14	10.98	13.93	15.48	16.68	30.30
Tributary 1	Confluence with Bourn near Water End	1.81	2.35	2.80	3.34	4.20	4.66	5.01	9.08
Tributary 2	Confluence with Bourn near Ashdon	2.68	3.52	4.23	5.07	6.41	7.12	7.66	13.93
Tributary 3	Confluence with Bourn near Knox End	4.88	6.47	7.82	9.39	11.91	13.23	14.25	25.90

3.7 Uncertainty of the design flows

Flood frequency estimates are inherently uncertain because they cannot be measured or formally validated against observed data. Sources of uncertainty include:

- Data uncertainty, for example due to inaccuracies in flow gauging or errors in (extrapolated) rating curves.
- Model uncertainty, for example in the parameters of the rainfall-runoff model and the way that it relies on a design event with a specified return period, duration, etc.
- Natural uncertainty, resulting from the inherent variability of the climate.

The uncertainty of QMED values when estimated solely from catchment descriptors can be obtained from FEH Volume 3. The 95% confidence limits are 0.42QMED, 2.40QMED. For example, at Water End, the 95% confidence interval for a QMED of 1.8m^3/s is between 0.75 and 4.32m^3/s. As shown in Table 3-1 following analysis of the 2007 event, the estimated 2 year peak is just above the upper limit of an estimate based on catchment descriptors.

The confidence in combined calibration of the hydrological and hydraulic model can be assessed relative to the large number of flood events experienced and is discussed further in Section 4.

3.8 Impacts of climate change

The potential effect of climate change on river levels and flood outlines was assessed using an additional 20% to all model inflows for the 100-year event. The modelled water levels for climate change scenarios of increase in inflows or increase in rainfall would be the same because the initial condition of soil moisture in the hydrological models used assumed saturated conditions.

4 HYDRAULIC MODEL

4.1 Model extents

The River Bourn and its three tributaries were modelled in ISIS v3. The extents of the new model are presented in Table 1-1. The length of modelled watercourse in this study is 3km. The hydraulic models are described in detail in Appendix B. This section gives a brief summary.

4.2 Topographic data

4.2.1 Survey

A river channel survey of the study reaches were carried out by Storm Geomatics during April 2008. The survey was carried out to the Environment Agency National Survey Specification v2.5[8].

4.3 Building the model

Flow within the river channel and the floodplain is represented using extended cross sections. The cross sections are modelled in ISIS using river section units as far as possible in accordance with the Environment Agency Best Practice Guidance[9]. Labels consist of a 4-letter code to identify the river; a digit to identify the reach, and a number to identify the chainage. For further details of the labelling refer to the hydraulic model check file in Appendix B.

4.3.1 Floodplains

The extended cross-section survey is sufficient to estimate water levels within the extents of the main channel and the floodplain.

Reservoir unit was used to represent the floodplain area around the village hall in Ashdon where there is an exchange of flow between the Bourn and Tributary 2. Reservoir unit assumes a level water surface. Flow between the channel and the floodplain is represented using spill units set at the level of the top of the riverbanks. The spill levels are estimated from the cross section survey. They are therefore approximate because of the large distances between cross sections.

4.3.2 Structures

The models include all hydraulic structures likely to have an influence on flood levels. These include bridges and culverts. All the modelled structures are included in the hydraulic model check file (Appendix B). Where bridges are likely to be bypassed or overtopped in flood conditions, this has been allowed for by adding spill units in parallel or bypassing via reservoir units. It is assumed that there is no blockage at structures in the model. The modelling methodology used for each individual structure is also given in Appendix B.

4.3.3 Channel roughness

Manning's n values represent roughness of channel and floodplain. The values are included in the model to best simulate flow. The channel and floodplains were divided into areas of similar landuse/ bed material and appropriate Manning's n values were selected for those areas. The values were derived considering channel materials, surface irregularities, shape and size of cross sections, obstructions, vegetation, flow conditions and meandering of channel.

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[8] Environment Agency (2005) *National Standard Contract and Specification For Surveying Services v2.5*

[9] Environment Agency. Using computer river modelling as part of a flood risk assessment. Best practice guidance.

Figure 4.1 shows example cross sections (BOUR01_2836 and BOUR01_2554) on Bourn. Manning's n values were derived for a number of cross sections along each of the watercourses and these were applied to other similar cross sections along each reach. A similar approach was taken when estimating Manning's n values for the floodplains.

Figure 4.1 River Bourn sections

The values ranged from 0.055 – 0.1 for channel roughness and 0.075 – 0.25 for floodplain roughness.

4.3.4 Inflows

Inflows to the model are specified using flow-time boundaries, using hydrograph shapes derived using the ReFH method. A different version of each model has been created for each of the various return periods required. The ReFH peak flow estimates are outlined in section 3.7 and Appendix A.

4.3.5 Downstream boundary

The river and floodplain is relatively uniform downstream of Knox End and a downstream boundary condition to the modelled reach was defined using a normal depth assumption and an estimated river bed slope of 1 in 160.

4.4 Calibration

The model was calibrated using the best available data which is primarily from the June 2007 flood event. There is no flow data available to calibrate the model through Ashdon as the only river gauge is downstream at Linton. However, observed flood levels and time to peak of the June 2007 event was available for calibration.

The calibration required joint hydraulic and hydrologic model calibration. Details of model calibration are outlined in section 6.1, Appendix B. Sensibility checks have taken place to ensure the properties that flooded from the watercourse in June 2007 were all flooded to similar levels by the 20-year event, which is of a comparable magnitude. The calibrated model matched well the observed flood levels and time to peak. Considering the large number of past flood events and their records, the calibrated model gives enough confidence for the frequently happening events. The calibration or verification of the model for more events was not carried out due to the limited available data.

4.5 Sensitivity

It is particularly important to test the sensitivity of a model to the chosen parameters when there is limited reliable data available for calibration as is the case through Ashdon. Tests were carried out on the design 100-year event so that sensitivity of the critical water levels could be assessed. The following parameters were tested for sensitivity:

- Channel roughness,

- Flow,
- Downstream boundary condition,

Channel roughness was adjusted by varying the values of Manning's n by ± 20%. These alterations test for the effects of uncertainty in the chosen values of hydraulic roughness.

Sensitivity to flow was tested by increasing model inflows by ± 20%. The increase of 20% in 100-year flows also allowed for the impacts of climate change to be assessed.

The effect of the downstream boundary on modelled water levels was tested by changing the riverbed slope and investigating how far upstream this effected model results. The model has been found sensitive for all the tested parameters.

Full results of the sensitivity tests are detailed in section 5.1 of Appendix B.

4.6 Uncertainty

4.6.1 Natural uncertainty

The largest source of uncertainty in modelled water levels quoted for a given return period is usually the natural uncertainty in the design flows. Flood frequency estimates are inherently uncertain because they cannot be measured or formally validated against observed data. Natural uncertainty results from the inherent variability of the climate. This tends to be the largest source of uncertainty in flood estimates for long return periods such as 100 years, because they are derived from growth curves fitted to flood peak series that rarely exceed 40 years in length.

A formal assessment of the uncertainty of a flood frequency curve is a major undertaking, requiring techniques such as resampling of pooled growth curves to investigate natural uncertainty. However, confidence limits for design flows are often quoted at ± 20-40%. Design flows for each return period may be improved in the future when further data is available.

4.6.2 Hydraulic model uncertainty

The equations generally used to model hydraulic systems are approximations of the physical processes involved but after decades of use and of continuous improvement the limitations and implications of the approximations are well understood. There is rather more uncertainty associated with choices made by the modeller relating to the structure of the model e.g. which parts to model as storage or how structures are bypassed. It is important that all decisions that may introduce model uncertainty are well documented.

4.6.3 Parameter uncertainty

Sensitivity analysis has been carried out to provide a semi-quantitative measure of parameter uncertainty with the water level being the dependent variable and hydraulic resistance and peak flow, being the independent variables. Alterations to the roughness values showed the system was reasonably sensitive to hydraulic roughness in some locations.

5 EXISTING FLOOD RISK

5.1 Model results at specified locations

The hydraulic model of the River Bourn was run for 2, 5, 10, 20, 50, 75, 100, 100+20% inflows, 100+20%rainfall, and 1000 year scenarios. 1D model generates a large volume of information for each run. Model results in the tables below are representative of the location though there may be variation within a site due to local topography.

The current standard of protection through Ashdon at which the first properties are affected is the 2-year return period.

5.2 Flood outlines

Map 2 shows the currently existing Environment Agency Flood zone 2 and 3 extents of the Bourn through Ashdon. New flood outlines were produced as part of this study for the 100 and 1000-year events. Map 4 shows the modelled flood extents and an extract of the modelled flood outlines is given in Figure 5.1. There is not a large increase flooded property numbers at 1:100 year flood relative to those properties flooded more frequently.

Figure 5.1 Extract of Map 4 Modelled Flood Extents for 1:100 and 1:1000 year events

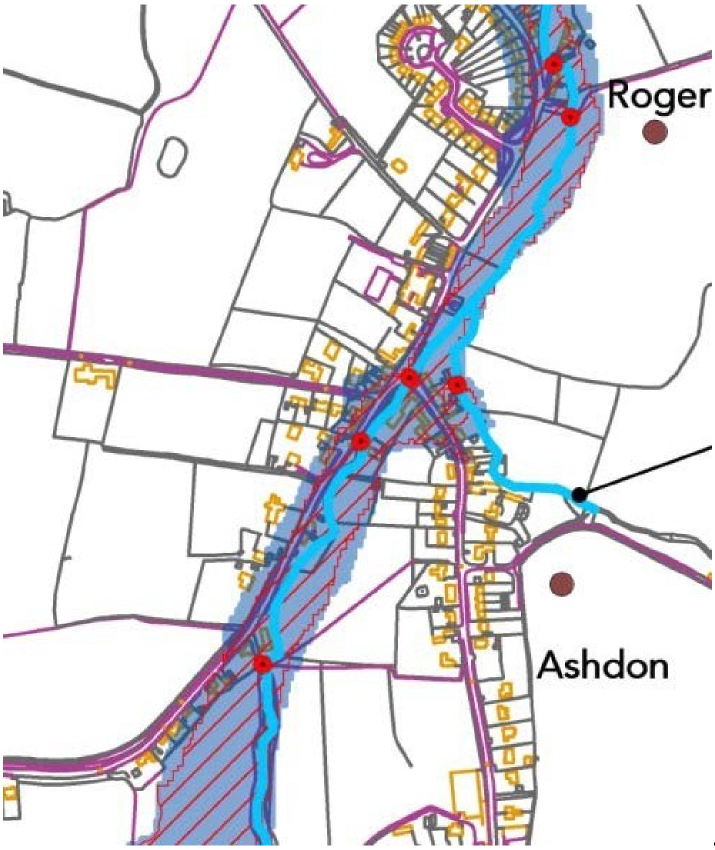


Table 5-1 Modelled peak water levels (mAOD)

ISIS Node Label	Nearby Properties	Threshold level (mOD)	Return period (years)								
			2	5	10	20	50	75	100	1000	100cc
BOUR01_2836	Bourn cottage	73.67	74.12	74.43	74.52	74.57	74.72	74.78	74.83	75.34	74.99
	White cottage	73.93									
BOUR01_1567	Brook house, 7 church hill	65.97	65.35	65.53	65.67	65.82	66.03	66.14	66.22	67.07	66.44
	Village museum	65.57									
BOUR01_1471	Jesters cottage	65.61	64.83	65.10	65.28	65.48	65.75	65.87	65.97	66.90	66.22
	Clayes cottage	65.52									
	Lynmas	65.44									
BOUR01_1229	Ashdon village hall	64.44	63.80	64.27	64.57	64.77	65.06	65.22	65.34	66.55	65.67
BOUR01_901	Thristalls	61.52	61.85	61.96	62.03	62.11	62.21	62.27	62.31	62.84	62.43
BOUR01_833	Brook cottage	60.87	61.19	61.34	61.47	61.64	61.78	61.87	61.93	62.55	62.10
	No.1 Bricklayers cottage	62.01									
	No.2 Bricklayers cottage	61.89									
BOUR01_739	Bourn stream	60.53	60.64	60.83	61.00	61.23	61.28	61.36	61.43	62.05	61.59
	Watermead	61.86									
BOU01_81du2	Knox end cottage	56.77	57.00	56.91	57.04	57.19	57.40	57.50	57.65	58.41	57.89
Note: 1) co-ordinates of key properties can be found in Table 2-1.											

6 MITIGATION MEASURES

6.1 Introduction

The current standard of flood protection through Ashdon is only a 2-year return period before properties can be flooded. A wide range of options and combinations of measures can be considered to improve this situation and the following options to mitigate floods in Ashdon have been investigated to illustrate whether a potentially viable scheme might be found:

- Modification of bridges and culverts
- The effect of storing water on the floodplains upstream of Ashdon on water levels through the village;
- The effects of widening the channel to convey more water away from the village.
- The effects of a maintenance program along the watercourse to allow water to flow away from the village more quickly;
- The relative timings of the hydrographs on Bourn and its tributaries;
- The possibility of providing a flood warning service to properties at risk.

6.2 Assessment of possible mitigation measures

6.2.1 Modification of key structures

The following key structures in Table 6-1 were identified as known flood problems during the site visit and modelling. Map 6 shows the location of these structures.

An initial investigation of possible flood alleviation measures at these locations was undertaken. This involved looking at remodelling the structures to avoid constriction and backing up of water. It is also important to consider what could be done at each structure independently as well as in a group.

Table 6-1 lists the tests done on individual modification to structures and their effect on nearby water level peaks. Improvements to the structures, typically lower upstream peak water levels but is several cases there is a noticeable increase downstream of structure.

There are a number of structures where modification would have little impact, they may already be of sufficient size or easily overtopped. The most significant modification that could be made would be to increase the capacity of the main Radwinter road arch bridge. This would impact greatly on the properties on the right hand side of the river, the predicted decrease in level if the capacity of the bridge was doubled would be 0.8m though this would result in an increase in peak level downstream.

Figure 6.1 The Radwinter Road Culvert (left) and Rock Cottage access bridge (right) have the highest impacts on upstream water levels

Table 6-1 Impact on water levels of modification of key structures

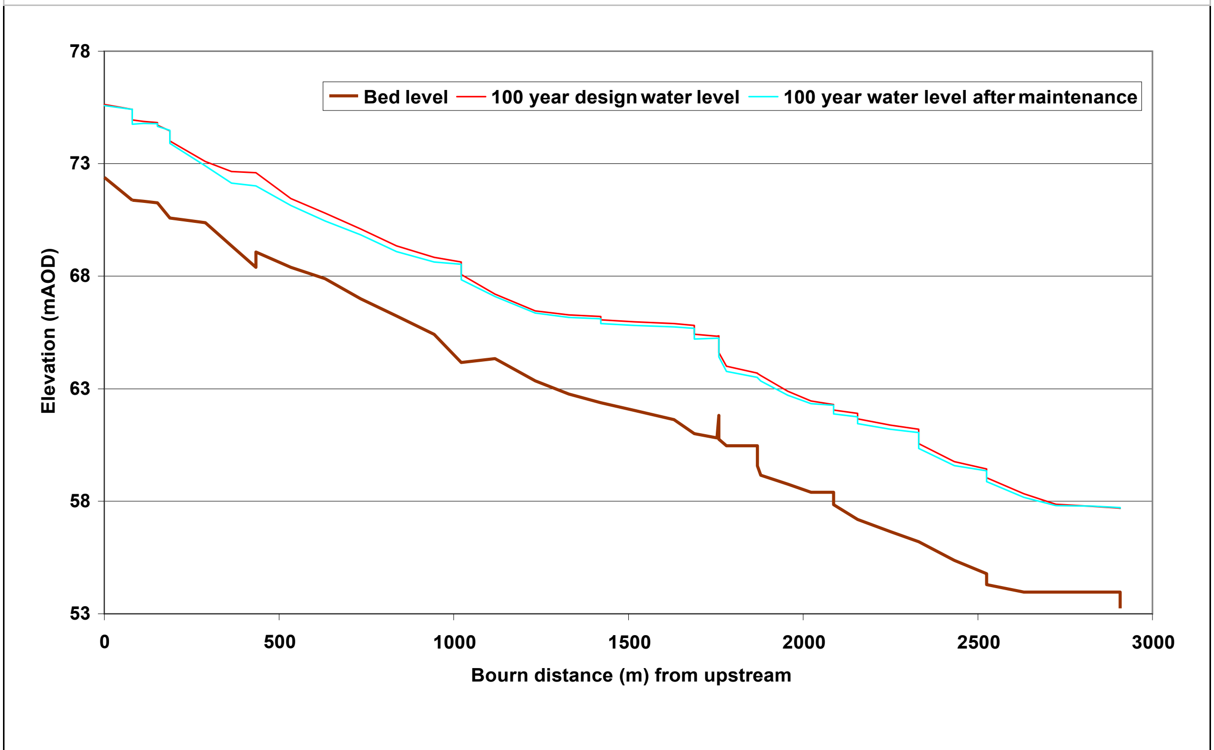
Watercourse	Location of structure	Modifications done to existing structure	Upstream of structure			Downstream of structure		
			Before (m AOD)	After (m AOD)	Difference (m)	Before (m AOD)	After (m AOD)	Difference (m)
Bourn	Access Bridge – Burnt House	Bridge widened. Arched bridge to flat deck slab. Soffit level increased by 0.3m. No piers.	74.46	74.45	0.01	74.01	74.01	0.00
	Access bridge – Rock Cottage	Bridge widened. Arched bridge to flat deck slab. No piers.	68.63	68.31	0.33	68.08	68.08	0.00
	Radwinter road culvert	Bridge widened. Arched bridge to flat deck slab. No piers. Opening area doubled.	65.34	64.54	0.81	64.00	64.20	-0.20
	Footbridge	Removed	62.31	62.09	0.22	62.08	61.95	0.13
Tributary 2	Foot bridge	Bridge widened. Arched bridge to flat deck slab. No piers.	64.92	64.69	0.23	64.42	64.40	0.02
Tributary 3	Access bridge	Bridge widened. Arched bridge to flat deck slab. No piers.	57.66	57.67	-0.02	57.64	57.66	-0.02
	Significant impact greater than 0.3m at 1:100 year flow							

6.2.2 Maintenance of the watercourse

The effects of a maintenance programme along the watercourse have been assessed in different ways. Firstly the effects of an annual programme of dredging of the channel and cutting back bank side vegetation were assessed.

The effects of increased maintenance along the channel were investigated by reducing the Manning's n value along the model reach by 0.02. This represents a substantial cutting back of vegetation along banks and clearing of debris from within the channel, and gave a mean drop in water levels for 100 year return period along the whole study reach of 0.17m. Figure 6.2 shows a longitudinal section of water levels under both scenarios.

Figure 6.2 Sensitivity to Manning's n



6.2.3 Increasing channel capacity

A scheme to increase the channel capacity was assessed. Due to the close proximity of the watercourse to properties and roads, uniformly widening the channel through the village, while maintaining a natural channel, is not feasible. An option to increase the channel capacity by lowering the bed of the river through the village was assessed. In this simulation, the bed level of the Bourn was reduced by 0.3m along the whole study reach.

These modifications to the channel gave a mean drop in 100-year water levels of 0.10m along the adjusted reach and a maximum drop in water levels of 0.31m at upstream of the Rock Cottage Access Bridge.

6.2.4 Upstream storage

The area between fishponds and farm access bridge, Water End is a potential site for upstream storage. Map 6 shows this potential storage site. An option of raising an embankment to form a storage area at this location was considered firstly using a volume calculations and then confirmed using the model.

For a typical 2m high bank and control structure above Water End the volume of storage that could be achieved is estimated as 20,351m^3 using the available ground information.

Assuming that the capacity of the Bourn to convey without flooding any property is 5.69m^3/s, the volume of storage that is required can be calculated for different return periods using the expected inflow hydrographs from the modelling and the results for storage required are as shown in Table 6-2.

Table 6-2 Volume of storage required

Return Period (years)	Volume of storage required (m^3)
2	2
5	13,800
10	32,786
20	58,913
50	106,181
75	132,548
100	153,426

It can be seen from this that, for example, to mitigate up to a 100-year return period, the volume of storage that is required upstream of Water End is 153,426m^3 which would require and high bank and major construction. A modest size bank in this location could achieve at most 5 to 10 year protection.

The effect of a limited amount of upstream storage on the village was modelled as a reservoir unit with a Q-H Control unit for reservoir releases. The reservoir was allowed to start storing when the inflow is greater than 5.69m^3/s. This means that it is not expected that there is not enough storage available at this location to hold a volume of water for a 100-year return period event but is is possible that the attenuation may still have a positive benefit.

This upstream storage of around 20,000 m^3 gave a mean peak flood level in the village 0.35m lower than currently experienced for a 5 year return period. Such a storage area would need an effective outlet control and a high flow spillway to allow for exceedence even if the storage was kept below 25000m^3.

The model was run with inflow hydrographs derived with a 4.5, 8.5 and 10.5 hour storm duration. Maximum water levels through Ashdon were compared from each of these runs and these showed very little change in water levels under each scenario, the maximum change being 0.06m for a 4.5 hour storm duration. This implies the system is relatively insensitive to storm duration.

There is a SSSI site, Ashdon Meadows, upstream of this potential storage site. The current condition of this SSSI is unfavourable and declining. Whilst reinstatement of the existing dam at the site would be beneficial, the flood storage that would be mobilised is small relative to the downstream site and would therefore have little impact.

Another possible site for upstream storage identified is along tributary 1 near its confluence with the Bourn. This is even less effective unless the major flow can be captured in the storage area.

For sites with stored volume greater than 25,000m^3, the flood storage area would fall under Reservoirs Act 1975.

6.2.5 Local channel improvements

There are a number of local problems that constrict the channel and exacerbate flooding. Examples of occur even outside of the modelled channels such as a small culvert across a driveway at Kate's Lane that causes flow to pass down towards the Radwinter road.

At Water End there is a very sharp meandering bend immediately downstream of the properties White and Bourn Cottages (Figure 6.3). This gives rise to a longer path length and poor approach to the road culvert. These properties have been flooded in the past events several times. Decreasing the sharpness of the meander was simulated which reduced the water level by around 0.15m for a 100-year return period flow.

Similar responses can be expected at other locations. The right hand side of Figure 6.3 illustrates the encroachment of the driveway to a house at Roger's End into the river channel making it narrower with sharper curvature and thus greater loss than would otherwise occur. Encroachment like this into the river will affect flood levels and should be avoided.

Figure 6.3 Channel locations for improvements

6.2.6 Land Use changes

The River Bourn experiences much more frequent flooding and higher flows than would be expected for a river of its catchment size and character. There is some suspicion that the higher than expected runoff rate is due to agricultural drainage and land management but, in common with other locations the evidence for this is poor.

Slowing down the response of the catchment to runoff would significantly decrease the occurrence of floods. If agricultural methods could be adapted to reduce surface runoff from fields and create ponds to attenuate the flood peaks then significant benefits could be expected. If the time to peak of the catchment could be increased from the calibrated 2.5hours to 3.5 hours then there would be a flow reduction of 20% and similarly if flow is further slowed to give a time to peak of 4.5 hours then flow is reduced by 33% turning a 50 year event into the equivalent of a current 10 year flood.

6.2.7 Raising channel banks at the Village Hall

The village Hall is in a particularly vulnerable location for flooding.

To prevent the flooding of the Village Hall on the right hand side floodplain of the Bourn, an option of raising the right bank of the Bourn near the Village Hall was considered

The modelling showed that raising the embankment wall to a level of 65.22m AOD can prevent the Village Hall from flooding up to a 20 year return period.

There would, however, be impacts of preventing a flood passage and constricting flow. For a 20 year return period flows, there is potentially an increase in water level by 0.29m upstream and by 0.06m downstream of the location. Work therefore needs to be considered carefully to ensure conditions elsewhere are not worsened by protecting the village Hall.

6.3 Combined options

This section presents the results of considering the combination of mitigation measures to reduce floods in Ashdon. Previous sections detailed the effect of individual mitigation measures. Table 6-3 lists the possible combination of mitigation measures.

Table 6-3 Combination of mitigation measure options

Scheme	Mitigation measures
MM1	Improved Annual maintenance
MM2	MM1 plus widening of key structures
MM3	MM2 plus increase in channel capacity
MM4	MM3 plus upstream storage

The combinations of mitigation measures were modelled for design events and the modelled water levels at key properties are shown in Table 6-4.

Table 6-4 Modelled peak water levels with mitigation measures (mAOD)

ISIS Node Label	Nearby Properties	Threshold level (mOD)	100 year return period			
			100 MM1	100 MM2	100 MM3	100 MM4
BOUR01_2836	Bourn cottage	73.67	74.78	74.55	74.36	74.03
	White cottage	73.93				
BOUR01_1567	Brook house, 7 church hill	65.97	66.11	66.02	65.95	65.88
	Village museum	65.57				
BOUR01_1471	Jesters cottage	65.61	65.81	65.60	65.47	65.01
	Clayes cottage	65.52				
	Lynmas	65.44				
BOUR01_1229	Ashdon village hall	64.44	65.25	64.49	64.03	63.80
BOUR01_901	Thristalls	61.52	62.29	61.97	61.87	61.48
BOUR01_833	Brook cottage	60.87	61.81	61.86	61.79	61.47
	No.1 Bricklayers cottage	62.01				
	No.2 Bricklayers cottage	61.89				
BOUR01_739	Bourn stream	60.53	61.21	61.24	61.17	60.43
	Watermead	61.86				
BOU01_81du2	Knox end cottage	56.77	57.70	57.72	57.46	57.10
Note: 1) Co-ordinates of key properties can be found in Table 2-1 .						

6.4 Flood warning systems

There is no flood warning system in force currently in Ashdon.

It is not currently practical to implement an effective warning with a lead time of greater than 2 hours as per the Environment Agency normal target. The catchment is, however responsive to rainfall and prior wetness and it may be possible in the future to link the Met office predictions of extreme rain into a simple system using a critical rainfall total to risk of flooding.

Although in the area there is currently a problem with mobile phone reception, other automated methods through landline phone would be suitable and would enable more effective mobilisation of emergency response including sand bag distribution.

6.5 Present value costs and benefits

The present value of property damages were estimated using the model and the depth damage relationships used in the Environment Agency's MDSF system. Indicative average annual damages and nett present values were calculated considering the flooding of the key properties and not additional damage to outhouses and secondary damages such as blockage of the roads. Table 6-5 shows the estimated present value damages avoided and discounted cost for the different schemes.

Table 6-5 Indicative Benefit & Costs of Alleviation Options

Scheme	Indicative present value damage avoided (million£)	PV Indicative costs (million £)	Ratio	Comments
MM0	1.85	1.0-1.5	1.2-1.8	Storage scheme around 20,000 m^3 only 5-10 year protection
MM1	0.32	0.30	1.07	Additional channel maintenance
MM2	0.91	2.00	0.45	Costs could depend on number of structures to be widened or removed
MM3	1.90	2.50	0.76	Costs would depend on depth of dredging
MM4	2.90	3.75	0.96	Upstream storage considered. Cost of storage area needs further consideration.

Whilst the above analysis is not a rigorous cost benefit analysis, it can be seen that whilst some local improvements at structures would have some benefit, it is likely that the most effective solution would be a storage area. Whilst a modest size storage area that would not prevent extreme flooding, because of the frequency of flooding in the village, if a site could be identified where a scheme could be built for less than £1.5m then a viable scheme could be identified.

The likely standard of service of a storage area would only be to provide relief to the current 1:5-1:10 year flood which is below the indicative standard expected within Defras guidance. The benefit ratio may be below that required to meet priority funding but further work would be desirable to improve the cost estimate of a storage area.

However the exceptional nature of the runoff from the catchment does also indicate that a reduction in flow due to improved agricultural practise ought also to be possible and if this were included in the planning for alleviation a higher standard might be attainable.

7 CONCLUSIONS

7.1 Flow estimation

The design flow estimates were obtained after comparing the results of statistical method and ReFH rainfall-runoff method. The statistical method underestimated design flows. Therefore, ReFH design flows were used.

Joint calibration of the hydrological and hydraulic model using detailed rainfall data and observed flood levels in 2007 indicate higher runoff than would be normally be anticipated in a stream with the catchment size and character of the Bourn but nevertheless the modelling agrees well with the observed number of floods that have occurred in recent years.

7.2 Hydraulic modelling

Hydraulic modelling was undertaken in ISIS v3.0; the hydraulic model was calibrated for June 2007 flood levels. The calibrated model with any blockages removed was run for 2, 5, 10, 20, 50, 75, 100, 1000, 100+20% flows and 100+20% rainfall design events.

The final models were tested to assess their sensitivity to flow, roughness and downstream boundary. The models were not found to be particularly sensitive to any of these parameters.

7.3 Flood risks

The current standard of protection through Ashdon is approximately the 2-year return period. This is very much lower than would generally be expected.

Flood outlines were produced for current 100 and 1000 year return periods.

7.4 Mitigation measures

Mitigation measures including upstream storage, channel deepening, widening structures, annual maintenance and channel improvements were assessed. A potential storage area on Bourn upstream of Water End was examined, but it was found that this area would not be able to provide adequate storage volume for more than around a 10 year return period.

The combination of mitigation measures and their effects on reducing floods through Ashdon have been studied. The individual effects of mitigation measures have also been studied. A combined scheme incorporating upstream storage, channel deepening, widening structures and channel maintenance has the most impact but is likely to be of excessive cost relative to the benefits predicted.

A storage area was found to be the most cost effective scheme in terms of reducing the flood damages. The blockage effect of the Radwinter Road culvert is also significant and improvements to the conveyance through this structure would be desirable if a cost effective solution could be identified. Local protection works such as being considered for the Village Hall also need to take account of impacts elsewhere.

Improvements to the channel at local channel constrictions such as due to a sharp meander at Water End could also give local benefits.

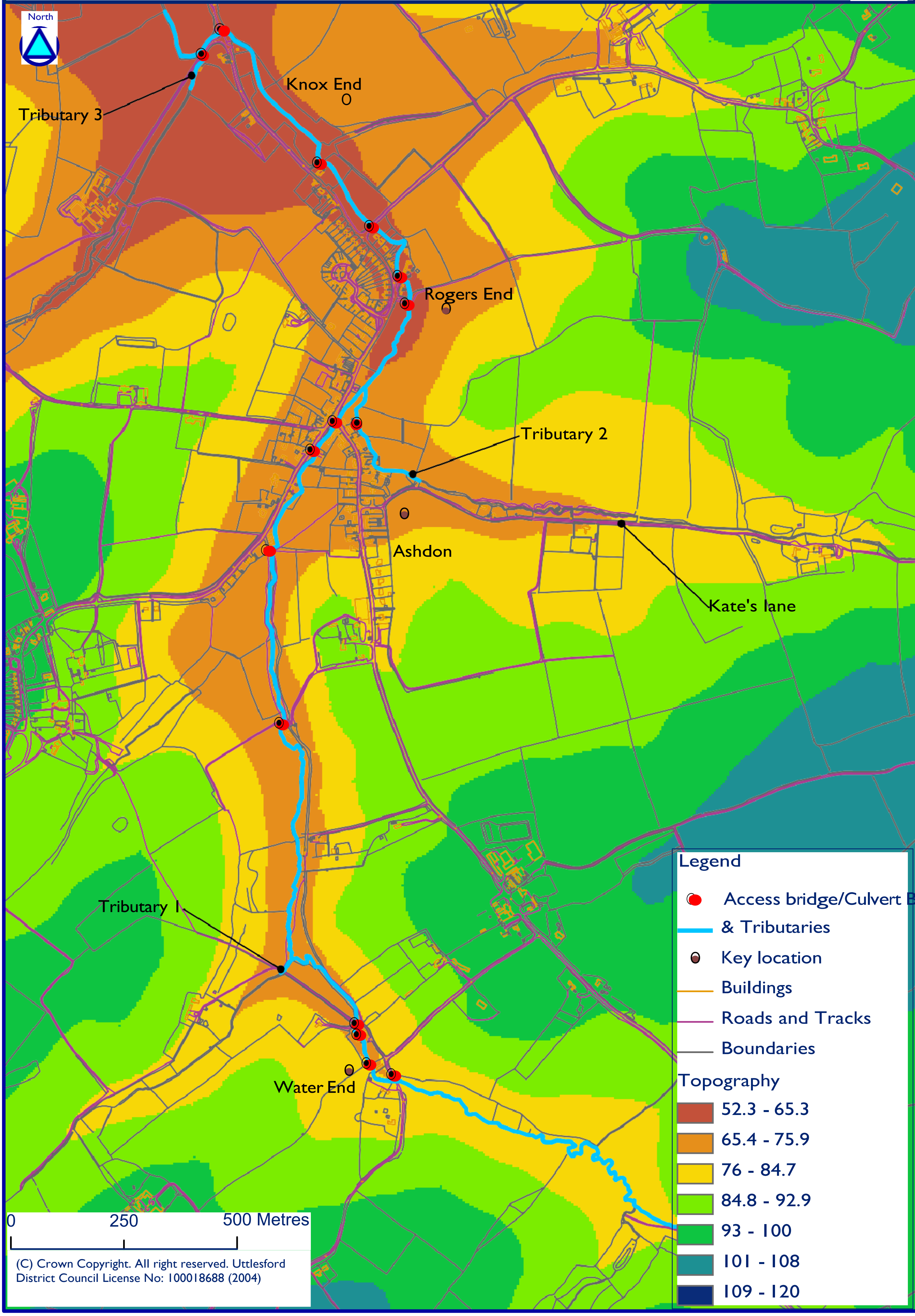
7.5 Pre Feasibility Study

The very high frequency of flooding in Ashdon has been studied and modelled. Whilst it may be difficult to reduce flooding to a typical 1:75-1:100 year standard, viable improvements have been identified and it is recommended that these are taken forward for more detail study and implementation.

This should also include discussions with landowners and Defra to consider how the rate of runoff could be reduced which potentially could contribute significantly to further reducing the frequency of flooding.

MAPS

MAP 1 STUDY AREA



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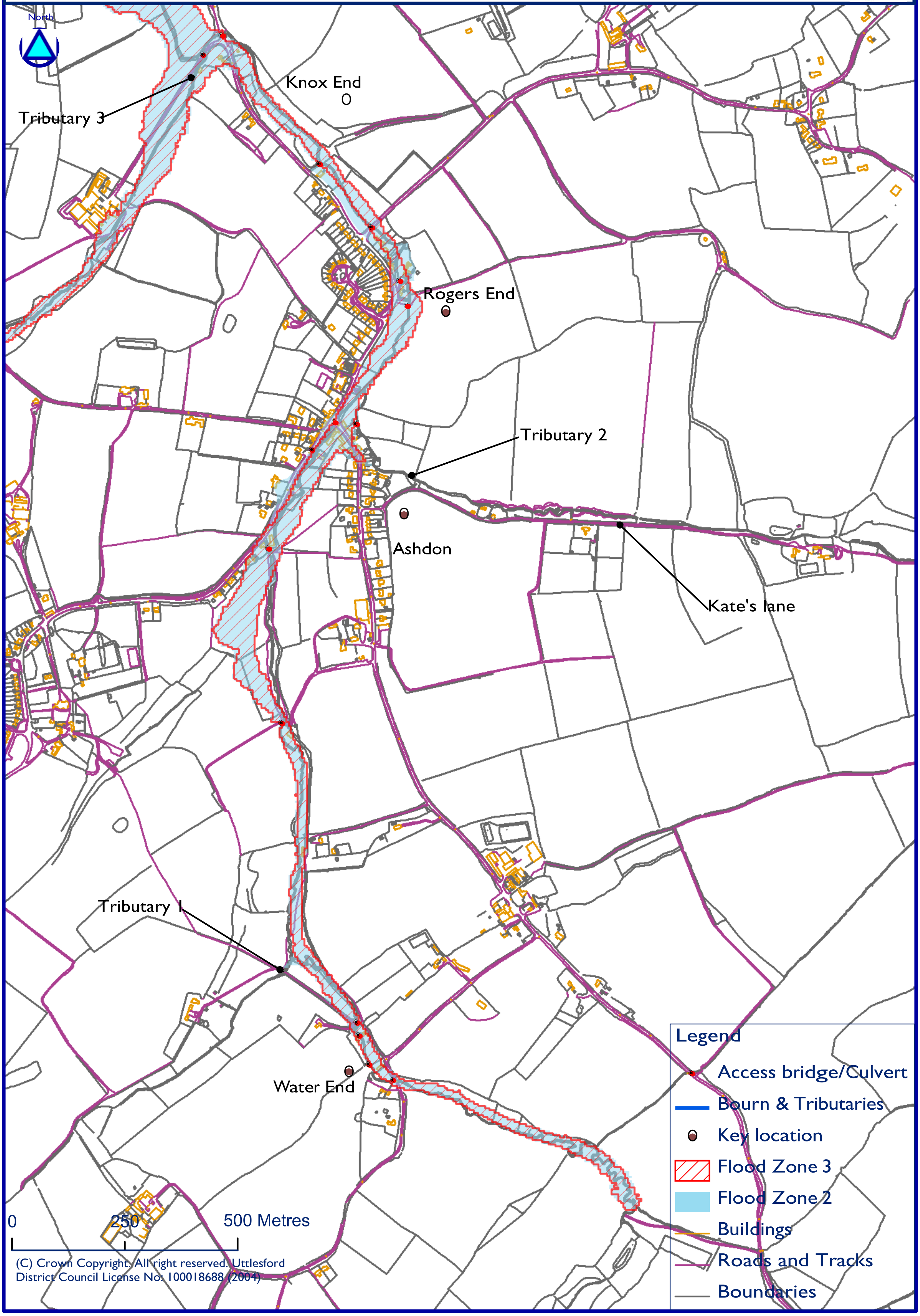
MAP 2 FLOOD ZONES



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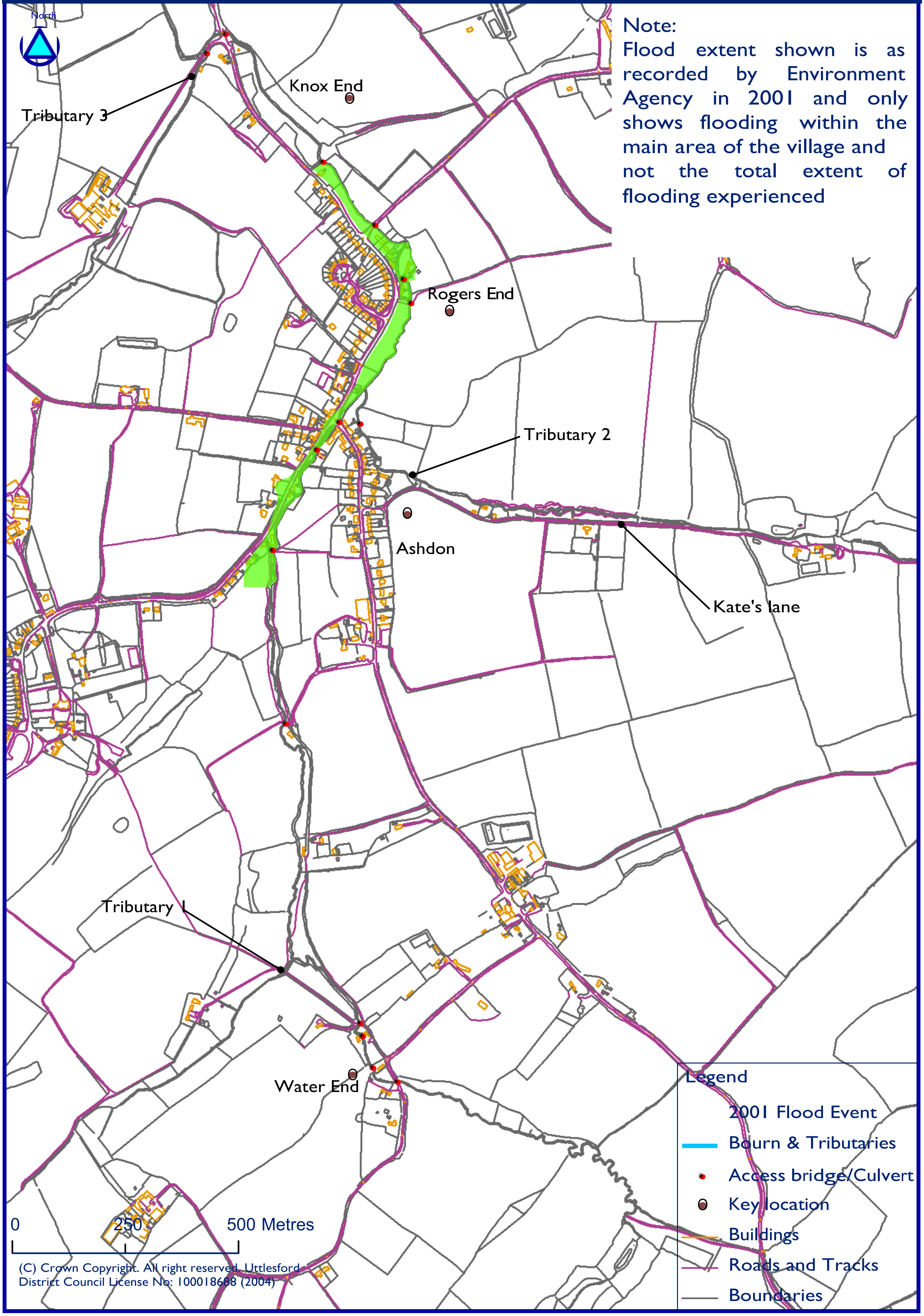
MAP 3 HISTORICAL FLOOD EXTENTS



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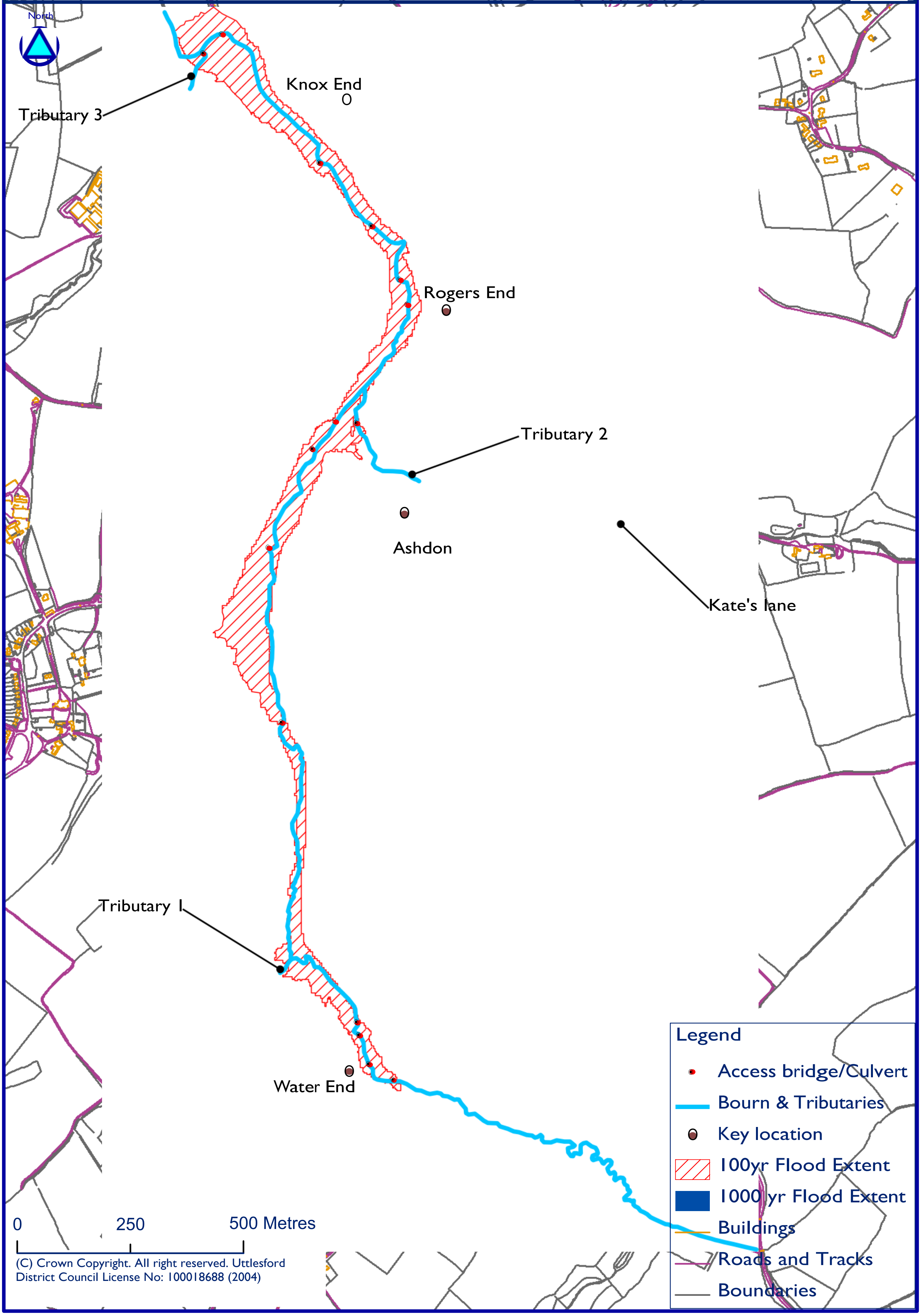
MAP 4 MODELLED FLOOD EXTENTS



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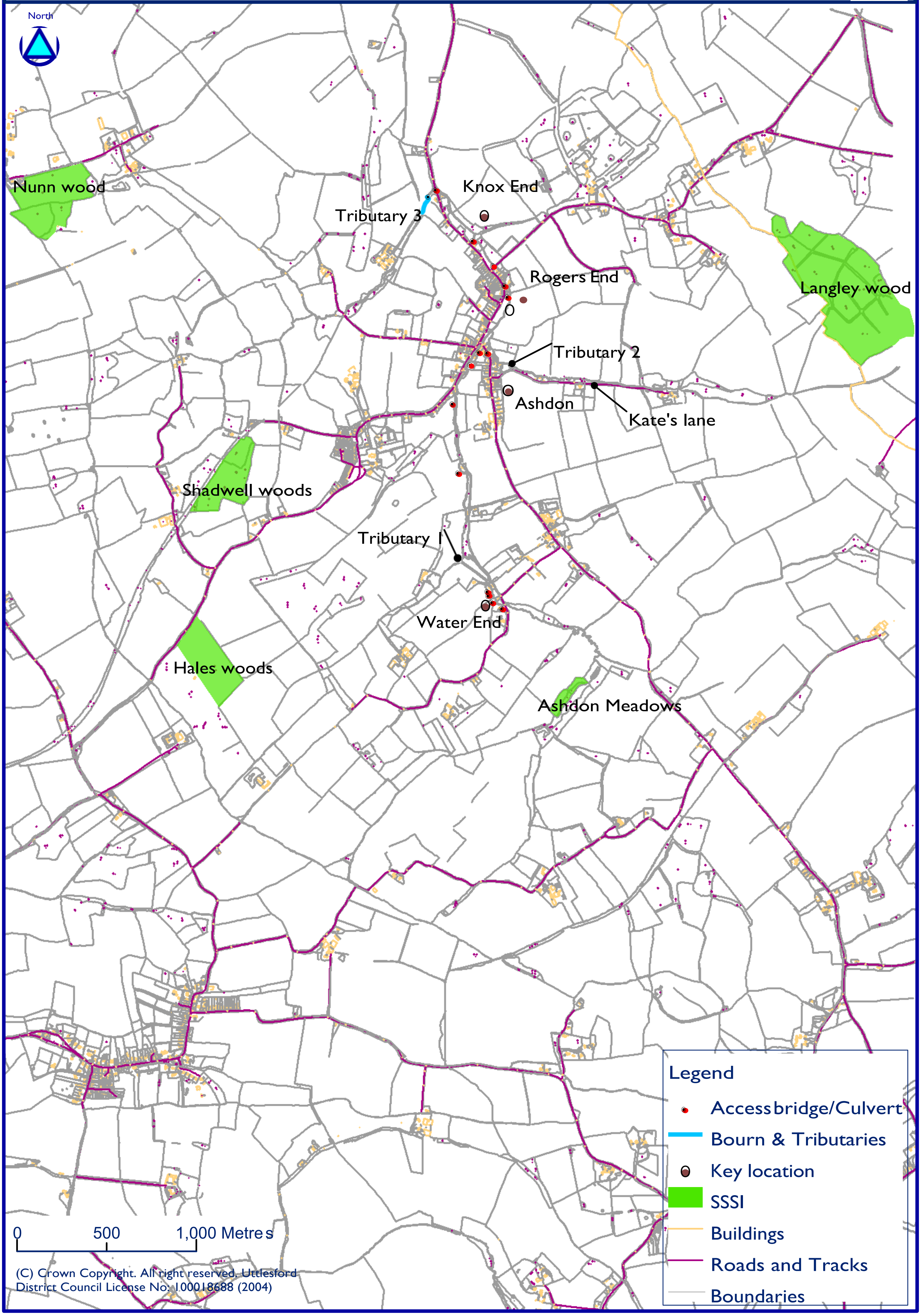
MAP 5 SITES OF SPECIAL SCIENTIFIC INTEREST



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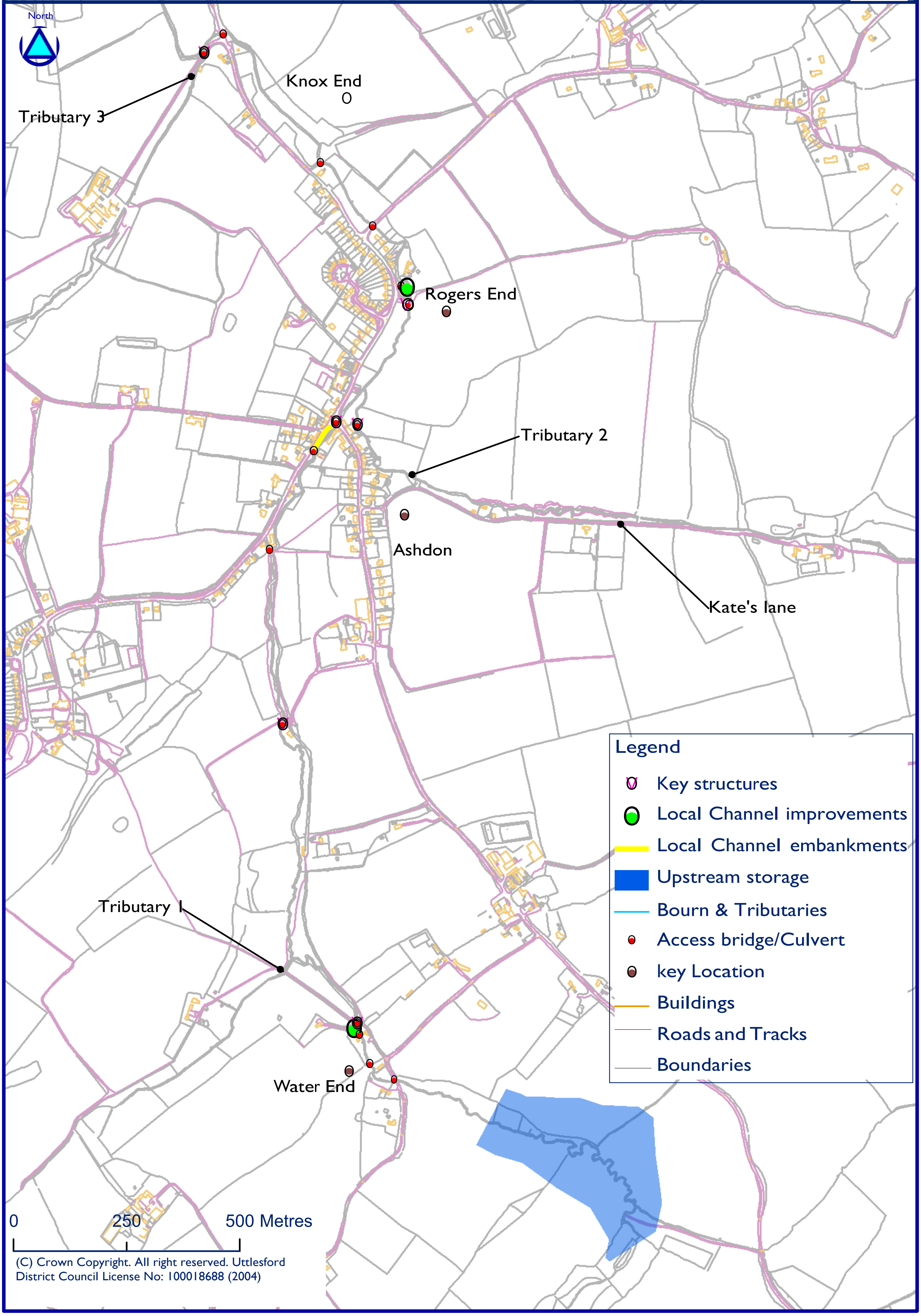
MAP 6 MITIGATION MEASURES



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APPENDICES

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Appendix A: - FEH Calculation Record

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INTRODUCTION

This document provides a record of the calculations and decisions made during flood estimation following the Environment Agency's Flood Estimation Guidelines. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future.

CONTENTS

APPROVAL

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:		Balaji Angamuthu BEng, MTech, MSc	
Calculations checked by:		Duncan Faulkner MA, MSc, DIC, MCIWEM	
Calculations approved by:		Duncan Faulkner MA, MSc, DIC, MCIWEM	

Environment Agency competence levels are covered in Section2.1 of the Guidelines:

- Entry Level Hydrologist
- Competent Hydrologist
- Professional Hydrologist
- Chartered Status Hydrologist

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
BFo	Initial baseflow
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
Cmax	Maximum soil moisture storage
Cini	Soil moisture content at onset of event
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
URBEXT	FEH index of fractional urban extent
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

A.1 METHOD STATEMENT

A.1.1 Overview of requirements for flood estimates

Item	Comments
Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations. Approx. time available	The study is to look at pre feasibility of flood mitigation measures for Ashdon on the Bourn. Some of the options involve storage therefore hydrographs will be needed as volumes will be important. Flood estimates will be needed for the upstream parts of Bourn and its tributaries. 2,5,10, 20, 50, 75, 100 and 1,000-year estimates will be needed.

A.1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The study area includes headwater area of the River Bourn and its tributaries. **River Bourn** flows through Water End, Ashdon, Rogers End and Knox End before it confluences with the River Granta at Bartlow. The size of catchment at Knox End is 18.66 km^2. River Bourn rises near Bourne Farm at Grigg's Grove, upstream of Water End**.** The catchment area is mostly rural with woods and farms. There are 2 fish ponds along the River Bourn upstream of Water End. Bourn and its tributaries drain the farmland drains. The catchment is very steep with elevation varying from 126mAOD at watershed to 57mAOD at Knox End within a distance of 6km.

A.1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made.	Yes – Version 2, May 2007 (supplied with WINFAP v2)

A.1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Period of record
-	-	-	-	-	-	-	-

A.1.5 Data available at each flow gauging station

Station name	Period of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling ?	Data quality check needed?	Other comments on station and flow data quality
-	-	-	-	-	-	-
Give link/reference to any further data quality checks carried out			n/a			

A.1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical	Rating review needed?	Reasons
-	-	-	-
Give link/reference to any rating reviews carried out		n/a	

A.1.7 Other data available and how it has been obtained

Flow gaugings (if planned to review ratings)	Not available
Historic flood data	Flooding occurred in: 1948, 1963, 1978, and 1987 (4 times), 1993, 2000, 2001 and 2007. Details will be included in the main report.
Flow data for events	River Bourn was ungauged and no observed flow data was available.
Rainfall data for events	Rainfall data at local gauges has been provided by the Environment Agency.
Results from previous studies (e.g. CFMPs, Strategies)	Not available
Other data or information (e.g. groundwater, tides)	Post flood survey data for the 1987 and 2007 flood events has been provided by the Uttlesford District Council. The Environment Agency provided post flood survey data for the 2001 flood event.

A.1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes – statistical and ReFH methods will be investigated.
Outline the conceptual model. Where are the main sites of interest? What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?	Main sites of interest in respect of flooding are Water End, Ashdon, Rogers End and Knox End. Flooding is likely to occur from flash flows as Bourn and its tributaries peak at the same time.

Is there a need to consider temporary debris dams that could collapse?	
Any unusual catchment features to take into account? e.g. • highly permeable (SPRHOST<20%) – avoid ReFH, use permeable catchment adjustment for statistical method • highly urbanised – prefer FEH statistical, or consider alternative methods • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing • extensive floodplain storage – consider choice of method carefully	No unusual factors to take into account. Adjacent catchment (Steeple Bumpstead) flooded in June 2007.
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	ReFH will be used to derive hydrograph peaks and shapes. Statistical estimates of peak flow will also be derived for comparison. The hydrographs might have to be scaled to these estimates if necessary.
Software to be used (with version numbers)	FEH CD-ROM v2 WINFAP-FEH v2 ReFH spreadsheet v1.4 ReFH Flood Modelling software v1.0 ISIS v3.0.0.27

A.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.

A.2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
Bourn US	Bourn	Upstream of Water End	558850	240650	5.71	
Trib 1	Tributary 1	Confluence with Bourn near Water End	558550	240900	1.63	
Trib 2	Tributary 2	Confluence with Bourn near Ashdon	558800	242150	2.49	
Trib 3	Tributary 3	Confluence with Bourn near Knox End	558350	242850	4.84	
Bourn DS	Bourn	At Knox End	558400	242950	18.66	
Reasons for choosing above locations		The above locations were chosen at confluences and at up and downstream extents of the model.				

A.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)	SPRHOST	URBEXT 2000
Bourn US	1.000	0.27	0.346	2.03	27.3	592	46.79	0.0013
Trib 1	1.000	0.26	0.394	3.29	36.2	590	43.54	0.0035
Trib 2	1.000	0.27	0.398	1.35	35.2	592	42.17	0
Trib 3	1.000	0.26	0.345	1.61	37.7	591	46.88	0
Bourn DS	1.000	0.26	0.399	2.31	38.7	590	43.61	0.0005

A.2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries were checked against NextMap data and contours on the OS 1:50,000 map. No discrepancies were found.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	SPRHOST values were checked against soil maps [1]. The catchment is mostly covered by loamy and clayey soils with impeded drainage. The SPRHOST values obtained from the FEH CD can be considered appropriate for these soil types.

[1] http://www.landis.org.uk/soilscapes/

Method for updating of URBEXT	CEH urban expansion formula (UEF)[2]. This updated formula is based on the model of urban expansion described in vol. 5 of the FEH. The UEF allows the URBEXT value to be more closely related to the period of record being used to adjust QMED.

[2] CEH (2006) *URBEXT2000 – A new FEH catchment descriptor: calculation, dissemination and application.* Defra/EA research project FD1919

A.3 STATISTICAL METHOD

A.3.1 Overview of estimation of QMED at each subject site

Site code	Method (1)	Initial estimate of QMED (m^3/s) (4)	AM or POT	Data transfer		Final estimate of QMED (m^3/s)
			Adjust-ment for climatic variation? (2)	NRFA numbers for donor/analogue sites used (see A.3.4) and reasons for choice(3)	QMED adjust-ment factor	
Bourn US	DT	1.26	-	36010 – analogue site HiFlows recommends good for QMED	1.46	1.8
Trib 1	DT	0.34	-	36010 – analogue site HiFlows recommends good for QMED	1.46	0.5
Trib 2	DT	0.57	-	36010 - analogue site HiFlows recommends good for QMED	1.46	0.8
Trib 3	DT	0.94	-	36010 - analogue site HiFlows recommends good for QMED	1.46	1.4
Bourn DS	DT	3.33	-	36010 - analogue site HiFlows recommends good for QMED	1.46	4.9
Are the values of QMED consistent, for example at confluences?			Yes			

Notes
1. Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.
2. Give details of any adjustment for climatic variation below.
3. If more than one donor or analogue has been used, give the weights used in the averaging.
4. Initial estimate of QMED from catchment descriptors

A.3.2 Search for donor or analogue sites for QMED

Comment on potential donor sites	None found.
Method for seeking out analogue sites	Suitable analogue site was identified using the search facility on the HiFlows website. Once identified further key catchment descriptors were checked for suitability.

A.3.3 Characteristics of potential donor and analogue sites

Subject sites needing donors or analogues						
Site code	**AREA**	**FARL**	**BFIHOST**	**SAAR**	**SPRHOST**	**URBEXT**
Bourn US	5.71	1.000	0.346	592	46.79	0.0013
Trib 1	1.63	1.000	0.394	590	43.54	0.0035
Trib 2	2.49	1.000	0.398	592	42.17	0
Trib 3	4.84	1.000	0.345	591	46.88	0

Bourn DS	18.66	1.000	0.399	590	43.61	0.0005

Potential donors and analogues								
NRFA no.	Watercourse	Station	AREA	FARL	BFIHOST	SAAR	SPRHOST	URBEXT
36010	Bumpstead Brook	Broad Green	27.5	0.999	0.387	588	44.57	0.008

A.3.4 Decision on choosing or rejecting donor and analogue sites

NRFA no.	Reasons for choosing or rejecting (mention location, catchment properties, data quality…)	Method (AM or POT)	Adjust-ment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
36010	Analogue site chosen (located within 10km) and good quality data (recommended in HiFlows).	-	-	6.87	4.72	1.46

A.3.5 Derivation of pooling groups

The composition of the pooling groups is given in the Annex.

Target return period (years) for all pooling groups			200	
Name of group	**Site code for which group derived**	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Distribution and reason for choice**	**Parameters (before urban adjustment)** Note any permeable catchment adjustments
Bourn Upstream	Bourn US	None	GL – recommended in WINFAP	Location: 1 Scale: 0.285 Shape: -0.089
Tributary1	Trib 1	None	GL – recommended in WINFAP	Location: 1 Scale: 0.290 Shape: -0.109
Tributary2	Trib 2	None	GL – recommended in WINFAP	Location: 1 Scale: 0.281 Shape: -0.108
Tributary3	Trib 3	None	GL – recommended in WINFAP	Location: 1 Scale: 0.295 Shape: -0.086
Bourn Downstream	Bourn DS	None	GL – recommended in WINFAP	Location: 1 Scale: 0.293 Shape: -0.050

A.3.6 Flood peak flow based on pooling groups

Site code	Flood peak (m^3/s) for the following return periods (in years)

	2	5	10	20	50	75	100	1,000
Bourn US	1.84	2.61	3.10	3.76	4.27	4.58	4.80	6.82
Trib 1	0.50	0.72	0.87	1.06	1.21	1.31	1.37	2.01
Trib 2	0.83	1.18	1.41	1.72	1.97	2.12	2.23	3.24
Trib 3	1.37	1.97	2.35	2.85	3.24	3.48	3.65	5.18
Bourn DS	4.87	6.91	8.17	9.77	10.98	11.70	12.21	16.60

A.3.7 Derivation of flood growth curves at subject sites based on pooling groups

Site code	Method: SS – Single site P – Pooled J – Joint	If P or J, name of pooling group (A.3.5)	If SS, distribution used and reason for choice If J, details of averaging	If SS, parameters of distribution (location, scale and shape)	Growth factor for 100-year return period
Bourn US	P	Bourn Upstream	-	-	2.62
Trib 1	P	Tributary1	-	-	2.73
Trib 2	P	Tributary2	-	-	2.67
Trib 3	P	Tributary3	-	-	2.66
Bourn DS	P	Bourn Downstream	-	-	2.51

A.3.8 Growth curve factors borrowed from analogue site

Analogue site										
NRFA no.	Watercourse	Station	Return Period (years)							
			2	5	10	25	50	75	100	1000
36010	Bumpstead Brook	Broad Green	1.00	1.63	2.08	2.71	3.25	3.59	3.84	6.44

A.3.9 Flood peak flow based on borrowed growth curve factors

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	75	100	1,000
Bourn US	1.80	2.94	3.74	4.88	5.84	6.45	6.91	11.59
Trib 1	0.50	0.82	1.04	1.36	1.62	1.79	1.92	3.22
Trib 2	0.80	1.31	1.66	2.17	2.60	2.87	3.07	5.15
Trib 3	1.40	2.29	2.91	3.80	4.54	5.02	5.38	9.01
Bourn DS	4.90	8.01	10.19	13.28	15.90	17.57	18.82	31.54

A.3.10 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	75	100	1,000
Bourn US	1.80	2.94	3.74	4.88	5.84	6.45	6.91	11.59
Trib 1	0.50	0.82	1.04	1.36	1.62	1.79	1.92	3.22

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	75	100	1,000
Trib 2	0.80	1.31	1.66	2.17	2.60	2.87	3.07	5.15
Trib 3	1.40	2.29	2.91	3.80	4.54	5.02	5.38	9.01
Bourn DS	4.90	8.01	10.19	13.28	15.90	17.57	18.82	31.54

A.4 REVITALISED FLOOD HYDROGRAPH (REFH) METHOD

A.4.1 Parameters for ReFH model

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method: FEA : Flood event analysis CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
Bourn US	CD	6	298.24	35.68	0.74
Trib 1	CD	5	340.67	35.21	0.87
Trib 2	CD	5.4	300.13	34.55	0.73
Trib 3	CD	6	344.59	39.38	0.86

Brief description of any flood event analysis carried out (further details should be given below or in a project report)	Flood Event Analysis was carried out for June 2007 flood event. Details are given below.

ReFH Flood Modelling software was used to carry out Flood Event Analysis of 14 June 2007 flood event. There was no observed flow data available to calibrate the rainfall-runoff model parameters, so modelled flows were input into the hydraulic model to verify the observed flood levels (at 5 locations along Bourn) and time to peak of June 2007 event. 15mm of rainfall occurred on the day before flooding. 33.7 mm of rainfall occurred on the day of flooding. Observed rainfall at 15 minutes interval was input into the model. BFo value of 0.3 cumecs was user defined for all catchments. Tp (0) of all catchments was set equal to 2.5 hours to match the observed time to peak of June 2007 flood event. It was found that modelled flows with Cini estimated based on antecedent rainfall and evaporation series needed a factor of 5 to be multiplied to match the observed flood levels and found there was no flooding for these flows. When Cini value of all catchments was set equal to Cmax, simulated flood levels came closer to observed flood levels but still were consistently lower by 0.5m at all the locations. When a factor of 1.2 multiplied to the modelled flows, observed levels were very closely reproduced. All other ReFH model parameters estimated from catchment descriptors were kept unchanged and carried forward along with BFo, Cini and Tp (0) to estimate design flows. Also, the factor 1.2 will be multiplied to the ReFH estimated design flows.

A.4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Bourn US	Rural	Winter	6.2	ARF = 0.96
Trib 1	Rural	Winter	4.6	ARF = 0.97
Trib 2	Rural	Winter	5.1	ARF = 0.97
Trib 3	Rural	Winter	6.2	ARF = 0.97

Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	No.

A.4.3 Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) or volumes (m^3) for the following return periods (in years)							
	2	5	10	20	50	75	100	1,000
Bourn US	5.69	7.56	9.14	10.98	13.93	15.48	16.68	30.30
Trib 1	1.81	2.35	2.80	3.34	4.20	4.66	5.01	9.08

Site code	Flood peak (m^3/s) or volumes (m^3) for the following return periods (in years)							
	2	5	10	20	50	75	100	1,000
Trib 2	2.68	3.52	4.23	5.07	6.41	7.12	7.66	13.93
Trib 3	4.88	6.47	7.82	9.39	11.91	13.23	14.25	25.90

A.5 DISCUSSION AND SUMMARY OF RESULTS

A.5.1 Comparison of results from different methods

A.5.2 Peak Flows

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

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years			Return period 100 years		
	ReFH	FEH rainfall-runoff	Other method	ReFH	FEH rainfall-runoff	Other method
Bourn US	3.16	-	-	2.41	-	-
Trib 1	3.62	-	-	2.61	-	-
Trib 2	3.35	-	-	2.49	-	-
Trib 3	3.49	-	-	2.65	-	-

Statistical method seems to be underestimating peak flows of all streams. More appropriate estimates of peak flow (when compared to observed data) were derived by ReFH method with parameters derived from catchment descriptors and flood event analysis, as detailed in section A.4.1.

A.5.3 Final choice of method

Choice of method and reasons	The statistical results seem to be significantly underestimating peak flows when compared to ReFH results. The estimates from statistical method are just based on analogue site whereas the ReFH method estimates are based on calibrated parameters of rainfall-runoff model for an observed event. When looking at storage options it is important that not only peak flows but volumes of water are taken into account, therefore hydrograph shapes were also needed. For these reasons, ReFH results were found to be most appropriate.

A.5.4 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	Cini was assumed to be equal to Cmax (i.e., soil is saturated at the beginning of an event).
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	Care should be taken extrapolating flow estimates outside the range derived in this study. Caution should also be exercised when looking at flow volumes outside this range.

Give what information you can on uncertainty in the results, for example in the QMED estimates using FEH **3** 12.5 or 13.8	95% confidence intervals for QMED can be derived as shown in FEH vol 3, as 0.42QMED, 2.40QMED when estimated solely from catchment descriptors. For Bourn at Water End (Bourn US) the 95% confidence interval for a QMED of 1.8m^3/s is between 0.75 and 4.32m^3/s.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The results of this study are appropriate to be used for future flood risk studies or feasibility studies into capital schemes outlined in the main report of this study.
Give any other comments on the study, for example suggestions for additional work.	

A.5.5 Checks

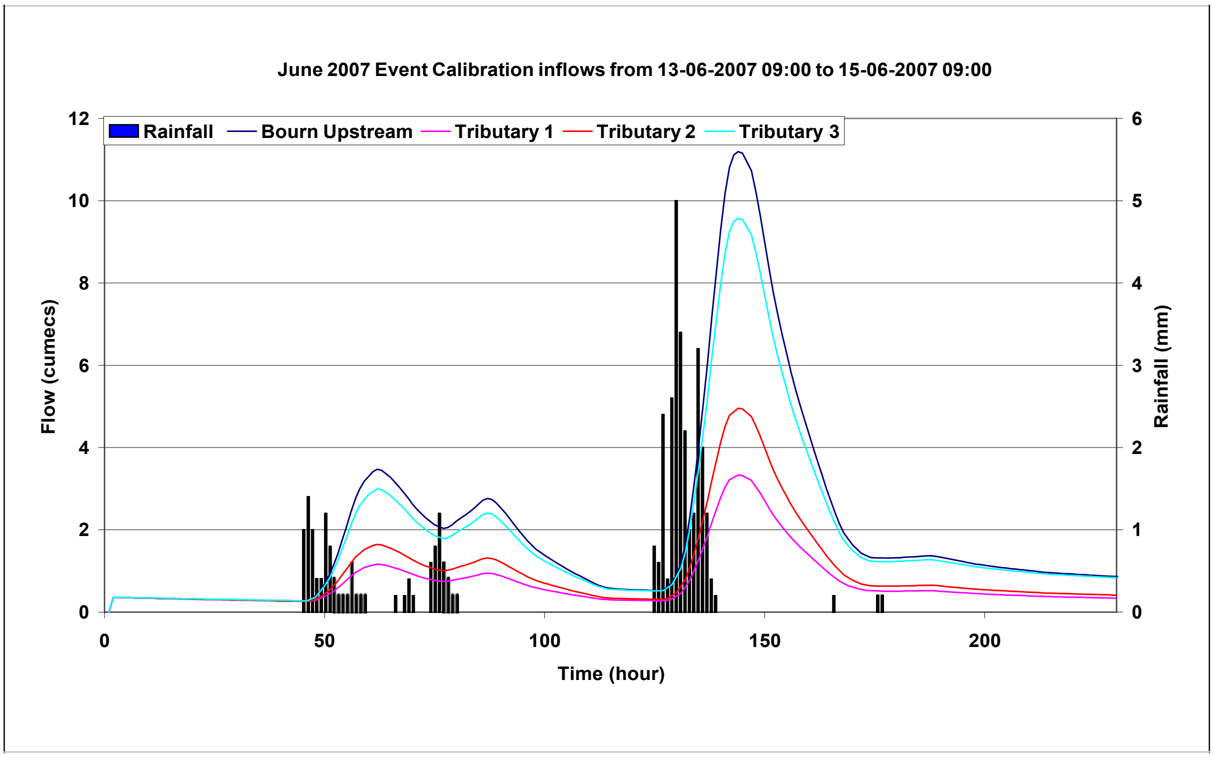
Are the results consistent, for example at confluences?	Yes.
What do the results imply regarding the return periods of floods during the period of record?	The estimates from the ReFH method imply that the most recent flooding event (June 2007) have a return period close to 20-years.
What is the range of 100-year growth factors? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	3.84 – Statistical Method 2.77 to 2.92 – ReFH Method
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.68 – Statistical Method 1.81 to 1.82 - ReFH method
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The 100-year specific runoffs (ReFH method) range from 27 – 30 l/s/ha. These values are higher than those that may be expected. However when checked against the post flood survey levels the specific runoff for the range of return periods seem appropriate.
How do the results compare with those of other studies?	No previous studies available.
Are the results compatible with the longer-term flood history?	Yes.
Describe any other checks on the results	Checks on flow peaks were carried out. See section A.5.1.

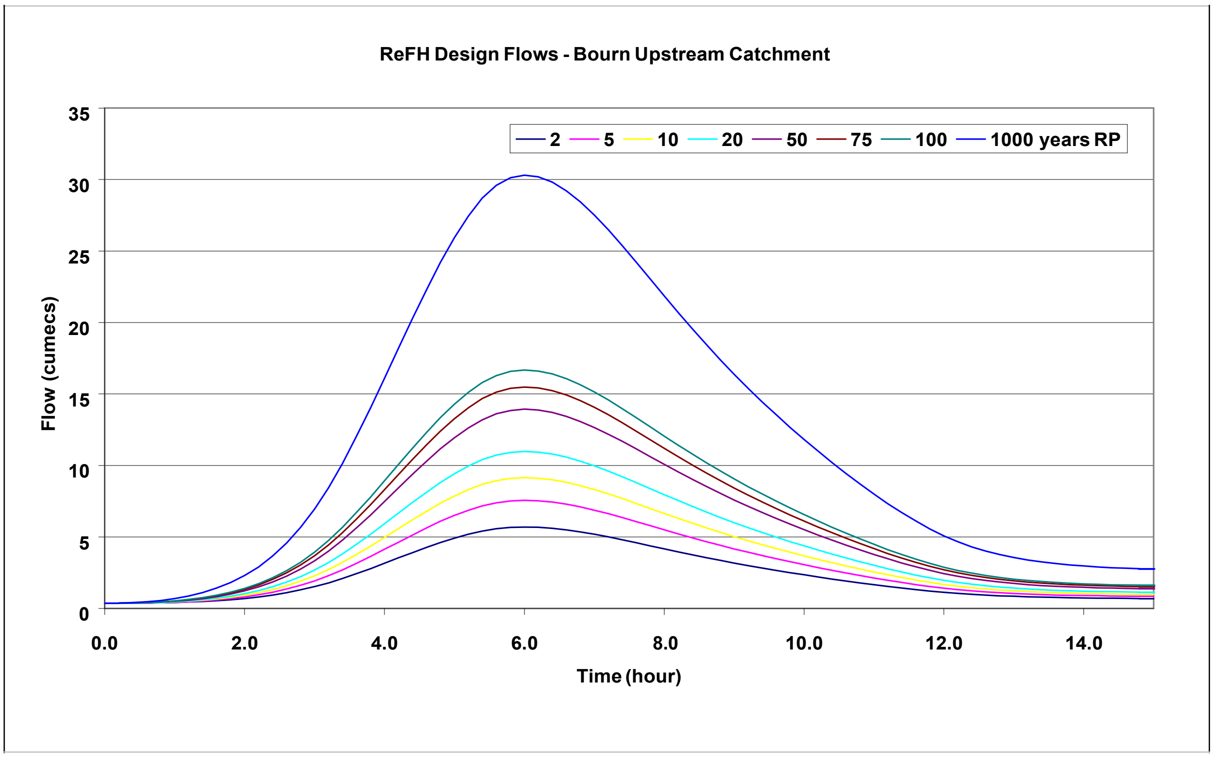
A.5.6 Final results

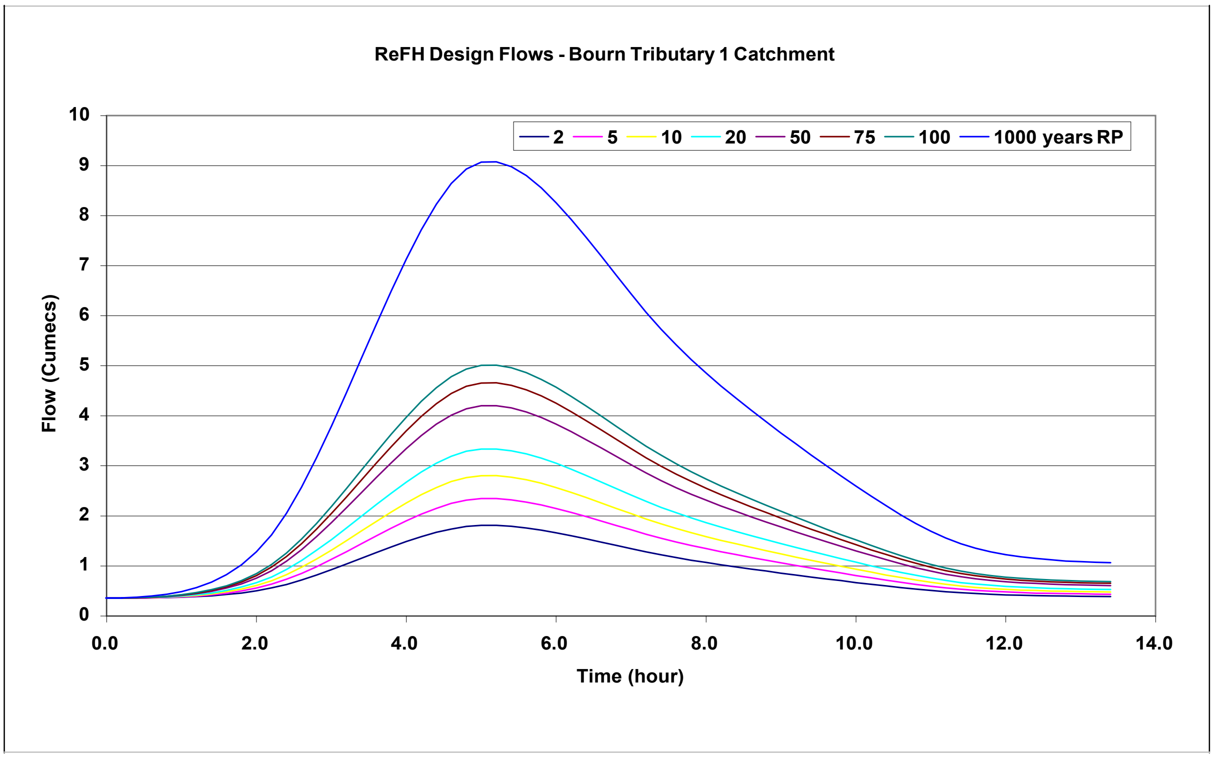
Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	25	50	75	100	1,000
Bourn US	5.69	7.56	9.14	10.98	13.93	15.48	16.68	30.30
Trib 1	1.81	2.35	2.80	3.34	4.20	4.66	5.01	9.08
Trib 2	2.68	3.52	4.23	5.07	6.41	7.12	7.66	13.93
Trib 3	4.88	6.47	7.82	9.39	11.91	13.23	14.25	25.90

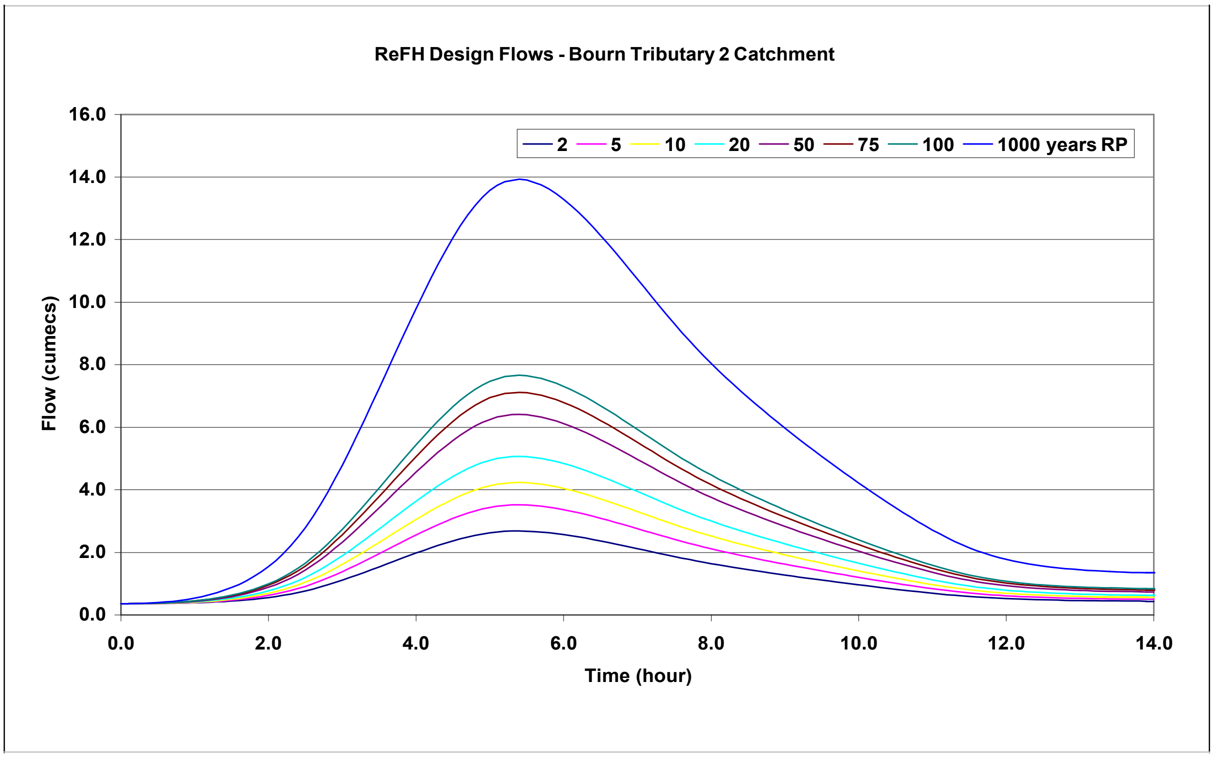
If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	N:\2007\Projects\2008s3144 - Uttlesford District Council - River Bourn Ashdon\Calculations\Hydrology Design Flows.xls

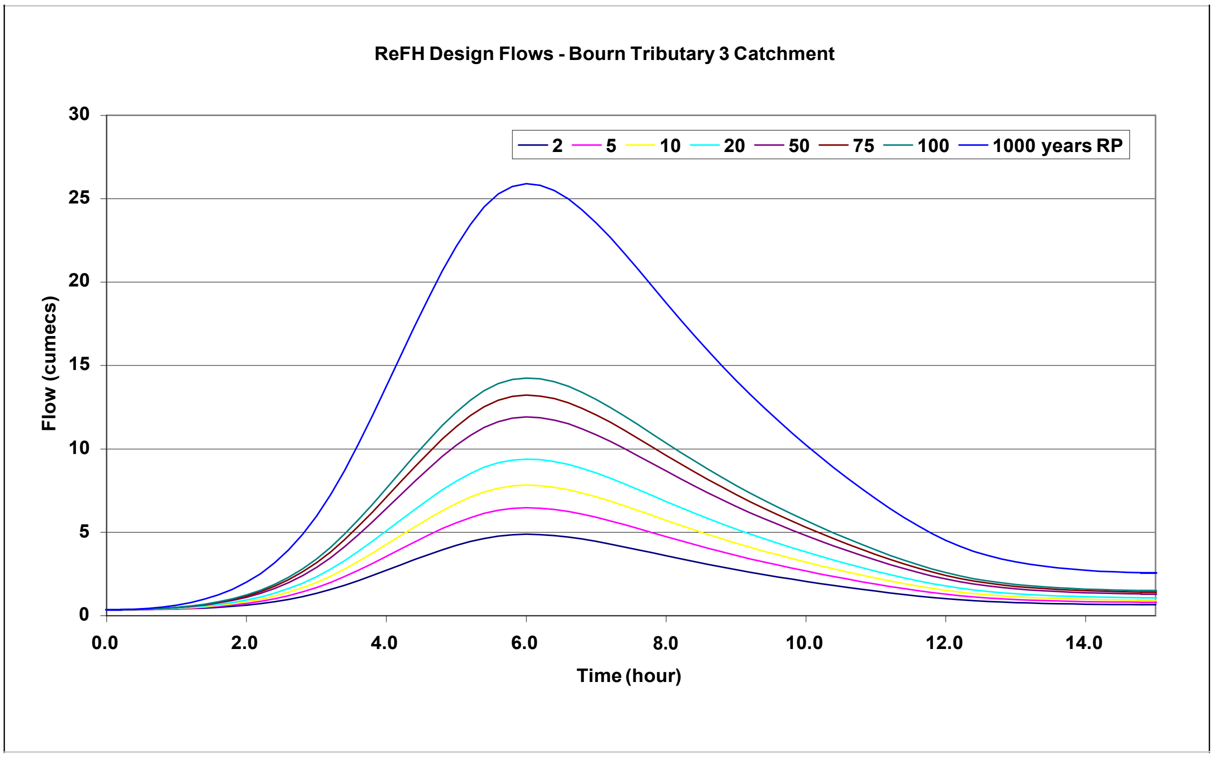
A.5.7 Hydrographs






ReFH Design Flows - Bourn Tributary 1 Catchment
2
5
10
20
50
75
100
1000 years RP
Flow (Cumecs)
Time (hour)
0
1
2
3
4
5
6
7
8
9
10
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0


ReFH Design Flows - Bourn Tributary 2 Catchment
2
5
10
20
50
75
100
1000 years RP
Flow (cumecs)
Time (hour)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0


ReFH Design Flows - Bourn Tributary 3 Catchment
2
5
10
20
50
75
100
1000 years RP
Flow (cumecs)
30
25
20
15
10
5
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Time (hour)

A.6 ANNEX - SUPPORTING INFORMATION

A.6.1 Pooling group composition

A.6.2 Composition of Pooling Group BournUpstream

Station Number	Watercourse	Location	Start Date	End Date
36009	Brett	Cockfield	07/08/1968	13/02/2003
36010	Bumpstead Brook	Broad Green	04/01/1968	03/02/2003
27051	Crimple	Burn Bridge	14/07/1973	02/01/2003
20002	West Peffer Burn	Luffness	19/11/1965	23/01/2003
36004	Chad Brook	Long Melford	13/03/1968	26/11/2003
37016	Pant	Copford Hall	28/11/1965	04/02/2003
24007	Browney	Lanchester	17/04/1968	02/06/1983
36012	Stour	Kedington	18/09/1965	03/02/2003
41020	Bevern Stream	Clappers Bridge	15/11/1969	21/01/2003
37013	Sandon Brook	Sandon Bridge	28/02/1964	02/02/2003
36002	Glem	Glemsford	05/03/1963	04/02/2003
27010	Hodge Beck	Bransdale Weir	02/06/1936	11/12/1977
33045	Wittle	Quidenham	05/11/1967	28/07/1963
37011	Chelmer	Churchend	18/11/1963	04/02/2003
37014	Roding	High Ongar	30/11/1963	04/02/2003
25019	Leven	Easby	13/08/1971	13/01/1997
37003	Ter	Crabbs Bridge	28/02/1964	02/02/2004
35008	Gipping	Stowmarket	14/03/1964	03/02/2003
33018	Tove	Cappenham Bridge	04/03/1963	09/03/2003
33012	Kym	Meagre Farm	26/10/1960	20/01/2003
22003	Usway Burn	Shillmoor	12/08/1966	23/01/2003
36007	Belchamp Brook	Bardfield Bridge	21/03/1965	04/02/2003
53017	Boyd	Bitton	09/02/1974	21/01/2003
24004	Bedburn Beck	Bedburn	21/01/1960	12/03/2003
38002	Ash	Mardock	14/10/1939	13/02/2003
203046	Rathmore Burn	Rathmore Bridge	02/01/1982	01/03/2003
41022	Lod	Halfway Bridge	08/02/1974	02/02/2003

A.6.3 Composition of Pooling Group Tributary1

Station Number	Watercourse	Location	Start Date	End Date
27051	Crimple	Burn Bridge	14/07/1973	02/01/2003
36009	Brett	Cockfield	07/08/1968	13/02/2003
36010	Bumpstead Brook	Broad Green	04/01/1968	03/02/2003
20002	West Peffer Burn	Luffness	19/11/1965	23/01/2003
25019	Leven	Easby	13/08/1971	13/01/1997
33045	Wittle	Quidenham	05/11/1967	28/07/1963
36004	Chad Brook	Long Melford	13/03/1968	26/11/2003
27010	Hodge Beck	Bransdale Weir	02/06/1936	11/12/1977
37016	Pant	Copford Hall	28/11/1965	04/02/2003

41020	Bevern Stream	Clappers Bridge	15/11/1969	21/01/2003
24007	Browney	Lanchester	17/04/1968	02/06/1983
37011	Chelmer	Churchend	18/11/1963	04/02/2003
36012	Stour	Kedington	18/09/1965	03/02/2003
203046	Rathmore Burn	Rathmore Bridge	02/01/1982	01/03/2003
53017	Boyd	Bitton	09/02/1974	21/01/2003
36007	Belchamp Brook	Bardfield Bridge	21/03/1965	04/02/2003
37003	Ter	Crabbs Bridge	28/02/1964	02/02/2004
36002	Glem	Glemsford	05/03/1963	04/02/2003
76011	Coal Burn	Coalburn	18/03/1941	26/01/2003
37014	Roding	High Ongar	30/11/1963	04/02/2003
36003	Box	Polstead	17/11/1963	04/02/2003
41022	Lod	Halfway Bridge	08/02/1974	02/02/2003
22003	Usway Burn	Shillmoor	12/08/1966	23/01/2003
29009	Ancholme	Toft Newton	06/10/1974	02/10/2001
38002	Ash	Mardock	14/10/1939	13/02/2003
37013	Sandon Brook	Sandon Bridge	28/02/1964	02/02/2003
203049	Clady	Clady Bridge	05/11/1982	01/03/2003

A.6.4 Composition of Pooling Group Tributary 2

Station Number	Watercourse	Location	Start Date	End Date
27051	Crimple	Burn Bridge	14/07/1973	02/01/2003
36009	Brett	Cockfield	07/08/1968	13/02/2003
36010	Bumpstead Brook	Broad Green	04/01/1968	03/02/2003
20002	West Peffer Burn	Luffness	19/11/1965	23/01/2003
36004	Chad Brook	Long Melford	13/03/1968	26/11/2003
24007	Browney	Lanchester	17/04/1968	02/06/1983
27010	Hodge Beck	Bransdale Weir	02/06/1936	11/12/1977
37016	Pant	Copford Hall	28/11/1965	04/02/2003
41020	Bevern Stream	Clappers Bridge	15/11/1969	21/01/2003
25019	Leven	Easby	13/08/1971	13/01/1997
33045	Wittle	Quidenham	05/11/1967	28/07/1963
36012	Stour	Kedington	18/09/1965	03/02/2003
37013	Sandon Brook	Sandon Bridge	28/02/1964	02/02/2003
36002	Glem	Glemsford	05/03/1963	04/02/2003
37011	Chelmer	Churchend	18/11/1963	04/02/2003
76011	Coal Burn	Coalburn	18/03/1941	26/01/2003
22003	Usway Burn	Shillmoor	12/08/1966	23/01/2003
37014	Roding	High Ongar	30/11/1963	04/02/2003
37003	Ter	Crabbs Bridge	28/02/1964	02/02/2004
203046	Rathmore Burn	Rathmore Bridge	02/01/1982	01/03/2003
53017	Boyd	Bitton	09/02/1974	21/01/2003
36007	Belchamp Brook	Bardfield Bridge	21/03/1965	04/02/2003
203049	Clady	Clady Bridge	05/11/1982	01/03/2003
41022	Lod	Halfway Bridge	08/02/1974	02/02/2003
24004	Bedburn Beck	Bedburn	21/01/1960	12/03/2003
35008	Gipping	Stowmarket	14/03/1964	03/02/2003
38002	Ash	Mardock	14/10/1939	13/02/2003

A.6.5 Composition of Pooling Group Tributary 3

Station Number	Watercourse	Location	Start Date	End Date
36009	Brett	Cockfield	07/08/1968	13/02/2003
36010	Bumpstead Brook	Broad Green	04/01/1968	03/02/2003
20002	West Peffer Burn	Luffness	19/11/1965	23/01/2003
27051	Crimple	Burn Bridge	14/07/1973	02/01/2003
36004	Chad Brook	Long Melford	13/03/1968	26/11/2003
33045	Wittle	Quidenham	05/11/1967	28/07/1963
37016	Pant	Copford Hall	28/11/1965	04/02/2003
25019	Leven	Easby	13/08/1971	13/01/1997
36012	Stour	Kedington	18/09/1965	03/02/2003
37011	Chelmer	Churchend	18/11/1963	04/02/2003
24007	Browney	Lanchester	17/04/1968	02/06/1983
36002	Glem	Glemsford	05/03/1963	04/02/2003
37003	Ter	Crabbs Bridge	28/02/1964	02/02/2004
41020	Bevern Stream	Clappers Bridge	15/11/1969	21/01/2003
36007	Belchamp Brook	Bardfield Bridge	21/03/1965	04/02/2003
37014	Roding	High Ongar	30/11/1963	04/02/2003
27010	Hodge Beck	Bransdale Weir	02/06/1936	11/12/1977
53017	Boyd	Bitton	09/02/1974	21/01/2003
38002	Ash	Mardock	14/10/1939	13/02/2003
36003	Box	Polstead	17/11/1963	04/02/2003
37013	Sandon Brook	Sandon Bridge	28/02/1964	02/02/2003
41022	Lod	Halfway Bridge	08/02/1974	02/02/2003
203046	Rathmore Burn	Rathmore Bridge	02/01/1982	01/03/2003
35008	Gipping	Stowmarket	14/03/1964	03/02/2003
20007	Gifford Water	Lennoxlove	10/02/1974	23/01/2003
33018	Tove	Cappenham Bridge	04/03/1963	09/03/2003
29009	Ancholme	Toft Newton	06/10/1974	02/10/2001

A.6.6 Composition of Pooling Group BournDownstream

Station Number	Watercourse	Location	Start Date	End Date
36009	Brett	Cockfield	07/08/1968	13/02/2003
36010	Bumpstead Brook	Broad Green	04/01/1968	03/02/2003
20002	West Peffer Burn	Luffness	19/11/1965	23/01/2003
36004	Chad Brook	Long Melford	13/03/1968	26/11/2003
37016	Pant	Copford Hall	28/11/1965	04/02/2003
36012	Stour	Kedington	18/09/1965	03/02/2003
37011	Chelmer	Churchend	18/11/1963	04/02/2003
36002	Glem	Glemsford	05/03/1963	04/02/2003
37014	Roding	High Ongar	30/11/1963	04/02/2003
37003	Ter	Crabbs Bridge	28/02/1964	02/02/2004
33045	Wittle	Quidenham	05/11/1967	28/07/1963
24007	Browney	Lanchester	17/04/1968	02/06/1983
35008	Gipping	Stowmarket	14/03/1964	03/02/2003
36007	Belchamp Brook	Bardfield Bridge	21/03/1965	04/02/2003
38002	Ash	Mardock	14/10/1939	13/02/2003
37013	Sandon Brook	Sandon Bridge	28/02/1964	02/02/2003
33018	Tove	Cappenham Bridge	04/03/1963	09/03/2003

36005	Brett	Hadleigh	18/11/1963	04/02/2003
37020	Chelmer	Felsted	14/11/1970	04/02/2003
41020	Bevern Stream	Clappers Bridge	15/11/1969	21/01/2003
38004	Rib	Wadesmill	25/12/1959	03/02/2003
53017	Boyd	Bitton	09/02/1974	21/01/2003
33012	Kym	Meagre Farm	26/10/1960	20/01/2003
27051	Crimple	Burn Bridge	14/07/1973	02/01/2003
36003	Box	Polstead	17/11/1963	04/02/2003
37017	Blackwater	Stisted	15/12/1969	27/07/2003
25019	Leven	Easby	13/08/1971	13/01/1997

Appendix B: - Hydraulic Model Check File

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INTRODUCTION

This report provides a detailed record of information on the hydraulic model constructed for the Bourn Flood Mapping Study together with the results of QA and validation checks. It complements the information in the main report which gives more general information on the model.

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REVISION HISTORY

Revision Ref./ Date Issued	Amendments	Issued to
Draft Report June 2008		Phil Hunt 1 copy

Modeller: .... Balaji Angamuthu BEng, MTech,MSc
Engineer

Reviewer: .... Tony Green BSc(Eng), PhD, CEng, MICE, MCIWEM
Technical Director

CONTENTS

B.1 MODELLING APPROACH

B.1.1 Available data

Item	Comments
Cross-section survey:	Extended Channel Cross section survey carried out by Storm Geomatics in April 2008.
LiDAR & other Topographic Data:	SAR data
Map Data:	OS Landline, OS 1:10,000 and OS 1:50,000 are available
Gauging station flows /levels	Not available
Gauging station rating curves	Not available
Rainfall data	Available at Ashdon
Flood history	1947, 1968, 1978, 1987 (4 times), 1993, 2000, 2001 and 2007 Post flood survey data of 1987, 2001 and 2007 flood events are available.
Does data justify a Model?	Yes ISIS v 3.0.0.27

B.1.2 Model build-up

Item	Notes	Comments
Backwater Length & Attenuation		The backwater length upstream of a point can be estimated using: L=0.7 D/S (after Samuels, 1989) Average slope S = 1 in 160 Average bankfull depth: 1.8m L=201.6m Limited attenuation through Ashdon.
What software & reason for choice:	ISIS v3.0.0.27	ISIS can model the open channel and structures within the reaches. A hydrodynamic model is necessary to represent attenuation by floodplain storage.
General Schematisation:		Schematisation complete. Structures data sheets completed.
Coefficients:	State documentary sources.	Estimation of roughness coefficient detailed in section B.2.1.
Model Proving:	Outline the test to be applied with the reason, the target accuracy and method of calculation.	Sensitivity Tests: *The sensitivity tests carried out on the models are outlined in section B.5.* *Calibration:* Details are given in section B.6.
Any limitations in the method of modelling used	e.g. If model is used for other flow rates would it require modification?	The model has been built with high flows in mind as it has been developed as part of a pre feasibility study for flood prevention works. If the model needs to be used outside its original remit, it may need modification.

B.2 OVERVIEW

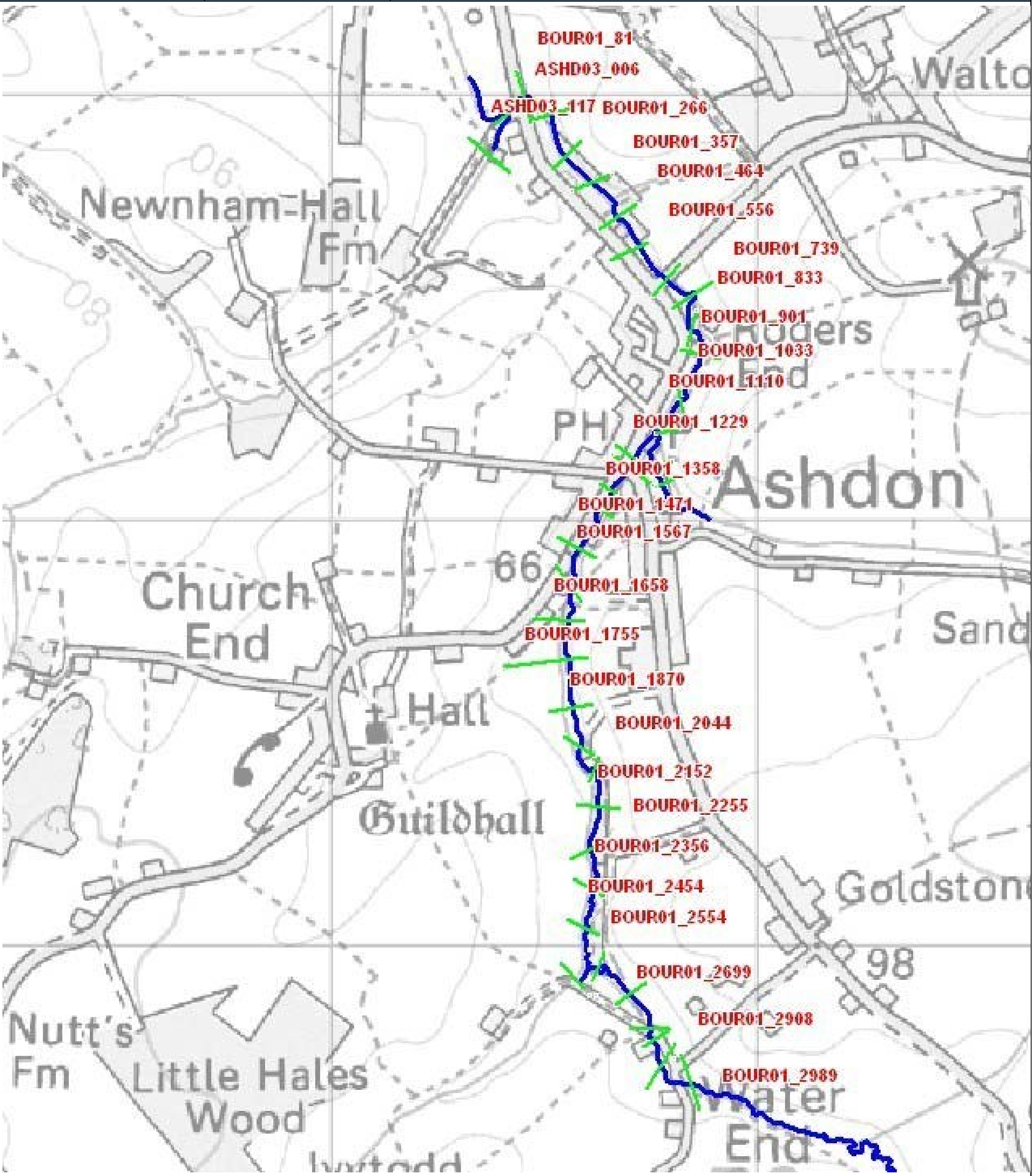
This section summarises how many distinct models have been created for this study – for instance to reflect changes in channel geometry or to look at options.

B.2.1 Overview of Models

	Model Ref/ Details	
	Model name:	**BOURN**
	Purpose:	**FLOOD MAPPING STUDY**
Upstream Boundaries:	BOUR01_2989 ASHD01_36 ASHD02_142 ASHD03_117	Upstream inflows to Bourn and its tributaries are modelled as ReFH boundary.
Downstream Boundaries:	BOUR01_0	A normal depth boundary type with an average slope of 1 in 160 was used as downstream boundary condition.
Length of Model (km):	3km	
Total Number of nodes and structures:	*Current Scenario* 129 Bridges: 7; Culverts (including orifices): 7; In-line Weirs: 0	
Model schematic:		

B.2.1 Overview of Models

	Model Ref/ Details	
	Model name:	**BOURN**
	Purpose:	**FLOOD MAPPING STUDY**



This map is reproduced from Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. Uttlesford District Council, 100018688 (2004).

River Bourn — Cross sections

B.2.1 Overview of Models

	Model Ref/ Details	
	Model name:	**BOURN**
	Purpose:	**FLOOD MAPPING STUDY**
Labelling/ Numbering System Used:	Model cross-sections are labelled as far as possible in accordance with the Environment Agency Flood Mapping Specification. Labels consist of a letter code to identify the river, a number to identify the reach, and a number to identify the chainage. The chainage is defined as: For reach 1 of Bourn, the distance in metres upstream of the last section at Knox End. For reach 1 of Tributary 1, 2 and 3, the distance in metres upstream of the confluence with the Bourn. For example, **BOUR01_1300** is on the **Bourn**, reach **1**, **1300**m upstream of the last section at Knox End.	
Hydraulic roughness values used	The value of Manning's n used can be a relatively subjective choice, yet can affect the model results significantly. Initially descriptions in Chow (1973)[3] were examined; these were checked using Cowan's method for estimating Manning's n values. For the floodplain an average of the land cover has to be implemented, as changing Manning's n to represent every change in the floodplain is impractical. For urban areas of the floodplain an average of the likely extreme values of 0.100 for large buildings and walls which will significantly restrict floodplain flow and 0.04 for the roads that run parallel to the channel which will easily convey water will be needed. For more rural areas a similar compromise is needed too because of vegetation growth depending upon season. The estimates from Cowan's method were utilised as they compared favourably with descriptions in Chow (1973)[3]. The values of Manning's n along the reach therefore vary based on the calculations for that area. Values of Manning's n used in the model for channel roughness range from 0.055 to 0.1 in sections that have sharp bend. Floodplain roughness values range from 0.075 to 0.25 accounting for vegetation, open fields with fences, small urban areas and meanders.	

[3] Chow, V.T. (1973) *Open-Channel Hydraulics*. McGraw-Hill.

B.3 STRUCTURES

B.3.1 General procedures for all structures

This section deals with every structure over the watercourse. A table is provided for each significant structure (bridge, culvert, and weir) that is formally included in the model scheme. All structure geometry was entered into the model by hand and unless otherwise stated, the source of survey data is from the 2008 survey undertaken by Storm Geomatics. Any assumptions made in the modelling of structures are recorded on the following pages.

Name of structure	**B.3.2 Access bridge – Farm Land**
Included in model (state reason if not):	Yes
Model label:	BOU1_2908
Type:	Small arched bridge – brick construction
How has structure been modelled?	Bridge (arch) unit has been used to model the structure. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	**B.3.3 Foot bridge**
Included in model (state reason if not):	Yes
Model label:	BOU1_2836
Type:	Flat Deck wooden bridge
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.3 Foot bridge

Name of structure	B.3.4 Access Bridge – Burnt House
Included in model (state reason if not):	Yes
Model label:	BOU1_2801
Type:	Small arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.5 Access bridge – Rock Cottage
Included in model (state reason if not):	Yes
Model label:	BOU1_1967
Type:	Small arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow. A spill has been used to model the flow over the structure and bypassing flow.

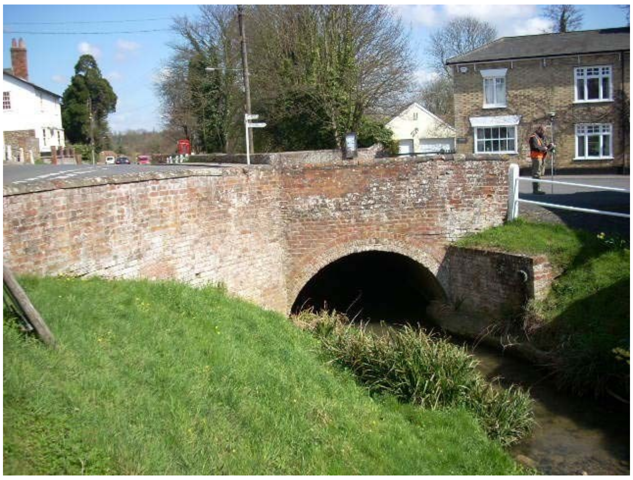
Name of structure	B.3.5 Access bridge – Rock Cottage

Name of structure	B.3.6 Foot bridge
Included in model (state reason if not):	Yes
Model label:	BOU1_1567
Type:	Flat deck bridge
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.7 Access bridge – Bracken house
Included in model (state reason if not):	Yes
Model label:	BOU1_1300
Type:	Flat deck bridge, concrete construction with brick parapets.
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.7 Access bridge – Bracken house

Name of structure	B.3.8 Culvert - Radwinter road
Included in model (state reason if not):	Yes
Model label:	BOU1_1229
Type:	Small arched bridge – brick construction
How has structure been modelled?	Sprung arch culvert units have been used to model flow in the channel below the soffit. Lateral spill connect to storage on the right bank upstream allowing water to bypass the structure.



Name of structure	B.3.9 Foot bridge
Included in model (state reason if not):	Yes
Model label:	BOU1_901
Type:	Small arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	**B.3.9 Foot bridge**

Name of structure	**B.3.10 Access bridge – Grove Cottage**
Included in model (state reason if not):	Yes
Model label:	BOU1_833
Type:	Flat deck footbridge
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	**B.3.11 Road bridge**
Included in model (state reason if not):	Yes
Model label:	BOU1_658
Type:	Arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.11 Road bridge
	

Name of structure	B.3.12 Footbridge
Included in model (state reason if not):	Yes
Model label:	BOU1_464
Type:	Flat deck wooden bridge
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.
	

Name of structure	B.3.13 Road bridge – Bartlow road
Included in model (state reason if not):	Yes
Model label:	BOUR01_81
Type:	Flat deck bridge
How has structure been modelled?	An orifice unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.13 Road bridge – Bartlow road

Name of structure	B.3.14 Footbridge
Included in model (state reason if not):	Yes
Model label:	ASHD02_88
Type:	Small arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.15 Access bridge – Newnham Hall Farm)
Included in model (state reason if not):	Yes
Model label:	ASHD03_6
Type:	Small arched bridge – brick construction
How has structure been modelled?	An arched bridge unit has been used to model in channel flow. A spill unit has been used to model flow over the bridge and bypassing flow.

Name of structure	B.3.15 Access bridge – Newnham Hall Farm)
	

B.4 STORAGE

This section deals with the floodplains within the model.

Floodplain Data Sheet

Name of Floodplain	**B.4.1 Ashdon village (Village hall side)**		
Model Labels:	BOU1_1229R		
OS Grid Refs:	558686 242104		
Approx. Area (m^2):	2,715m^2		
Source of Topographic Data:	Surveyed levels	**Method of modelling:** *(extended cross-section, reservoir unit?)*	Reservoir
Fill/ Emptying mechanism:	The reservoir unit is connected to two lateral spill units. One lateral spill on the right bank of the Bourn between BOUR01_1229 and BOUR01_1229d and the other lateral spill on the left bank of the Tributary 2 between ASHD02_6 and ASHD02_6d.		
Is this active storage or Conveyance:	Storage		
Any other relevant details/ comments:	This storage area is in all models. The area-elevation relationship has been derived from the surveyed levels. Lateral spill connected to the Bourn levels have also been adjusted in the options runs.		

Floodplain Data Sheet

Name of Floodplain	**B.4.2 Bourn Upstream Storage (Mitigation measure)**		
Model Labels:	RESIF		
OS Grid Refs:	559290 240510		
Approx. Area (m^2):	37,700m^2		
Source of Topographic Data:	SAR	**Method of modelling:** *(extended cross-section, reservoir unit?)*	Reservoir
Fill/ Emptying mechanism:	A ReFH boundary representing the catchment upstream of Water End fills the reservoir unit. A QH control unit empties the reservoir unit.		
Is this active storage or Conveyance:	Storage		
Any other relevant details/ comments:	This storage area is only present in the models evaluating upstream storage options. The area-elevation relationship used in ISIS has been derived from SAR.		

B.5 SENSITIVITY

B.5.1 Details of sensitivity runs

The 100-year model was tested for sensitivity to:

- Increased flow: an increase of 20% was used to test sensitivity to the uncertainty in design flows.
- Reduced flow: a reduction of 20% was used to test sensitivity to the uncertainty in design flows.
- Increased channel and bank hydraulic roughness values by 20%.
- Reduced channel and bank hydraulic roughness values by 20%.
- Downstream boundary condition.

Table B.5. 1 summarises the results of the sensitivity analysis on flows and hydraulic roughness.

Table B.5. 1 Results of the Sensitivity Tests

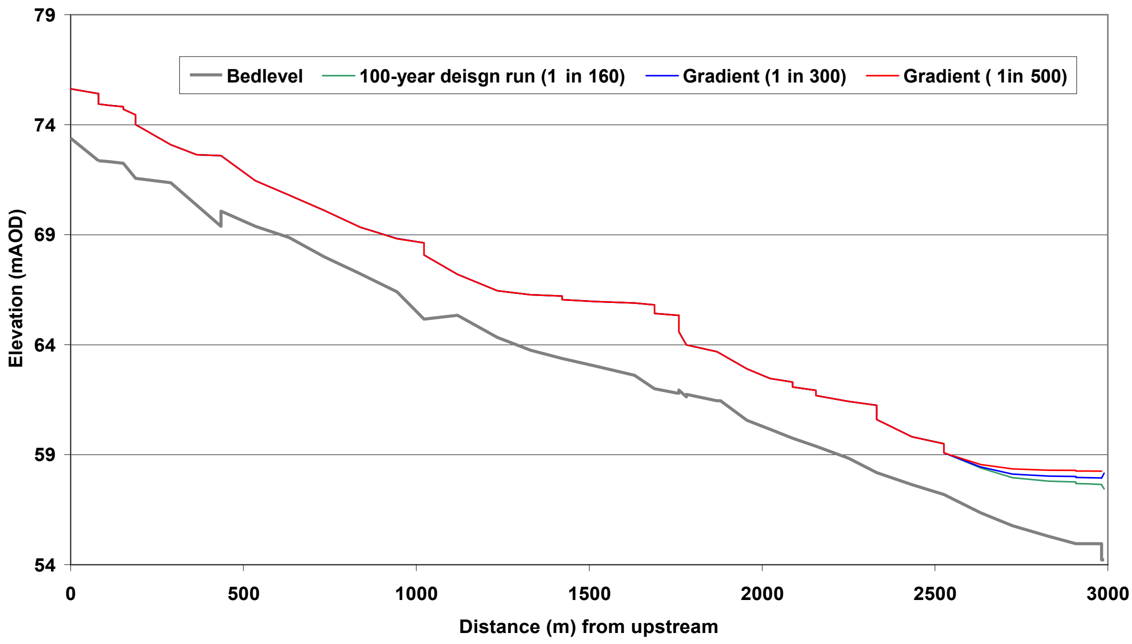
Change to the Model	Mean Change in peak water levels (m)	Maximum increase in peak water levels (m)	Maximum decrease in peak water levels (m)
Increased roughness	0.11	0.20	-
Reduced roughness	-0.12	-	0.22
Inflows increased by 20%	0.16	0.33	-
Inflows reduced by 20%	-0.18	-	0.36

The mean changes in water levels in the tables above are relatively small. Decreased flow has the largest effect on water levels, both in terms of mean change and maximum fall. The largest changes in water levels are found upstream of structures due to restriction in the channel.

An increase in roughness by 20% (0.055 to 0.066 and 0.075 to 0.090) produced an average increase in water level of 0.11 m. A decrease in roughness by 20% (0.055 to 0.044 and 0.075 to 0.060) produced an average decrease in water level of 0.12 m.

It is important to realise that all these sensitivity tests have only examined the impact on the magnitude of the 100-year flood levels. Changes in hydraulic roughness may have a greater relative effect on the magnitude and frequency of more minor floods, for example due to the fact that more of the flow will be in-bank.

The downstream boundary is defined by a normal depth boundary condition with user defined gradient of 1 in 160. As part of the sensitivity analysis, the water levels used were raised by changing the gradient (1in 300 and 1 in 500) at the downstream boundary to see how far upstream any effect would persist. It was shown that the effect of the downstream boundary would only influence water levels up to 360m upstream of the last section of the model, meaning the study reach in Ashdon is not affected. The long section below shows this graphically.



Sensitivity to downstream boundary

B.6 CALIBRATION

B.6.1 General Approach to Calibration

The model has been calibrated for June 2007 flood levels, using the best available data. There is no flow data available to calibrate the model through Ashdon as the only river gauge is downstream at Linton. The available data are flood levels at 5 locations and time to peak at one location.

During June 2007 flood event, the Bourn channel was blocked significantly at two locations. This needs to be represented in the hydraulic model to calibrate the model for June 2007 event. The Bourn was completely blocked upstream of the footbridge to Brook house by washed away wooden sleepers. This has been represented in the model by a weir at section BOUR01_1567. The partial blockage happened upstream of section BOUR01_901 was represented by changing bed level of Arch bridge unit at section BOUR01_901.

Channel and floodplain roughness were kept the same as in section B.2.1. The flows estimated using ReFH Flood Modelling software was input to model the observed flood levels and time to peak; details are given in section4.1, Appendix A.

Table6. 1shows comparison of modelled and observed flood levels.

Table6. 1Recommended design flows for each location

Location	ISIS Node	Flood levels		
		Observed (mAOD)	Modelled (mAOD)	Difference (m)
Footbridge to White Cottage, Water End	BOUR01_2836	74.74	74.73	0.01
Brook House, Ashdon	BOUR01_1567	65.97	65.94	0.03
Village Hall, Ashdon	BOUR01_1229R	64.58	64.58	0.00
Footbridge, Rogers End	BOUR01_0464	59.46	59.28	0.18
Knox End Cottage, Knox End	BOUR01_0081du2	56.84	57.19	-0.35

The observed and modelled flow peak time is the same, 14-June-07 at 21:30.

B.7 MODEL RUNS

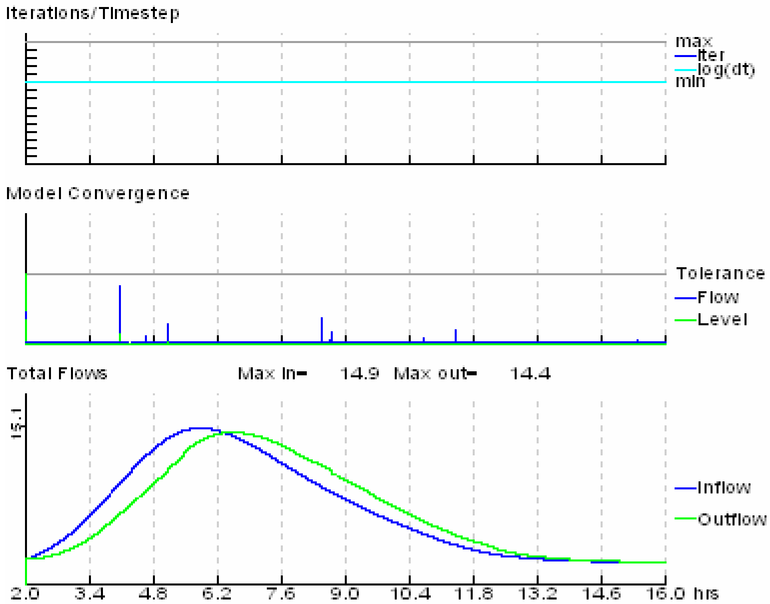
This section deals with every model run which has been included in the Hydraulic Modelling Report.

ISIS Model Run Summary Sheet

<table>
<tr><td>RUN REFERENCE</td><td colspan="3">B.7.1 Design runs – current scenario</td></tr>
<tr><td>Purpose of Runs:</td><td colspan="3">Baseline model run for comparison</td></tr>
<tr><td rowspan="5">ISIS Version:</td><td rowspan="5">3.0.0.27</td><td colspan="2">File names:</td></tr>
<tr><td>2yrv1_20per.dat</td><td>5yrv1_20per.dat</td></tr>
<tr><td>10yrv1_20per.dat</td><td>20yrv1_20per.dat</td></tr>
<tr><td>50yrv1_20per.dat</td><td>75yrv1_20per.dat</td></tr>
<tr><td>100yrv1_20per.dat</td><td>1000yrv1_20per.dat</td></tr>
<tr><td>Notes:</td><td colspan="3">All model files have identical geometry. The only difference between these models is the inflow hydrographs, which are for return periods 5, 10,20,50,75,100, 1000 and 100+20% years respectively.</td></tr>
<tr><td>Run Time:</td><td colspan="3">4 minutes</td></tr>
<tr><td>Return period(s) / dates of flow profile(s):</td><td colspan="3">2, 5, 10, 20, 50, 75, 100, 1000, 100CC (flows) and 100 CC (rainfall).</td></tr>
<tr><td>Boundary Conditions:</td><td colspan="3">Normal depth downstream boundary.
ReFH inflows upstream</td></tr>
<tr><td>Run Settings:</td><td colspan="3">Unsteady (Fixed timestep) run.
Timestep 10; maximum number of iterations increased to 15</td></tr>
<tr><td>Comments on results</td><td colspan="3">Some periods of poor convergence related to structures switching modes. This doesn’t have major effects on flow/stage hydrographs.</td></tr>
</table>

Simulation Time = 16.00 hours (100%)

Timestep = 3.0 seconds



Datafile: ...\ISIS\DESIGN EVENTS\2YRV1_20PER.DAT
Results: ...\ISIS\DESIGN EVENTS\2YRV1_20PER.zzl
Ran at 15:31:56 on 14/06/2008
Ended at 15:35:45 on 14/06/2008
Start Time: 2.000 hrs
End Time: 16.000 hrs
Timestep: 3.0 secs

Current Model Time: 16.00 hrs
Percent Complete: 100 %

ISIS Model Run Summary Sheet

<table>
<tr><td>RUN REFERENCE</td><td colspan="3">B.7.2 Mitigation Measures</td></tr>
<tr><td>Purpose of Runs:</td><td colspan="3">Assess the effect of the proposed schemes – upstream storage, widening openings, lowering channel bed and annual maintenance</td></tr>
<tr><td rowspan="5">ISIS Version:</td><td rowspan="5">3.0.0.27</td><td colspan="2">File names:</td></tr>
<tr><td>2yrMM1v1.dat</td><td>5yrMM1v1.dat , 5yrMM2v1.dat</td></tr>
<tr><td>10yrMM1v1.dat , 10yrMM2v1.dat 10yrMM3v1.dat</td><td>20yrMM1v1.dat , 20yrMM2v1.dat, 20yrMM3v1.dat, 20yrMM4v1.dat</td></tr>
<tr><td>50yrMM4v1.dat</td><td>75yrMM4v1.dat</td></tr>
<tr><td colspan="2">100yrMM4v1.dat</td></tr>
<tr><td>Notes:</td><td colspan="3"></td></tr>
<tr><td>Run Time:</td><td colspan="3">3 minutes</td></tr>
<tr><td>Return period(s) / dates of flow profile(s):</td><td colspan="3">2,5,10,20, 50, 75 and 100</td></tr>
<tr><td>Boundary Conditions:</td><td colspan="3">Normal depth downstream boundary.
ReFH inflows upstream</td></tr>
<tr><td>Run Settings:</td><td colspan="3">Unsteady (Fixed timestep) run.
Timestep 5; maximum number of iterations increased to 15</td></tr>
<tr><td>Comments on results</td><td colspan="3">Some periods of poor convergence related to structures switching modes. This doesn't have major effects on flow/stage hydrographs.</td></tr>
</table>

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