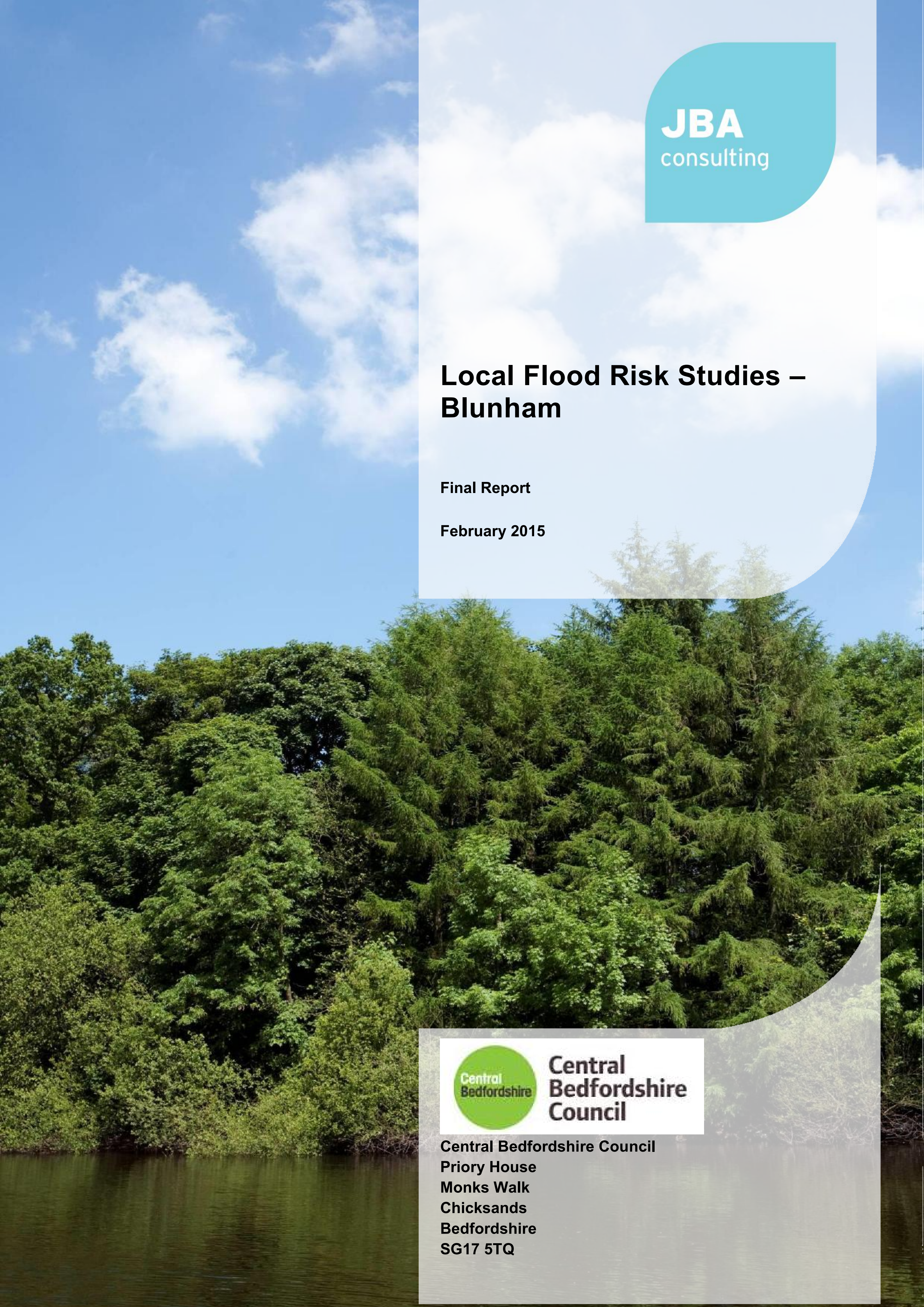

Local Flood Risk Studies – Blunham

Final Report

February 2015

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
Draft Report v1.0 (November 2014)		Iain Finnigan, Central Bedfordshire Council
Final Report v1.0 (December 2014)		Iain Finnigan, Central Bedfordshire Council
Final Report v2.0 (February 2015)	Updated Recommendations	Iain Finnigan, Central Bedfordshire Council

Contract

This report describes work commissioned by Central Bedfordshire Council, by a letter dated 07 July 2014. Central Bedfordshire Council's representative for the contract was Iain Finnigan. Joanne Chillingworth, David Kearney, Andrew Waite and Enora Lucas of JBA Consulting carried out this work.

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Purpose

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JBA Consulting has no liability regarding the use of this report except to Central Bedfordshire Council.

Acknowledgements

JBA Consulting would like to thank Central Bedfordshire Council, Anglian Water, Thames Water, the Environment Agency for their data provision, and Blunham Parish Council for their local knowledge and assistance with the study.

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Executive Summary

Introduction

JBA Consulting was commissioned by Central Bedfordshire Council in July 2014 to undertake three Local Flood Risk studies to better understand flood risk in these communities and to consider small-scale options available to reduce flood risk. This report focuses on flood risk in Blunham.

The flood risk study includes hydrological analysis to obtain river inflows for a variety of flood events, the construction of a hydraulic model to determine existing flood risk mechanisms, and an assessment of small-scale flood mitigation options using the hydraulic model. A preferred option will be identified and indicative costs provided where a solution may be viable.

Approach

Peak flows for a variety of flood events were derived using FEH methodologies, and were input into the hydraulic model at the upstream model extent and representing other small incoming surface water flow routes down the catchment. The modelled flood events were the 5-year, 20-year, 30-year, 100-year, 100-year plus climate change (100-year+25%) and the 1,000-year return period flood events.

A new hydraulic model was constructed of the watercourse for a distance of approximately 0.5km, based on channel topographic survey collected by Maltby Land Surveys Ltd. The hydraulic model used ESTRY-TUFLOW software, and used head vs. time hydrographs from the River Ivel's 5-year flood event as the downstream boundary. The floodplain was represented by detailed 1m LIDAR ground level data providing a good level of accuracy.

A number of assumptions and limitations have been recorded based on data availability and data quality checks, with recommendations for improvement.

Baseline model results

Baseline modelling identified key flooding locations and mechanisms, which allowed the identification of several small-scale flood mitigation options for the options modelling phase. Key locations included the High Street road due to water spilling out of bank at the culvert, which is heavily silted, and in higher return period flood events along part of the Tempsford Road.

Blockage analysis was also undertaken at the High Street culvert simulating a 90% blockage, as a 75% blockage was incorporated into the existing condition due to heavy siltation.

Flood mitigation options testing

A number of small-scale flood mitigation options were tested in the baseline model to try and reduce flood risk in Caddington. The following options were tested:

Option	Action
Option 1	Channel conveyance improvements, including simulating the high street culvert as unblocked.
Option 2	Upsizing the high street culvert to improve conveyance.
Option 3	Combining Options 1 and 2 above.
Option 4	Upsizing the high street culvert and diverting to the other side of Tempsford Road.

Preferred option

Based on the analysis of flood extents and water peak water levels of the 100-year plus climate change event the recommended preferred option for reducing flood risk to Blunham is the following:

- Improved channel conveyance along the length of the watercourse to remove dense vegetation <u>and</u> siltation from the culvert. This was modelled as Option 1.
- Upsizing the High Street culvert. As part of Option 1, blockage was removed from the culvert which was assumed to be a build-up of silt. The recent CCTV survey shows

elements of the culvert are displaying surface cracks and crazing and therefore further monitoring is recommended and if possible the opportunity should be taken to upsize the culvert to provide increased capacity. At the culvert replacement stage, the potential for diversion should be explored to decide whether the culvert's existing alignment should remain, or whether it should follow a different route away from the Tempsford Road property.

Indicative costs based on the Environment Agency's 2010 update to the 2007 Unit Cost Database have been provided for the preferred option, which may highlight to CBC which parts of the preferred options are viable or not for further detailed consideration. An indicative total cost for the preferred option (culvert upsizing and improved channel conveyance for an estimated 200m reach) is in the region of £157,860. Approximately £157,205 of this would be for the culvert upsizing at the High Street. This cost would increase if a diversion was installed due to the additional length required. It is recommended at this stage to add a 50% contingency pending more detailed hydraulic modelling, site investigation and detailed design.

Recommendations

- It is recommended that before any of the options are considered further or designed, that the hydraulic model should be updated with more accurate information to ensure that the representation of flood risk is as accurate as possible. A detailed design would then be recommended for the preferred option, in order to refine results, dimensions and costs. The design process will need to be followed to ensure suitable and robust options are produced for each area. This is summarised by the RIBA Plan of Work 2013 Stage[1]. Works are likely to be CDM applicable and therefore a CDM coordinator would need to be appointed.
- At present a number of modelling assumptions have been made due to the accuracy of the existing data. Improved topographic data in the heavily vegetated topographic depression would allow a more accurate representation of flow paths preceding the flapped culvert inlet, in addition to the other model improvements outlined in Section 2.6.3.
- If property threshold survey becomes available, it could be incorporated into the model to improve the representation of flood risk near properties.
- With the current condition of the channel being predominantly densely vegetated, improvements to the channel conveyance are recommended, such as by cutting back/ removing vegetation and culvert clearance (of silt/ debris) to prevent flows being impeded in the event of a flood. This may require an ecology survey to be undertaken. To improve the flow conveyance through the channel an option was modelled to simulate the removal of vegetation to increase channel capacity which is included in the preferred option. It is recommended this is carried out.
- The culvert under the High Street is shown in the site visit to be heavily silted at the downstream face, and Central Bedfordshire Council also believe that from a recent CCTV survey, elements of the culvert are displaying surface cracks and crazing, therefore continued monitoring of the condition of the culvert is recommended to CBC Highways.
- If the culvert diversion option is to be explored further, it is recommended to collect channel topographic survey data of the drainage ditch/ Ivel flapped outlet on the opposite side of the Tempsford Road to improve model representation and interaction with the River Ivel (currently represented by coarsely lowering LIDAR topographic levels along a single cell alignment with no flap valve present). Services under the road should also be investigated as to inform the feasibility of this option.
- Asset and riparian ownership should be established in Blunham to allow CBC to identify where works are necessary and who has responsibilities for these works. The 2003 report suggests that the responsibility for other piped systems and open ditches is not established but that if they are under roads they are likely to be the responsibility of the Bedfordshire County Council as highway authority, but elsewhere the owner of the land which piped and ditches pass will be responsible.
- If the preferred option, or aspects of the preferred option, are found to be unviable due to costs, it is recommended that property level protection (PLP) is considered, which would provide more specific flood protection to the properties which have flooded historically.

[1] RIBA Plan of Work 2013 http://www.ribaplanofwork.com/About/Concept.aspx

- New developments or changes in land practices within the catchment which could alter the flows draining to the watercourse or surface water overland flow patterns should be considered and modelled in more detail.
- The costs provided in this report are approximate, based on the EA's 2010 Unit Cost Database update, pre-feasibility information and broadscale modelling, and hence a contingency of 50% should be added. They aim to show an outline indication and comparison between different flood mitigation options, and should be improved based on more detailed information when available. A full cost-benefit analysis should be undertaken once the model has been refined.

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Abbreviations

CBC .... Central Bedfordshire Council
CC .... Climate change
CCTV .... Closed-circuit television
1D 1-dimensional
2D 2-dimensional
DEFRA .... Department for Food and Rural Affairs
DTM .... Digital Terrain Model
EA .... Environment Agency
ESTRY .... 1D hydraulic modelling software
FEH .... Flood Estimation Handbook
GIS .... Geographical Information Systems
Ha .... Hectares
HQ .... Head vs. Flow boundary
LIDAR .... Light Detection and Ranging

LFRM .... Local Flood Risk Management
M AOD .... Metres Above Ordnance Datum
OS.................................... Ordnance Survey
PLP .... Property Level Protection
ReFH............................... Revitalised Flood Hydrograph
uFMfSW .... Updated Flood Map for Surface Water
URBEXT .... Urban Extent

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1 Introduction

1.1 Terms of Reference

JBA Consulting were commissioned by Central Bedfordshire Council in July 2014 to undertake three Local Flood Risk studies to better understand flood risk in the communities of Caddington, Wrestlingworth and Blunham, and to consider small-scale options available to reduce flood risk. This report focuses on Blunham.

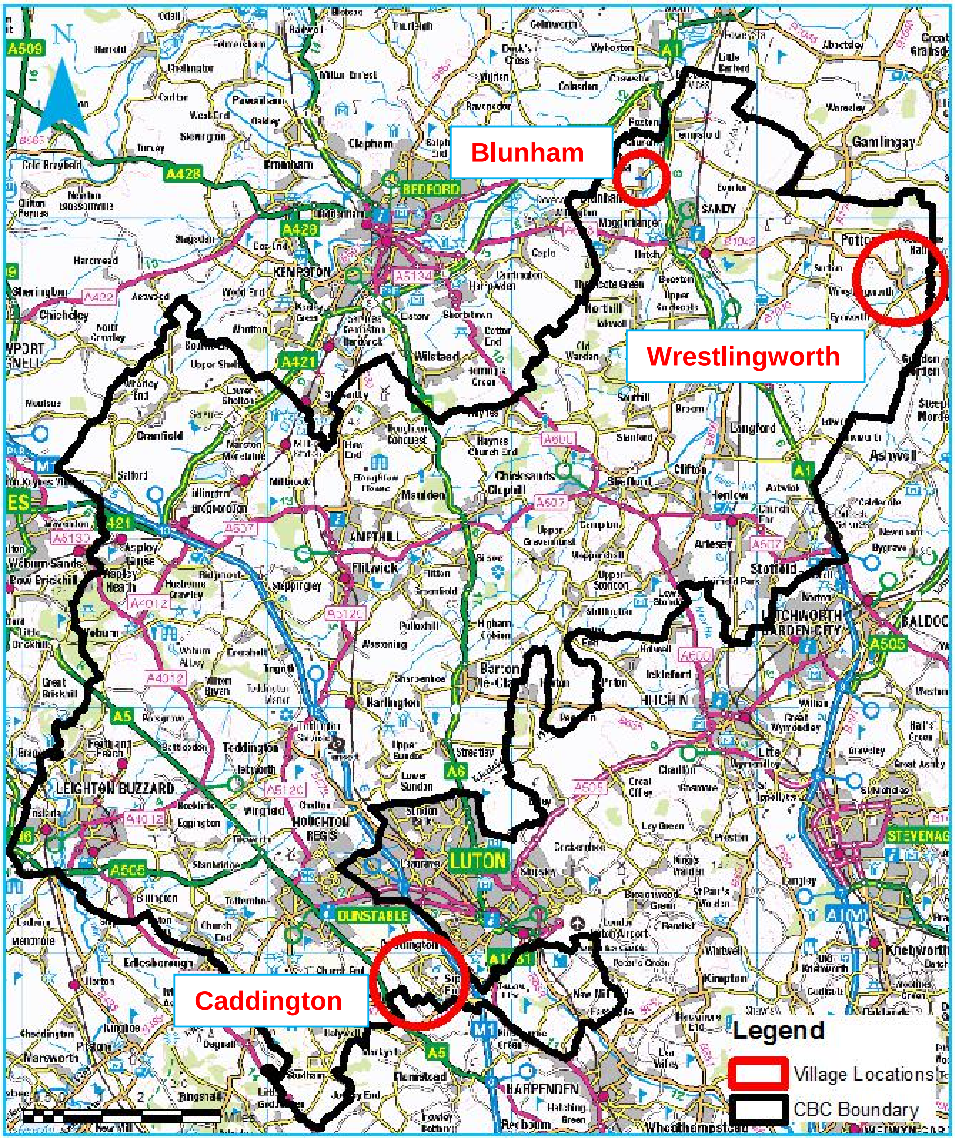
1.2 Scope of the study

The flood risk study includes a hydrological analysis to obtain river and surface water estimates over the study catchment for a variety of flood events, the construction of a hydraulic model per village to determine existing flood risk mechanisms, and an assessment of small-scale flood mitigation options using the hydraulic models. A preferred option will be identified and indicative costs provided where a solution may be viable.

1.3 Study area

The study area for the Local Flood Risk Studies is presented in Figure 1-1 below. Wrestlingworth and Blunham are located in the north-western corner of the Central Bedfordshire County boundary, with Caddington located in the south-eastern corner near Luton.

Figure 1-1: Local Flood Risk Studies - Study Locations



1.4 Blunham background

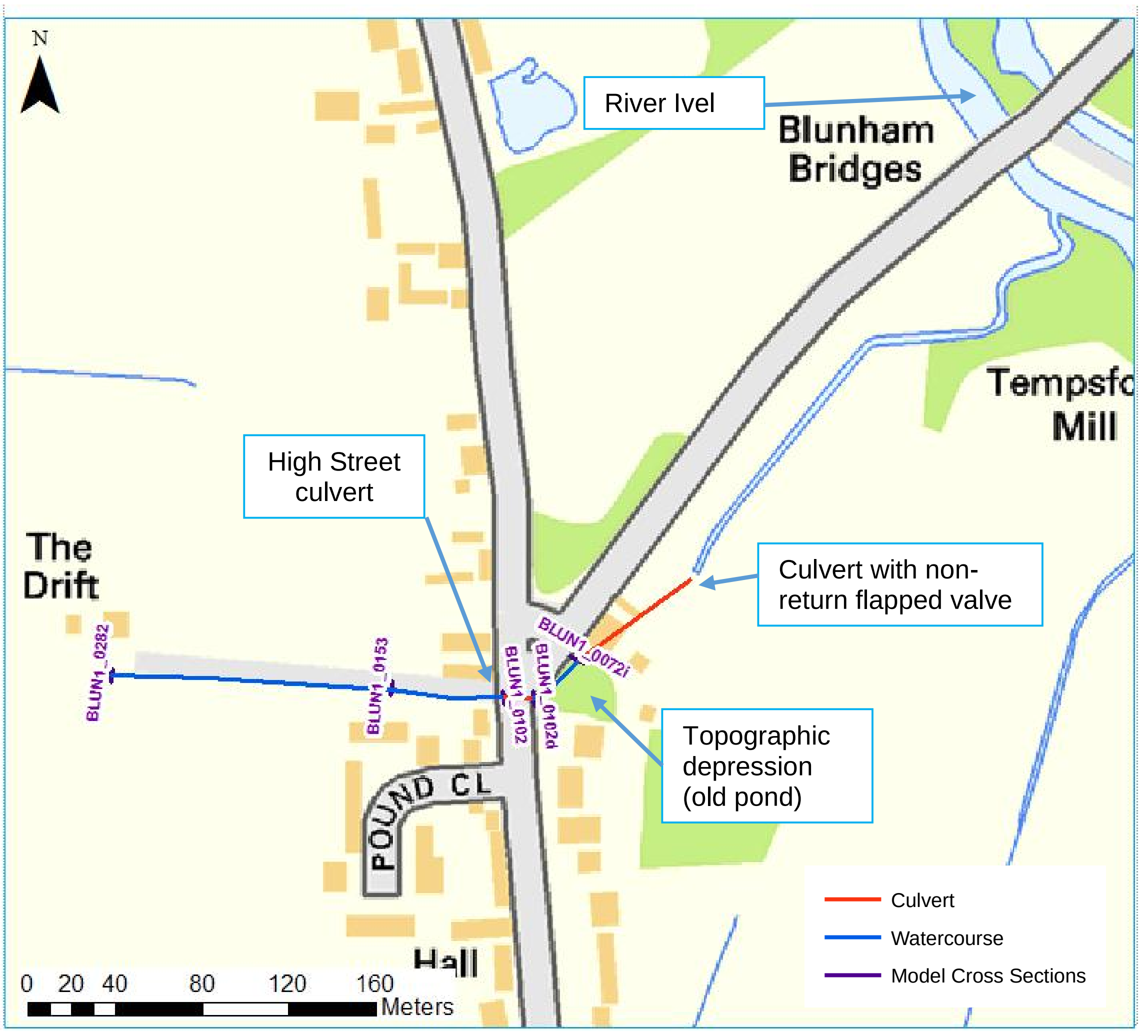
Blunham is situated in the north-east corner of the CBC boundary, and is a small village near Sandy. To the north of the village, the study drain joins the River Ivel, with the village having a double humpback bridge over the River Ivel and the Mill Stream. The drain to be modelled flows from the west of Tempsford Road/ High Street road junction, under this road junction, through a small depression and out to the River Ivel via a flapped sluice structure which prevents the River Ivel from backing up the drain, parallel with Tempsford Road.

The watercourse extent to be modelled is approximately 0.5km long to its downstream confluence with the River Ivel. The drainage catchment is very small due to the number of other drains in the locality, and the River Ivel catchment.

The Soil Map of England and Wales shows generally freely-draining and loamy, with loamy, clayey floodplain soils at the downstream end along the River Ivel. There is no attenuation in the catchment from reservoirs and the catchment is characterised as essentially rural with some degree of permeability in the soils.

Figure 1-2 shows the study area in Blunham.

Figure 1-2: Blunham Study Area



1.5 Flooding in Blunham

With regards to flooding mechanisms, flooding occurs primarily from the high street culvert being undersized and displaying surface cracks and crazing, essentially causing a blockage (along with heavy vegetation in the channel) with water flowing rapidly downhill towards the culvert and backing up, and spilling onto the road junction.

The 2003 report entitled 'Flooding Problems at Blunham', by David Noble and Associates, highlighted a flood event on the 2nd-3rd January 2003 due to extremely high levels in the River Ivel, flooding into Blunham affecting gardens and properties. The new non-return flapped valve at the culvert structure further downstream prevents water backing up from the Ivel, which has improved flooding conditions from this source of flooding in this part of Blunham.

Following flashy storms, the watercourse may respond to the sudden increase in water and cause out of bank flooding in the floodplain or at structures, which can sometimes affect properties and infrastructure in the village.

In the past, the overgrown topographic depression downstream of the high street culvert used to be a bigger pond providing more attenuation. At some stages the inflow to the pond would exceed the outflow capacity, causing water to overspill in numerous directions. There is less capacity now due to the heavily overgrown nature of the basin, which may further exacerbate flooding in this location. The 2003 report states that the outlet of surface water from lower Blunham is via the village pond, through a culvert and then open channel towards the River Ivel. Surface water enters the pond by a piped drain running alongside the east of High Street, and through a culvert beneath high street fed by an open ditch draining predominantly agricultural land to the west (the study ditch). This ditch creates the highest flows at the culvert beneath high street, which even if free from siltation, is not designed to take exceptional flow and therefore accepting that overspilling on the highway would occur.

It is acknowledged that there may be more surface water overland flow routes than those able to be incorporated into the model. A meeting with the Parish Council highlighted that there are several flooding problems in Blunham, where other drains discharge into the old pond, or become full to capacity very quickly and hence surface water runoff is an issue. It is also believed that land use practice changes over time in the upper catchment cause water to runoff in the village much more rapidly now, in the vicinity of the public house.

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2 Approach

2.1 Context

This study has been commissioned to improve the understanding of local flood risk issues in Blunham. To do this, a hydraulic model has been constructed to simulate existing flood risk and identify flooding mechanisms. This model has then been used to test several small-scale flood mitigation measures aimed at reducing flood risk. A 'preferred' option will be chosen, discussed with the Parish Council and CBC regarding the viability of the option, and informed by indicative costs.

2.2 Data Availability

Table 2-1: Data Availability for the Local Flood Risk Studies

Data	Source	Comment
Mastermap OS Mapping	CBC GIS Team	For channel survey, 2D materials files, and mapping
Watercourse surveys	Maltby Land Surveys Ltd	Channel topographic survey (including structures)
uFMfSW DTM	CBC	No LIDAR data present so DTM from the uFMfSW has to be used
Highways/ drainage gully locations and sizes	HA/ CBC	No information provided
Surface Water GIS data	Anglian Water (Blunham and Wrestlingworth)	Data provided but mostly foul water
Surface Water GIS data	Thames Water (Caddington)	Data provided. Manhole cover levels used to improve representation of road levels where differences in survey/ uFMfSW found
River Ivel model	Environment Agency	To attach to Blunham as the downstream boundary
Observed rainfall data	Environment Agency	To compare against modelled rainfall events *Not yet received, but no longer required with the removal of rainfall from the model*
Old reports/ drawings	CBC	Caddington Flood Relief Scheme drawings, Wrestlingworth Surface Water Drainage Investigation (1991), Flooding Problems at Blunham (2003)

2.3 Hydrology

2.3.1 Fluvial Flows

The hydrological analysis is fully documented in the FEH Calculation Record, in Appendix A, which should be read in conjunction with this section.

For the hydraulic modelling, the following return period events were modelled: 5-year, 20-year, 30-year, and 100-year, 100-year + CC and the 1,000-year. Regarding Climate Change, the 100yr + 25% (peak river flow to 2115) was considered, in line with the September 2013 EA guidance ‘Climate change allowances for planners: Guidance to support the NPPF’, for Anglian and Thames catchments.

Catchment descriptors were obtained from a nearby catchment on the FEH CD-ROM v3.0[1], and applied to a manually drawn catchment boundary based on OS 1:10,000 and 1:50,000 scale mapping and 1m LIDAR. This is because the catchment is so small it is not recognised on the FEH CD-ROM. The catchment boundaries are shown in Figure 2-1.

The FEH statistical method and the Revitalised Flood Hydrograph (ReFH) method were used to derive fluvial flows in the Blunham catchment. The FEH statistical method benefits from an up-to-date flood peak dataset, sourcing flow estimates on growth curves from hydrologically similar catchments (pooled analysis). The ReFH method is a rainfall-runoff approach. The ReFH estimates were slightly higher than the Statistical estimates. As there are no suitable donor gauges available to improve flow estimates, both methods have calculated flows from catchment descriptors alone. There was very little difference between the peak flows from both methods, therefore the ReFH peak flows were adopted for inclusion in the hydraulic model as these were slightly more conservative and the method provides time vs. flow hydrographs for the modelling phase.

Table 2-2 shows the final peak flows that were applied to the upstream cross section of the model and Figure 2-1 shows the catchment inflow points.

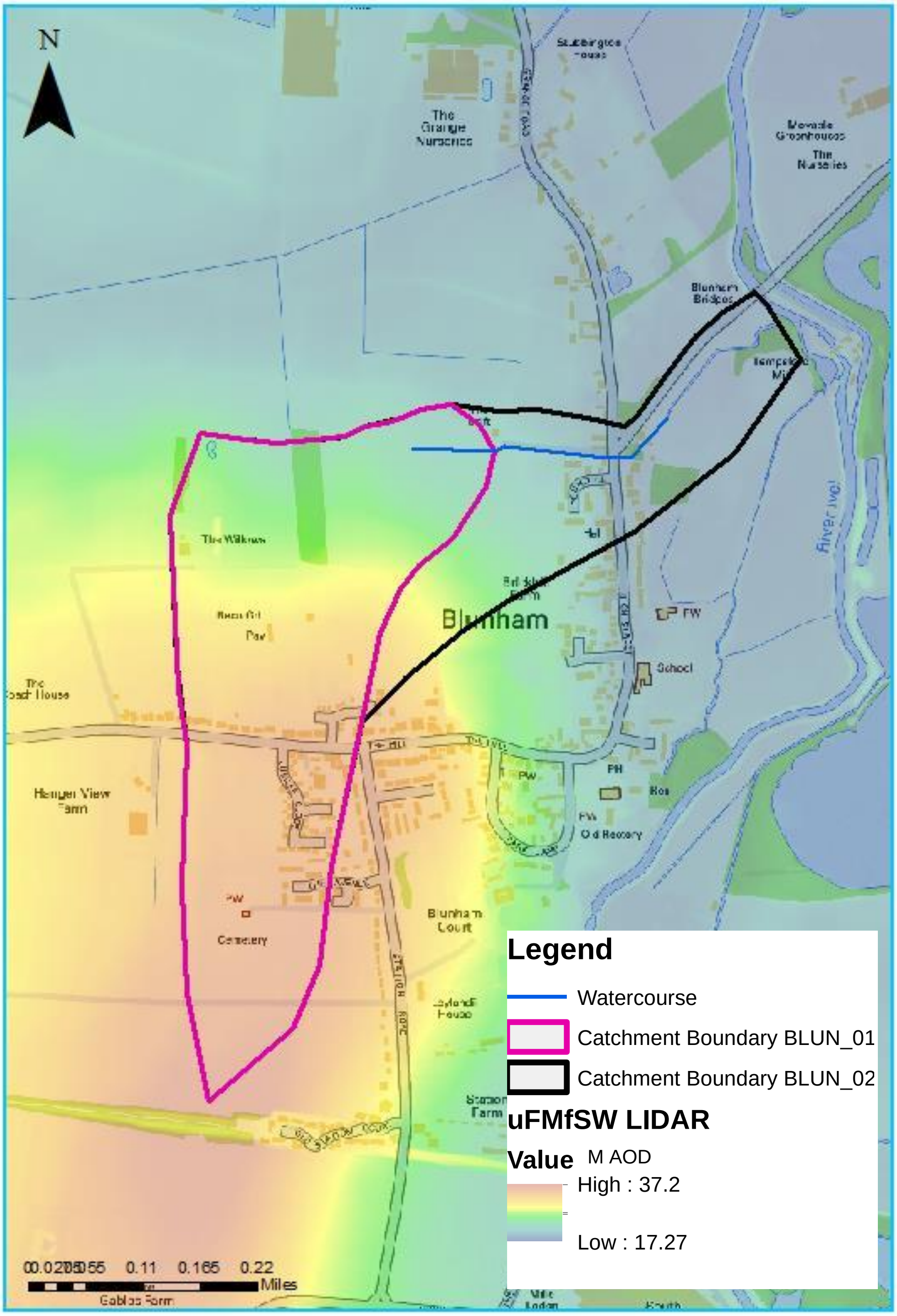
Table 2-2: Peak Flows

Site code	Flood peak (m3/s) for the following return periods (in years)									
	2	5	10	20	30	50	75	100	100+CC (25%)	200	1,000
BLUN_01	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.07	0.09	0.09	0.17

The Environment Agency's Surface Water flood map does not show any significant areas of water ponding in the vicinity of the study area, therefore it can be assumed that flood risk is fluvial-driven.

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

Figure 2-1: Blunham Catchment Inflows



2.4 Model Construction

2.4.1 Method and model software

Standard hydraulic modelling approaches have been used to build and develop the models. These have been discussed in more detail in the hydraulic model check files which can be found in Appendix B. This document should be read in conjunction with this chapter.

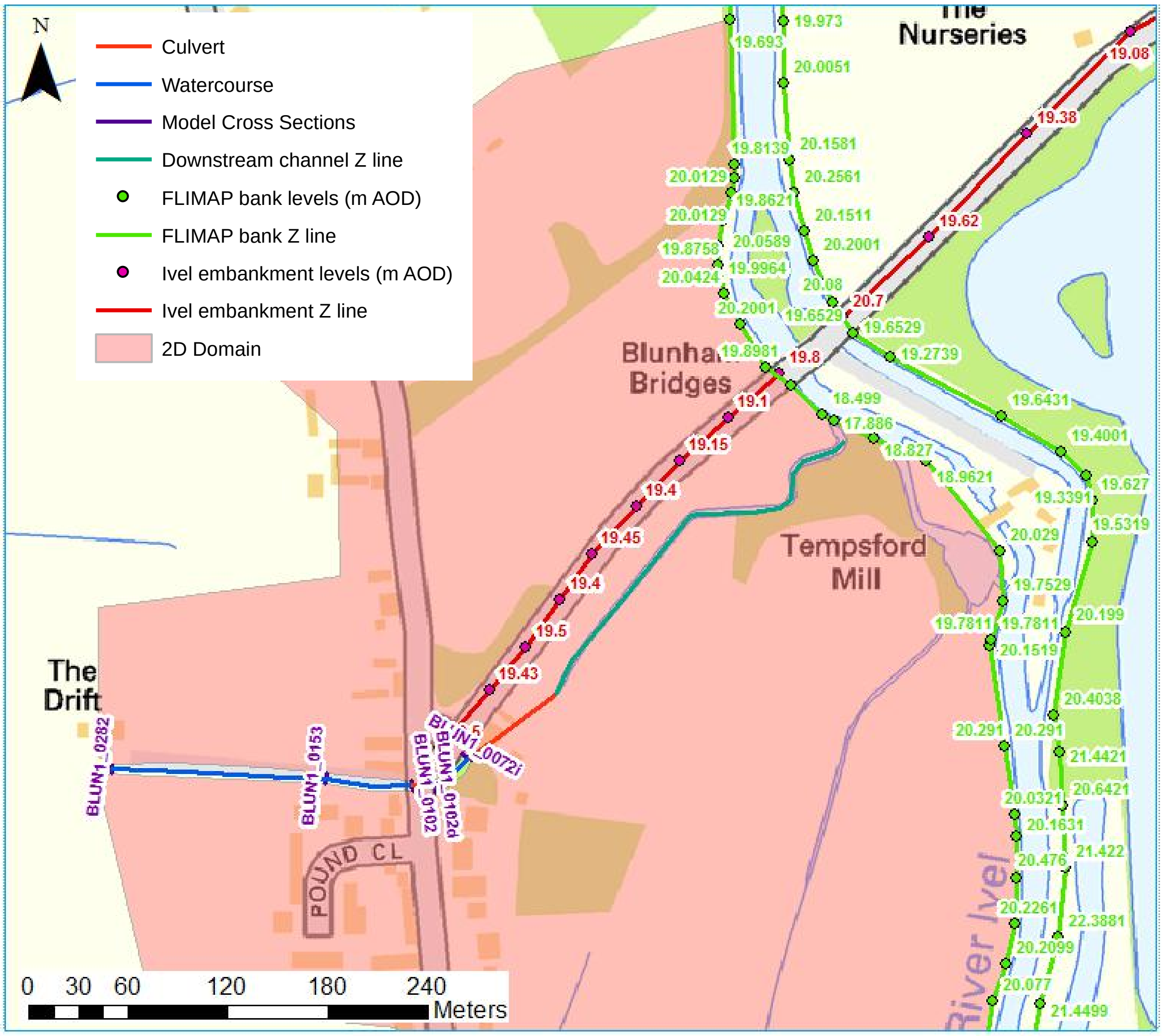
The 1D-2D ESTRY-TUFLOW modelling software was chosen to model this watercourse, because ESTRY better represents culverts and low flows than the ISIS software. TUFLOW is the 2D component of the model, when water flows out of bank into the floodplain.

There is an existing River Ivel ESTRY-TUFLOW model, created in 2010 as part of the River Ivel Hazard Mapping project. This was subsequently updated as part of an embankments stage 3 study in 2013, and was obtained from the Environment Agency. This model was re-run to obtain head vs. time hydrographs for the selected return period flood events, which were used as the downstream boundary to the Blunham drain model.

2.4.2 Model schematisation

The 1D-2D ESTRY-TUFLOW model extends from cross section BLUN1_0282 down to the confluence with the River Ivel, approximately 0.5km downstream. The 1D domain includes the river channel and small portion of the floodplain beyond the bank tops, collected by Maltby Land Surveys Ltd, with the rest of the floodplain represented by a 2D domain in TUFLOW. Figure 2-2 shows the model schematisation of the watercourse through Blunham. Further details on the model schematisation can be found in the hydraulic model check files in Appendix B, along with model cross section labels.

Figure 2-2: Hydraulic Model Schematisation



2.4.3 Model Geometry

The watercourse was represented in the 1D domain using cross sections constructed from newly collected channel survey, conducted by Maltby Land Surveys Ltd in August 2014. The survey included open channel cross sections at regular intervals as well as, where possible, the upstream face of structures. Interpolated sections were generated based on this survey to represent the downstream face of structures, assuming a constant gradient. The channel downstream of the non-return flapped valve culvert was represented in the 2D domain, with representative levels to allow water from the River Ivel to back up and fill like a channel. This part of the drain was not in the existing River Ivel model, and was not surveyed to form a part of this assessment in Blunham.

To form the basis of the 2D domain a digital terrain model (DTM) was directly read in by TUFLOW. Detailed 1m resolution LIDAR data was available in Blunham due to its proximity to the River Ivel.

In total the 2D domain has an area of 0.35km^2, with a 4m grid resolution. The orientation of the grid is west to east, which picks up the main direction of floodplain flows.

2.4.4 Model Parameters

Manning's n used to represent the channel and bank roughness was selected based on survey and site visit photographs. Typically channel roughness was set at 0.06 in the channel, which represents fairly vegetated scrub as shown in the photographs below, with bank tops the same, or more maintained at 0.04, which is a typical in-channel roughness value. The roughness of the 2D domain was determined by survey, photography (as shown below) and Mastermap data, and allows a detailed categorisation of floodplain features, such as roads, buildings and roadsides.

Figure 2-3: Photographs depicting channel characteristics

This photograph shows the drain facing upstream, with the heavy vegetation in the channel, hence applying a higher channel roughness value

This photograph shows the drain facing downstream towards the culvert and road junction

2.4.5 Key Structures

The key structures along the watercourse were captured in the channel topographic survey by Maltby Land Surveys Ltd. There are two modelled structures along the modelled reach; one being the small culvert flowing under the main high street, and the other being a longer flapped culvert preventing the River Ivel from backing up into this part of Blunham. For further details on how structures have been modelled and assumptions that have been made please refer to the hydraulic model check file in Appendix B.

The Ivel embankment levels and Tempsford Road levels from the existing River Ivel embankments model were applied in this model, to maintain consistency with the previous study.

2.4.6 Downstream boundary

The existing River Ivel ESTRY-TUFLOW model (embankment study update 2013) was re-run to obtain head vs. time hydrographs for the selected return period flood events. These were then applied along an interpolated downstream boundary allowing the interaction of the River Ivel to be appropriately represented without the need to construct a full confluence model. The 5-year flood event results were used from the Ivel as the watercourses would not peak at the same time, nor likely be a like-for-like flood event. The 5-year provides the interaction up the Blunham drain required without hindering the viewing of flooding results from the Blunham drain.

Within the 2D domain a normal-depth boundary has been applied.

2.5 Floodplain mapping

The flood outlines are provided in digital GIS format for all modelled return period events. The 1D-2D hydraulic model also outputs maximum flood water depth, water surface elevation, velocity, and hazard grids, which are available for both the baseline and options models.

2.6 Assumptions and Limitations

2.6.1 Limitations to modelling approach

During any hydraulic modelling study, there will always be associated limitations, for example with uncertainty, data availability and model stability.

The hydrological and modelling methodologies adopted were informed by best practice and this study was undertaken using the best available data. Flow estimates should be reviewed again in the event of a large flood in the area, or if a gauge is installed in the catchment.

New channel survey was commissioned for the watercourse in Blunham to provide channel cross sections to be used within the hydraulic model. In time, the model may need to be revised and/ or include more detailed bank top survey at more regular interval along the banks rather than allowing the hydraulic model to interpolate bank levels along these reaches. Although survey has been provided there are still a number of uncertainties relating to certain structures. The culvert underneath the High Street is believed to be displaying surface cracks and crazing and is heavily silted requiring a blockage to represent the existing situation. The culvert inlet in the heavily vegetated topographic depression was not recorded, requiring assumptions to be made based on upstream cross section geometry and the downstream dimensions of the culvert.

2.6.2 Data Quality check

A number of QA checks were performed on the topographic data to determine the accuracy and how it should be applied to the hydraulic model. The main data check involved the comparison of surveyed points within the floodplain by Maltby Land Surveys Ltd to the DTM from EA Geomatics, which is of a good resolution (1m). Checks were also made against the previous study maps and report where practical, though a report for the embankment study update was not available.

2.6.3 Improvements to the model

The following future improvements could be made to the model:

- Instabilities associated with the amount of water from the River Ivel be improved should more accurate data become available.
- Along the majority of the study reach, the elevations along the TUFLOW 'HX lines' are modified through use of topography Z line commands designed to set elevations to match the top of river bank elevations in the 1D model. This approach is acceptable but could be improved by more detailed top of bank survey data along the river reach to ensure that bank levels are accurately represented.
- More topographic data could be gathered in the area of the topographic depression where access is difficult, at the downstream end of the Blunham drain, and the drainage ditch on the other side of the Tempsford Road to explore the option of a culvert diversion. At present levels have been estimated from LIDAR altering a single cell alignment.

3 Model Results - Baseline

3.1 Flood Outlines

Flood outlines were produced for the 5-year, 20-year, 30-year, 100-year, 100-year plus climate change (25%) and 1,000-year return period flood events. Maps showing the flood extents for each return period can be found in Appendix C. Figure 3-1 shows the 5-year, 20-year and 30-year flood extents where flooding initially occurs. Figure 3-2 shows the remaining return periods flood outlines.

Figure 3-1: 5-year, 20-year and 30-year (Baseline) Flood Outlines

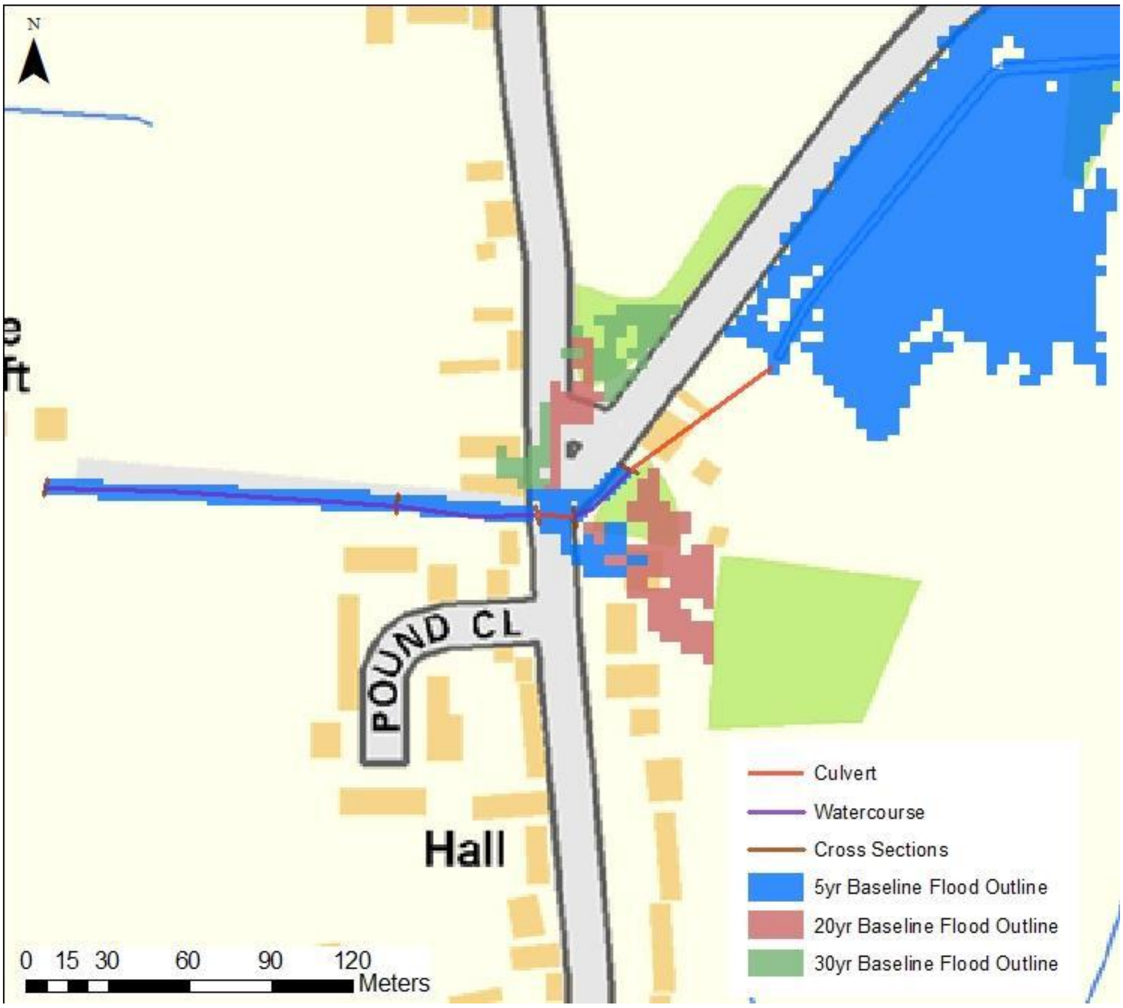
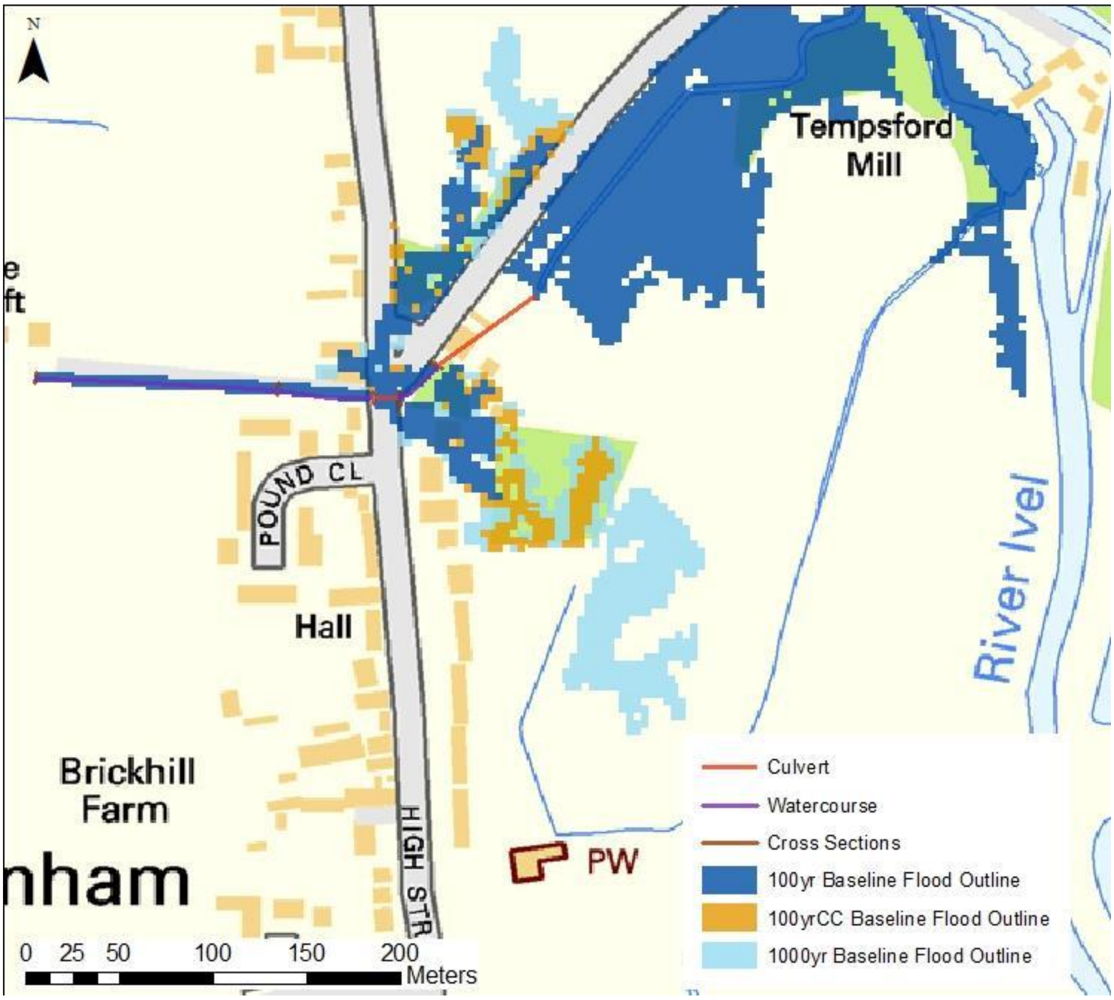


Figure 3-2: 100-year, 100-year plus Climate Change and 1,000-year (Baseline) Flood Outlines



3.2 Peak Water Levels

Table 3-1 shows the peak water levels for all the return periods for the baseline scenario at each cross section.

Table 3-1: Peak Water Level for Baseline Scenarios

Cross Section	Peak Water Levels (m AOD)					
	5-year	20-year	30-year	100-year	100-year +CC	1,000-year
BLUN1_0282	21.03	21.04	21.07	21.12	21.16	21.27
BLUN1_0153	19.74	19.76	19.77	19.8	19.82	19.93
BLUN1_0102	19.73	19.74	19.74	19.74	19.75	19.77
BLUN1_0102d	19.08	19.08	19.1	19.08	19.11	19.17
BLUN1_0072i	18.82	18.82	18.82	18.82	18.88	19.13

3.3 Flooding mechanisms identified

Based on the baseline scenarios a number of locations were determined to be sources of out of bank flows. Flooding occurs in the lowest modelled return period (e.g. 5-year) with flow shown to surcharge the culvert under the High Street and flow across the road. With greater return periods the flood extents extend to two directions: towards the junction of Tempsford Road and High Street and east towards the River Ivel. Flooding is shown to be caused by the backing up of water behind the High Street culvert but also potentially by the flapped outfall becoming significantly inundated to prevent flow.

It should be noted that the baseline scenario for the hydraulic model consisted of significant vegetated areas within the channel which were represented by a higher than average Manning's n of 0.06 or 0.075. Based on a site visit by JBA staff, a blockage was also added to the High Street culvert to account for heavy siltation of the downstream outlet and also that the culvert according to Central Bedfordshire Council staff that could be in poor condition / displaying surface cracks and crazing along its length. The High Street culvert was modelled as 75% blocked to represent the 'existing' condition. This is because photographic evidence from the site visit shows the culvert outlet as heavily silted.

The photograph below shows the culvert outlet:

Figure 3-3: Photograph depicting the blocked culvert outlet

The culvert outlet is significantly blocked with silt and material debris, hence a 75% blockage of the culvert has been modelled as the existing condition.
The photograph is looking upstream towards the road from the culvert outlet.

3.4 Blockage Scenarios

As well as model sensitivity runs, a 90% blockage was also tested at the High Street culvert. To assess how flood risk would be impacted if the culvert were to be blocked significantly. This is a realistic possibility given the relatively small dimensions of the culvert and the large amount of siltation and vegetation noted on site. Figure 3-4 & Figure 3-5 shows the blockage scenario for the 5-year and 100-year events.

Figure 3-4: Flood extent during the 5-year 90% blockage scenario

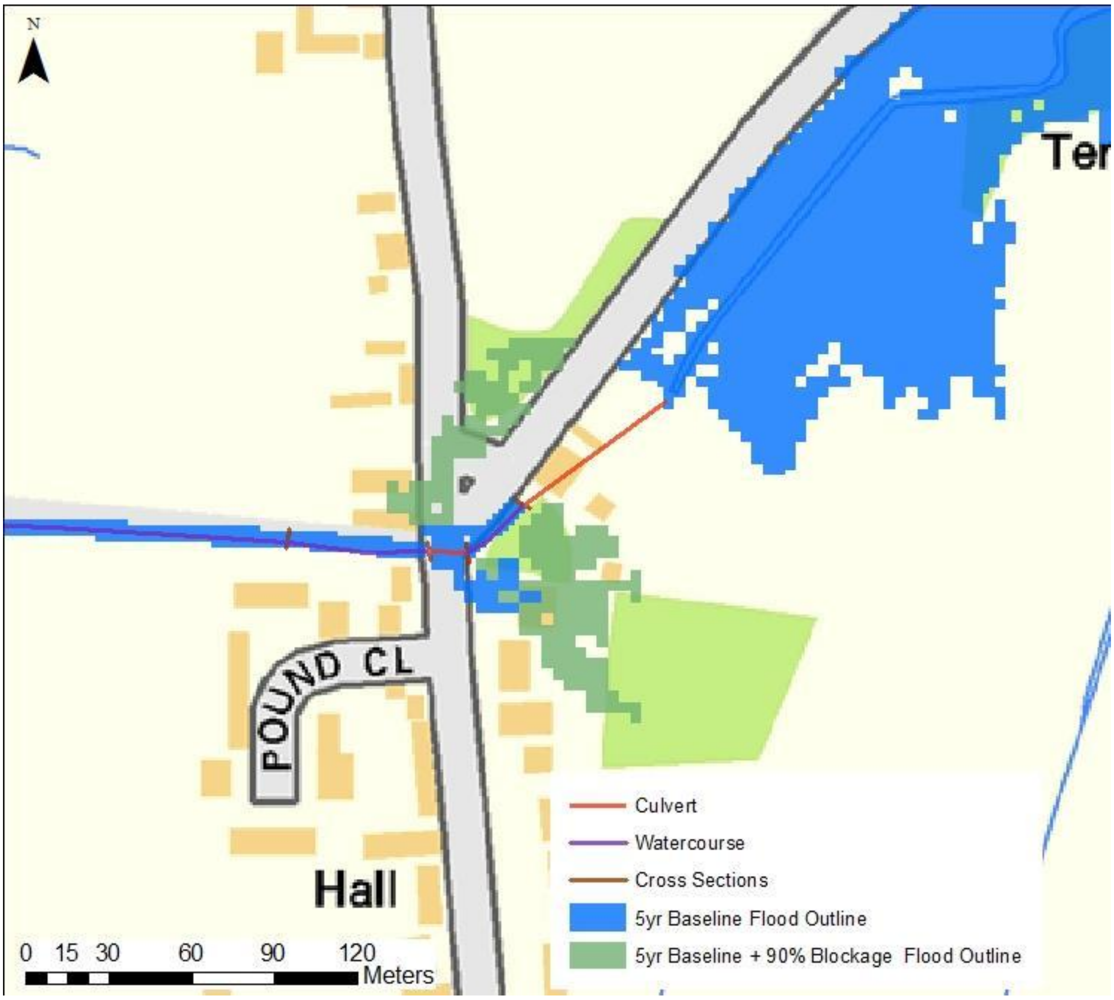


Figure 3-4 shows that with a 90% blockage there is a significant increase in flood extent compared to the baseline flood event for the 5-year event. Flood is still shown to be relatively shallow across the High Street with a maximum depth with the 90% blockage scenario of <0.05m.

3.5 Higher River Ivel Levels

A sensitivity test was also conducted using a higher return period flood event for the River Ivel stage vs. time hydrographs which are applied at the downstream boundary. Whilst the flood extent from the River Ivel up to the flapped valve on the Blunham drain was obviously larger, there were no significant differences noted around the High Street/ Tempsford Road junction area in terms of flood extent, as the flap valve would still prevent the water backing up the Blunham drain.

Figure 3-5: Flood extent during the 100-year 90% blockage scenario

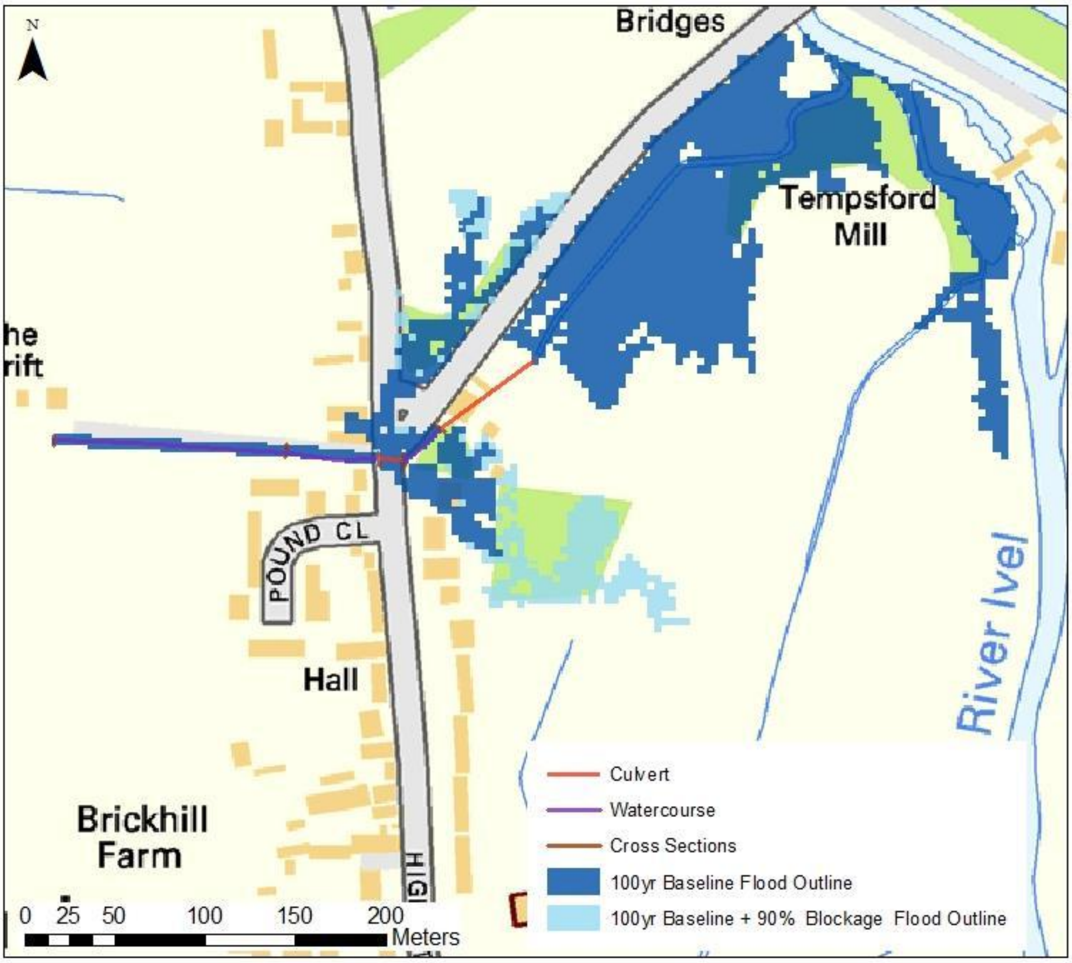


Figure 3-5 shows that with a 90% blockage there is a significant increase in flood extent compared to the baseline flood event for the 100-year event. Flood is still shown to be relatively shallow across the High Street with a maximum depth with the 90% blockage scenario of <0.05m although the flood extent is shown to increase. Elsewhere water is shown to flow in rural areas either side of the Tempsford Road.

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4 Flood Mitigation Options Testing

4.1 Small-scale mitigation options

In order to address flood risk at the local scale, a number of small-scale flood mitigation options were tested in the baseline model to try and reduce flood risk in Blunham.

The following options were tested:

Option	Action
Option 1	Channel conveyance improvements, including simulating the high street culvert as unblocked.
Option 2	Upsizing the high street culvert to improve conveyance.
Option 3	Combining Options 1 and 2 above.
Option 4	Upsizing the high street culvert and diverting it to the other side of Tempsford Road.

4.2 Previous Studies

The David Noble and Associates 2003 report considered options for flood mitigation. Several related to the River Ivel embankments and backwater effect, which have since been updated in a 2010 modelling study, and the installation of a non-return flapped valve. The options relevant to this study are to investigate the possibility of preventing property flooding accepting that on occasions water will surround them. PLP is mentioned as a potential solution.

It states that whilst beneficial improvements can be made to the local drainage system, this alone will not alleviate flooding, unless achieved through a more effective control of water backing up from the Ivel.

The 2003 report reported on evidence that the channel is heavily silted in places, and generally assumes an appearance indicating a lack of vegetation removal for some years.

4.3 Hydraulic model representation

The hydraulic model was amended to represent each of the options independently. Once it had been determined whether an option was viable at reducing flood risk, it was included within a combined option which would simulate the simultaneous application of options on flood risk.

4.3.1 Option 1 – Improved Channel Conveyance

The site visit undertaken in July 2014 highlighted that the channel contained dense vegetation in most locations, which would impede flows and reduce channel capacity in the event of a flood.

To improve the flow conveyance through the channel an option was modelled to simulate the removal of vegetation. To represent the removal of vegetation and hence improved channel conveyance, roughness was reduced in the channel cross sections by 20%, increasing channel capacity. The table below shows the typical channel roughness values of the baseline scenario and the option representing improved channel conveyance (which may require an ecological survey).

Scenario	Typical Channel Roughness (Manning's 'n')
Baseline	0.040 – 0.075
Option 1 – Improved channel conveyance	0.040 – 0.06

Additionally the culvert had a reduction in 'pBlockage' value from 75% to 0% assuming that the culvert was regularly cleared of siltation and that the condition of the culvert was improved with any damage within the culvert being repaired.

4.3.2 Option 2 – Upsizing the High Street culvert

To improve conveyance the High Street culvert was upsized to try and improve conveyance, lowering water levels and possibly reducing the about of out of bank flow upstream of culvert. Originally the structure was represented as a 'C' type circular culvert with a diameter of 0.30m. For the options testing this was changed to be an 'R' type rectangular culvert with a height of 0.30m and a width of 0.60m. This was determined to be the maximum size that the culvert could be upsized to without having to dramatically alter the channel cross section or the highway ground levels.

4.3.3 Option 3 – Combination

This option combined both the culvert upsizing and improved channel conveyance options outlined above.

4.3.4 Option 4 – Culvert upsize and Diversion

An option was explored at the meeting held with Blunham Parish Council on 13th November, which involves potentially diverting the culvert from its current inlet location, across the High Street and Tempsford Road junction, to an outlet on the other side of the Tempsford Road where ground levels currently form a depression, with a ditch flowing parallel to Tempsford Road towards the River Ivel. This is with the idea of reducing flood risk to the property on the Tempsford Road, as when the flap valve is in operation preventing the Ivel from backing up into the village, the Blunham drain is unable to discharge and therefore causes localised flooding here in combination with the out of bank flood water on the High Street junction.

It was agreed to model the culvert in its upsized dimensions (0.3x0.6m), and the invert of the culvert outlet was taken as an appropriate ground level in the vicinity of the outlet (18.61m AOD). The culvert length was taken as 50m long.

This scenario offers a coarse model representation beyond the culvert outlet as there is no survey available of the existing ditch or flap valve at the Ivel. Therefore, a Z line was connected to the culvert outlet, lowering topographic ground levels to simulate a small ditch using LIDAR and an estimated gradient, and was applied to the model. The Z line ended just the other side (landward) of the River Ivel embankments.

5 Model Results - Options Testing

5.1 Options vs. baseline flood outlines

5.1.1 Option 1 - Improved Channel Conveyance

Figure 5-1 shows the comparison of the baseline and Option 1 flood outlines for the 100-year plus climate change event.

Figure 5-1: Option 1 comparison with baseline scenario

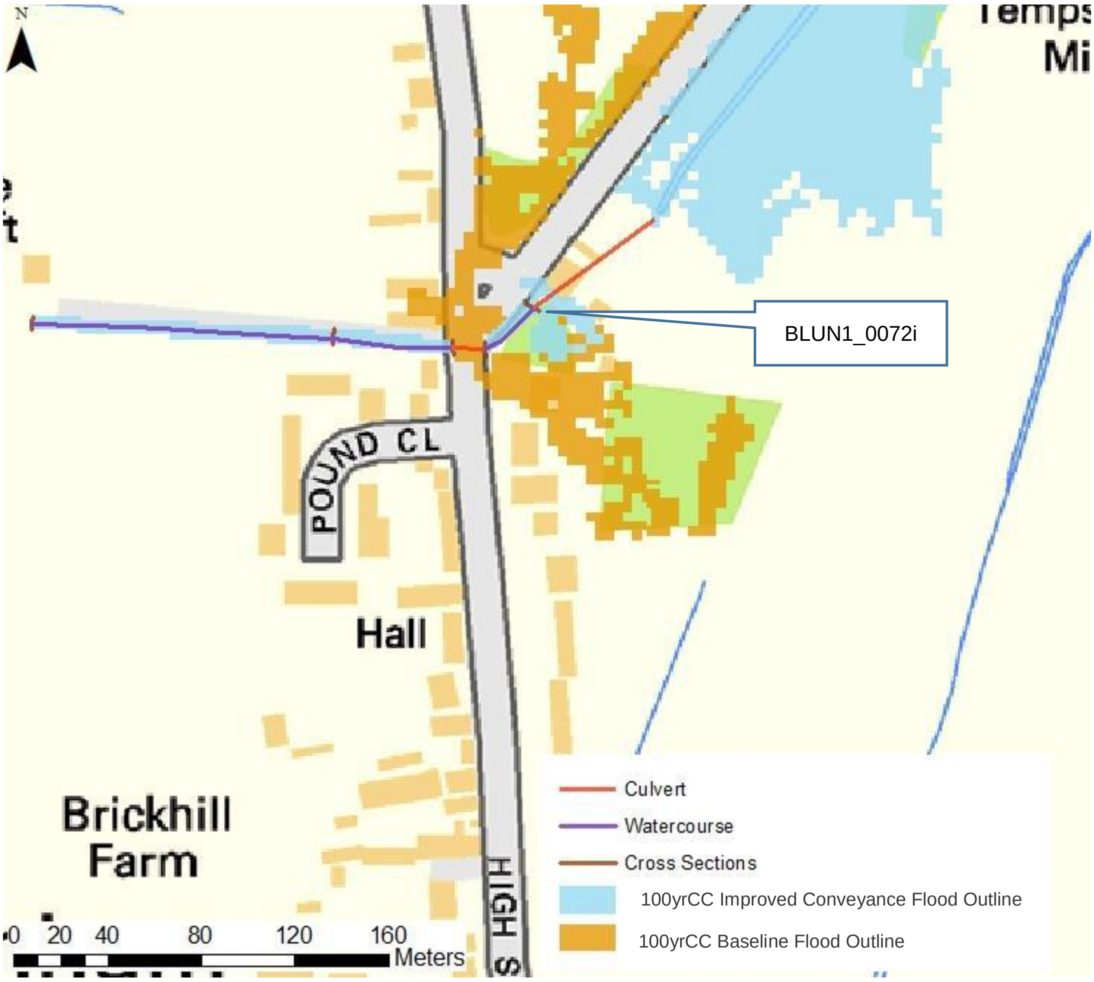

Figure 5-1 shows that as a result of the improved channel conveyance and improved culvert (siltation removed and any damage repaired) that there is no flooding across the High Street up to events greater than the 100-year plus climate change event. The only flooding during the Option 1 scenario is shown at the upstream face of the flapped culvert (BLUN1_0072i). This is likely to relate to the flapped outfall of the culvert being surcharged and therefore preventing flow from being discharged downstream. It is recommended that based on the model results that channel conveyance is improved to control the build-up of vegetation and siltation would greatly improve flood risk in the local vicinity. Additionally considering that repairing the culvert under the High Street may require some form of highway works the possibility of upsizing the culvert should also be considered to improve the conveyance capacity. Due to the cost of these works it is recommended that the recent CCTV survey is assessed regarding the condition of the culvert to determine any structural faults.

5.1.2 Option 2 – Upsizing the High Street culvert

Figure 5-2 shows the comparison of the baseline and Option 2 flood outlines for the 100-year plus climate change event.

Figure 5-2: Option 2 comparison with baseline scenario

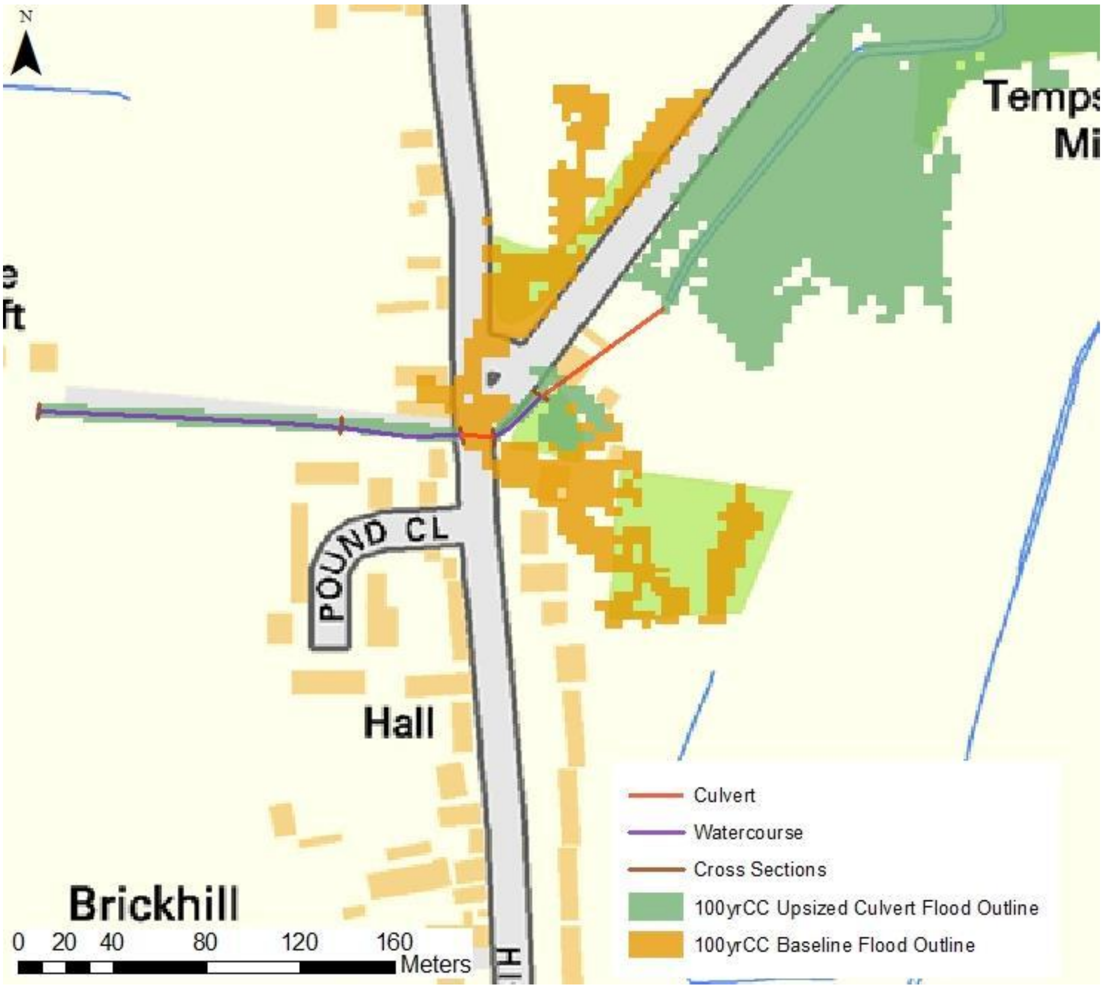

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Figure 5-2 shows that by upsizing the culvert under the High Street that flood risk is greatly reduced with no flooding shown in the modelled scenarios below the 100-year plus climate change event. Similar to Option 1 shown in Figure 5-1 the flooding is originating from the upstream face of the flapped culvert (BLUN1_0072i). This is likely to relate to the flapped outfall of the culvert being surcharged and therefore preventing flow from being conveyed downstream. It is recommended that before this option is considered that a detailed assessment is conducted of the culvert to determine its condition and any structural faults which may need to be addressed.

Testing flood storage in the rural land upstream of the drain was not deemed necessary due to the flood risk appearing much reduced due to channel conveyance improvements and an upsizing of the culvert.

5.1.3 Option 3 – Combination

This is deemed the 'preferred option' and is documented in Section 6.

5.1.4 Option 4 – Culvert Diversion and Upsize

Figure 5-3 shows the comparison of the baseline and Option 4 flood outlines for the 100-year plus climate change event.

Figure 5-3: Option 4 comparison with baseline scenario

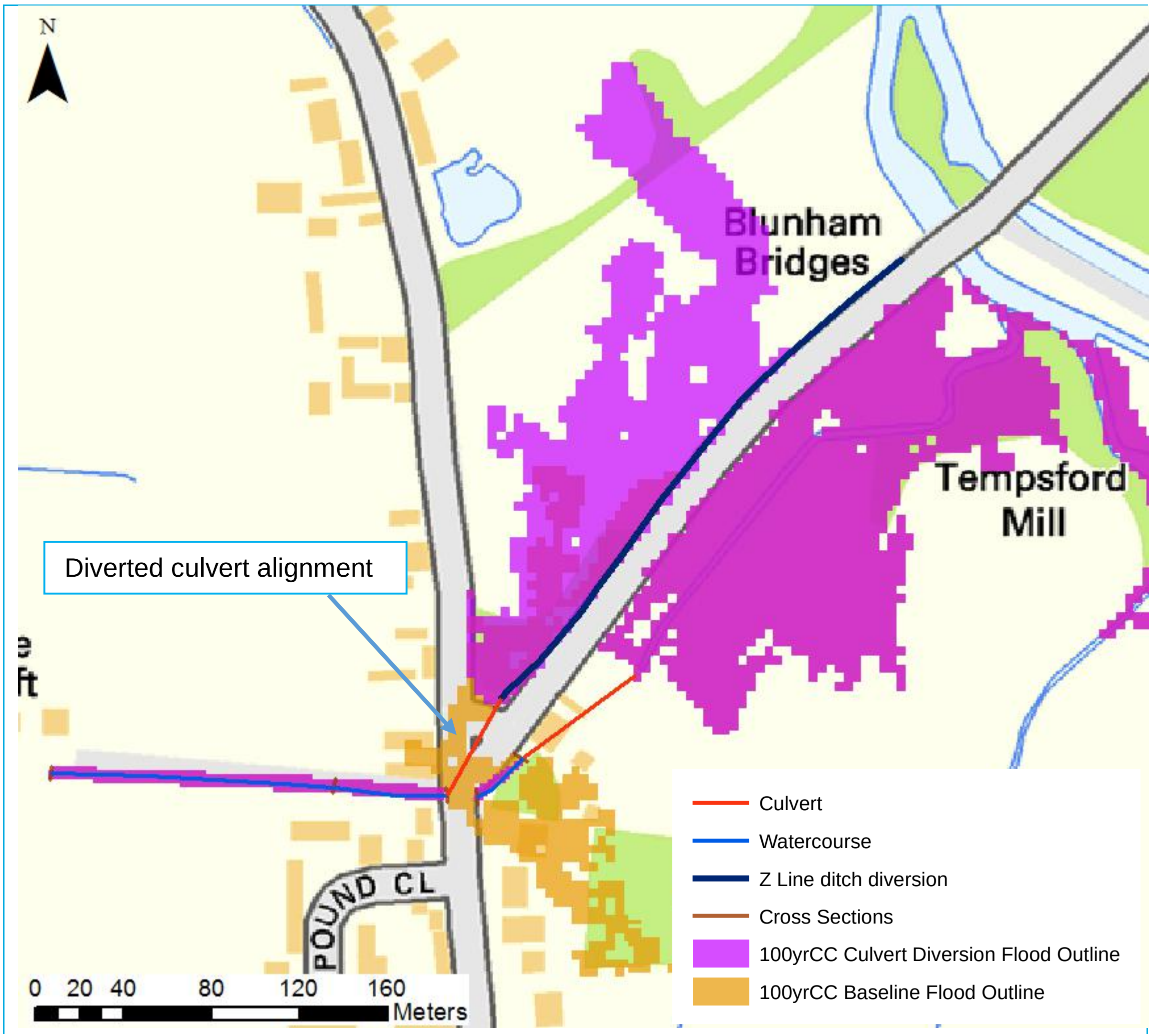

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Figure 5-3 shows that as a result of the culvert upsizing and diversion across the junction to the other side of the Tempsford Road, flood risk across the road and ain the vicinity of the depression/ property on Tempsford Road is reduced. This is because when the culvert was upsized in its previous alignment, more water was conveyed to the upstream culvert entrance in the depression and property location. When the flap valve downstream is closed, this prevents water discharging downstream from the drain. By re-aligning the High Street culvert away from this area, flood risk is reduced in this location and instead ponds and floods the fields to the north of Tempsford Road. There is a topographic depression at the new culvert outlet position which acts as a natural basin for water to pond in. Water would then follow the alignment of the existing ditch (survey unavailable; estimated by using a Z Line to lower topography) towards the River Ivel. The flood extent shows water following LIDAR levels and ponding in areas of lower ground. An improvement would be to gain channel survey of the existing ditch parallel with the Tempsford Road, and dimensions of the flapped valve at the Ivel, and update the model to better represent the floodplain flow paths downstream of the diverted culvert outlet.

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6 Preferred Option

Based on the analysis of flood extents and water peak water levels of the 100-year plus climate change event, the recommended preferred option for reducing flood risk to Blunham is the following, in the stated order:

- Improved channel conveyance along the length of the watercourse to remove dense vegetation and siltation from the culvert. This was modelled as Option 1.
- Upsizing the High Street culvert. As part of Option 1, blockage was removed from the culvert which was assumed to be a build-up of silt. The recent CCTV survey shows elements of the culvert are displaying surface cracks and crazing and therefore further monitoring is recommended and if possible the opportunity should be taken to upsize the culvert to provide increased capacity. At the culvert replacement stage, the potential for diversion should be explored to decide whether the culvert's existing alignment should remain, or whether it should follow a different route away from the Tempsford Road property.

The preferred flood extent is shown in Appendix C2.

It is recommended that before any of the options are considered further or designed that the hydraulic model should be updated with more accurate information to ensure that the representation if flood risk is as accurate as possible.

6.1.1 Identification of culverts requiring CCTV

Recent CCTV survey shows that elements of the High Street culvert are displaying surface cracks and crazing. No further CCTV is required but further monitoring is recommended.

6.1.2 Indicative property numbers at risk/ benefit

Appendix D presents a table outlining indicative property numbers at flood risk in the baseline and options scenarios for a range of flood events, along with properties benefited.

6.2 Indicative costings for preferred option

The Environment Agency's *"Flood Risk Management Estimating Guide: Unit Cost Database 2007"* - *'Update 2010'* was consulted to gain indicative costs for some of the flood mitigation options tested.

The source of this information is based on more than 450 EA capital projects, with a value of more than £500 million.

Costs are also presented with inflation since 2010. For reference, inflation has changed as follows since 2010: 2010 = 4.6%, 2011 = 5.2%, 2012 = 3.2%, 2014 = 3.0%.

It should be noted that these unit costs include and exclude the following:

Table 6-1: Unit cost inclusions and exclusions

Unit Cost Inclusions	Unit Cost Exclusions
• Contractors direct consultation costs • Overheads and Profit • Elemental costs including associated construction works	• VAT • External costs such as consultants, land, compensation costs etc. • Fee allowances • Design planning and co-ordination allowances • Contractors/ project risk allowance

Other costs which may be relevant are as follows:

- Management and supervision – around 20% of proposed works cost;
- Welfare, storage and offices including services, fuel etc – around 5% of proposed work costs;
- Transport – personnel, plant and equipment – around 5% of proposed works cost;

- Fencing and signage – around 2.5% of proposed works cost;
- Security – around 2.5% of proposed works cost.

It is also assumed there is no presence of Japanese Knotweed or other invasive species that require in-situ treatment.

It is therefore recommended at this stage to add a 50% contingency to the costs pending more detailed hydraulic modelling and detailed design.

6.2.1 New culvert/ culvert upsizing

As part of the preferred option, the high street culvert is recommended for upsizing as it is displaying surface cracks and crazing.

The 2010 guidance suggests that the minimum cost for any size or length of culvert is approximately £53,000. With inflation to 2014, this would be approximately £61,994.

The unit costs include additional costs such as headwalls, screens, fencing and drainage etc.

Table 6-2: EA (2010) Unit costs for box culverts

Cost per metre length of box culvert (£)			
Length (m)	**Cross sectional area (m^2)**		
	0.5	**1.0**	**2.0**
10	8,400	10,600	13,500
50	2,900	3,700	4,700
100	1,800	2,300	3,000
200	1,200	1,500	1,900
300	900	1,100	1,500

For the High Street culvert, highlighted in red, this would require approximately 16m length of culvert re-sizing and for a $0.18m^2$ cross-sectional area, this could cost £8,400 per metre, hence £134,400 based on 2010 prices. With inflation to 2014 this could total £157,208.

For a culvert diversion of a 50m length, with the same cross-sectional area, this could cost £145,000 based on 2010 prices. With inflation to 2014 this could total £169,607.

6.2.2 Channel maintenance

Indicative channel maintenance costs which the IDB industry use are outlined below:

• Flail mowing banks*	30-40p/metre
• Removal of emergent growth in a channel*	40-50p/metre
• De-silting	50-60p/metre

**These types of maintenance are dependent on the presence of non-native and invasive species.*

NB: It should be noted that these costs are based on *very large areas* (tens of kilometres) and therefore costs are likely to increase substantially for smaller reaches. The cost will also depend on the requirement to dispose of any arisings. It would be prudent to assume an **increase by a factor of 3** to the costs above.

Based on JBA's experience on previous projects where dredging works have been costed, the quoted minimum cost per cubic metre of material dredged is £5.00, assuming a simple dredging technique and no double-handling of material, spreading material locally on the floodplain.

For approximately 200m of channel maintenance required (from the upstream modelled extent to the flapped culvert), applying a factor of 3 to the above costs, an indicative cost could be assumed at £300 for removal of growth in channel, and £360 for desilting.

6.2.3 Property Level Protection

The Government's *Making Space for Water* strategy, and Sir Michael Pitt's review following on from the flooding of June and July 2007, have both recognised the need to use a portfolio of measures to manage flood risk and the necessity to include in this portfolio the use of property-level protection (PLP) measures. In 2008 Defra announced a £5 million Property-level Flood Protection Grant Scheme as part of the Government's response to the Pitt Review. Grants could be applied for by local authorities and a total of 63 such schemes were completed during this 2 year pilot. PLP is seen as cost-effective way to provide flood mitigation to communities which are unlikely to qualify for traditional community flood defence schemes on cost-benefit criteria.

Flood resistance and resilience measures are flood risk management options which aim to reduce the likelihood of flood water ingress to a building (resistance measures) and limit the damage if water does enter (resilience measures). Since 2007 there has been an increase the use of these measures, with Environment Agency and local authority funding many schemes for individual properties. During the widespread flooding in 2012 many of these measures were tested for the first time.

Flood resistance measures are those which aim to limit flood water ingress. This is achieved through the recommendation and use of, wherever possible, Kitemark approved products which are either manually deployed upon receipt of a flood warning, or which remain in situ and operate passively. This include, barriers for doorways, covers for air vents, self-closing airbricks and one-way (non-return) valves for sewage and waste pipes. Flood doors are now also available. All sources of flooding much be considered, and integral to the package of resistance measures is the recommendation for pumps (either situated in a sump in a void beneath the floor, or operated manually to evacuate any rising groundwater).

Flood resilience measures are approaches which aim to limit the damage should flood water enter a buildings, and reduce the time before it can become habitable again. This can include raised electrical sockets and wiring, the use of tiled floor covering instead of carpets, and raised electrical appliances.

The installation of such measures will not always guarantee that the property will be watertight. Reasons for this include that there may be hidden water ingress routes, or that the standard provided by the mitigation measures may be exceeded. Therefore the following is a list of (resilience) options that can help reduce the damage once flood waters enter a property:

1. ensuring all electrical sockets on the ground floor are situated above the maximum expected height of flooding
2. ensure all ground floors are of concrete having a suitable damp proof membrane connected to the external walls
3. ensuring all external walls are waterproof; this may be achieved through application of waterproof render
4. waterproof internal walls and skirting
5. raised kitchen units and appliances
6. waterproof floor coverings.

Average PLP schemes cost approximately £3,750 per property. Including average survey costs of £450 and average administration costs of £700, this brings an average total cost of **£4,500 to £5,000 per property**. This assumes conventional PLP measures, such as making a property flood resistant (flood barriers/ doors, air brick vent covers etc).

6.3 Stakeholder engagement

A meeting was held on November 13th in Blunham with JBA Consulting, Central Bedfordshire Council and representatives from the Parish Council to discuss the modelled flood mitigation options detailed above.

Dialogue was exchanged about the following, which was beneficial for all parties:

- They hydraulic modelling work undertaken – baseline flood risk and options testing.
- Local knowledge transfer about existing flooding in Blunham and from other flow routes
- Confirmation of what the baseline modelled outlines show in terms of existing flood risk extents, and properties/ areas that have flooded in the past.
- The feasibility of flood mitigation measures proposed, their risks and likely costs.

7 Summary and Recommendations

7.1 Summary

JBA Consulting was commissioned by Central Bedfordshire Council in July 2014 to undertake three Local Flood Risk studies to better understand flood risk in these communities and to consider small-scale options available to reduce flood risk. This report focuses on flood risk in Blunham.

Peak flows for a variety of flood events were derived using FEH methodologies, and were input into the hydraulic model at the upstream model extent and representing other small incoming surface water flow routes down the catchment. The modelled flood events were the 5-year, 20-year, 30-year, 100-year, 100-year plus climate change (25%) and the 1,000-year return period flood events.

A new hydraulic model was constructed of the watercourse for a distance of approximately 0.5km, based on channel topographic survey collected by Maltby Land Surveys Ltd. The hydraulic model used ESTRY-TUFLOW software, and used head vs. time hydrographs from the River Ivel's 5-year flood event as the downstream boundary. The floodplain was represented by detailed 1m LIDAR ground level data providing a good level of accuracy.

Baseline modelling identified key flooding locations and mechanisms, which allowed the identification of several small-scale flood mitigation options for the options modelling phase. Key locations included the High Street road due to water spilling out of bank at the culvert, which is heavily silted, and in higher return period flood events along part of the Tempsford Road.

Blockage analysis was also undertaken at the High Street culvert simulating a 90% blockage, as a 75% blockage was incorporated into the existing condition due to heavy siltation.

A number of small-scale flood mitigation options were tested in the baseline model to try and reduce flood risk in Caddington. The following options were tested:

Option	Action
Option 1	Channel conveyance improvement, including simulating the high street culvert as unblocked.
Option 2	Upsizing the high street culvert to improve conveyance.
Option 3	Combining Options 1 and 2 above.
Option 4	Upsizing the high street culvert and diverting it to the other side of Tempsford Road.

Based on the analysis of flood extents and water peak water levels of the 100-year plus climate change event the recommended preferred option for reducing flood risk to Blunham is the following:

- Improved channel conveyance along the length of the watercourse to remove dense vegetation and siltation from the culvert. This was modelled as Option 1.
- Upsizing the High Street culvert. As part of Option 1, blockage was removed from the culvert which was assumed to be a build-up of silt. The recent CCTV survey shows elements of the culvert are displaying surface cracks and crazing and therefore further monitoring is recommended and if possible the opportunity should be taken to upsize the culvert to provide increased capacity. At the culvert replacement stage, the potential for diversion should be explored to decide whether the culvert's existing alignment should remain, or whether it should follow a different route away from the Tempsford Road property at flood risk.

Indicative costs based on the Environment Agency's 2010 update to the 2007 Unit Cost Database have been provided for the preferred option, which may highlight to CBC which parts of the preferred options are viable or not for further detailed consideration. An **indicative total** cost for the preferred option (culvert upsizing and improved channel conveyance for an estimated 200m reach) is in the region of £157,860. Approximately £157,205 of this would be for the culvert upsizing at the High Street. This cost would increase if a diversion was installed due to the additional length required. It is recommended at this stage to add a 50% contingency pending more detailed hydraulic modelling, site investigation and detailed design.

7.2 Recommendations

- It is recommended that before any of the options are considered further or designed, that the hydraulic model should be updated with more accurate information to ensure that the representation of flood risk is as accurate as possible. A detailed design would then be recommended for the preferred option, in order to refine results, dimensions and costs. The design process will need to be followed to ensure suitable and robust options are produced for each area. This is summarised by the RIBA Plan of Work 2013 Stage[1]. Works are likely to be CDM applicable and therefore a CDM coordinator would need to be appointed.
- At present a number of modelling assumptions have been made due to the accuracy of the existing data. Improved topographic data in the heavily vegetated topographic depression would allow a more accurate representation of flow paths preceding the flapped culvert inlet, in addition to the other model improvements outlined in Section 2.6.3.
- If property threshold survey becomes available, it could be incorporated into the model to improve the representation of flood risk near properties.
- With the current condition of the channel being predominantly densely vegetated, improvements to the channel conveyance are recommended, such as by cutting back/ removing vegetation and culvert clearance (of silt/ debris) to prevent flows being impeded in the event of a flood. This may require an ecology survey to be undertaken. To improve the flow conveyance through the channel an option was modelled to simulate the removal of vegetation to increase channel capacity which is included in the preferred option. It is recommended this is carried out.
- The culvert under the High Street is shown in the site visit to be heavily silted at the downstream face, and Central Bedfordshire Council also believe that from a recent CCTV survey, elements of the culvert are displaying surface cracks and crazing, therefore continued monitoring of the condition of the culvert is recommended to CBC Highways.
- If the culvert diversion option is to be explored further, it is recommended to collect channel topographic survey data of the drainage ditch/ Ivel flapped outlet on the opposite side of the Tempsford Road to improve model representation and interaction with the River Ivel (currently represented by coarsely lowering LIDAR topographic levels along a single cell alignment with no flap valve present). Services under the road should also be investigated as to inform the feasibility of this option.
- Asset and riparian ownership should be established in Blunham to allow CBC to identify where works are necessary and who has responsibilities for these works. The 2003 report suggests that the responsibility for other piped systems and open ditches is not established but that if they are under roads they are likely to be the responsibility of the Bedfordshire County Council as highway authority, but elsewhere the owner of the land which piped and ditches pass will be responsible.
- If the preferred option, or aspects of the preferred option, are found to be unviable due to costs, it is recommended that property level protection (PLP) is considered, which would provide more specific flood protection to the properties which have flooded historically.
- New developments or changes in land practices within the catchment which could alter the flows draining to the watercourse or surface water overland flow patterns should be considered and modelled in more detail.
- The costs provided in this report are approximate, based on the EA's 2010 Unit Cost Database update, pre-feasibility information and broadscale modelling, and hence a contingency of 50% should be added. They aim to show an outline indication and comparison between different flood mitigation options, and should be improved based on more detailed information when available. A cost-benefit analysis should be undertaken once the model has been refined.

[1] RIBA Plan of Work 2013 http://www.ribaplanofwork.com/About/Concept.aspx

Appendices

A Appendix - FEH Calculation Record

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B Appendix - Hydraulic Model Checkfile

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C Appendix – Flood Outlines

C.1 Baseline Scenario

C.2 Preferred Option

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D Appendix – Indicative Properties Flooded/ Benefited

Blunham		
Baseline Events	**Properties affected by flood outlines**	**Properties benefited**
5yr	2	-
20yr	3	-
30yr	4	-
100yr	4	-
100yrCC	7	-
1000yr	7	-
Preferred Option		
5yr	0	2
20yr	0	3
30ur	0	4
100yr	0	4
100yrCC	2	5
1000yr	6	1
Option 1		
5yr	0	2
20yr	0	3
30ur	0	4
100yr	2	2
100yrCC	2	5
1000yr	8	-1*
Option 2		
100yr	0	4
100yrCC	2	5
1000yr	6	1
Channel Diversion		
30yr	0	4
100yr	0	4
100yrCC	0	7
Options		
Option 1: Improving channel conveyance by vegetation removal (including removal of culvert blockage).		
Option 2: Upsizing the road culvert		
Preferred Option: A combination of Option 1 and Option 2.		
As a result of increased conveyance towards the upstream entrance of the flapped culvert.		

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