Local Flood Risk Studies - Caddington

Final Report

February 2015

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Revision History

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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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Acknowledgements

JBA Consulting would like to thank Central Bedfordshire Council, Anglian Water, Thames Water, the Environment Agency for their data provision, and Caddington 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 the communities of Caddington, Wrestlingworth and Blunham and to consider small-scale options available to reduce flood risk. This report focuses on flood risk in Caddington.

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. River inflow points were added 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 2.3km, based on channel topographic survey collected by Maltby Land Surveys Ltd. The hydraulic model used ESTRY-TUFLOW software; the 1D domain includes the river channel and a small portion of the floodplain (represented by ESTRY), with the rest of the floodplain represented by a 2D domain in TUFLOW. The floodplain was represented by ground level data (LIDAR) from the Updated Flood Map for Surface Water (uFMfSW); this was a particularly coarse resolution and means that floodplain representation and results further from the channel (where more detailed topographic survey was collected) are less certain.

A number of assumptions and limitations have been recorded based on data availability and data quality checks, with recommendations for improvement, for example obtaining more detailed LIDAR data to allow the incorporation of rainfall to route surface water overland flows.

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.

The key flooding locations identified are as follows:

- Dunstable Road – a surface water overland flow route combined with water out of bank at the road culvert causes flooding across the Dunstable Road and has in the past affected the 5 properties opposite.
- Flood Relief Culvert (FRC) – only in the 1,000-year flood event does water bypass the FRC.
- Mancroft Road at Aley Green – flooding occurs from the culvert near the junction of Pipers Farm to Aley Green, along Mancroft Road.
- Upstream of Woodside Road Bridge – out of bank flow upstream of the bridge

Blockage analysis was also undertaken at the Dunstable Road culvert and Pipers Lane culvert, simulating a 75% blockage.

Flood mitigation options testing

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 Caddington. The following options were tested:

Option	Action
Option 1	Inclusion of berm and new/ upsizing of culverts. Additional storage in form of a two-stage channel downstream of Dunstable Road until the Flood Relief

Option	Action
	culvert. This option was tested with the individual features to determine the extent of the proposed option.
Option 2	Upsizing the Woodside Road Bridge to increase conveyance.
Option 3	Implementing a two-stage change between Pipers Lane and Heron Farm on the right hand bank. A small berm was used to try and prevent flows onto Mancroft Road.
Option 4	Modelling improved channel conveyance. This was represented by reducing the channel roughness (to simulate vegetation removal) by 20%.
Option 5	Upsizing the culvert at Pipers Lane / Mancroft Road.
Option 6	Investigating potential effects of a new development proposed at Dunstable Road.
Do Nothing	A 'do nothing' scenario was also tested simulating vegetation growth in the channel.

Preferred option

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

- Improved channel conveyance along the length of the watercourse by removing dense vegetation. This was modelled as Option 4.
- Development of a combination of methods at Dunstable Road, modelled as Option 1. This would include a berm to collect overland flow, a new culvert to convey flows to the channel, upsizing of the Dunstable Road culvert and implementing a two-stage channel on the right hand bank between Dunstable Road and the flood relief culvert.
- Upsizing the Pipers Lane / Mancroft Road culvert.

The preferred option has been modelled for both the 100-year plus climate and 30-year events.

Indicative costs based on the Environment Agency's 2010 update to the 2007 Unit Cost Database have been provided for the preferred options, 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 (three culverts, one flood bund and a two-stage channel) is in the region of £1,140,452. Approximately £702,985 of this would be for the improvements at Dunstable Road if a two-stage channel is also incorporated, and the remaining for the upsizing of the Pipers Lane/ Mancroft Road culvert. Removal of vegetation has not been included in this figure. It is recommended at this stage to add a 50% contingency pending more detailed hydraulic modelling, site investigation and detailed design.

A high-level indicative cost-benefit appraisal was undertaken, which showed that the preferred option, which provides the greatest reduction in flood risk to properties within Caddington is not cost beneficial with the estimated costs exceeding the benefits of the scheme. In almost all of the options modelled, the same number of properties are at flood risk in the 30-year flood event, with only a reduction of 2 properties in the 100-year+CC flood event. The preferred option gives the greatest reduction in properties at flood risk of 6 properties out of all the individual options tested, but only in the higher order flood events. It may therefore be appropriate to consider a partial solution or other more financially viable mitigation measures, though the individual options testing also proved to provide little benefit to property numbers compared with the baseline, and compared with the total scheme costs it is unlikely the score would be high enough to warrant further pursuit.

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.

- CCTV survey is recommended of the flood relief culverts and longer culverts such as the structure located at Pipers Lane/ Mancroft Lane, and the Dunstable Road culvert. Without detailed CCTV survey it is difficult to be aware of any changes in elevation or pipe size that may happen along the length.
- At present a number of modelling assumptions have been made due to the accuracy of the existing data. Improved floodplain topographic data (finer resolution LIDAR) would allow a more robust approach which would more accurately represent flood flow routes and the mitigation options tested, in addition to the other model improvements outlined in Section 2.6.3. This would reduce uncertainty and assumptions in the modelling results away from the surveyed channel, *which may alter the number of properties affected by flood risk*. In addition, it would allow the application of a rainfall runoff model to examine the interactions between the watercourse and overland flow routes. Including rainfall would improve the surface water flood risk and overland flow representation in the hydraulic model.
- If property threshold survey becomes available, it should be incorporated into the model to improve the representation of flood risk near properties and to enable a more accurate cost-benefit analysis to be undertaken.
- The results of the 'do nothing' scenario show that whilst there is little increase to the flood extents in the floodplain, it would be unfavourable to not maintain channel conveyance as in-channel water levels would increase, along with chances of blockage. With the current condition of the channel being predominantly densely vegetated, channel improvements should be undertaken such as removing vegetation to improve conveyance and prevent flows being impeded in the event of a flood (which was modelled in the preferred option), along with channel maintenance. This may require an ecology survey to be undertaken.
- The preferred option from a flood risk perspective is not economically viable for the number of properties it benefits, as shown in the high-level cost-benefit appraisal. For a number of the individual options, the property benefits would still be very low compared with the total scheme costs and it is unlikely the score would be high enough to warrant further pursuit. Other mitigation options could still be considered, such as improved channel conveyance by the removal of vegetation and investigation of upstream bund/ storage (with its associated culvert) to reduce flooding from the *surface water flow route* over the Dunstable Road. Consideration could be given to improving debris capture upstream of the Dunstable Road culvert to further reduce the risk of the trash screen becoming blocked, whilst still allowing water through the culvert. Technical advice notes such as the EA's 'Trash and Security Screen Guide 2009' should be referred to, to inform an evaluation of potential debris load and appropriate trash screen components. A maintenance regime needs establishing to ensure the grill is kept clear.
- The maintenance arrangement of 6th February 2007 should be followed by CBC and any remaining open channels should be maintained by the riparian landowners.
- It is recommended that property level protection (PLP) is considered, which would provide more specific flood protection to the properties which have flooded historically for a lower cost than implementing flood bunds and upsizing culverts.
- It is recommended to understand the impact of the proposed new development's surface water drainage strategy to ensure there will be no increase in surface water runoff which could affect water on the Dunstable Road. There could be potential for joined-up thinking regarding routing the surface water flows to the 'preferred option' bund and culvert which would meet in the same location.
- 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. More detailed floodplain topographic data (and post-development topographic data) and rainfall runoff inclusion as outlined above would be required for this level of detail in the hydraulic model, allowing for pre- and post-development comparisons to be made.

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

- 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 and property data is obtained.

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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
FRC .... Flood Relief Culvert
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 Caddington.

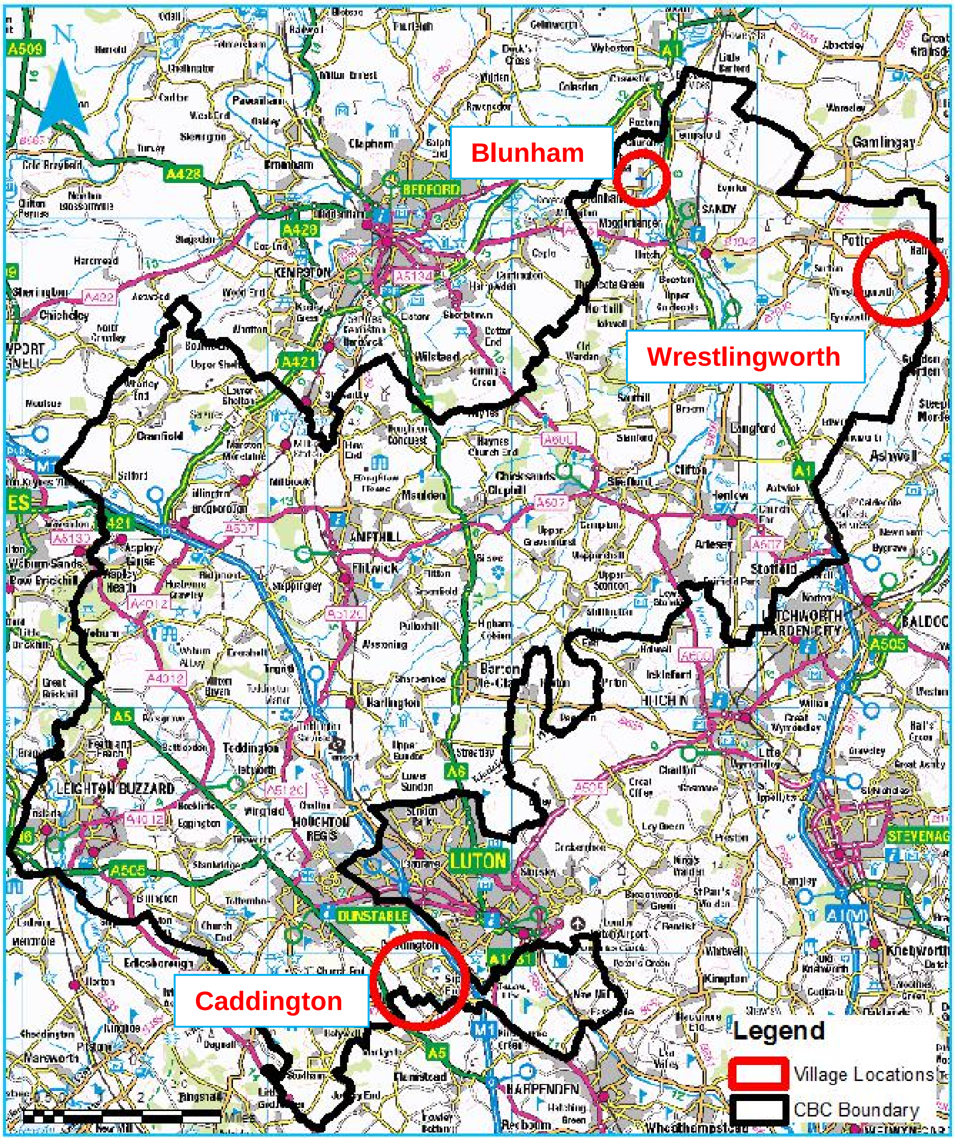
1.2 Scope of the study

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 Caddington background

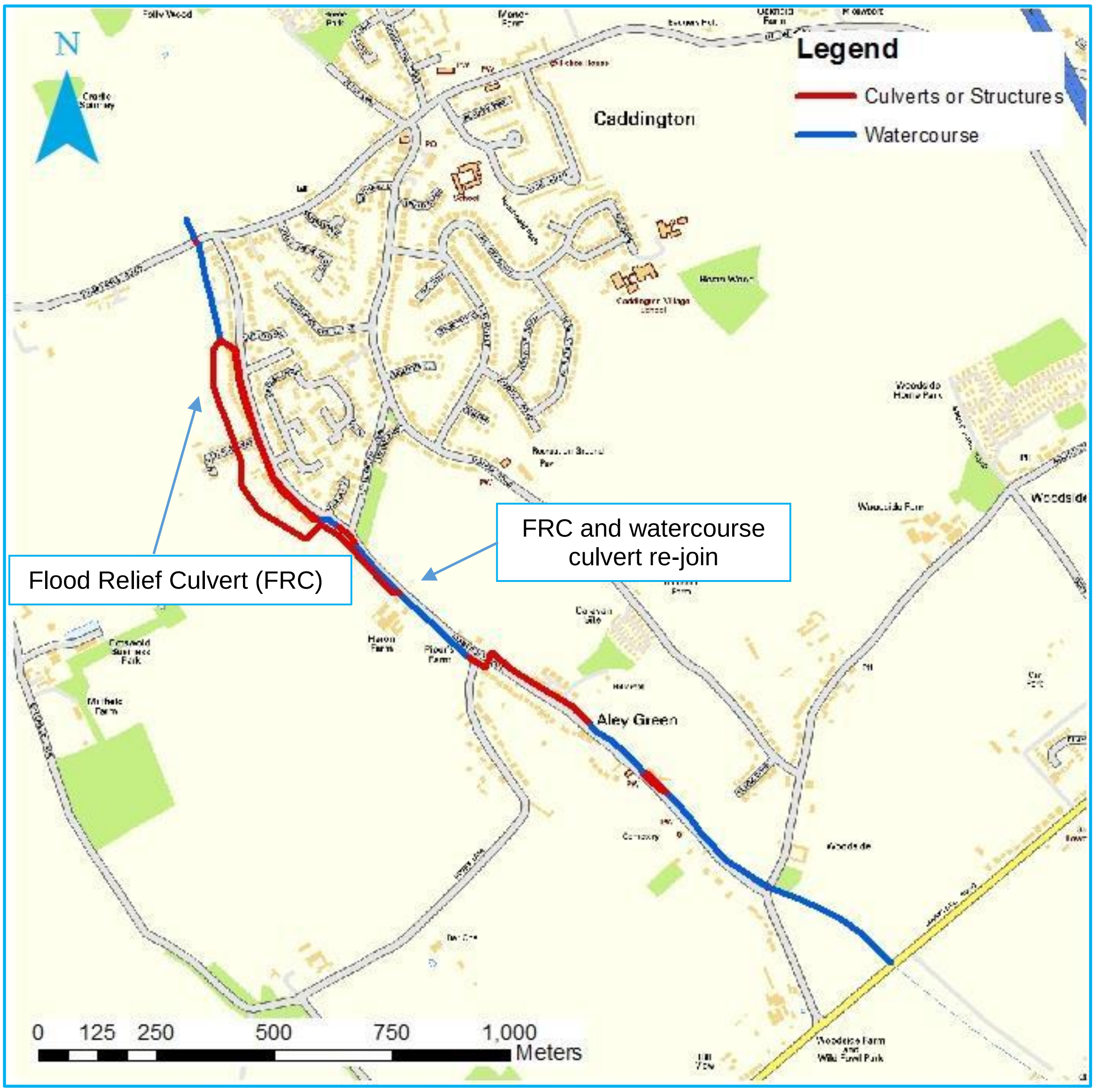
Caddington is located between Dunstable and Luton in the south of the Central Bedfordshire County boundary. The study area focuses on the drain flowing from just upstream of the Dunstable Road, alongside Mancroft Road and Caddington village in a south-easterly direction, through Aley Green to Markyate Road Bridge.

The watercourse extent to be modelled is approximately 2.30km long to its downstream extent. There are a number of small incoming drains or topographic depressions allowing surface water overland flows to be funnelled towards the watercourse.

The Soil Map of England and Wales shows slightly acid clay and loam soils with some impeded drainage. There is no attenuation in the catchment from reservoirs and the catchment is characterised as essentially rural upstream, changing to moderately urbanised downstream beyond Caddington.

Figure 1-2 shows the study area in Caddington.

Figure 1-2: Caddington Study Area



1.5 Flooding in Caddington

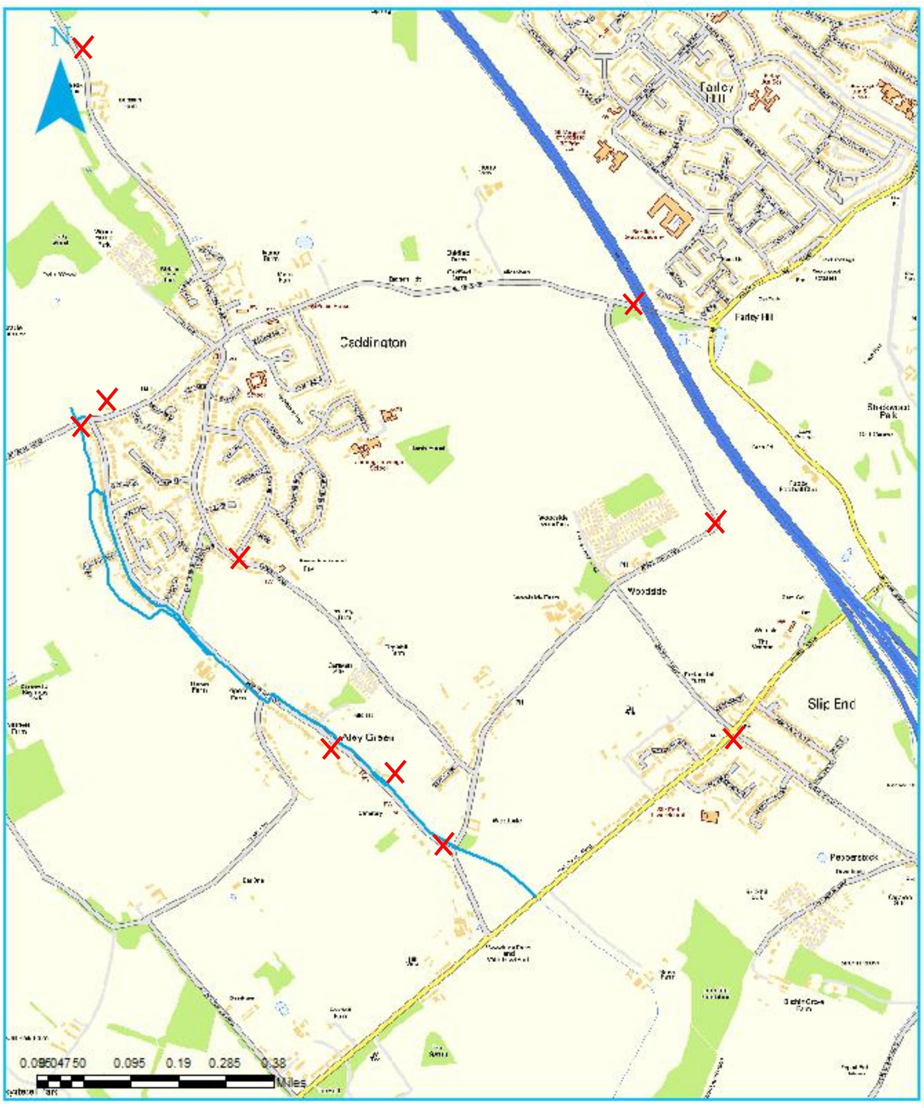
With regards to flooding mechanisms, flooding occurs primarily from surface water runoff from the fields when land is saturated, flowing overland via topographic depressions towards the watercourse, which in a flood event is at its capacity if not exceeded. Out of bank flows from the watercourse, for example at culvert entrances, cause water to bypass the channel and flow down roads affecting properties and causing disruption. 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.

Flooding has occurred recently in Caddington as a result of the winter 2014 storms. Photographic evidence has been provided by Central Bedfordshire Council (CBC) from the January flooding, showing the Mancroft Road in flood. In February 2014 flooding to property is known to have occurred at two properties at Aley Green which front the Mancroft Road as a result of out of bank flows down the road and to the properties which have a low threshold level via a dipped kerb. Five properties on Dunstable Road also experienced flooding in February 2014 where the culvert directly opposite was bypassed and water flowed across the Dunstable road into the properties via the dipped kerb in front of the gardens.

Flooding has occurred elsewhere in Caddington, to other gardens in Aley Green, and two properties on the northern side of the Dunstable Road. Flooding from surface water overland flows occurs notably along roads and highways and causes disruption to village traffic. Locations such as Mancroft Road, Dunstable Road, Woodside Road, Chaul End Road and under the M1 Bridge have flooded in previous flood events, and can affect main access routes to/ from the village.

It is acknowledged that there may be more surface water overland flow routes than those able to be incorporated into the model (such as down Pipers Lane, and an ancient waterway adjacent to Millfield Way).

Figure 1-3: Flooding hotspots in Caddington causing disruption (marked X)



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2 Approach

2.1 Context

This study has been commissioned to improve the understanding of local flood risk issues in Caddington. 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 (25%) 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 the FEH CD-ROM v3.0[1], and catchment boundaries were checked against OS 1:10,000 and 1:50,000 scale mapping. Any errors in the FEH catchment boundaries were manually adjusted using the Updated Flood Map for Surface Water (uFMfSW) LIDAR data and contour data.

The FEH statistical method and the Revitalised Flood Hydrograph (ReFH) method were used to derive fluvial flows in the Caddington 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 (CADD_01).

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
CADD_01 (INFLOW)	0.3	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.3	1.2	2.0

2.3.2 Surface Water Inflows

Direct rainfall modelling was considered to be the most suitable technique for modelling flood risk in the intervening catchment (the catchment between the upper catchments fed by a fluvial inflow and the downstream end of the catchment), based on the expected flooding mechanisms and the nature of the watercourses in the vicinity of the villages.

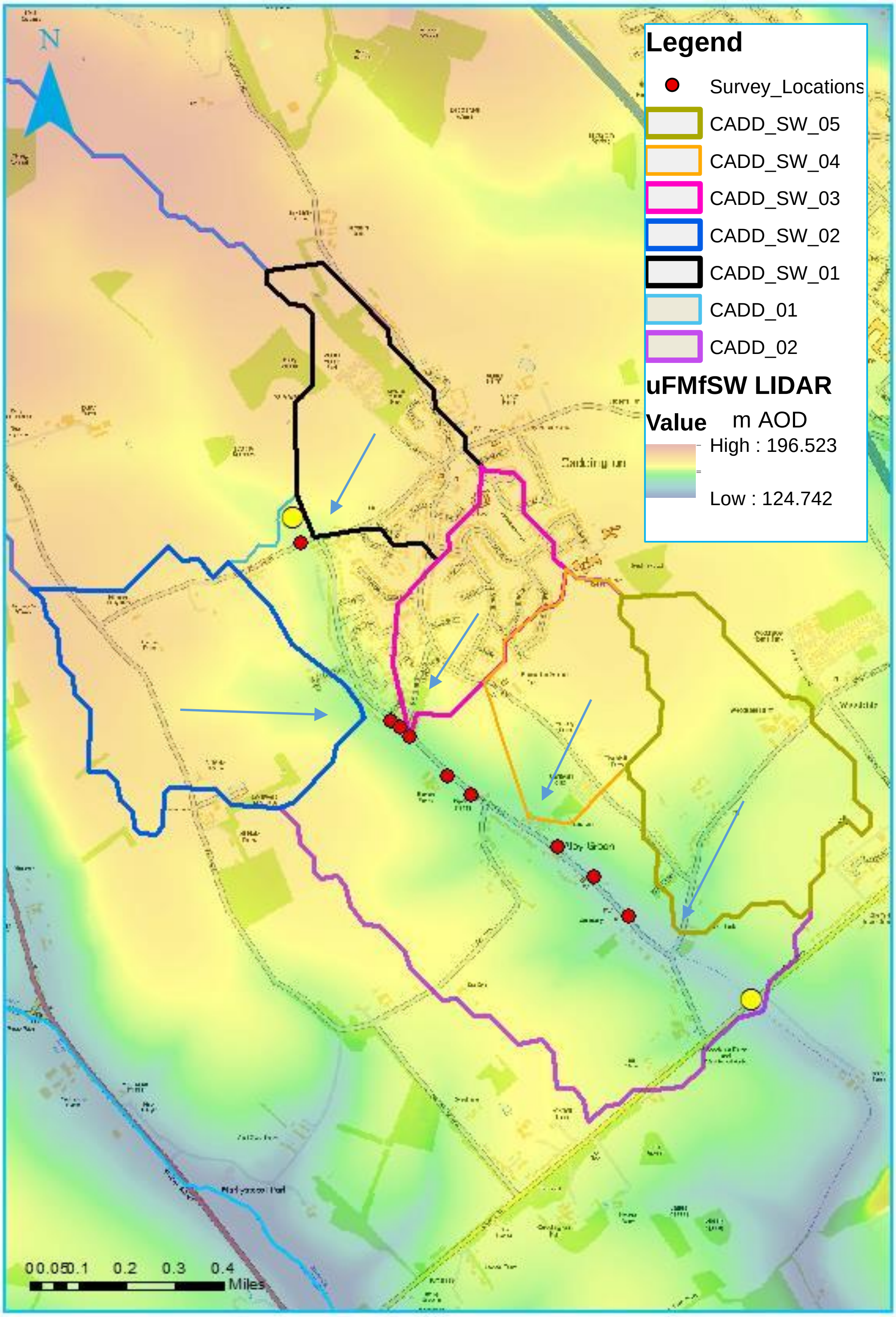
A rainfall-runoff approach would provide a more accurate representation of flow routes within the site and surrounding area, which will subsequently inform opportunities for intercepting these flows and mitigating flood risk.

This approach was tested in the model by applying the rainfall hyetographs for like-for-like return period events representing surface water flood risk onto the uFMfSW LIDAR in the intervening catchment. However, due to the uFMfSW LIDAR being poorer quality than that of 2m LIDAR coverage, and discrepancies where detailed survey data aligns with the more coarsely represented floodplain, the model experienced some instabilities and rainfall was shown to pond to depths greater than 2m where it was not deemed realistic. As a result, rainfall was removed from the hydraulic model and fluvial inflows representing surface water drains were derived. This allowed a representation of several incoming ‘drains’ down the catchment. A series of inflows were estimated based on the Environment Agency’s Surface Water Flood Map (uFMfSW), as shown in Figure 2-1. These inflows will be applied to the hydraulic model at the locations where the water would come naturally into the watercourse from topographic surface water flow routes.

It is acknowledged that there may be more surface water overland flow routes than those incorporated into the model (such as Pipers Lane, and an ancient waterway adjacent to Millfield Way), which would be better represented in a combined fluvial-rainfall model allowing rainfall to be applied everywhere and flowing along the topographic floodplain. However, as this was not possible to represent, the best use of available data has been made and the inclusion of these additional inflows down the watercourse provides an additional level of detail based on known overland flow routes.

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

Figure 2-1: Additional inflows representing surface water flow routes



2.4 Model Construction

2.4.1 Method and model software

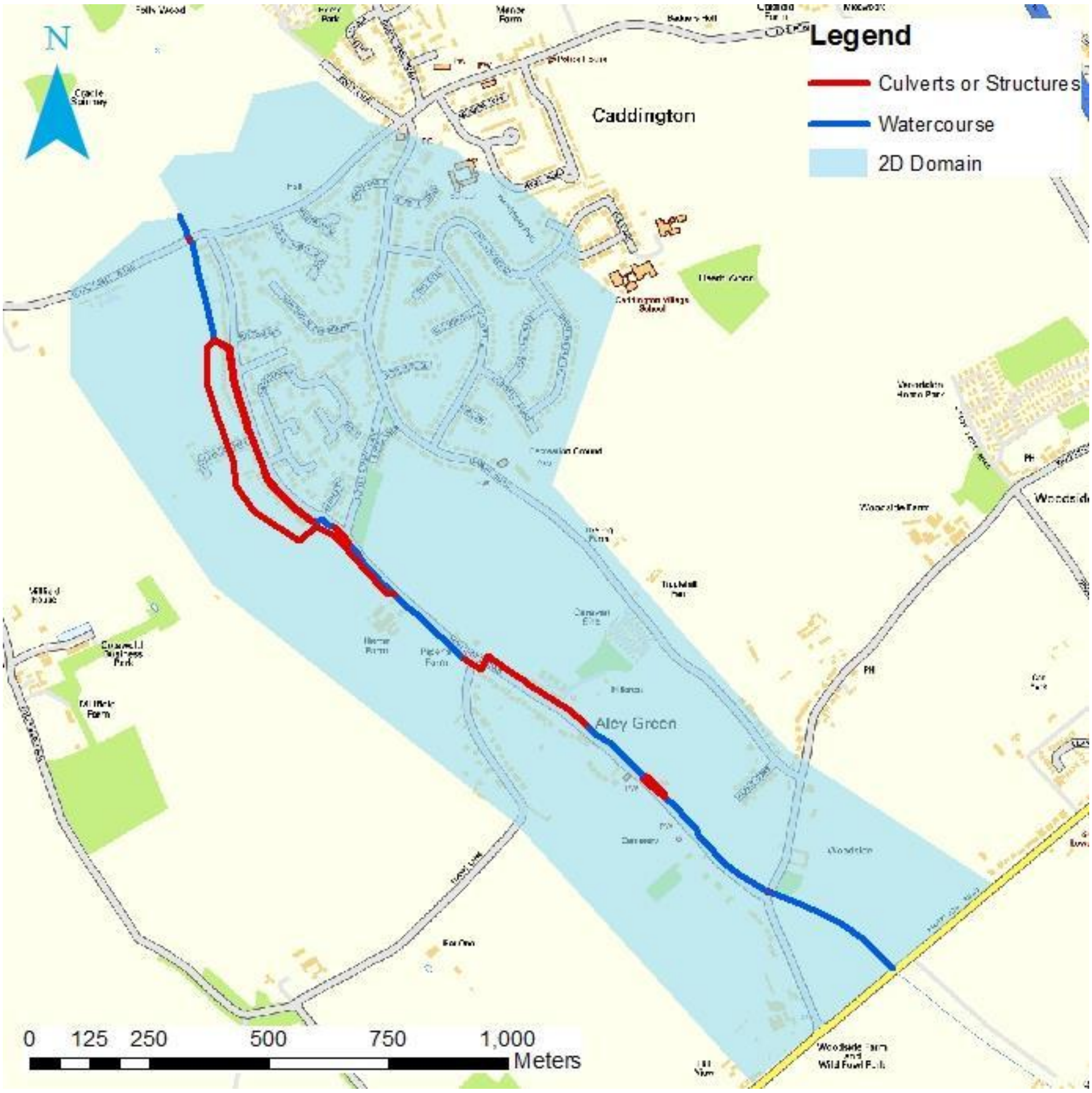
Standard hydraulic modelling approaches have been used to build and develop the models. These have been discussed in more detail, along with details of model sensitivity testing, in the hydraulic model check file which can be found in Appendix B. This document should be read in conjunction with this 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.

2.4.2 Model schematisation

The 1D-2D ESTRY-TUFLOW model extends from cross section CADD1_2278 upstream of the Dunstable Road to CADD1_0016 at Markyate Road, for a distance of approximately 2.3km. 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 Caddington. 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



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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. To form the basis of the 2D domain a digital terrain model (DTM) was directly read in by TUFLOW. Detailed 2m resolution LIDAR data was not available in Caddington, therefore the study used the Updated Flood Map for Surface Water (uFMfSW) LIDAR data (at a coarser 5m resolution) from the Local Flood Risk Management Strategy study, completed by JBA Consulting for CBC earlier in 2014.

It should be noted that this data did not correspond well with topographic survey points collected from Maltby Land Survey Ltd where data overlapped. As such, representation of flood risk is less accurate moving away from the channel and the detailed channel survey.

2.4.4 Key Structures

The key structures along the watercourse were captured in the channel topographic survey by Maltby Land Surveys Ltd. There are 8 modelled structures along the modelled reach, as detailed in Appendix B Model Check File. This includes the Flood Relief Culvert (FRC) structure, which was based on the South Bedfordshire District Council 1996 drawings (hard copies provided by CBC), of the inlet structure. It is important to note that for the longer culverts (which includes the flood relief culvert and a number of culverts along Mancroft Road), assumptions have been made regarding the invert levels within the pipes. Without detailed CCTV survey it is difficult to be aware of any changes in elevation or pipe size that may happen along the length. 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.

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 Caddington 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 Flood Relief Culvert and a number of other culverts are particularly long and therefore may change size and gradient along their length. As no CCTV information was available for these culverts, assumptions were made that the culverts along Mancroft Road fall at a constant gradient. For the Flood Relief Culvert it was assumed that the culverts followed a similar gradient to that of the sewer system along Mancroft Road. This data was supplied by Thames Water.

Other limitations were introduced by using the LIDAR from the uFMfSW data, as stated in Section 2.4.3. This dataset was shown to be significantly different from other surveyed levels due to the coarseness of the resolution. Assumptions have therefore been made on road levels and other levels adjacent to the channel to try and better represent flooding flow paths and as such the accuracy of the hydraulic model results decreases moving out of the 1D domain and away from the channel.

Also as a result of poorer LIDAR quality, combined with discrepancies where detailed survey data aligns with the more coarsely represented floodplain, the model experienced some instabilities when rainfall was applied to the model. Rainfall was shown to pond to depths greater than 2m in locations where it was not deemed realistic; therefore, rainfall was removed from the modelling and surface water was represented by fluvial inflows based on surface water flow route locations identified on the uFMfSW.

2.6.2 Data Quality check

A number of QA (quality assurance) 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 the uFMfSW data. As the channel survey was of a higher degree of accuracy this was assumed to be the more accurate of the datasets. On comparison it was shown that the DTM from the uFMfSW dataset was shown to be >1m higher than a number of surveyed points. Unfortunately the DTM was not shown to be generically higher than the survey points and therefore it could not be universally adjusted to match the survey. As there is no other more accurate data to represent the floodplain this data was used. It was improved by representing road and path levels based on Anglian Water's sewer data based on cover levels of manholes. These levels were shown to correspond well to the channel survey which extended onto Mancroft Road. Although the road levels would be generalised between manhole locations, this was deemed as the most accurate way of representing conveyance routes along the road network.

2.6.3 Improvements to the model

The following future improvements could be made to the model:

- Instabilities still remain in the hydraulic model which are a result of inaccuracies of the DTM data and data within the longer structures. This should be improved should more accurate data become available.
- Along the majority of the study reach, the bank elevations are projected across from one cross section to another. 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.
- Developments planned for the land north of Dunstable Road have not been incorporated into the model. These should be incorporated into the model when more details have been finalised regarding how surface water will be managed.
- New LIDAR should be flown to allow better representation of the floodplain within the 2D domain. This would allow for an improved understand of out of bank flows, removing the need for as many assumptions on elevations of flood routes.
- With the majority of flooding being linked to overland flow routes, a rainfall component should be added to the model. Although this was attempted, the inaccuracies of the DTM caused instabilities and resulted in unrealistic results. Should more accurate DTM information become available this option should be reinvestigated.
- Should more detailed DTM data become available it would be advisable to decrease the cell size from 4m to 2m to better represent flow routes within the floodplain. This was not considered with the existing data as it would offer no benefit due to the number of assumptions made on topographic data.
- CCTV should be used to investigate the condition and construction of the longer culverts, including the flood alleviation scheme. At present a number of assumptions have been made based on the elevation of inverts and size of culverts. With the introduction of improved culvert survey data, the conveyance potential can be more accurately represented.

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 100-year and 1,000-year baseline scenarios which exhibit the main flooding locations along Dunstable Road and Mancroft Road.

Figure 3-1: 100-year and 1,000-year (Baseline) Flood Outlines

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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
CADD1_2278	161.23	161.31	161.33	161.42	161.52	161.68
CADD1_2233	160.85	160.95	160.98	161.13	161.35	161.56
CADD1_2229	160.83	160.93	160.96	161.12	161.35	161.56
CADD1_2229d	160.22	160.28	160.30	160.37	160.44	160.58
CADD1_2189i	159.80	159.90	159.93	160.04	160.14	160.49
CADD1_2115i	159.44	159.52	159.55	159.62	159.64	160.39
CADD1_2014	158.41	158.51	158.54	158.66	159.22	160.37
CADD1_2008	158.30	158.43	158.47	158.61	159.22	160.37
CADD1_2008d	152.83	152.97	153.01	153.15	153.33	153.71
CADD1_1551	152.59	152.71	152.74	152.87	153.14	153.66
CADD1_1529	151.76	151.86	151.90	152.07	152.28	152.47
CADD1_1529	151.76	151.86	151.90	152.07	152.28	152.47
CADD1_1473	151.71	151.81	151.84	152.02	152.25	152.45
CADD1_1473d	151.70	151.79	151.82	151.93	152.05	152.19
CADD1_1420i	150.89	150.96	151.00	151.12	151.27	151.43
CADD1_1336i	150.21	150.31	150.34	150.46	150.54	150.65
CADD1_1267	149.34	149.45	149.48	149.54	149.63	149.71
CADD1_1175	148.51	148.64	148.68	149.16	149.20	149.25
CADD1_1175d	148.16	148.30	148.35	149.12	149.15	149.19
CADD1_0838	146.27	146.36	146.39	146.46	146.51	146.56
CADD1_762i	145.56	145.65	145.67	145.75	145.82	146.08
CADD1_690	144.98	145.13	145.18	145.36	145.42	145.92
CADD1_690d	144.13	144.27	144.32	144.47	144.58	144.75
CADD1_518	143.38	143.47	143.48	143.48	143.48	143.48
CADD1_329	142.13	142.28	142.33	142.46	142.57	142.80
CADD1_329d	142.03	142.13	142.16	142.25	142.34	142.48
CADD1_213i	140.88	141.00	141.04	141.14	141.24	141.40
CADD1_100i	139.70	139.83	139.87	139.99	140.10	140.30
CADD1_0016	138.76	138.93	138.98	139.14	139.31	139.60

3.3 Flooding mechanisms identified

Based on the baseline scenarios a number of locations were determined to be sources of out of bank flows. These are discussed in the following sections.

3.3.1 Dunstable Road

Figure 3-2 shows the main flooding mechanisms at the junction of Dunstable Road and Mancroft Road.

Figure 3-2: Flood mechanisms at Dunstable Road

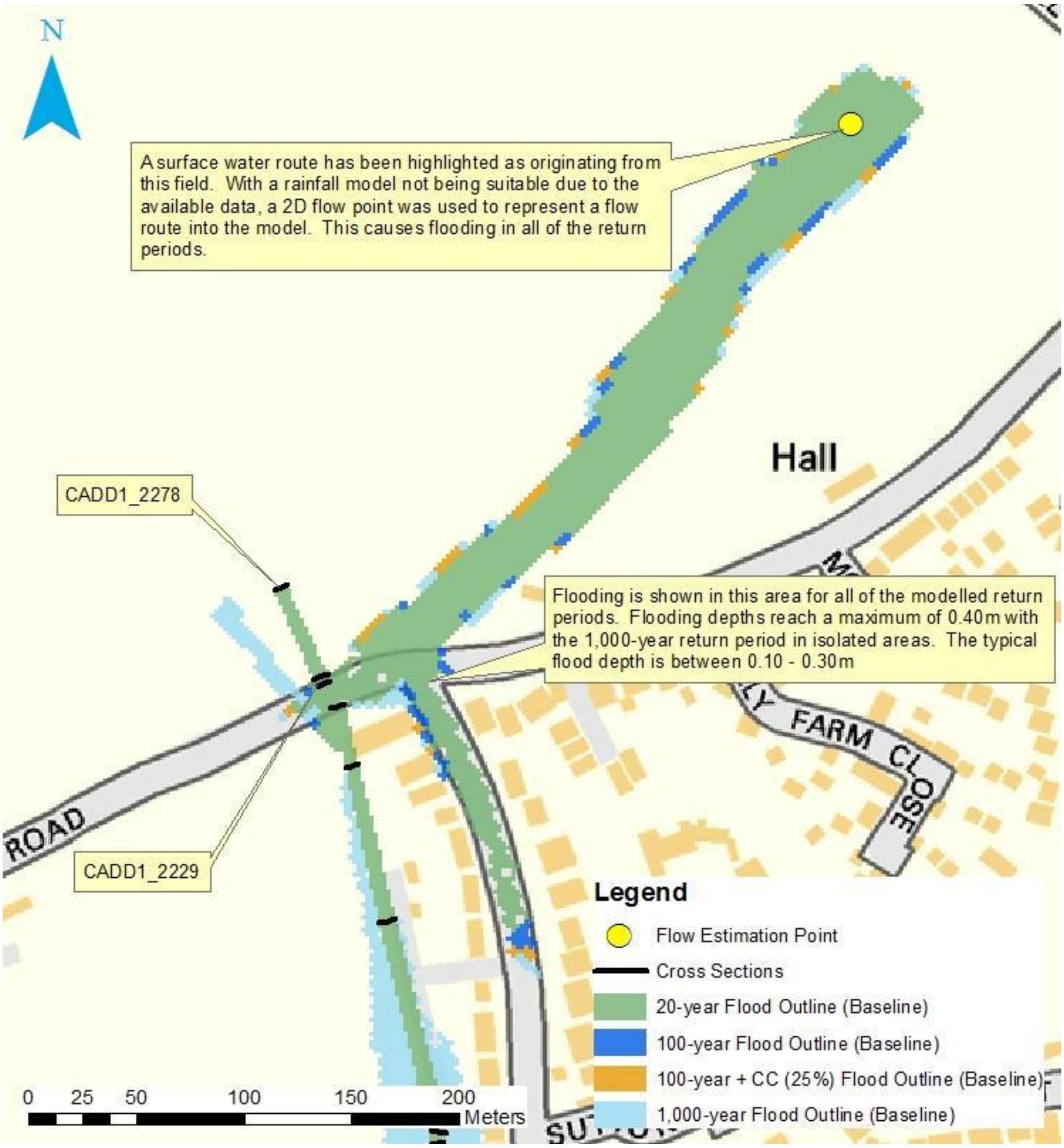

Figure 3-2 shows that the model representation of a surface water flow route causes water to pool on Dunstable Road and flow in a southerly direction down Mancroft Road. Typical flood depths in this location are between 0.10 – 0.30m. Isolated areas show larger depths with the largest depths being approximately 0.40m in the 1,000-year event. Additionally flooding is shown to also originate from the culvert running under Dunstable Road which appears to lack the capacity to convey flows downstream. This leads to water flowing over Dunstable Road before returning back into the channel. Figure 3-3 shows photographs that illustrate this in the flooding of January 2014, where the Dunstable Road culvert appears to be at capacity with some debris blockage. This could also be related to the backing up of water in downstream sections of the channel.

Figure 3-3: Flood Photos at Dunstable Road Culvert (7th January 2014)

	Upstream view of Dunstable Culvert
	Downstream view of Dunstable Culvert
Photographs provided by Central Bedfordshire Council (2014).	

Five properties have been identified by Central Bedfordshire Council to flood on the corner of Dunstable Road and Mancroft Road (numbers 85 to 93). The hydraulic model shows flooding to the driveways of these properties mainly in the 1,000-year event. Due to the inaccuracy of the data these properties may flood in smaller more frequent flood events, but the uFMfSW LIDAR is not detailed enough in resolution to show the flooding which has historically occurred. Therefore the hydraulic model may underestimate flood risk in some locations, such as at Dunstable Road.

It is recommended that to reduce flooding in this location the following options should be assessed:

- A barrier in the form of a berm to prevent overland flow routes north of Dunstable Road.
- Increasing the capacity of the Dunstable Road culvert.
- Providing additional channel storage downstream of Dunstable Road to compensate for increased conveyance downstream of an upsized culvert.

3.3.2 Flood Relief Culvert

Figure 3-4 shows the main flooding mechanisms in the vicinity of flood relief scheme in Caddington.

Figure 3-4: Flood mechanisms in the vicinity of the flood relief culvert

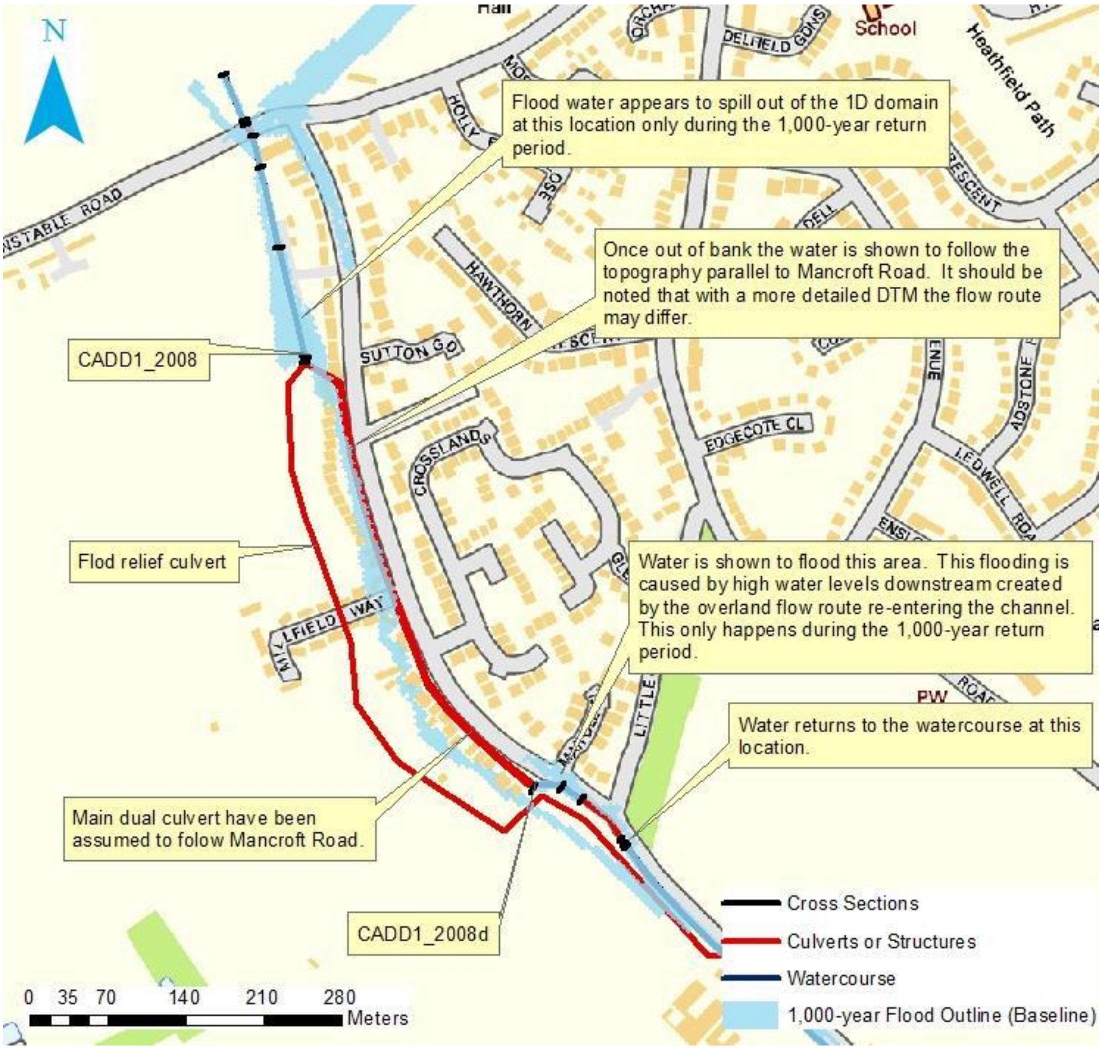

Figure 3-4 shows that the flood relief culverts are only bypassed during the 1,000-year flood event. Flooding originates from overtopping of the left-hand bank. Once out of bank the overland flow follows the topography, running parallel to Mancroft Lane and re-entering the channel upstream of cross section CADD1_1267. Additional flooding is also experienced in the 1,000-year return period event at Mardle Close. This flooding is experienced before the overland flow route re-joins the watercourse and is likely to be caused by the backing up of water at the culvert located at the junction of Mancroft Road and Pipers Lane (cross section CADD1_1175d). This flooding is only shown in the 1,000-year event.

No recommendations have been made on how to manage this flooding issue as it is only active during the most extreme event. However, due to the number of modelling assumptions made for this area it should be revisited and remodelled when the following information becomes available:

- A more accurate DTM to determine road and ground levels in close proximity to the bank with greater accuracy.
- Property threshold survey to improve ground level representation at the properties known to flood.
- CCTV survey of both the dual culverts and the flood relief culvert. This would allow a more accurate representation of invert levels within the culverts as well as any change in dimensions, as stated in the assumptions in Section 2.6.2.

3.3.3 Mancroft Road at Aley Green

Figure 3-5 shows the main flood mechanisms on Mancroft Road at Aley Green.

Figure 3-5: Flood mechanisms at Aley Green

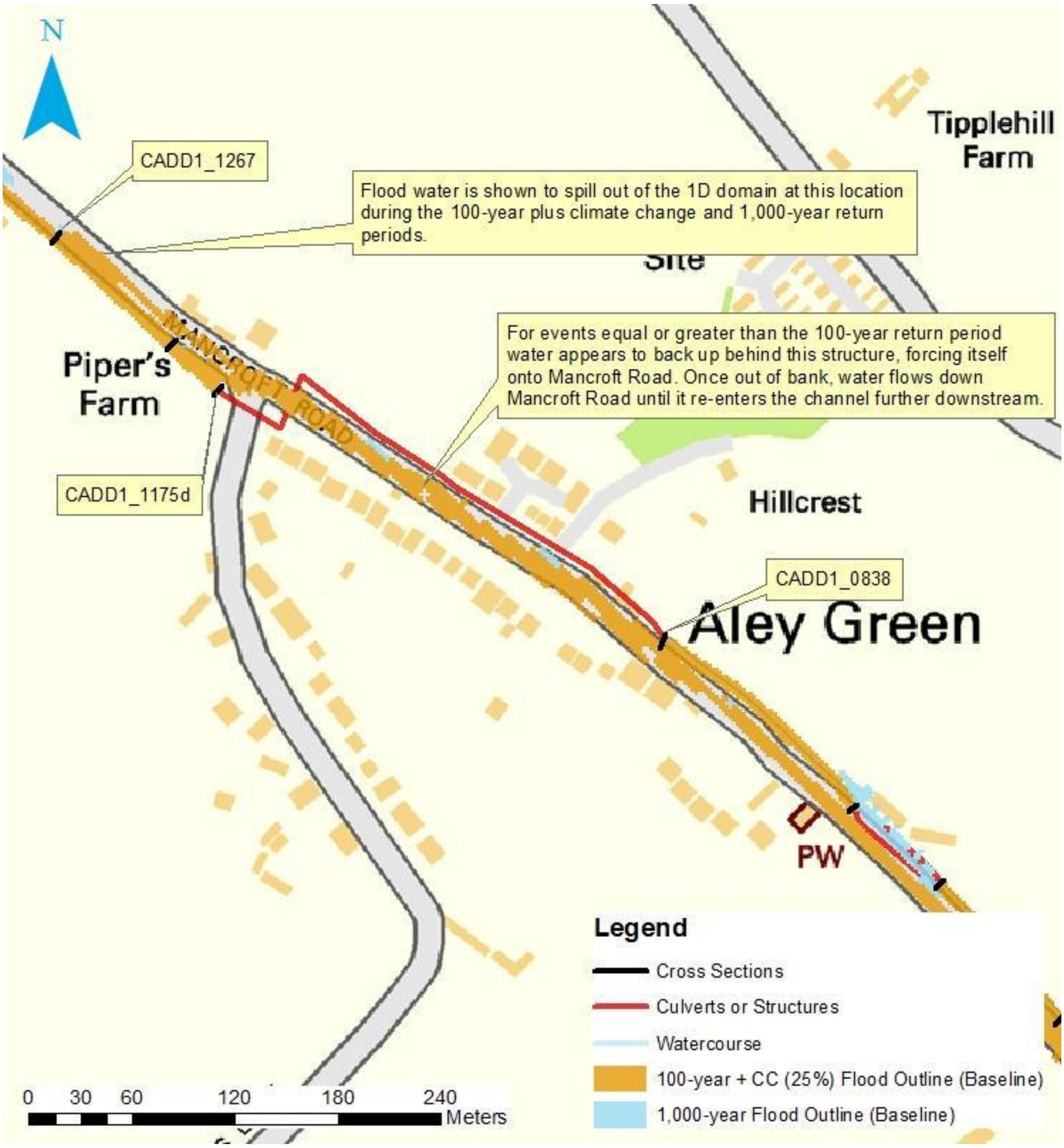

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Figure 3-5 shows that flooding at this location originates from the culvert running from the junction of Pipers Farm (cross section CADD1_1175d) to Aley Green (cross section CADD1_0838). Water appears to get out of bank on the left hand bank and flows down Mancroft Road before re-entering the channel further downstream in Aley Green. This is likely to be caused by the culvert connecting open channel sections having insufficient capacity to convey water. This flood route is only present in the 100-year plus climate change and 1,000-year events. This flooding corresponds to photographic evidence provided by Central Bedfordshire Council that show water close to properties located on the roadside (see Figure 3-6).

Figure 3-6: Flood Photographs at Aley Green (7th January 2014)

<table>
<tr><td></td><td>Upstream face of culvert (CADD1_1175d) located at the junction of Mancroft Road and Pipers Lane. This is shown to be a location within the model were water spills out of bank.</td></tr>
<tr><td></td><td>View north along Mancroft Road at the junction between Mancroft Road and Pipers Lane. Similar to the photo the hydraulic model shows flooding in this area in event equal or greater than the 100-year event.</td></tr>
<tr><td></td><td>View of downstream face of culvert (CADD1_0838). The hydraulic model shows similar pooling of water in this location, especially for the 100-year plus climate change and 1,000-year events. Flood depths for these events are approximately 0.20 – 0.30m.</td></tr>
<tr><td colspan="2">Photographs provided by Central Bedfordshire Council (2014).</td></tr>
</table>

In order to reduce flooding, initial recommendations are to increase the capacity of this culvert (though this could increase flows downstream). A CCTV survey of the Piper Lane / Mancroft Road culvert would allow a more accurate representation within the model. Assumptions have been made that the culvert falls at a constant gradient and does not change shape along its length. It is also unclear as to the exact path the culvert takes between the open channel sections.

3.3.4 Upstream of Woodside Road Bridge.

Figure 3-7 shows the main flood mechanisms upstream of Woodside Road Bridge.

Figure 3-7: Flood mechanisms at Woodside Road Bridge

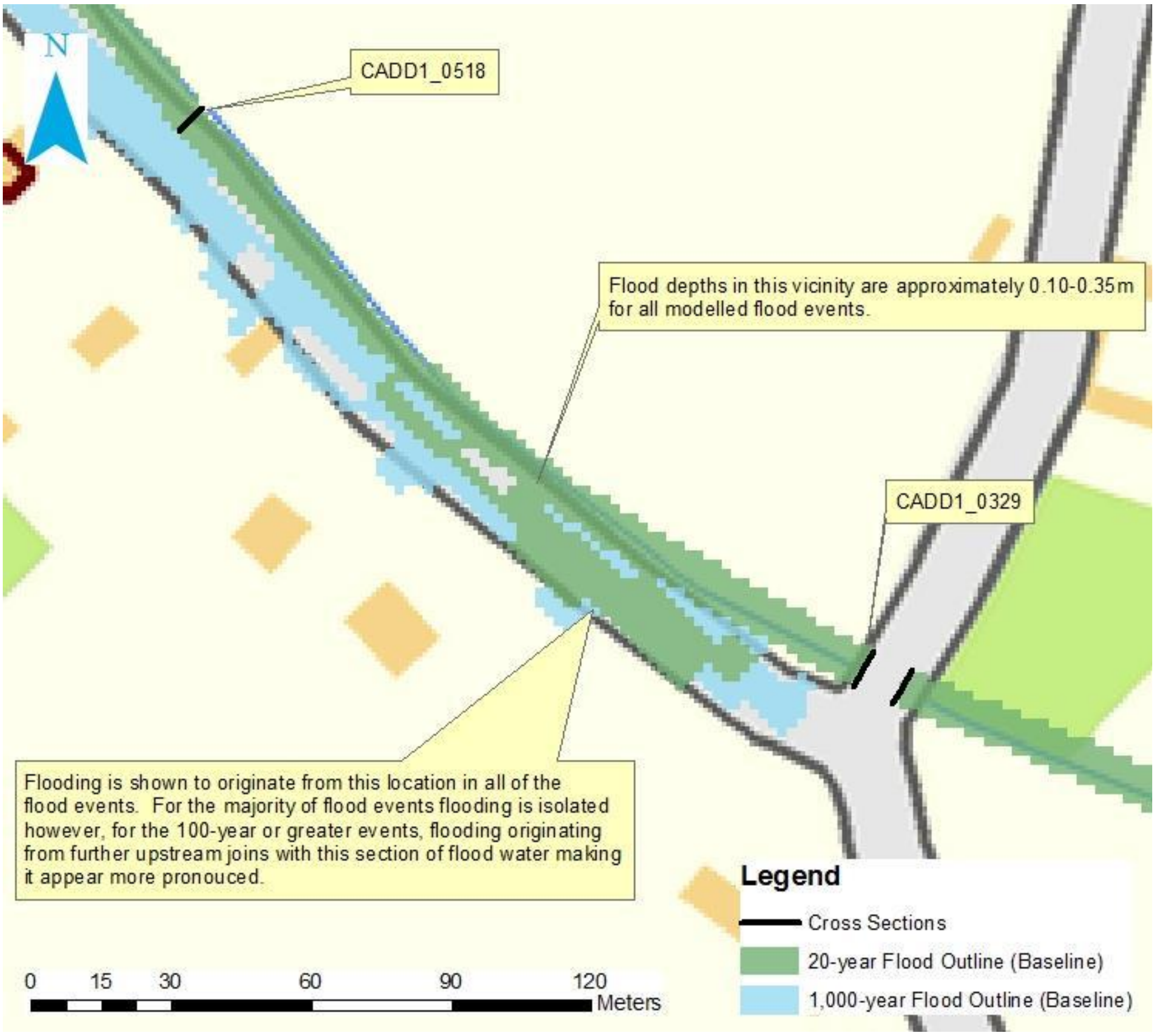


Figure 3-7 shows that the main flood mechanism is out of bank flow just upstream of Woodside Road Bridge. This is experienced in the majority of flood events except for the 5-year event. It is not caused by surcharging of the road bridge culvert as this only reaches capacity in the 100-year or greater events. Instead, it is likely to be caused by water spilling out of a low spot in the right hand bank. Considering bank level data is interpolated it is difficult to determine whether this is accurate. One possible option of reducing flood risk would be to increase the capacity of the culvert to determine whether it is related to the channel capacity. Although this is to be investigated it is unlikely that the cost-benefit of such an option would warrant it being actioned.

3.4 Blockage Scenarios

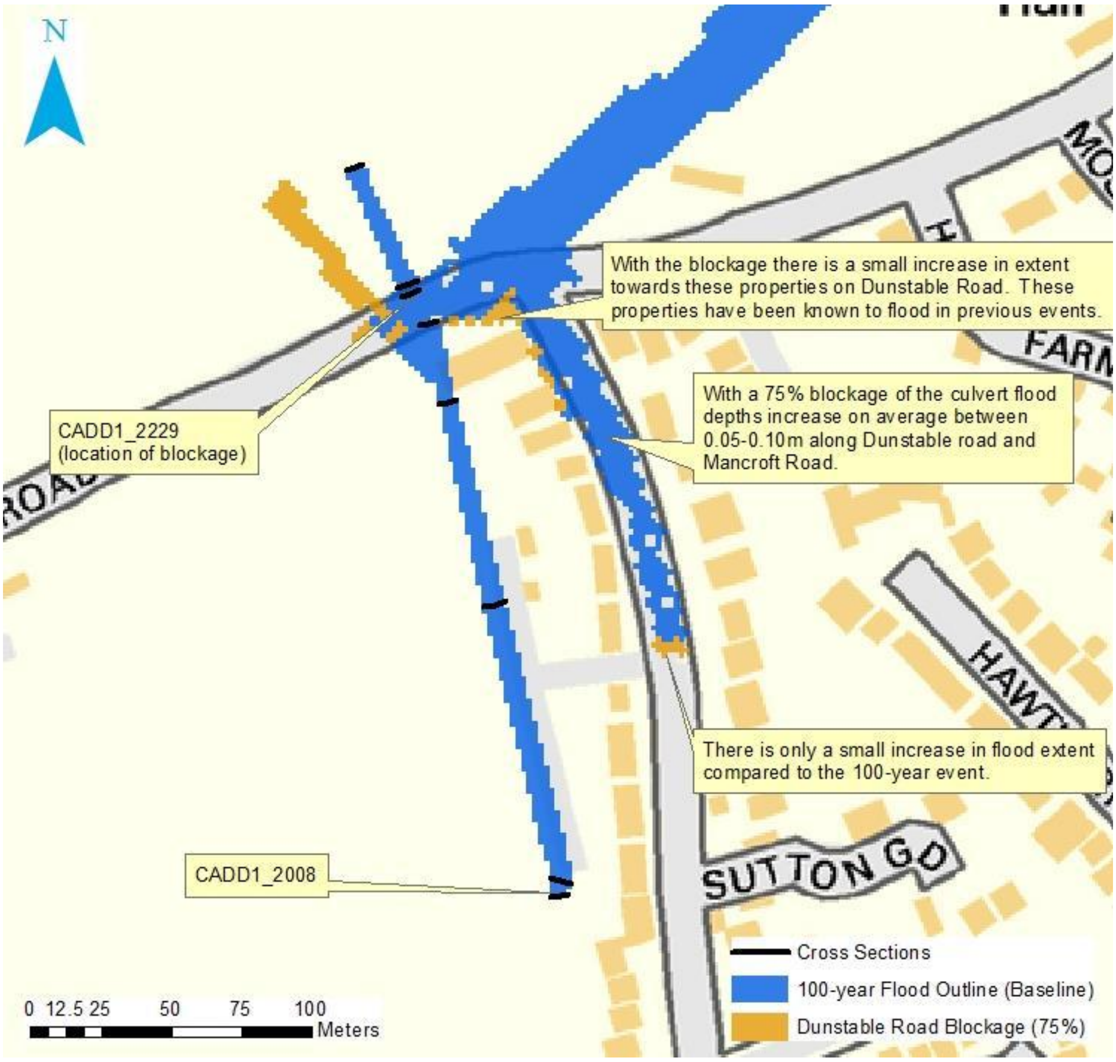
As well as model sensitivity runs, a 75% blockage was also tested at key locations for the 100-year flood event. These locations were the following:

- The Dunstable Road Culvert
- The Pipers Lane / Mancroft Road Culvert

3.4.1 Dunstable Road

Figure 3-8 shows the flood outline for the 75% blockage of the Dunstable Road culvert compared to the 100-year baseline event.

Figure 3-8: 75% Blockage of the Dunstable Road Culvert Flood Outline



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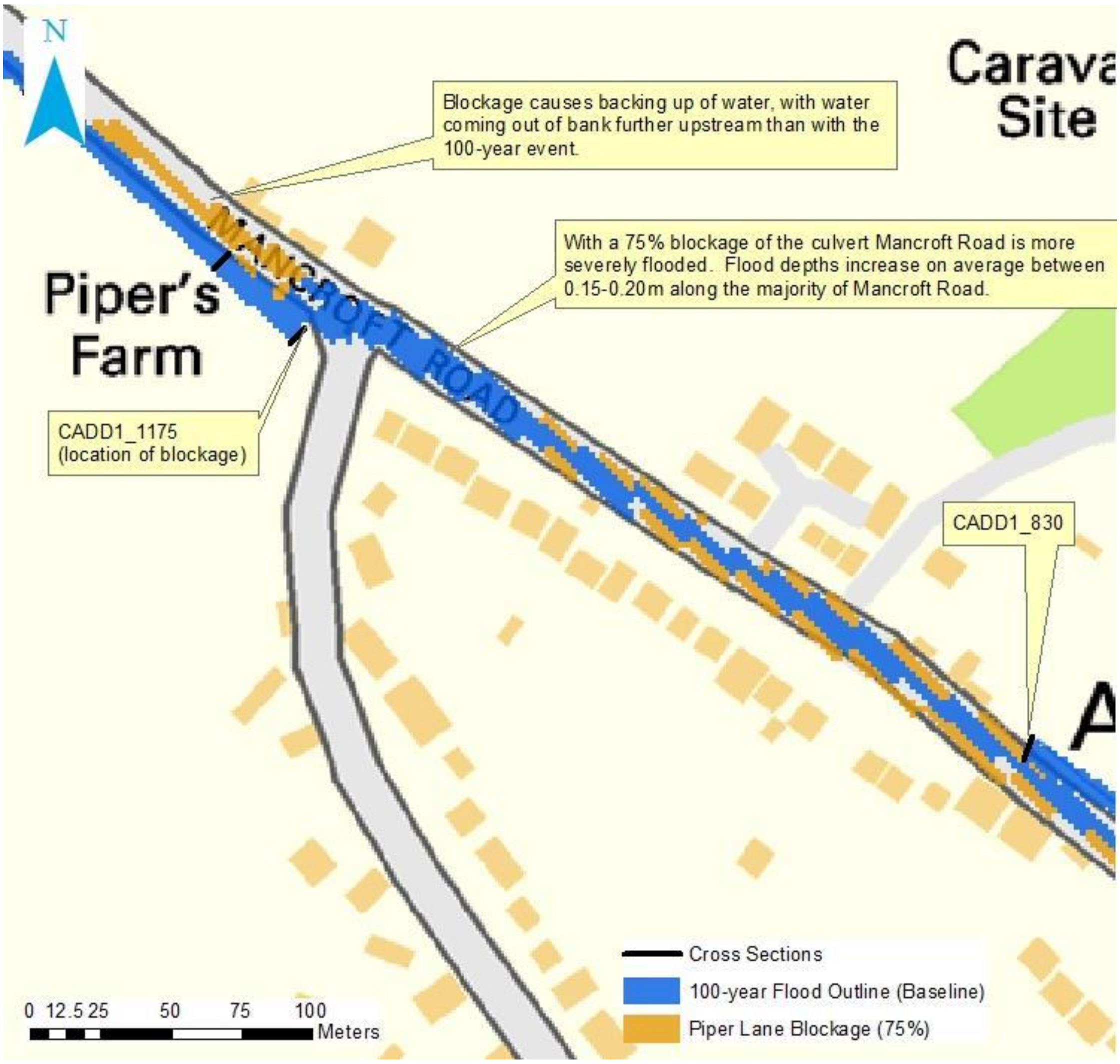
With a 75% blockage of the Dunstable Road culvert during the 100-year event, there is shown to be only a small increase in flood extent in the vicinity of Dunstable Road and the top of Mancroft Road. Average depths in this location increase by approximately 0.10m. Within the channel there is a maximum increase upstream of the blockage in peak water levels of approximately 0.44m. There is also a small increase of approximately 0.01m in peak water levels between Dunstable Road and the flood relief culverts due to increased overtopping of Dunstable Road. Interestingly, properties that have been identified as having previously flooded by Central Bedfordshire Council appear to have their driveways flooded as highlighted in the figure above. Although the model does have a crude representation of topography away from the watercourse, this indicates that the blockage of this culvert could have contributed to these properties previously flooding.

3.4.2 Pipers Lane

Figure 3-9 shows the flood outline for the 75% blockage of the Pipers Lane culvert compared to the 100-year baseline event.

Figure 3-9: 75% Blockage of the Pipers Lane Culvert Flood Outline



With a 75% blockage of the Pipers Lane culvert during the 100-year event, there is shown to be only a small increase in flood extent along Mancroft Road. Average depths in this location increase by approximately 0.15-0.20m. Water is shown also to get out of bank further upstream of the culvert blockage due to the localised increase in peak water levels. Within the channel there is a maximum increase upstream of the blockage in peak water levels of approximately 0.13m. As a result of the blockage there are decreases in peak water level of approximately 0.05-0.15m downstream of the blockage where water is no longer being conveyed.

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 Caddington.

The following options were tested:

Option	Action
Option 1	Inclusion of berm and new/ upsizing of culverts. Additional storage in form of a two-stage channel downstream of Dunstable Road until the Flood Relief culvert. This option will be tested with the individual features to determine the extent of the proposed option.
Option 2	Upsizing the Woodside Road Bridge to increase conveyance.
Option 3	Implementing a two-stage change between Pipers Lane and Heron Farm on the right hand bank. A small berm was used to try and prevent flows onto Mancroft Road.
Option 4	Modelling improved channel conveyance. This was represented by reducing the channel roughness (to simulate vegetation removal) by 20%.
Option 5	Upsizing the culvert at Pipers Lane / Mancroft Road.
Option 6	Investigating potential effects of a new development proposed at Dunstable Road.

Appendix E shows the results of a 'do nothing' scenario, where vegetation would be allowed to grow in the channel along the whole modelled extent, to show a comparison against flood mitigation.

4.2 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.

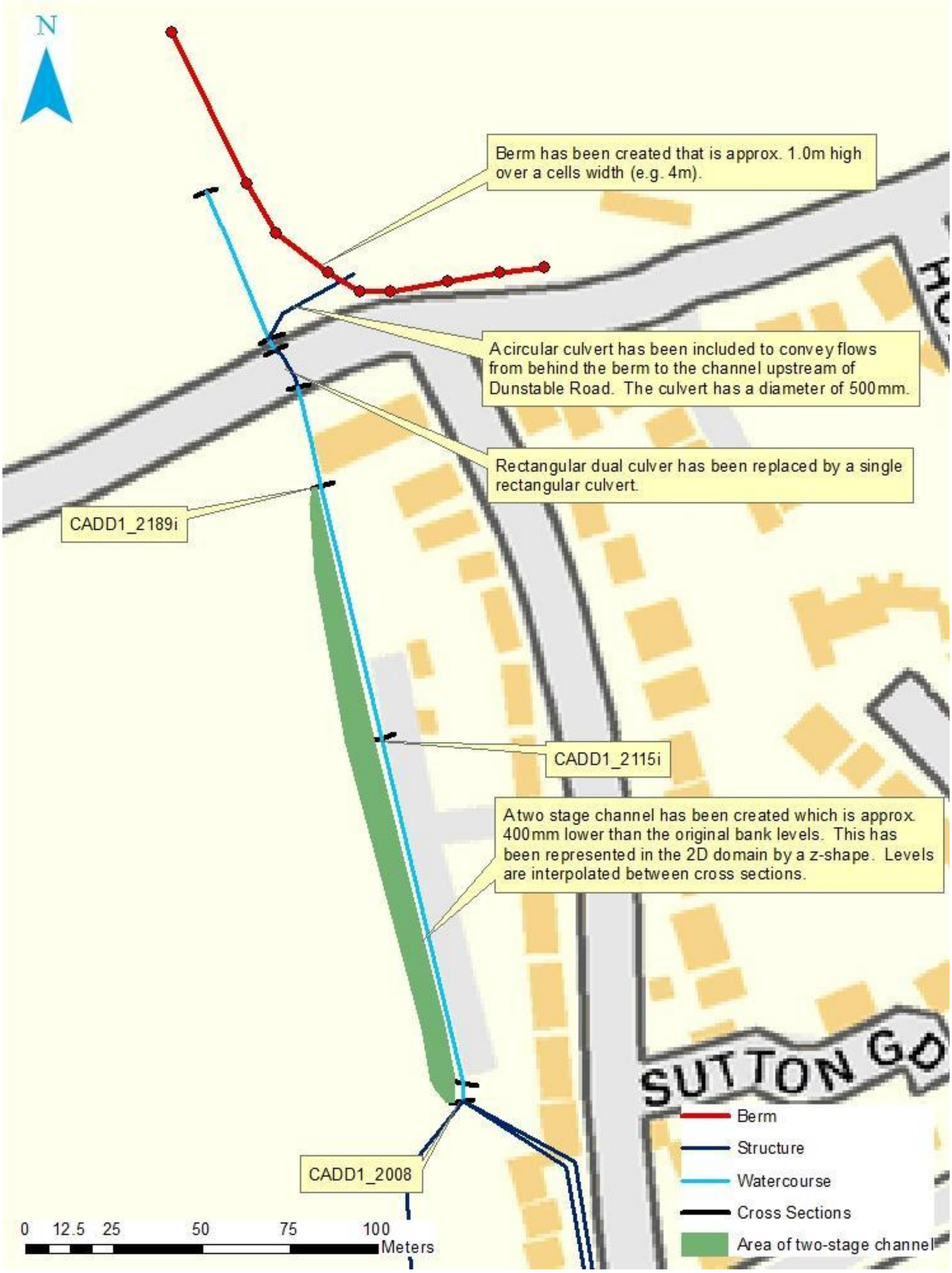
4.2.1 Option 1 – Flood mitigation of Dunstable Road

Figure 4-1 shows the layout of features for Option 1, which is designed to reduce flood risk at Dunstable Road and to the five properties previously affected by flooding.

The main components of the option are a berm in the field adjacent to the watercourse which is designed to stop a surface water flow route towards Dunstable Road. This berm would be approximately 1m above existing ground levels. Water backing up is conveyed to the channel via a 500mm circular culvert. The Dunstable Road culvert was upsized from a dual culvert to a single rectangular culvert of the same width but increased capacity by removing the dual split in the middle. Additional storage capacity was provided between Dunstable Road and the Flood Relief Culvert to compensate for any increase in flow conveyance from the upsizing of the Dunstable Road culvert.

The option will be tested with the individual features to determine the extent of the proposed option. Option 1 will consist of all of the features. Option 1B will consist of the Dunstable Road upsized culvert and berm. Option 1C will comprise only the upsized Dunstable Road culvert.

Figure 4-1: Option 1 Layout



4.2.2 Option 2 – Upsizing the Woodside Road Bridge

To improve conveyance the Woodside Road Bridge was upsized to try and improve conveyance, lowering water levels and possibly reducing the about of out of bank flow upstream of Woodside Road Bridge. Originally the structure was represented as an 'R' type rectangular culvert. For the options testing this was changed to be a 'B' type bridge. It was assumed that the new bridge would be a single span bridge with a soffit at the same level as the original structure.

4.2.3 Option 3 - Two-stage channel at Pipers Lane / Mancroft Road

To try and improve the flood risk at the junction of Pipers Lane and Mancroft Road, a small two-stage channel was introduced on the right hand bank. This was represented within the 1D domain and consisted of cutting the bank out to a level approximately 600mm above the bed level. The banks of the two-stage channel were designed to have a 1:2 gradient returning to a similar level as they are now. This resulted in the channel being widened by approximately 2m. The two-stage channel was introduced between CADD1_1175 and CADD1_1225i (Pipers Lane to Heron Farm). Additionally a berm was placed along the roadside to try and restrict the movement of flood water at the culvert. This berm extended the same distance as the 2-stage channel and was approximately 500mm above existing ground levels. It should be noted that in some cases increasing capacity increases the risk of deposition of sediment.

4.2.4 Option 4 – 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 this improvement in flow conveyance, roughness was reduced in the channel cross sections by 20%. The table below shows the typical channel roughness values of the baseline scenario and the option representing improved channel conveyance by the removal of vegetation. This option may require an ecological survey.

Scenario	Typical Channel Roughness (Manning's 'n')
Baseline	0.050 – 0.060
Option 4 – Improved channel conveyance	0.040 – 0.048

4.2.5 Option 5 – Upsizing the culvert at Pipers Lane / Mancroft Road

The Pipers Lane / Mancroft Lane culvert has been determined to be a key location for flood risk, with water overtopping the structure and flowing down Mancroft Road. Although a number of assumptions have been made to represent this culvert it was decided that testing should be conducted to determine whether increasing the capacity would help alleviate flooding. The culvert was increased in size to an 'R' type rectangular culvert opposed to an 'I' type irregular culvert that currently exists. The dimensions of the new culvert are 1.75m wide and 0.65m high. This increases the surface area of the culvert from 0.74m^2 to 1.14m^2.

4.2.6 Option 6 – Investigating proposed new development at Dunstable Road

A planning application for a new development on the Dunstable Road has been submitted to the CBC planning portal, in the locality of the modelled watercourse at Dunstable Road. The planning application reference is '*CB/10/03478/OUT - Land fronting Dunstable Road*'. This new development of 1.46ha comprises a residential housing estate with flats, houses, associated gardens, parking areas and a pond/ swale.

A test was undertaken by increasing the URBEXT (urban extent) value in the catchment descriptors which represent the surface water flow route crossing the new development in a south-westerly direction towards the Dunstable Road culvert. It was estimated from the site plan that 70% of the 1.46ha development was to be impermeable ground, which was used for updating URBEXT. This was a more conservative estimate than the impermeable area stated in the Flood Risk Assessment on the planning portal.

Increasing the urban extent in the catchment for this new development area showed no discernible difference in peak flows, and therefore the model was not run as no differences would be seen in the results.

The existing Flood Risk Assessment submitted on the planning portal addresses surface water flood risk mitigation, stating that flows will be attenuated on site up to the 100-year plus climate change (30%) flood event, via four systems; roof drainage, road drainage, pervious paving, and overland flow. The surface water overland flows are currently proposed to be routed along the existing topographic drainage path represented in the hydraulic model, towards the watercourse at Dunstable Road. Whilst this proposal may change, it is a requirement that all new developments ensure no detrimental impact on surrounding developments by effectively managing surface water runoff to pre-development levels or below. This is expected to be achieved through the use of Sustainable Drainage Systems (SUDS).

5 Model Results - Options Testing

5.1 Options vs. baseline flood outlines

5.1.1 Option 1

Figure 5-1 shows the comparison of the baseline and Option 1 (comprising two-stage channel, upsized culvert and berm) flood outlines for the 100-year plus climate change event.

Figure 5-1: Option 1 comparison with baseline scenario

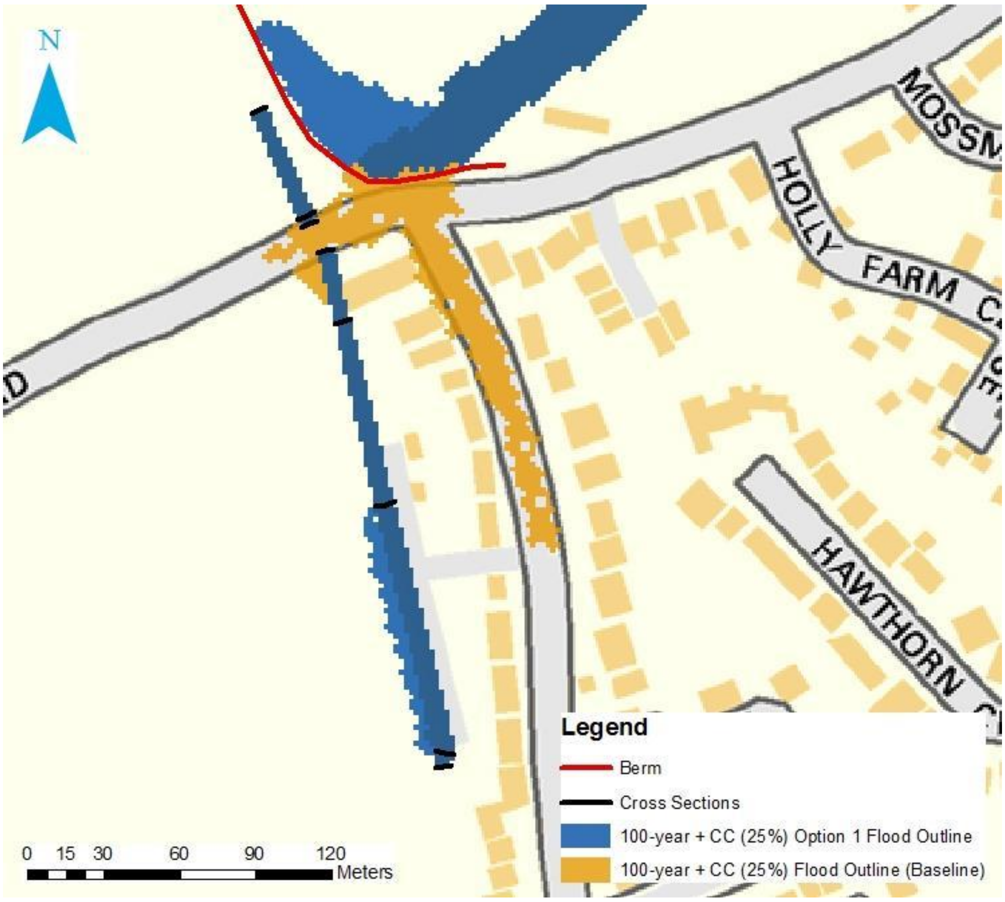


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Figure 5-1 shows that the presence of the berm prevents the hydraulic model's representation of overland flows from flooding Dunstable Road and the top of Mancroft Road. Water backs up behind the berm to a depth of approximately 0.80m in the 100-year plus climate change event. The new 500mm culvert is shown to surcharge during the 100-year plus climate change event; however, when the option was simulated with the smaller 30-year event it was shown to have sufficient capacity. This would indicate that the culvert is adequately sized to deal with the more common surface water flows. With regards to the upsized culvert under Dunstable Road, it is shown to be at capacity in the 30-year event and to have its capacity exceeded in the 100-year plus climate change event. Although it is at capacity, water does not back up to a level which would overtop the structure. It should be noted though that the upsizing of the culvert does reduce water levels by 0.14m at the upstream face of the structure. Considering the size of the culvert it would be impractical to upsize it any further. In total the average decrease in water level along the length of the watercourse is 0.02m. The maximum decrease in water levels are felt directly upstream of the culvert.

It is recommended that this option is further investigated although more detailed information such as improved topographic information may be required to model this option in more detail. Also this option would benefit from a rainfall modelling approach to better represent the overland flow routes of the area.

5.1.2 Option 1B

Figure 5-2 shows the comparison of the baseline and Option 1B (which consists of the upsized culvert and berm) flood outlines for the 100-year plus climate change event.

Figure 5-2: Option 1B comparison with baseline scenario

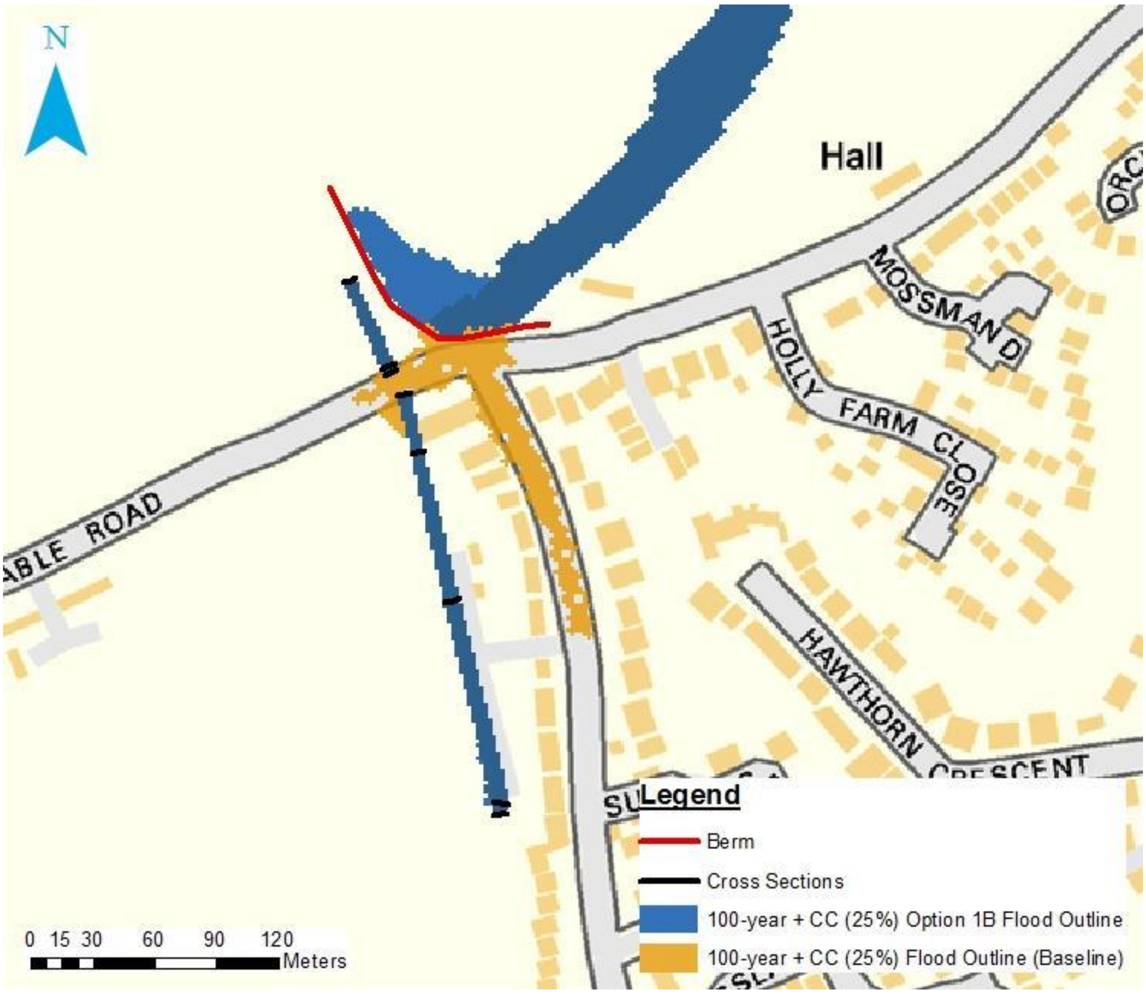

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Figure 5-2 shows that with Option 1 just including the upsized culvert and berm that flooding is still significantly reduced in comparison with the baseline scenario for the 100-year plus climate change event. However, without the two-stage channel there is shown to be an increase in peak water levels of 0.11m downstream at CADD1_2014 & CADD1_2014 (flood relief culverts). This indicates that by increasing the conveyance of the culvert that flood risk could be increased elsewhere, therefore it would seem appropriate to retain the two-stage channel to provide additional channel capacity.

5.1.3 Option 1C

Figure 5-3 shows the comparison of the baseline and Option 1C (which comprises only the upsized Dunstable Road culvert) flood outlines for the 100-year plus climate change event.

Figure 5-3: Option 1C comparison with baseline scenario

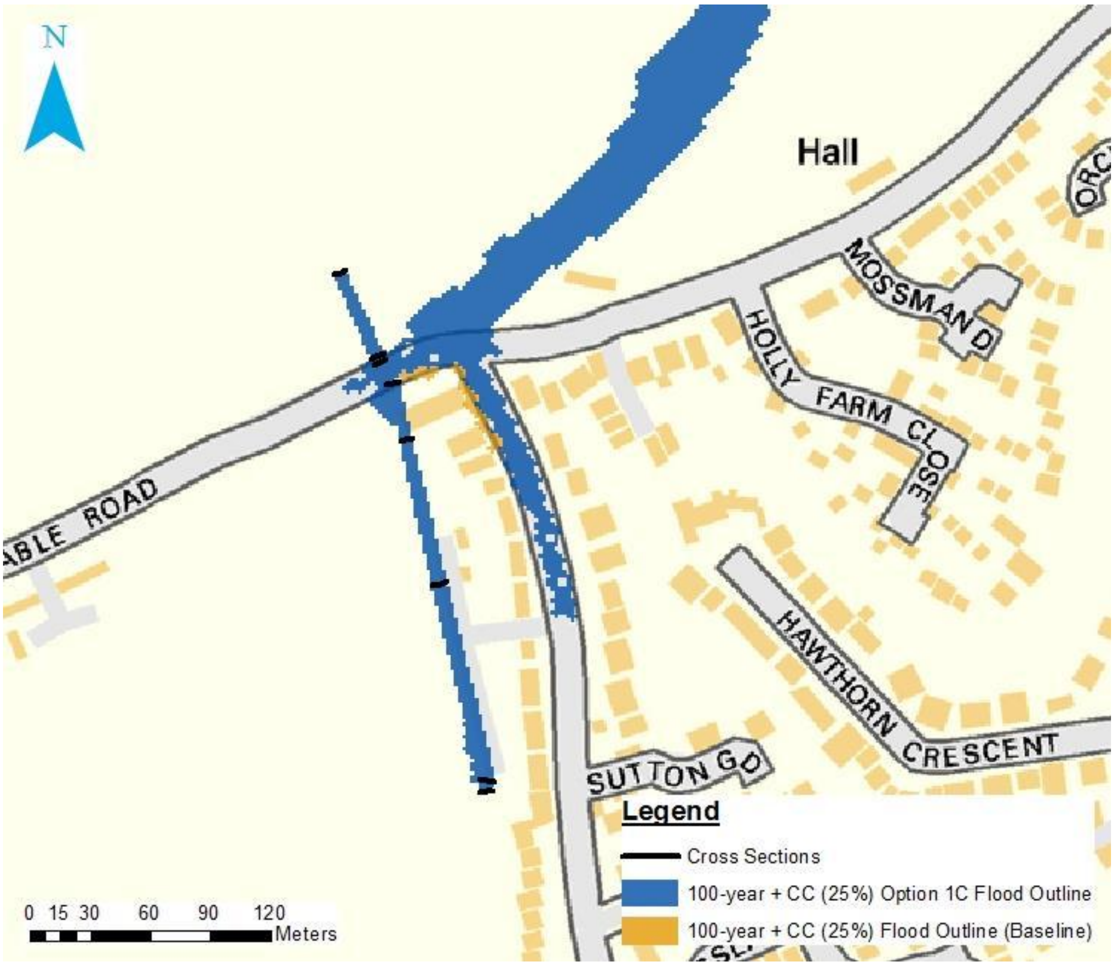

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Figure 5-3 shows that with the modelled representation of the overland flow route, without the presence of the flood berm the flood extent is similar to that of the baseline scenario for the 100-year plus climate change event. This indicates that regardless of the upsizing of the Dunstable Road culvert, the road junction is still likely to flood from the overland flow route from the north-east. The upsizing of the culvert at Dunstable Road should therefore be compared with other features as suggested in Option 1.

5.1.4 Option 2

Figure 5-4 shows the comparison of the baseline and Option 2 flood outlines for the 100-year plus climate change event.

Figure 5-4: Option 2 comparison with baseline scenario

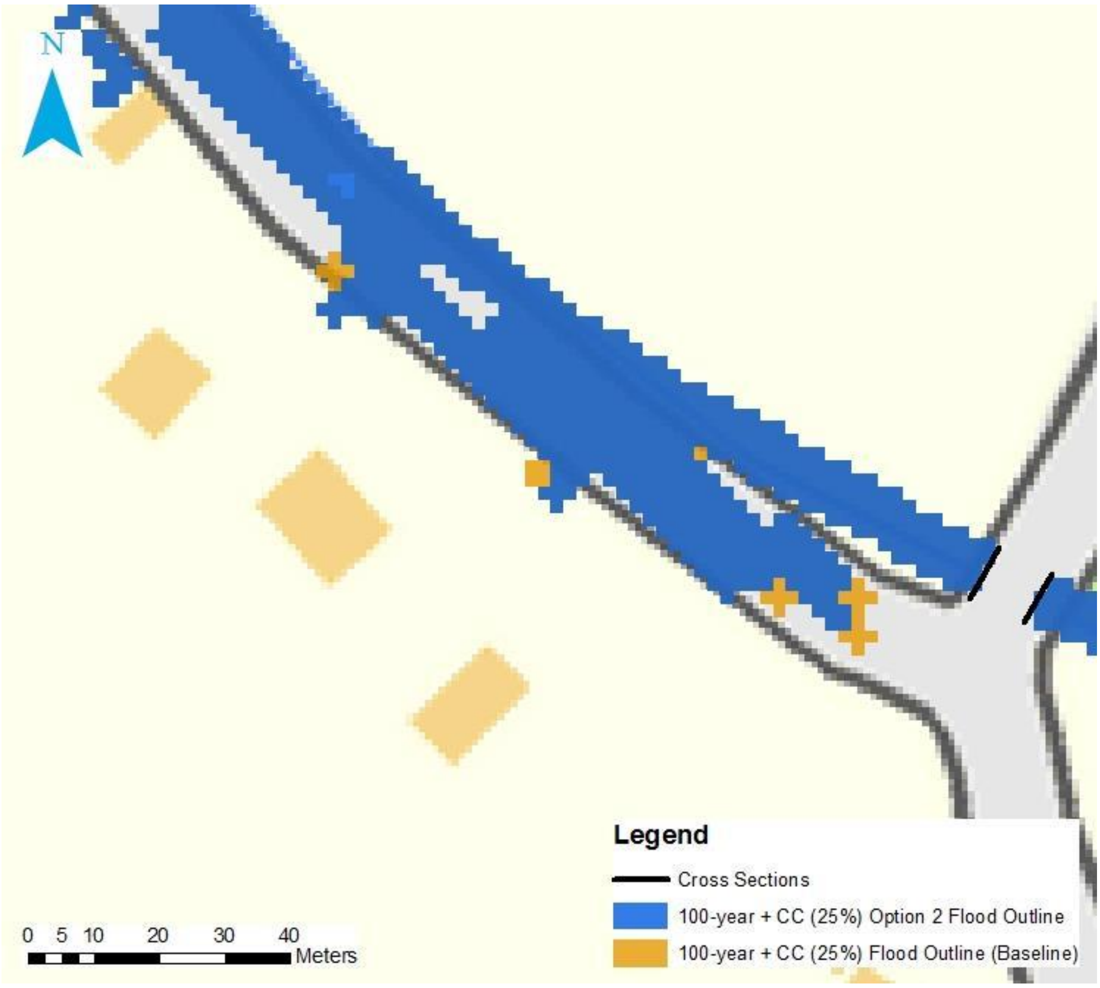

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Figure 5-4 shows that even with widening the opening geometry of the Woodside Road Bridge from a culvert to a single span bridge, there is not a significant change in flood extents between the option and the baseline scenario even though there is a decrease of 0.22m in peak water level at the upstream face of the structure. It is therefore unlikely that increasing capacity of this structure would be economically viable consisting the small impact it would have on overall flood risk.

5.1.5 Option 3

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

Figure 5-5: Option 3 comparison with baseline scenario

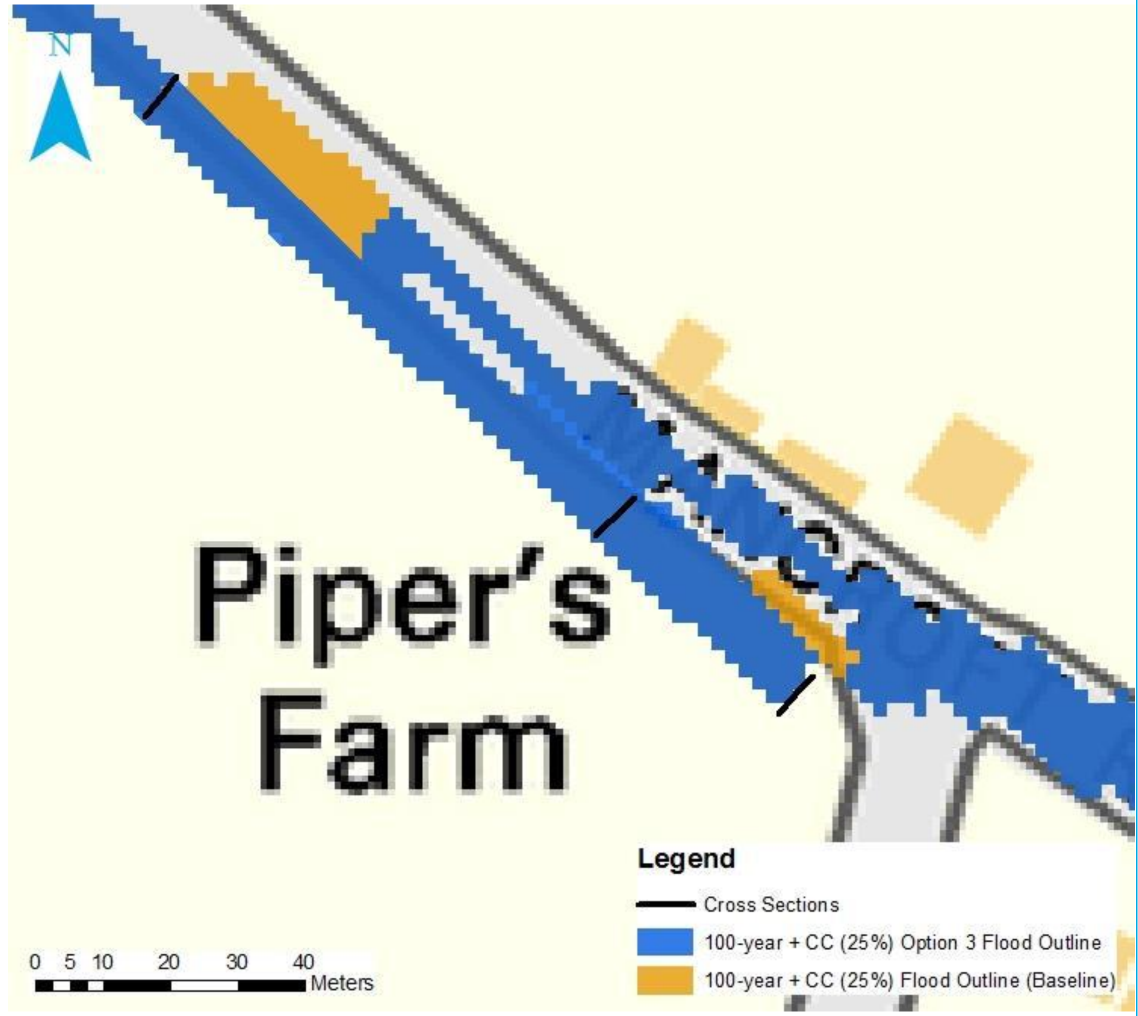

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Figure 5-5 shows that there is still significant flooding along Mancroft Road with this option compared to the baseline. It appears that the presence of the berm increases water levels within the channel at the upstream face of the structure. Increases at cross section upstream of the Pipers Lane / Mancroft Road culvert (CADD1_1175d & CADD1_1175) are approximately 0.25m. This backing up of water behind the structure and berm causes water to come out of bank further upstream, and hence still resulting in flooding down Mancroft Road. It is recommended that his option is not further explored as the conveyance capacity of the Pipers Lane / Mancroft Road culvert is the main driver of flooding in the area.

5.1.6 Option 4

Figure 5-6 shows the comparison of the baseline and Option 4 flood outlines for the 100-year plus climate change event.

Figure 5-6: Option 4 comparison with baseline scenario

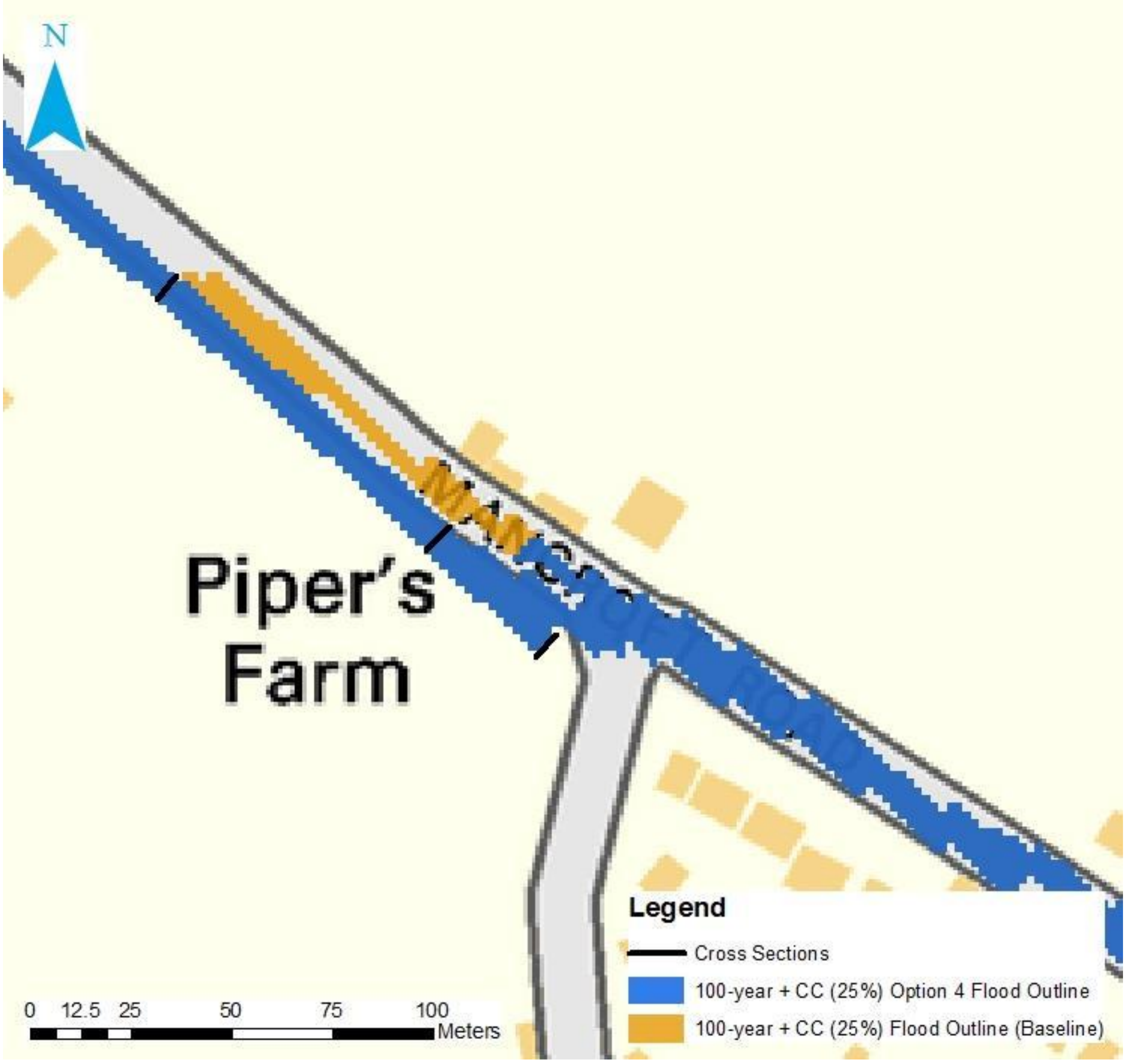

Figure 5-6 shows the main difference in the flood extents between the baseline and Option 4 at Pipers Farm. By reducing the Manning's 'n' roughness value at cross sections, flow conveyance through the model has been improved. Although flooding still occurs at the Pipers Lane junction, it appears to be only originating from the surcharging of the culvert, as opposed to further upstream. Overall improved conveyance in the channel results in an average decrease of 0.05m in peak water levels in the 100-year plus climate change event. The largest decrease in peak water level is at Heron Farm (CADD1_1267) at 0.11m. Increases water levels are only found at the upstream face of the Woodside Road Bridge where peak water levels increase by 0.09m. It is recommended that this option should be investigated in greater detail as it does appear to help reduce flood risk up to the 100-year plus climate change event.

5.1.7 Option 5

Figure 5-7 shows the comparison of the baseline and Option 5 flood outlines for the 100-year plus climate change event.

Figure 5-7: Option 5 comparison with baseline scenario

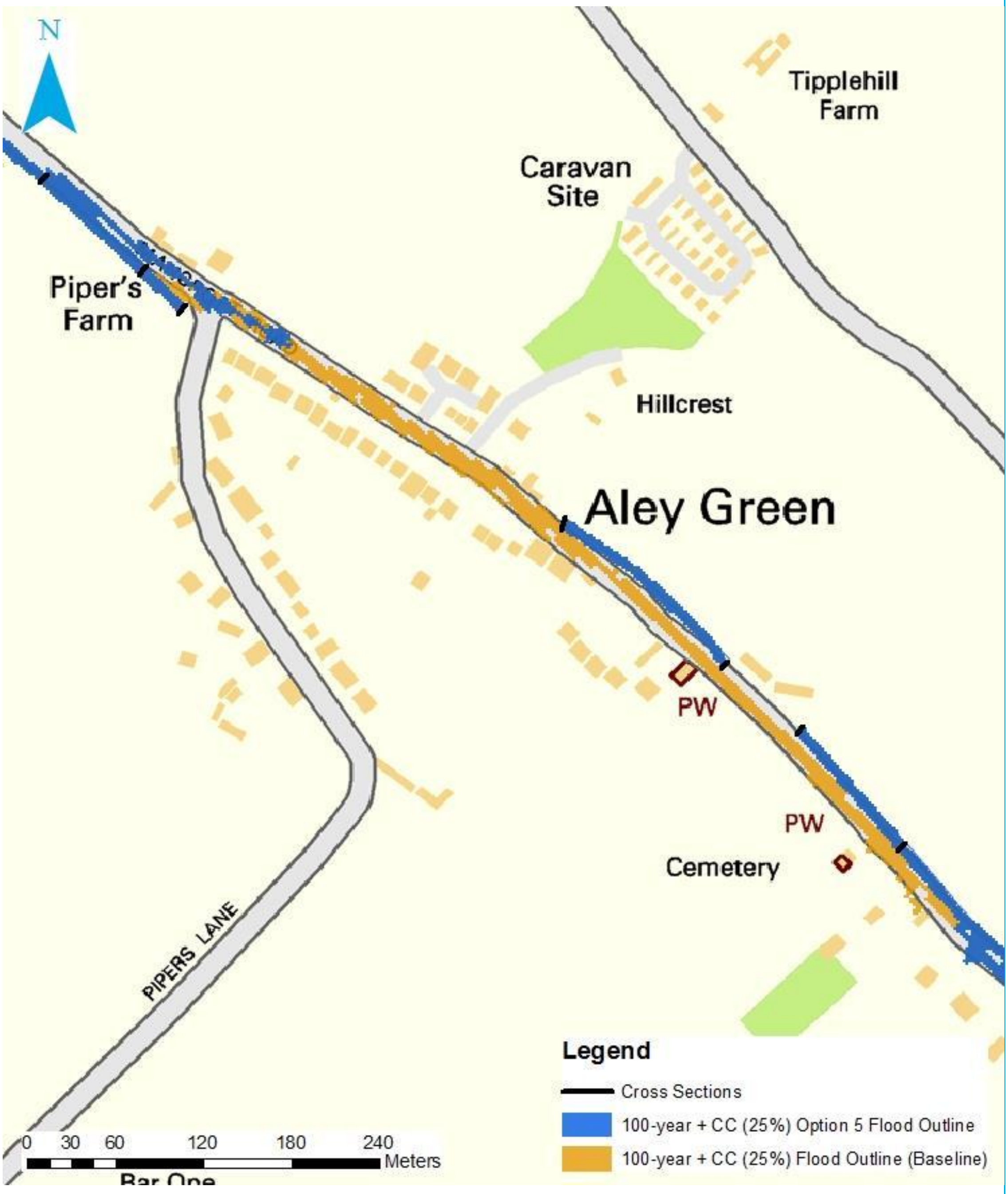

Figure 5-7 shows that with upsizing of the Pipers Lane / Mancroft Road culvert that there is a reduction in flood extent which extended down Mancroft Road in the baseline scenarios. The maximum decrease in peak water levels are exhibited at the upstream face of the culvert (CADD1_1175d) with decreases of 0.59m. There is shown to be a small increase downstream of the upsized culvert due to the increase in conveyance, although this is relatively insignificant with an average increase in peak water levels of 0.04m. On average there is a decrease in peak water levels of 0.02m along the length of the watercourse in the 100-year plus climate change event.

Based on the results of Option 4, Option 5 was further investigated to determine whether a combination of improved channel conveyance and upsizing of the culvert would further improve flood risk. Figure 5-8 shows the comparison of the baseline and Option 5 flood outlines for the 100-year plus climate change event but with the option including the representation of vegetation removal (to improve flow conveyance).

Figure 5-8: Option 5 + improved channel conveyance comparison with baseline scenario

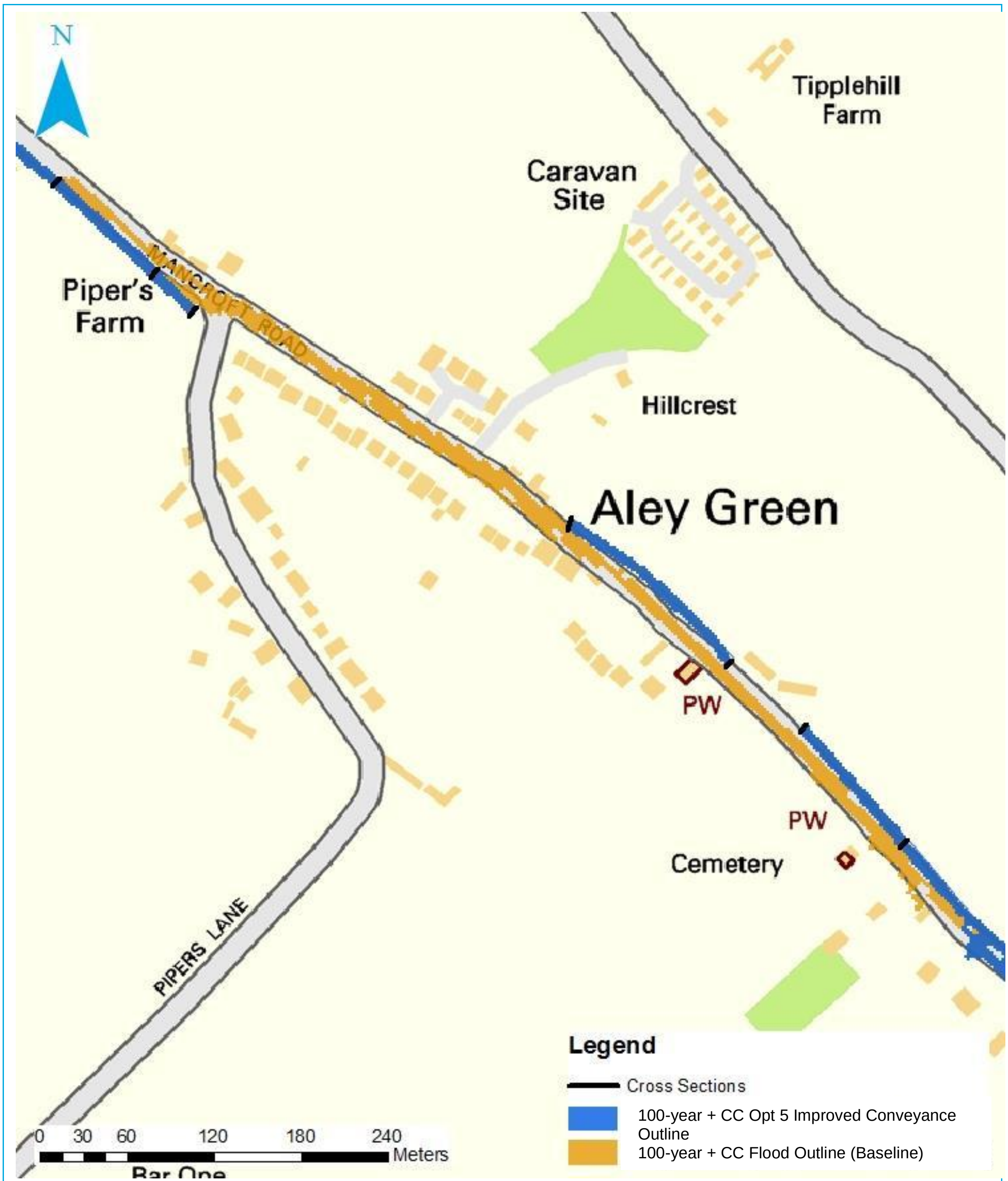

Figure 5-8 shows that the combination of Option 4 and Option 5 result in removal of flooding from Mancroft Road which previously originated from the Pipers Lane / Mancroft Road culvert. On average there is a decrease in peak water levels of 0.07m along the length of the watercourse with the 100-year plus climate change event. The maximum decrease in peak water levels are exhibited at the upstream face of the culvert (CADD1_1175d) with decreases of 0.65m. It is recommended that this combined option is further investigated although more detailed information such as culvert CCTV survey and improved topographic information may be required to model this option in more detail.

5.2 'Do Nothing' Scenario

This additional scenario aims to give an estimate of the possible flood extents in Caddington if maintenance/ conveyance of the watercourse was not maintained and vegetation built up within the channels. The method, results and conclusions are presented in Appendix E, and a summary is provided below:

- There is a maximum increase of approximately 0.10m in peak water levels during all return periods as a result of the increased channel roughness. This is mainly exhibited at the downstream end of the model.
- There is only a minimal average increase of approximately of 0.10m in peak water levels along the length of the model with all return periods.
- There is no significant increase in flood extent for any of the return periods as a result of the increased channel roughness, as once water is out of bank it has little impact in the floodplain.
- No additional properties are shown to flood in this scenario for any of the return periods.

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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 Caddington is the following:

- Improved channel conveyance along the length of the watercourse by the removal of dense vegetation. This was modelled as Option 4.
- Development of a combination of methods at Dunstable Road, modelled as Option 1. This would include a berm to collect surface water overland flows, a new culvert to convey these flows to the channel, upsizing of the Dunstable Road culvert and implementing a two-stage channel on the right hand bank between Dunstable Road and the flood relief culvert.
- Upsizing the Pipers Lane / Mancroft Road culvert, modelled as Option 5.

The preferred option has been modelled for both the 100-year plus climate and 30-year events. Maps can be found in Appendix C.2. 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. This would include obtaining CCTV survey of the flood relief culverts and longer culverts such as the structure located at Pipers Lane. It would also include obtaining detailed topographic data to represent to represent the floodplain, which may alter the number of properties affected by flood risk. At present a number of modelling assumptions have been made due to the accuracy of the existing data. Improved topographic data would allow a more robust approach which would more accurately represent flow paths but also allow the application of a rainfall runoff model to examine the interactions between the watercourse and overland flow routes.

A 'partial solution' approach to the preferred option could be considered to allow improvement (whilst not eradication) of flood risk in the short-medium term, if the preferred option does not prove cost-beneficial.

6.1.1 Culvert capacities

In consideration of which culverts may be under capacity and whether the options would adversely impact on the culverts downstream, the modelled preferred option included a 2-stage channel to counteract an increase in flow conveyance downstream. However, looking at the options modelled, the flood relief culvert becomes surcharged with all the events modelled as it has a lower invert level than the dual culvert. The dual culverts at this location become surcharged in events greater than the 100-year flood event. Although it is not been explicitly modelled, it is likely that the removal of the two-stage channel will reduce the capacity of the channel and with additional water being conveyed into this portion of the channel will result in an increase in peak water levels for lower return periods. This may also result in the surcharging of the flood relief and dual culverts. The modelling of the individual options showed that for Option 5 (upsizing Pipers Lane/Mancroft Rd culvert) with the 100-year +CC event there was a small increase in peak water levels downstream of the upsized Pipers Lane culvert, but this was not significant enough to cause further flooding. The preferred option for the 100-year + CC showed a decrease in peak water levels on average of 0.09m along the length of the model. Whilst water levels are shown to decrease there is still limited capacity with a number of the culverts shown to surcharge.

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.

6.1.3 Identification of culverts requiring CCTV

Based on the modelling results and known gaps in the existing data the following structures are shown to be candidates for CCTV survey.

- Flood relief culvert and dual culverts located at the flood relief scheme. These culverts are particularly long and modelling assumptions have been made based on the size and invert levels within the structure. Further survey would allow a more accurate representation of the conveyance potential of these structures.

- Mancroft/ Pipers Lane culvert. This culvert has been identified as a key structure where flooding of Mancroft Road originates. Currently modelling assumptions have been made based on the location and size of the culvert. Further survey would help refine this approach.

6.2 Stakeholder engagement

A meeting was held on October 3rd in Caddington with JBA Consulting, Central Bedfordshire Council and representatives from Caddington 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 Caddington, such as at Dunstable Road and Mancroft Lane downstream, and other surface water 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 new development proposed at Dunstable Road.
- The feasibility of flood mitigation measures proposed, their risks and likely costs.

6.3 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.

6.3.1 New bund

In order to prevent water from the surface overland flow route flooding the Dunstable Road, an option was tested to hold water back by a 1m high bund, with a new pipe leading to the culvert at the Dunstable Road. This bund was modelled at a length of 140m to contain the flows. It has been estimated that a 1m high bund, with a width of 2m would be a volume of 2m^3 per metre. Multiplied by the proposed length, a volume of 280m^3 would be required.

The estimate in red would mean a potential cost of £52,640 using 2010 prices. With inflation to 2014, this cost could be in the region of £61,573.

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

Cost per m^3 fill volume (£/m^3)		
Volume	**<500m^3**	**500-5,000m^3**
Average	188	94
20th percentile	118	39
80th percentile	238	122

The EA's 2010 guidance states that key issues to consider in addition to physical lengths/ volumes, are transported distance for material, access, and weather, economies of scale and type / source of material.

6.3.2 New culvert/ culvert upsizing

As part of the preferred option, a number of culverts are recommended for upsizing (Dunstable Lane, Pipers/Mancroft Lane), including the potential construction of a new pipe taking water from the surface water flow route at the proposed bund into the watercourse at Dunstable Lane.

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 6-3: 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 Dunstable Road culvert, highlighted in red, this would require approximately 12m length of culvert re-sizing and for a 0.9m^2 cross-sectional area, this could cost £10,600 per metre, hence £127,200 based on 2010 prices. With inflation to 2014 this could total £148,785.

The proposed new pipe feeding surface water runoff into the channel upstream of Dunstable road would require a pipe of approximately 0.5m diameter (0.78m^2 cross sectional area) for a distance of 30m, therefore an indicative cost of £8,400 per metre with £252,000 for 30m, at a 2014 inflation cost of £294,764. *It should be noted that the table above presents costs for larger box culverts not small circular pipes, and so these costs are likely to be less for this type of new pipe.*

The Piper Lane/ Mancroft Lane culvert upsizing would require a culvert of 340m in length with a cross sectional area of 1.14m^2, therefore could cost £1,100 per metre with a total of £374,000 over a 340m length. With inflation to 2014 this could total £437,467.

6.3.3 Two-stage channel

The channel guidance from the EA's 2010 unit cost database has been consulted to provide an indicative cost of cutting a soft channel into the ground (to represent the cutting out of a two-stage channel). An average width is assumed of 2.9m for an earth channel with an average depth of 1.6m.

Table 6-4: EA (2007) approximate unit cost for channel

Length (m)	Cost/m (£/m)	
	Earth	Hard
50	7,200	4,700
250	1,300	1,200

For a proposed length of approximately 170m from Dunstable Road to the Flood Relief culvert, this could cost approximately £221,000 based on the EA's 2007 figures. With inflation to 2014, this could cost in the region of £279,034. These guidance costs are primarily for a completely new channel, rather than a two-stage channel.

Based on a case-study survey developed as part of the WFD mitigation measures information for the EA (2009), the average cost for incorporating a low flow channel (two-stage) was £1,000 per metre. For 170m this would be £170,000 based on 2009 costs, and up to £197,863 with inflation to 2014.

Costs will also depend on the distance to transport material to landfill, contamination of sediment (that can increase landfill cost x10), and access to the watercourse.

6.3.4 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.

6.3.5 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).

It is understood that a DEFRA scheme for PLP at 5 properties on Dunstable Road (properties 85-93) is proposed, which looks to construct a 600mm high flood wall/ bund along the property garden frontages, including gates for access. This scheme would incur different costs to the indicative PLP costs provided above, due to the construction costs associated with a flood bund.

6.3.6 Further Work Stages

The summary below provides indicative costs of further work recommended in order to take forward the preferred option and future project stages, such as outline and detailed design. Quotations for this work have not been sought; these figures aim to provide a high-level indication of anticipated next steps to better inform decision makers.

Table 6-5: Indicative Costs of Further Work

<table>
<tr><th>Work Stage</th><th>Tasks</th><th>Guideline Total Costs</th></tr>
<tr><td rowspan="3">Outline Design</td><td>New LIDAR to be flown
(£8-10k)</td><td rowspan="3">£~30k</td></tr>
<tr><td>Additional survey if proposed storage is to be taken forward (to extend the hydraulic model further upstream)
£1-2k (for 1-2 days)</td></tr>
<tr><td>Site Visit
Services Search
Refinement of Options</td></tr>
</table>

	Design Input Statement Final Outline Design and Drawings Designer's Risk Assessment Initial Engineering Cost Estimate Early Contractor Involvement Environmental Appraisal (£2-3k, or £5-6 if WFD compliance element)	
Ground Investigation	Price depends on a number of factors, e.g. the size and location of an embankment	**Min £10k+**
Detailed Design	Similar to Outline above, using outcomes of outline design to form detailed design study	**£~30k** (depending on outcomes of outline design stage)
Construction of scheme	As detailed in costings section (excluding contingency etc). - Inclusion of berm and new culvert/ upsizing of Dunstable Road culvert. Additional storage in form of a two-stage channel downstream of Dunstable Road until the Flood Relief culvert, improved channel conveyance, and upsizing Pipers Lane/ Mancroft Lane culvert (Preferred Option)	**Preferred Option £1,140,500**
Whole scheme	**Ball-park total for whole scheme**	**£1,210,500** **(Preferred Option)**

6.3.7 High-level cost-benefit information

Damages have been derived using the WAAD (Weighted Annual Average Damages) from the Multi-coloured Manual for residential properties. This approach produces high level estimates only as it makes no allowance for the depth of flooding or the type or size of property. The number of properties predicted to flood in a given return period has been estimated using the data available for the baseline and following the scheme, and is shown in Appendix D. Given the limited number of model runs completed at this stage it has been necessary in some cases to apply the most suitable flood available to the return period quoted.

Table 6-6: Weighted Annual Average Damages (WAAD) (2013/4 prices) assuming variable threshold Standards of Protection (SoP)

Existing SoP	No warning (£)	<8 hour warning (£)	>8 hour warning (£)
No protection	4,728	4,559	4,513
2 years	4,728	4,559	4,513
5 years	2,828	2,727	2,700
10 years	1,400	1,350	1,336
25 years	612	590	584
50 years	261	252	249
100 years	65	63	62
200 years	33	32	32

NB. This is Table 4.33 in the MCM 2013

Estimates have been derived for the baseline and each of the 'with scheme' scenarios separately. These values are then converted to present day value damages over a 100 year appraisal period using the Present Value factor of 29.8, which assumes discount rates in line with treasury guidance. The difference between the present value damages (PV) for the baseline and 'with scheme' scenario provides an estimate of the scheme benefits over the design life of the scheme in each case.

The resulting PV damages and scheme benefits have been derived below. The benefit cost ratio has then been derived by comparison of the scheme benefits against the scheme costs.

Table 6-7: High-level Cost-Benefit Summary Table

Option	Total AAD (£)	PV Damage (£)	Property Benefits (rounded £)	Whole Scheme Costs including Optimism Bias (50%)	Provisional Benefit-Cost Ratio
Baseline	**9,358**	**278,990**	-	-	-
Preferred Option	2,448	72,982	206,008	**1,210,500** + 50% = **1,815,750**	**0.1**
Option 1B (Preferred Option without two-stage channel)	2,580	76,918	202,072	**942,589** + 50% = **1,413,890**	**0.1**

The above table demonstrates that the 'Preferred Option' which provides the greatest reduction in flood risk to properties within Caddington is not cost beneficial with the estimated costs exceeding the benefits of the scheme. In almost all of the options modelled, and as shown in Appendix D, the same number of properties are at flood risk in the 30-year flood event, with only a reduction of 2 properties in the 100-year+CC flood event. The preferred option gives the greatest reduction in properties at flood risk of 6 properties out of all the individual options tested, but only in the higher order flood events. Whilst a partial solution may be considered in terms of implementing some aspects of the preferred option, which would give an improved cost-benefit ratio (due to lower scheme costs), the property benefits would still be very low compared with the total scheme costs and it is unlikely the score would be high enough to warrant further pursuit, as shown by presenting Option 1B (preferred option without two-stage channel) in the table above.

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 Caddington.

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 2.3km, based on channel topographic survey collected by Maltby Land Surveys Ltd. The hydraulic model used ESTRY-TUFLOW software. The floodplain was represented by ground level data (LIDAR) from the Updated Flood Map for Surface Water (uFMfSW); this was a particularly coarse resolution and means that floodplain representation further from the channel (where more detailed topographic survey was collected) is less certain, and therefore so are the model results away from the channel.

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 Dunstable Road, Mancroft Road at Aley Green near the junction of Pipers Farm and upstream of Woodside Road Bridge. Blockage analysis was also undertaken at the Dunstable Road culvert and Pipers Lane culvert, simulating a 75% blockage.

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	Inclusion of berm and new/ upsizing of culverts. Additional storage in form of a two-stage channel downstream of Dunstable Road until the Flood Relief culvert. This option was tested with the individual features to determine the extent of the proposed option.
Option 2	Upsizing the Woodside Road Bridge to increase conveyance.
Option 3	Implementing a two-stage change between Pipers Lane and Heron Farm on the right hand bank. A small berm was used to try and prevent flows onto Mancroft Road.
Option 4	Modelling improved channel conveyance. This was represented by reducing the channel roughness (to simulate vegetation removal) by 20%.
Option 5	Upsizing the culvert at Pipers Lane / Mancroft Road.
Option 6	Investigating potential effects of a new development proposed at Dunstable Road.
Do Nothing	A ‘do nothing’ scenario was also tested simulating vegetation growth in the channel.

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 Caddington is the following:

- Improved channel conveyance along the length of the watercourse by removing dense vegetation. This was modelled as Option 4.
- Development of a combination of methods at Dunstable Road, modelled as Option 1. This would include a berm to collect overland flow, a new culvert to convey flows to the channel, upsizing of the Dunstable Road culvert and implementing a two-stage channel on the right hand bank between Dunstable Road and the flood relief culvert.

- Upsizing the Pipers Lane / Mancroft Road culvert, modelled as Option 5.

Indicative costs based on the Environment Agency's 2010 update to the 2007 Unit Cost Database have been provided for the preferred options, 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 (three culverts, one flood bund and a two-stage channel) is in the region of £1,140,452. Approximately £702,985 of this would be for the improvements at Dunstable Road if a two-stage channel is also incorporated, and the remaining for the upsizing of the Pipers Lane/ Mancroft Road culvert. Removal of vegetation has not been included in this figure. It is recommended at this stage to add a 50% contingency pending more detailed hydraulic modelling, site investigation and detailed design.

A high-level indicative cost-benefit appraisal was undertaken, which showed that the preferred option, which provides the greatest reduction in flood risk to properties within Caddington is not cost beneficial with the estimated costs exceeding the benefits of the scheme. In almost all of the options modelled, the same number of properties are at flood risk in the 30-year flood event, with only a reduction of 2 properties in the 100-year+CC flood event. The preferred option gives the greatest reduction in properties at flood risk of 6 properties out of all the individual options tested, but only in the higher order flood events. It may therefore be appropriate to consider a partial solution or other more financially viable mitigation measures, though the individual options testing also proved to provide little benefit to property numbers compared with the baseline, and compared with the total scheme costs it is unlikely the score would be high enough to warrant further pursuit.

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.

- CCTV survey is recommended of the flood relief culverts and longer culverts such as the structure located at Pipers Lane/ Mancroft Lane, and the Dunstable Road culvert. Without detailed CCTV survey it is difficult to be aware of any changes in elevation or pipe size that may happen along the length.
- At present a number of modelling assumptions have been made due to the accuracy of the existing data. Improved floodplain topographic data (finer resolution LIDAR) would allow a more robust approach which would more accurately represent flood flow routes and the mitigation options tested, in addition to the other model improvements outlined in Section 2.6.3. This would reduce uncertainty and assumptions in the modelling results away from the surveyed channel, *which may alter the number of properties affected by flood risk*. In addition, it would allow the application of a rainfall runoff model to examine the interactions between the watercourse and overland flow routes. Including rainfall would improve the surface water flood risk and overland flow representation in the hydraulic model.
- If property threshold survey becomes available, it should be incorporated into the model to improve the representation of flood risk near properties and to enable a more accurate cost-benefit analysis to be undertaken.
- The results of the 'do nothing' scenario show that whilst there is little increase to the flood extents in the floodplain, it would be unfavourable to not maintain channel conveyance as in-channel water levels would increase, along with chances of blockage. With the current condition of the channel being predominantly densely vegetated, channel improvements should be undertaken such as removing vegetation to improve conveyance and prevent flows being impeded in the event of a flood (which was modelled in the preferred option), along with channel maintenance. This may require an ecology survey to be undertaken.

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

- The preferred option from a flood risk perspective is not economically viable for the number of properties it benefits, as shown in the high-level cost-benefit appraisal. For a number of the individual options, the property benefits would still be very low compared with the total scheme costs and it is unlikely the score would be high enough to warrant further pursuit. Other mitigation options could still be considered, such as improved channel conveyance by the removal of vegetation and investigation of upstream bund/ storage (with its associated culvert) to reduce flooding from the *surface water flow route* over the Dunstable Road. Consideration could be given to improving debris capture upstream of the Dunstable Road culvert to further reduce the risk of the trash screen becoming blocked, whilst still allowing water through the culvert. Technical advice notes such as the EA's 'Trash and Security Screen Guide 2009' should be referred to, to inform an evaluation of potential debris load and appropriate trash screen components. A maintenance regime needs establishing to ensure the grill is kept clear.
- The maintenance arrangement of 6th February 2007 should be followed by CBC and any remaining open channels should be maintained by the riparian landowners.
- It is recommended that property level protection (PLP) is considered, which would provide more specific flood protection to the properties which have flooded historically for a lower cost than implementing flood bunds and upsizing culverts.
- It is recommended to understand the impact of the proposed new development's surface water drainage strategy to ensure there will be no increase in surface water runoff which could affect water on the Dunstable Road. There could be potential for joined-up thinking regarding routing the surface water flows to the 'preferred option' bund and culvert which would meet in the same location.
- 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. More detailed floodplain topographic data (and post-development topographic data) and rainfall runoff inclusion as outlined above would be required for this level of detail in the hydraulic model, allowing for pre- and post-development comparisons to be made.
- 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 and property data is obtained.

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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

Caddington		
Baseline Events	**Properties affected by flood outlines**	**Properties benefited**
5yr	3	-
20yr	3	-
30yr	4	-
100yr	6	-
100yrCC	10	-
1000yr	51	-
Preferred Option		
30yr	4	0
100yrCC	4	6
Option 1		
30yr	4	0
100yrCC	8	2
Option 1B		
30yr	4	0
100yrCC	8	2
Option 1C		
30yr	4	0
100yrCC	8	2
Option 2		
30yr	4	0
100yrCC	10	0
Option 3		
30yr	4	0
100yrCC	8	2
Option 4		
30yr	4	0
100yrCC	9	1
Option 5		
30yr	4	0
100yrCC	8	2
Options		
Option 1: Inclusion of berm and new/ upsizing of culverts. Additional storage in form of a two-stage channel downstream of Dunstable Road until the Flood Relief		
Option 1B: Option 1 excluding the two-stage channel.		
Option 1C: Option 1 excluding the two-stage channel and flood berm.		
Option 2: Upsizing the Woodside Road Bridge to increase conveyance		
Option 3: Implementing a two-stage change between Pipers Lane and Heron Farm on the right hand bank. A small berm was used to try and prevent flows onto Mancroft Road.		
Option 4: Modelling increased channel conveyance in the channel. This was represented by reducing the channel roughness by 20%.		
Option 5: Upsizing the culvert at Pipers Lane / Mancroft Road.		
Preferred Option: A combination of Option 1, Option 4 and Option 5.		

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E Appendix - ‘Do Nothing’ Scenario

JBA consulting

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Doncaster
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