Local Flood Risk Studies - Wrestlingworth

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

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Executive Summary

Introduction

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

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

Approach

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

A new hydraulic model was constructed of the watercourse for a distance of approximately 1.2km, 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.

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:

- Butchers Lane/ High Street, and
- Victoria Close/ Braggs Lane.

Flood mitigation options testing

The following options were tested:

Option	Action
Option 1	Upsizing of numerous culverts throughout Wrestlingworth. The following culverts have been identified as requiring upsizing based on the hydraulic model: • WRES1_1057C (Upstream of Victoria Close) • WRES1_0937C (Upstream of Braggs Lane) • WRES1_0853C (Opposite Braggs Lane) • WRES1_0825C (Downstream of Braggs Lane) • WRES1_0669C (Butchers Lane / High Street junction) The culverts will be tested individually to assess the impact that upsizing has at each location as well as having a scenario combining all of the upsizing options are tested together.

Option 2	Provision of off-line storage upstream of Wrestlingworth with the aim of reducing the volume of watercourse entering the village. This storage is in the form of a two-stage channel.
Option 3	Provision of a storage upstream of Wrestlingworth with the aim of reducing the volume of watercourse entering the village. This storage is in the form of an embankment in which out of bank flooding would bank up against.
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 water peak water levels of the 100-year plus climate change event the recommended preferred option for reducing flood risk to Wrestlingworth is the following:

- Upsizing of culverts along the High Street. This considers of upsizing five culverts to increase conveyance and to prevent the watercourse from overtopping its banks as water backs up behind numerous structures.

  Important Note: Whilst flood risk is reduced in the vicinity of each upsized culvert, the conveyance of flood water downstream is increased as a result of culvert upsizing, and hence water levels are increased water levels further downstream.

- Development of a combination of methods north of Wrestlingworth to create a flood storage area, attenuating flows within rural land rather than within the village itself. A flow constriction structure would be used to restrict flows. This was modelled as a 3m circular culvert of 0.50m diameter. A berm which stretches for approximately 250m would be used to prevent out of bank flows moving downstream and create a flood storage area in an area of land currently used for agriculture.

  Important Note: Storage in the 100-year plus climate change event causes a large head of water that, depending on the volume stored, could be considered a reservoir. There is little benefit shown in the flood extents in this flood event therefore it would be recommended to consider a lower standard of protection. The feasibility is likely to be questioned if this option is taken forward due to the required bund heights and associated risks with head of water/ breach flood risk in extreme 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 (culvert upsizing and storage option) is in the region of £1,512,279. Approximately £1,409,136 of this would be for upsizing all five suggested culverts. 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, in terms of mitigating flood risk, is not cost-beneficial with the estimated costs exceeding the benefits of the scheme. It may therefore be appropriate to consider a partial solution, such as storage-only to a lower order SoP, which had the highest cost-benefit ratio of 2.1. The storage-only scheme doesn't prevent all flooding in Wrestlingworth as the report shows properties are still at flood risk downstream due to culverts and surface water flow routes, but it reduces the number of properties at flood risk by holding back flows coming in to Wrestlingworth from upstream. The benefit cost ratio even for this scheme is low and to qualify for funding from GiA it is likely additional contributions will need to be sourced, from the council or otherwise.

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 for certain culverts which are longer culverts or where culverts change shape through their length and assumptions in the modelling have been made as detailed in section 6.1.2.
- 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. 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.
- A partial solution or phased approach to the preferred option could be considered to allow reduction (whilst not eradication) of flood risk in the short-medium term. This is based on the high-level cost-benefit appraisal indicating that the full preferred option is not cost-beneficial.
- If flood storage is to be considered further, it is recommended to gather additional cross section survey in the upper catchment to allow the model to be extended and more accurately represent storage capacity. The location tested is the most downstream advised location, but other positions could be tested, including on the other branch of the watercourse. The aim in this study is to show how a reduction in river flows being passed forward from a bund/ storage feature could reduce flood levels downstream. Landownership should be investigated in relation to the feasibility of storage in the upper catchment and implementation of a bund. Also, due to a large build-up of water behind the modelled bund in the more extreme flood events, storage should be considered for lower more frequent flood events to avoid complex issues relating to reservoirs if the volume stored is within this designation and reducing residual flood risk from breaches.
- Whilst vegetation removal to improve channel conveyance has not been modelled in Wrestlingworth, Parish Councillors have identified areas downstream near Battle Bridge where there is a build-up of silt, and erosion/ undercutting of the banks. CBC have been made aware of these issues. It is understood that there is an annual tidy-up of the culvert grills etc by residents, but more prominent siltation or debris build-up should be incorporated to improve channel conveyance in the short-medium term. 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.
- Consideration could be given to improving debris capture at culverts 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.
- In the longer term, CCTV survey to inform the upsizing of culverts could be incorporated to form the preferred option as part of a phased approach. Consideration could be given to those areas in greatest need in terms of the localised flood risk caused. **It should be recognised however that individual culvert upsizing for example, increases flood water conveyance and hence water levels downstream.**
- Property level protection (PLP) could be considered if preferred options are unviable, 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.
- 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

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

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.

- Asset and riparian ownership should be established in Wrestlingworth to allow CBC to identify where works are necessary and who has responsibilities for these works. The 1991 report suggests maintenance of the watercourse is the responsibility of the riparian owners, with some occasional maintenance previously being carried out by the District Council, charged to the riparian owner concerned. Investigation and co-ordination of riparian ownership could provide improvements to channel conveyance by the removal of vegetation through Wrestlingworth.
- 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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Contents

List of Figures

List of Tables

Abbreviations

CBC .... Central Bedfordshire Council

CC .... Climate change

CCTV .... Closed-circuit television

1D 1-dimensional

2D 2-dimensional

DEFRA .... Department for Food and Rural Affairs

DTM .... Digital Terrain Model

EA .... Environment Agency

ESTRY .... 1D hydraulic modelling software

FEH .... Flood Estimation Handbook

GIS .... Geographical Information Systems

Ha .... Hectares

HQ .... Head vs. Flow boundary

LIDAR .... Light Detection and Ranging

LFRM .... Local Flood Risk Management

M AOD .... Metres Above Ordnance Datum

OS .... Ordnance Survey

PLP .... Property Level Protection

ReFH .... Revitalised Flood Hydrograph

uFMfSW .... Updated Flood Map for Surface Water

URBEXT .... Urban Extent

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1 Introduction

1.1 Terms of Reference

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

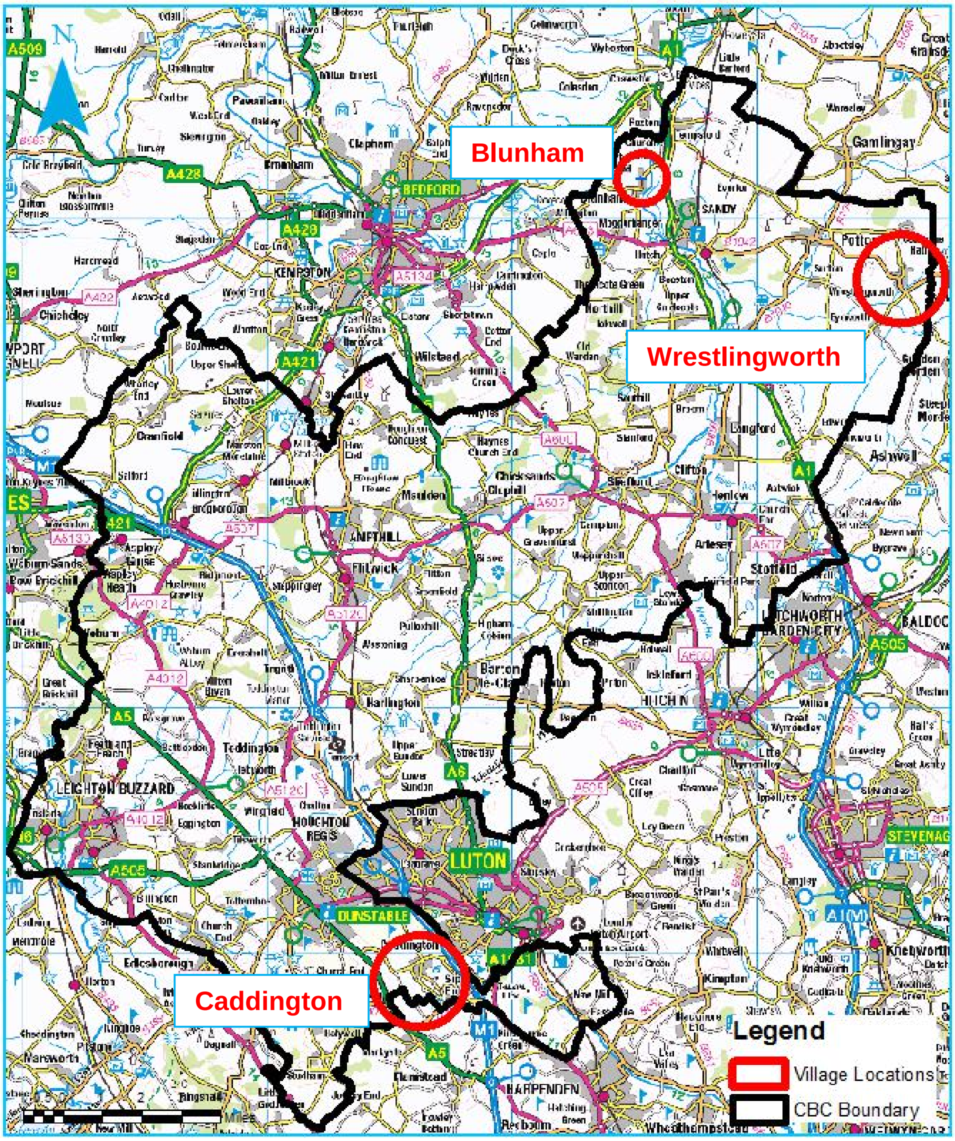
1.2 Scope of the study

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 northern and north-eastern corner of the Central Bedfordshire County boundary, with Caddington at the southern end.

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



1.4 Wrestlingworth background

Wrestlingworth is located approximately 7km from Biggleswade, at the north-eastern CBC boundary. The watercourse to be modelled through the village starts upstream of the town, with another drain joining at the High Street Bridge shortly south of Hatley Road. The watercourse then flows parallel to the main road and houses/ gardens, sometimes crossing from one side of the road to another, down to its confluence with an incoming left-bank drain at High Street Bridge by Water End road.

The watercourse extent to be modelled is approximately 1.2km long from the modelled inflow points to the downstream modelled extent. There is a surface water overland flow/ drain running down Potton Road and joining the watercourse through Wrestlingworth.

The Soil Map of England and Wales shows lime-rich loams and clays. There is no attenuation in the catchment from reservoirs and the catchment is characterised as essentially rural. Topography is predominantly lowland and undulating.

Figure 1-2 shows the study area in Wrestlingworth.

Figure 1-2: Wrestlingworth Study Area

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1.5 Flooding in Wrestlingworth

With regards to flooding mechanisms, flooding occurs primarily out of bank flows at the upstream faces of culverts; of which there are many along the watercourse, flowing parallel to the main high street. If culverts reach their capacity water will spill out of bank and follow topographic overland flow routes.

Out of bank flows from the watercourse, for example at culvert entrances, cause water to bypass the channel and flow down the main high street 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 could affect properties in more extreme events and infrastructure in the village. Flooding to gardens is also known to have occurred due to a debris blockage at one of the culverts. Flooding is mostly disruptive with regards to access in the village and to houses.

The Plandescil 1991 Surface Water Drainage Investigation Report provides a historical flooding record. Both the road at Battle Bridge and in the centre of the village flood regularly in periods of high rainfall, though floodwaters recede quickly. Key events from past flooding are the 1947 event; due to rapid snowmelt on a frozen catchment, the 1989 event; though no details were provided, and the 1990 event; with flooding at several locations including some properties experiencing ground floor flooding, and highway from No.5 High Street to Battle Bridge. It is noted in the report that it is predominantly gardens and roads which flood in Wrestlingworth, with an occasion of a blocked culvert inlet which caused property flooding.

It is acknowledged that there may be more surface water overland flow routes than those able to be incorporated into the model. Local knowledge suggests that runoff is known to flow down Potton Road, which is sometimes unable to enter the watercourse even if the watercourse is in-bank. Flow routes exist down local footpaths from farmland near Braggs Lane and towards Butchers Lane.

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2 Approach

2.1 Context

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

2.2 Data Availability

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

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

2.3 Hydrology

2.3.1 Fluvial Flows

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

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

Catchment descriptors were obtained from 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 Wrestlingworth 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 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 more conservative and the method provides time vs. flow hydrographs for the modelling phase.

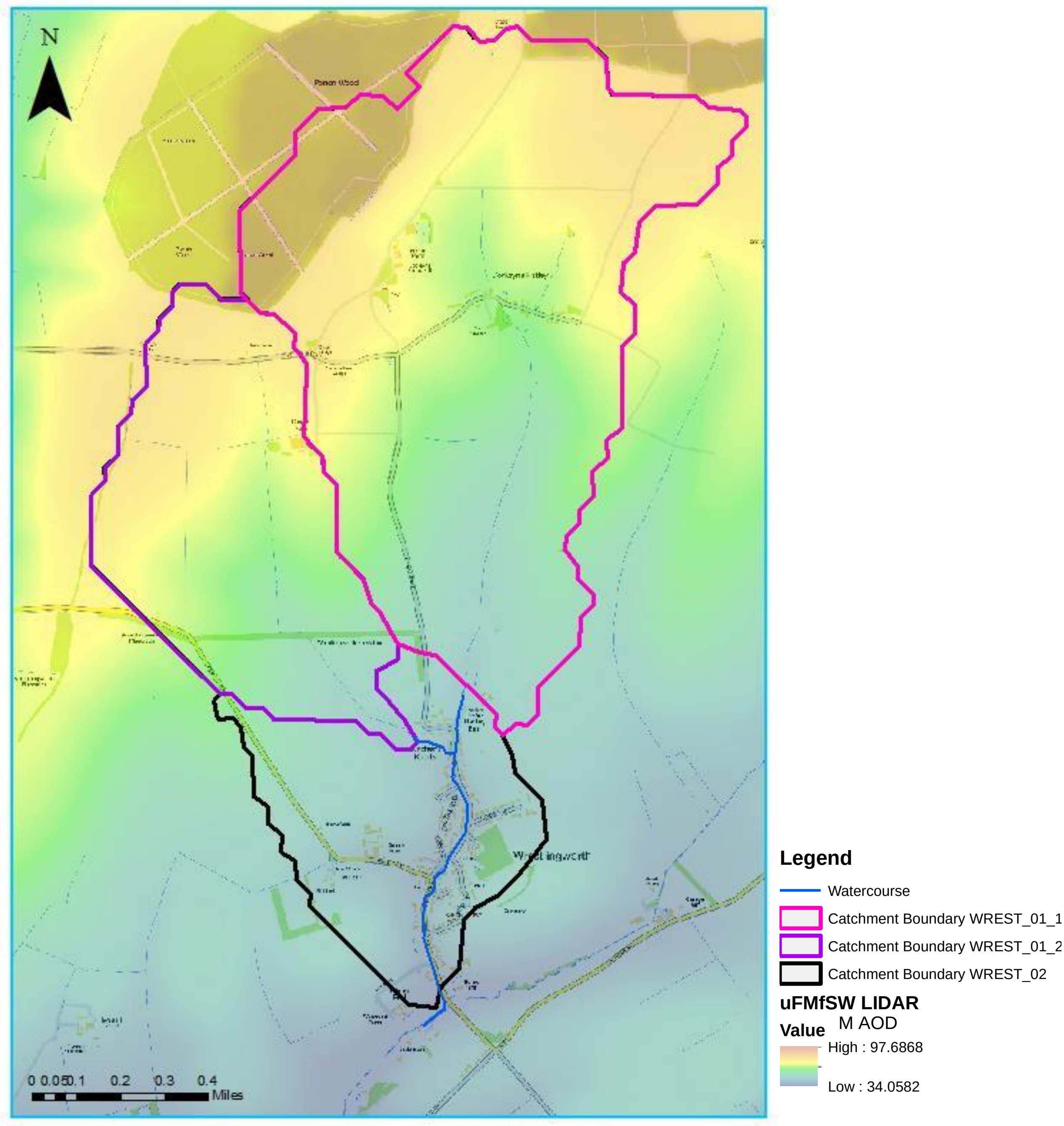
Table 2-2 shows the final peak flows that were applied to the upstream cross section of the model, and Figure 2-1 shows the catchment inflow points.

Table 2-2: Peak Flows

Site code	Flood peak (m3/s) for the following return periods (in years)									
	2	5	10	20	30	50	75	100	100+CC (25%)	200	1,000
WREST_01_1	0.7	1.0	1.2	1.4	1.5	1.7	1.8	2.0	2.5	2.4	3.7
WREST_01_2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.3	1.2	2.0

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

Figure 2-1: Wrestlingworth Catchment Inflows



2.3.2 Surface Water Inflows

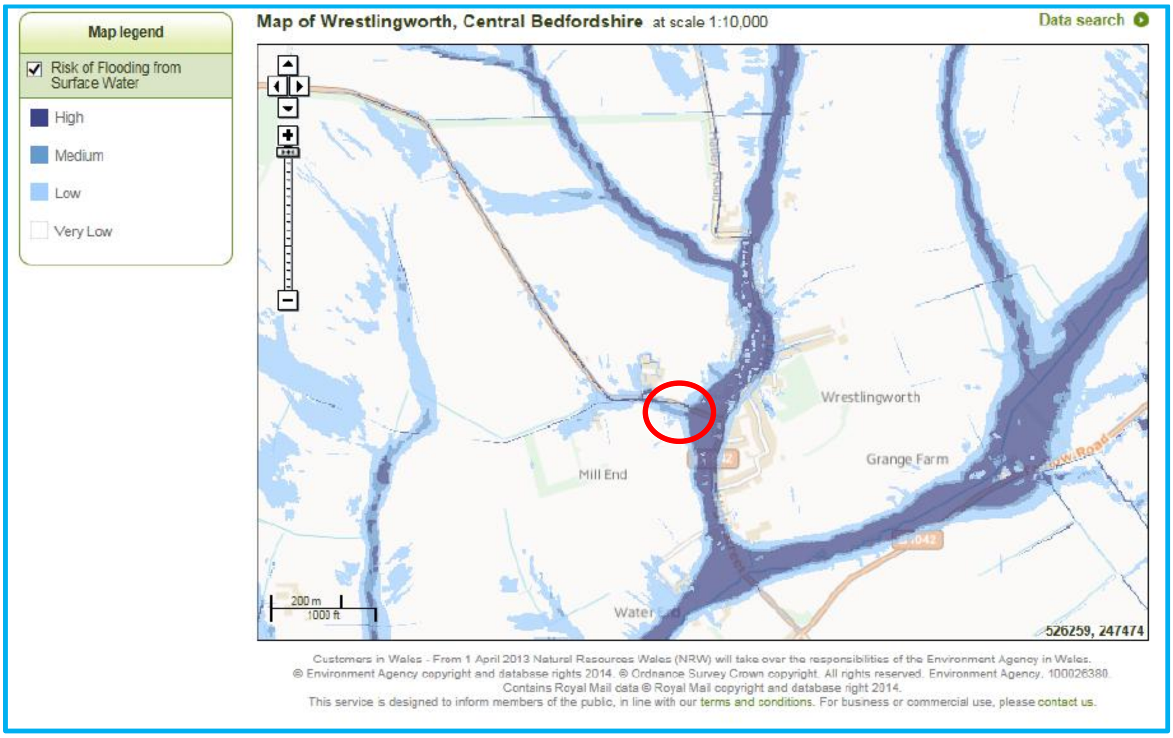
Direct rainfall modelling was considered to be the most suitable technique for modelling flood risk in the intervening catchment (the catchment between the upper catchments fed by a fluvial inflow and the downstream end of the catchment), based on the expected flooding mechanisms and the nature of the 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 a lateral inflow was applied to represent the catchment between the upstream and downstream extents of the model. This was applied to several cross sections down the model, weighted more heavily more towards where an incoming drain is shown to enter on the Environment Agency's Surface Water Flood Map (uFMfSW), as shown in red in Figure 2-2.

It is acknowledged that there may be surface water overland flow routes present which are unable to be accounted for in the model, which would be better represented in a combined fluvial-rainfall model allowing rainfall to be applied everywhere and flowing along the topographic floodplain.

Figure 2-2: Environment Agency's Surface Water Flood Map



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.

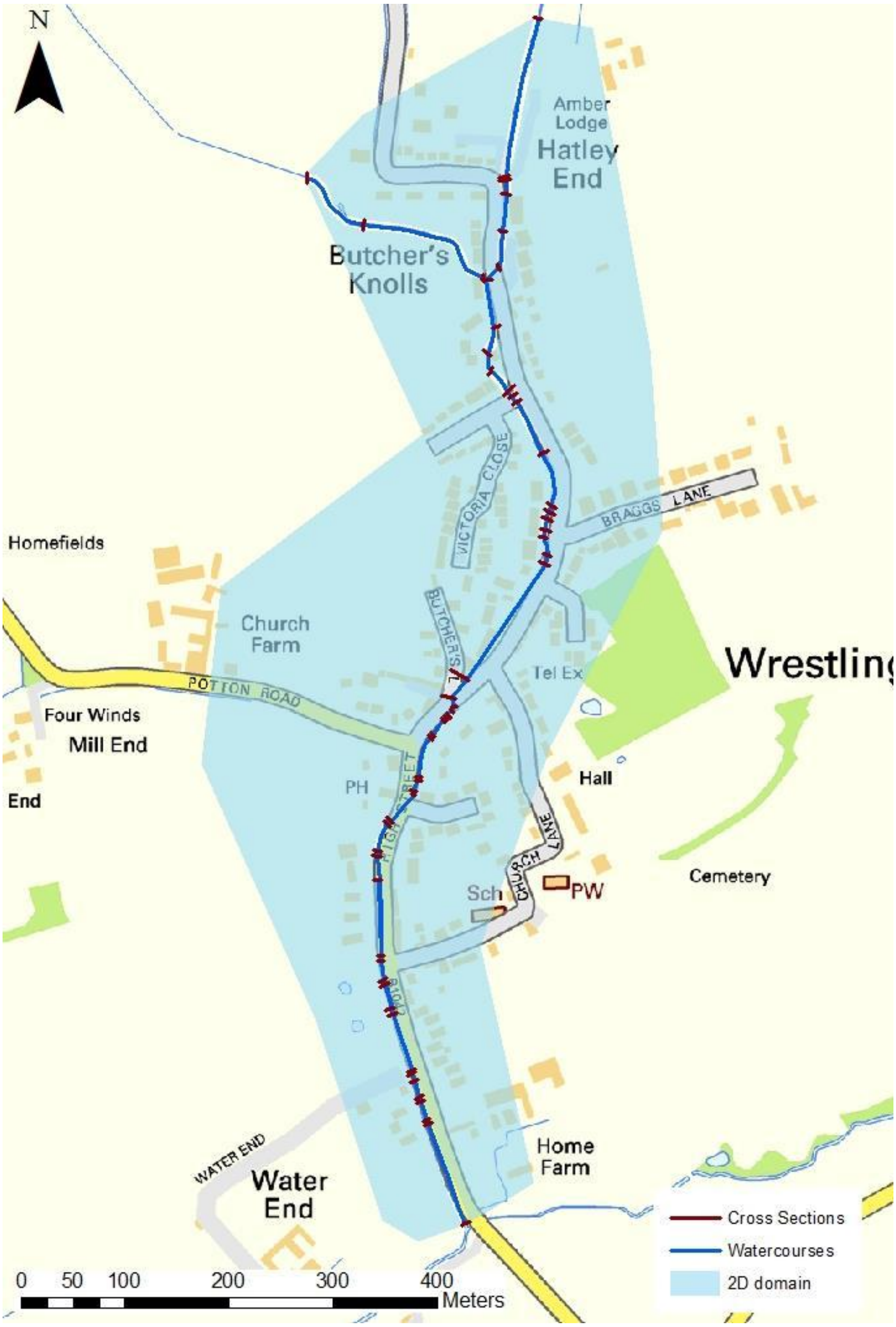
The versions of the modelling software used for this study are ESTRY and TUFLOW, which were the most current versions of each at the time the study was undertaken.

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 WRES2_0231i & WRES1_1229 to the confluence with another unnamed watercourse upstream of the High Street and Tadlow Road junction. 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 2-3 shows the model schematisation of the watercourse through Wrestlingworth. 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 2-3: 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 Wrestlingworth, therefore the study initially 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. Unfortunately the data did not correspond well with topographic survey points collected from Maltby Land Survey Ltd with some points being >1m the survey water DTM and as such other DTM options were explored. After further investigation an OS dataset known as Terrain 5 was used to represent the 2D domain topography.

It should be noted that although this data was a better match to survey points than the surface water DTM it still 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.

In total the 2D domain has an area of 0.28km^2, with a 2m grid resolution. The orientation of the grid is north to south, which picks up the main direction of floodplain flows.

2.4.4 Model Parameters

Manning's n used to represent the channel and bank roughness was selected based on survey and site visit photographs. Typically channel roughness was set at a uniform 0.04, with bank tops at 0.06. The roughness of the 2D domain was determined by survey, photography and Mastermap data, and allows a detailed categorisation of floodplain features, such as roads, buildings and roadsides.

2.4.5 Key Structures

The key structures along the watercourse were captured in the channel topographic survey by Maltby Land Surveys Ltd. There are 24 modelled structures along the modelled reach. Not all the structures were surveyed due to the scope of the study. The main structures to be surveyed were culverts which were considered to be key to flood risk in the area. Other constraining structures such as driveway bridges were only had soffit and invert levels surveyed. Assumptions were deduced from photographs of the type of structure and channel shape. Survey cross section in close proximity were then amended to match surveyed invert levels. In the majority of cases the driveways in Wrestlingworth were assumed to be single span bridges. 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.

2.4.6 Downstream boundary

For the 1D domain a Head-Flow (HQ) boundary was derived and applied to WRES1_0100 (the downstream modelled cross section). This was derived by using ISIS to create a simple model downstream open channel network with a normal-depth boundary to allow flow to leave the model. Increasing amounts of flow were then applied and head and flow data extracted. Within the 2D domain a normal-depth boundary has been applied.

2.5 Floodplain mapping

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

2.6 Assumptions and Limitations

2.6.1 Limitations to modelling approach

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

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

New channel survey was commissioned for the watercourse in Wrestlingworth 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. A number of the culverts appear particularly long (e.g. >20m) or to change shape along their lengths. It would be beneficial if such structures were surveyed using CCTV to determine key constrictions which could not be picked up in this study. CCTV would also allow an assessment of the condition of such culverts and therefore give a greater understanding of flood mechanisms in the area. Conservative modelling assumptions have also been used to model numerous driveways and structures which change in dimension over there length. This should be refined if more data becomes available to produce a more realistic model.

Other limitations were introduced by using the LIDAR from the Terrain 5 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, rainfall runoff modelling was deemed to not be appropriate. A conservative representation of surface water inflows was applied by an intervening fluvial based on a surface water flow route location identified on the uFMfSW DTM. This was applied to several locations between the upstream inflows and the downstream end of the model, weighted to assume the majority of this inflow was at Potton Road.

2.6.2 Data Quality check

A number of QA checks were performed on the topographic data to determine the accuracy and how it should be applied to the hydraulic model. The main data check involved the comparison of surveyed points within the floodplain by Maltby Land Surveys Ltd to the DTM from 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 an alternative, an OS Open Data set called Terrain 5 was investigated. This is a coarse 5m grid cell DTM which covered the whole study area. Upon investigation the Terrain 5 data set appeared to have a better correlation to the survey points obtained by Maltby Land Surveys Ltd. However, it should be noted that there were still discrepancies between the Terrain 5 and Maltby Land Surveys Ltd data. As such polygons representing the road and roadside were used to smooth out such discrepancies. Road levels were generally obtained from the extended cross sectional survey. Although this meant values were interpolated along the polygons this was deemed acceptable for representing overland flow paths and given the data constraints of the study.

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 elevations along the TUFLOW 'HX lines' are modified through use of topography Z line commands designed to set elevations to match the top of river bank elevations in the 1D model. This approach is acceptable but could be improved by more detailed top of bank survey data along the river reach to ensure that bank levels are accurately represented.
- 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 a portion 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.

- CCTV should be used to investigate the condition and construction of the longer culverts, and where culverts are suspected of changing geometries. 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 5-year, 20-year and 30-year flood extents where flooding initially occurs. Figure 3-2 shows the remaining return period flood outlines.

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

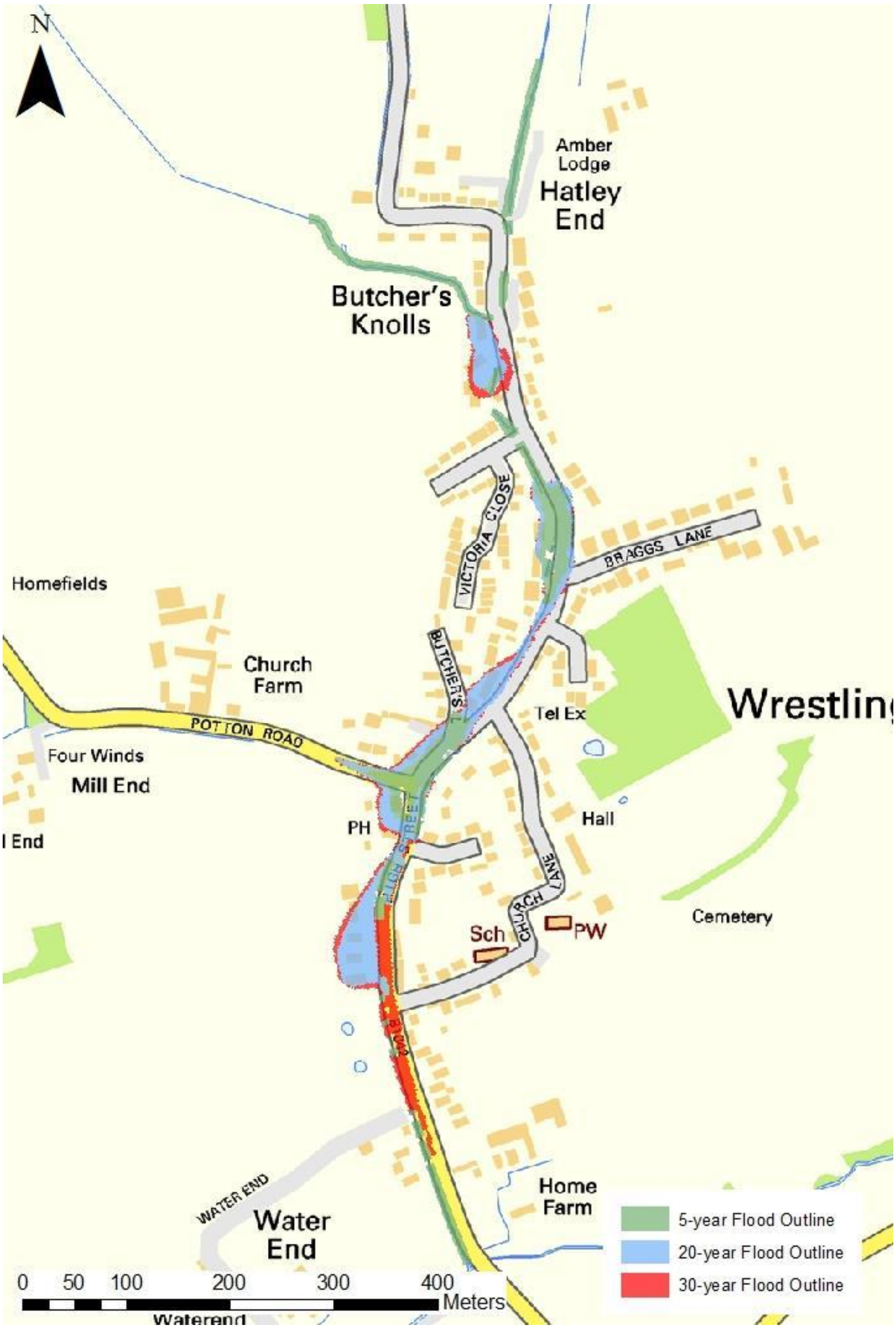

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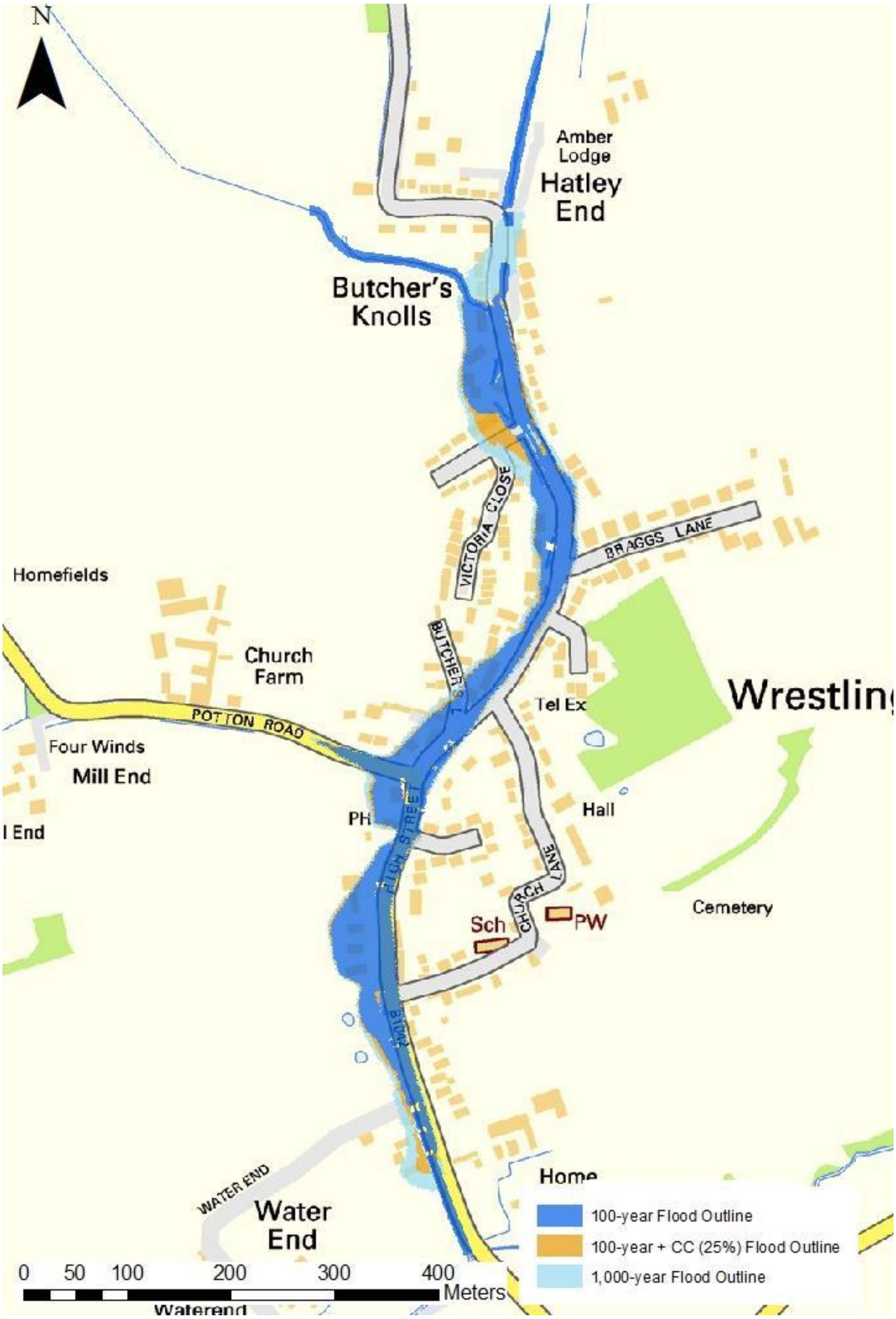
Figure 3-2: 100-year, 100-year plus Climate Change and 1,000-year (Baseline) Flood Outline



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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
WRES1_1385	42.65	42.74	42.77	42.86	42.94	43.11
WRES1_1229	41.22	41.48	41.64	41.89	42.10	42.33
WRES1_1229d	40.71	41.03	41.12	41.49	41.78	42.27
WRES1_1212	40.64	41.00	41.09	41.48	41.77	42.27
WRES1_1212d	40.38	40.82	40.86	40.99	41.05	41.17
WRES1_1140	40.35	40.80	40.84	40.95	41.00	41.11
WRES1_1120	40.34	40.78	40.81	40.89	40.92	40.99
WRES1_1073	39.95	40.37	40.51	40.76	40.80	40.88
WRES1_1057	39.95	40.36	40.51	40.76	40.80	40.88
WRES1_1033	39.68	39.79	39.82	39.96	40.07	40.36
WRES1_1006	39.67	39.78	39.81	39.96	40.07	40.36
WRES1_0999	39.67	39.78	39.81	39.96	40.07	40.36
WRES1_0999d	39.62	39.68	39.69	39.73	39.75	39.79
WRES1_0937	39.62	39.67	39.69	39.72	39.75	39.78
WRES1_0883	39.25	39.36	39.37	39.40	39.42	39.47
WRES1_0877iu	39.25	39.36	39.37	39.40	39.42	39.47
WRES1_0877id	38.52	39.08	39.11	39.20	39.24	39.33
WRES1_0858	38.52	39.08	39.11	39.20	39.24	39.33
WRES1_0852	38.52	39.08	39.11	39.20	39.24	39.33
WRES1_0852d	38.27	38.86	38.90	39.02	39.06	39.15
WRES1_0825	38.26	38.86	38.90	39.02	39.06	39.15
WRES1_0673	37.13	37.32	37.38	37.51	37.56	37.68
WRES1_0669	37.12	37.31	37.38	37.50	37.56	37.67
WRES1_0660	36.73	37.28	37.36	37.48	37.54	37.65
WRES1_655	36.73	37.28	37.36	37.48	37.54	37.65
WRES1_655d	36.73	37.28	37.35	37.48	37.53	37.64
WRES1_0646i	36.72	37.28	37.35	37.48	37.53	37.64
WRES1_0646id	36.72	37.27	37.35	37.47	37.52	37.63
WRES1_0626i	36.69	37.27	37.35	37.47	37.52	37.63
WRES1_0626id	36.69	37.27	37.34	37.47	37.52	37.62
WRES1_0609i	36.67	37.27	37.34	37.47	37.52	37.62
WRES1_0582i	36.65	37.26	37.34	37.46	37.52	37.62
WRES1_0582id	36.65	37.25	37.33	37.46	37.51	37.61
WRES1_0565	36.64	37.25	37.33	37.45	37.51	37.61

Cross Section	Peak Water Levels (m AOD)					
	5-year	20-year	30-year	100-year	100-year +CC	1,000-year
WRES1_0562	36.64	37.25	37.33	37.45	37.51	37.61
WRES1_0529	36.56	37.09	37.20	37.34	37.39	37.47
WRES1_0525	36.55	37.09	37.20	37.34	37.39	37.47
WRES1_0498i	36.55	37.09	37.20	37.34	37.39	37.47
WRES1_0498id	36.09	36.88	37.18	37.33	37.37	37.45
WRES1_0469	36.07	36.88	37.18	37.33	37.37	37.45
WRES1_0469d	36.00	36.74	37.05	37.26	37.29	37.35
WRES1_0393	36.00	36.74	37.05	37.26	37.29	37.35
WRES1_0393d	35.62	36.16	36.37	36.86	36.95	37.05
WRES!_0371	35.62	36.16	36.37	36.86	36.95	37.05
WRES1_0371d	35.57	36.11	36.31	36.75	36.82	36.90
WRES1_0339	35.56	36.11	36.30	36.74	36.82	36.90
WRES1_339d	35.41	35.78	35.90	36.14	36.22	36.34
WRES1_0280i	35.41	35.78	35.90	36.14	36.22	36.34
WRES1_0280id	35.01	35.13	35.17	35.40	35.62	36.00
WRES1_0256	34.94	35.05	35.10	35.32	35.57	35.97
WRES1_0256d	34.93	35.05	35.09	35.28	35.39	35.67
WRES1_0232i	34.81	34.92	34.96	35.15	35.25	35.56
WRES1_0232id	34.81	34.92	34.96	35.14	35.24	35.47
WRES1_0125	34.25	34.36	34.40	34.75	34.77	34.94
WRES2_212i	41.81	41.84	41.85	41.90	41.95	42.08
WRES2_0138	40.85	40.92	40.94	41.01	41.07	41.20
WRES2_0067i	40.35	40.78	40.82	40.90	40.93	41.00
WRES2_0000	40.34	40.78	40.81	40.89	40.92	40.99

3.3 Flooding mechanisms identified

Based on the baseline scenarios a number of locations were determined to be sources of out of bank flows. With flooding occurring in the lowest modelled return period (e.g. 5-year) the mechanisms of flooding have been examined with these in mind. Flooding from larger return period events originates from similar locations but at a greater extent. The flooding mechanisms of Wrestlingworth are discussed in the following sections.

3.3.1 Butchers Lane / High Street

Figure 3-3 shows the main flooding mechanisms at the junction Butchers Lane and the High Street.

Figure 3-3: Flood mechanisms at Butchers Lane / High Street

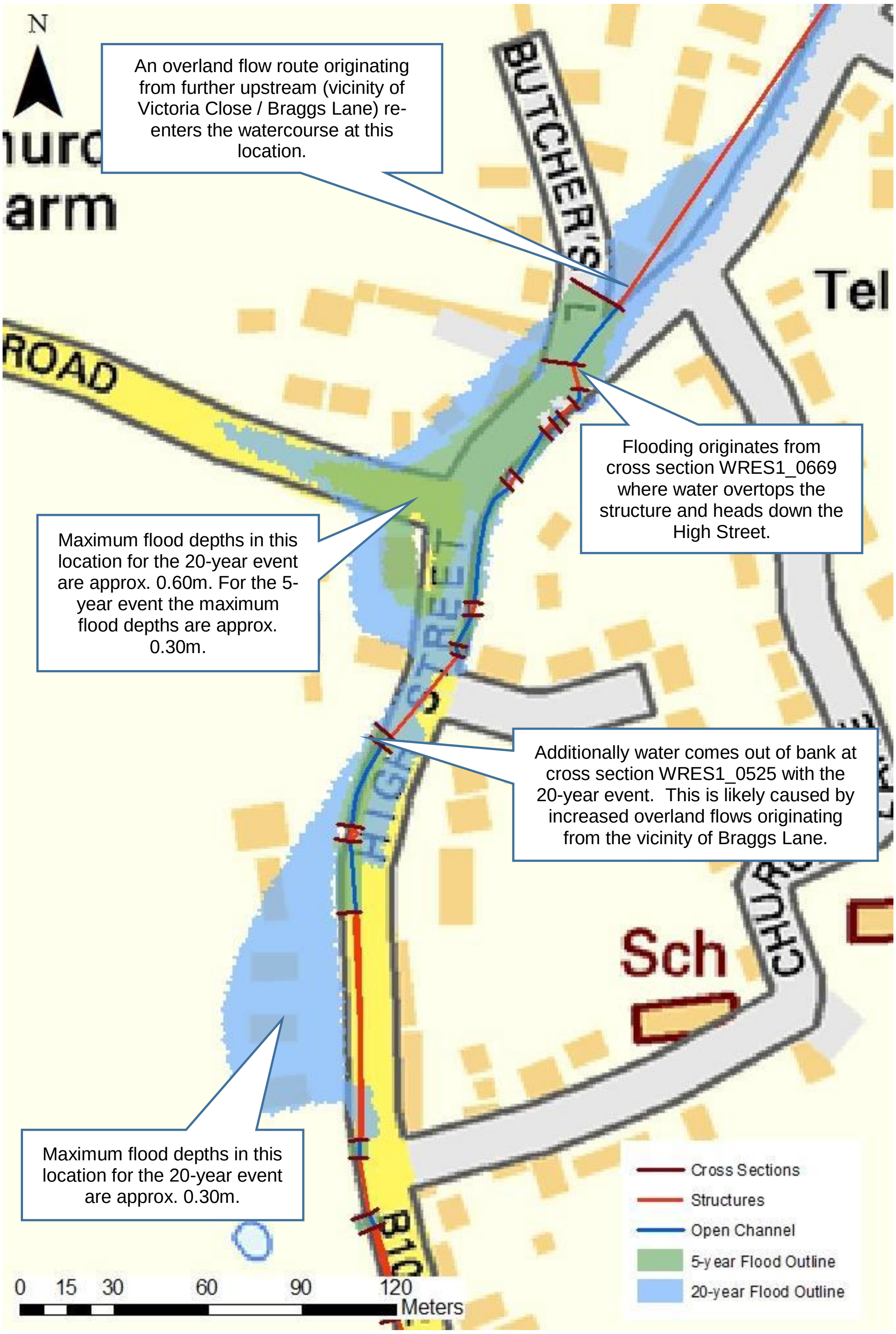
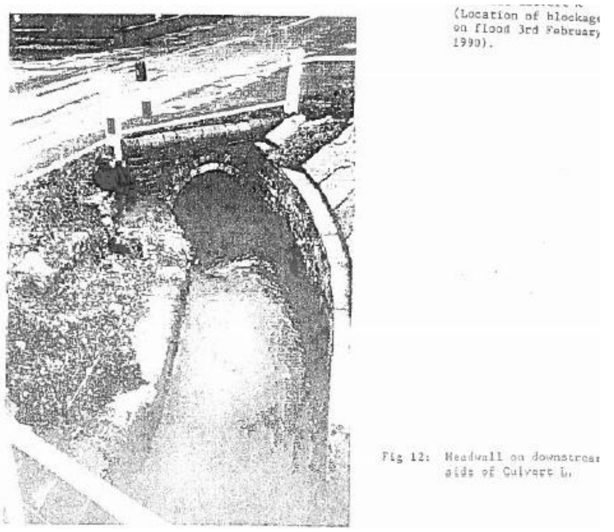


Figure 3-3 illustrates that the first instance of flooding occurs at WRES1_0669 where a culvert passes under the High Street. This culvert is 600mm in diameter and is shown to lack the capacity to convey flows. Flood water then pools at the junction of Potton Road and the High Street. For the 5-year event maximum flood depths are approximately 0.30m. In the 20-year event maximum flood depths at this location are approximately 0.60m which is sufficient for water to flow down the High Street. For the 100-year maximum flood depths at this location are approximately 0.80m.

In addition to the flood water originating from WRES1_0669, additional flood water is conveyed to the area via an overland flow route which begins in the vicinity of Victoria Close and Braggs Lane. Model animations show that shortly after this overland flow re-enters the channel at Butchers Lane, out of bank flow originates from WRES1_0525, a likely consequence of an increased volume in the channel. Water then ponds adjacent to the High Street up to depths of 0.30m in the 20-year event.

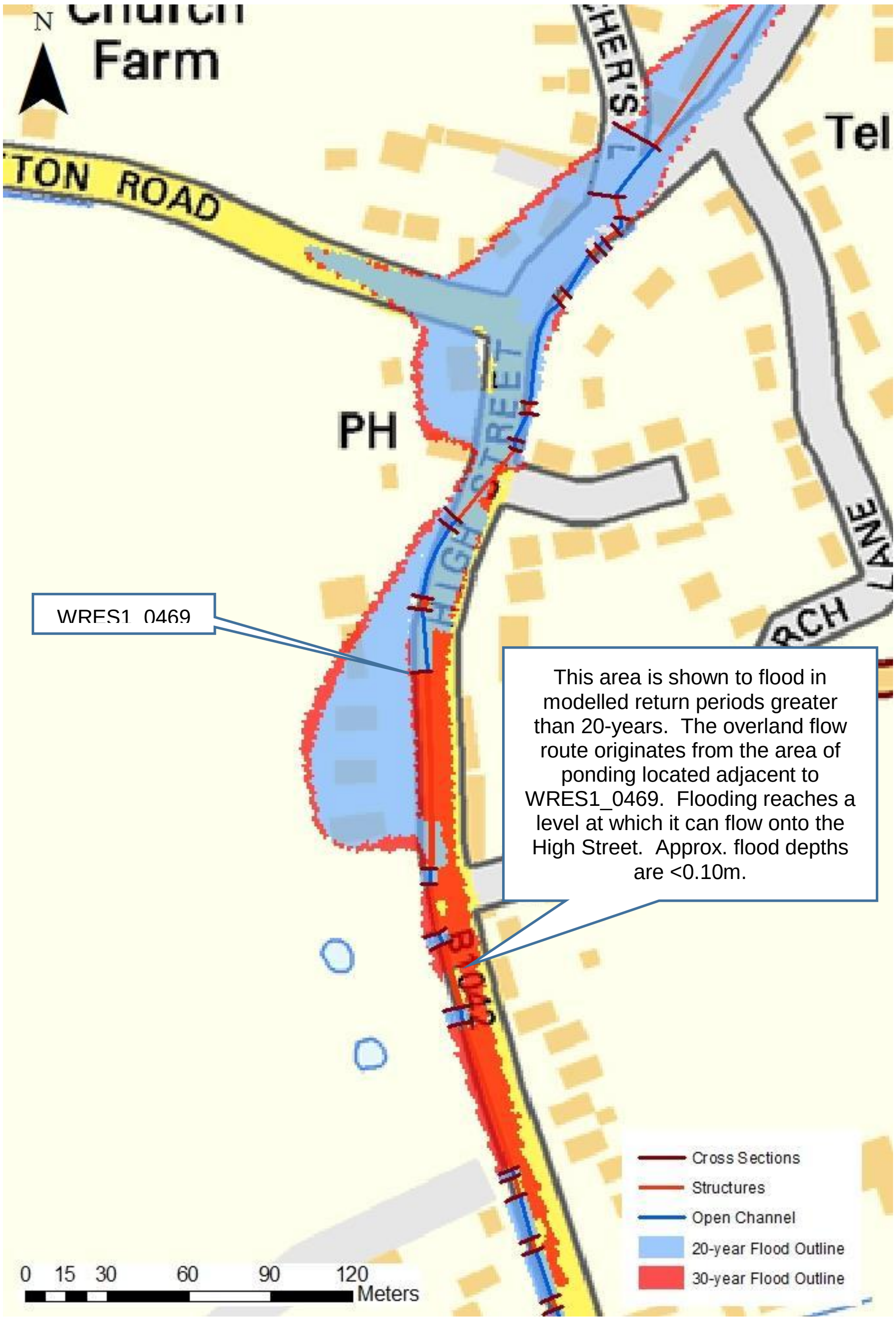
Figure 3-4 shows photographs of the culvert at WRES1_0669 which appears to be the source of initial flooding. This is a 600mm diameter culvert which is likely to be undersized to convey flows. Also the channel does not have much capacity and therefore out of bank flow is likely soon after the culvert is surcharged.

Figure 3-4: Culvert at WRES1_0669

	Upstream view of WRES1_0669 Culvert, installed approximately 5 years ago. Photographs provided by Maltby Land Surveys Ltd (2014).
	Downstream view of WRES1_0669 Culvert Photographs provided by Maltby Land Surveys Ltd (2014).
	Plandescil 1991 report – photograph of 700mm x 1050mm brick semi-circular culvert. The area of this culvert would have been 0.77m^2 whereas the existing culvert today shown above is a 600mm circular culvert with an area of 0.28m^2, showing the culvert has since been re-constructed and downsized. This is discussed further in Section 3.4

Further downstream in the vicinity of Church Lane further overland flow routes are created due to the build-up of water in events greater than the 20-year. This is illustrated in Figure 3-5 below.

Figure 3-5: Flood mechanisms in the vicinity of Church Lane



3.3.2 Victoria Close / Braggs Lane

Figure 3-6 shows the main flooding mechanisms in the vicinity of Victoria Close and Braggs Lane.

Figure 3-6: Flood mechanisms in the vicinity of Victoria Close / Braggs Lane

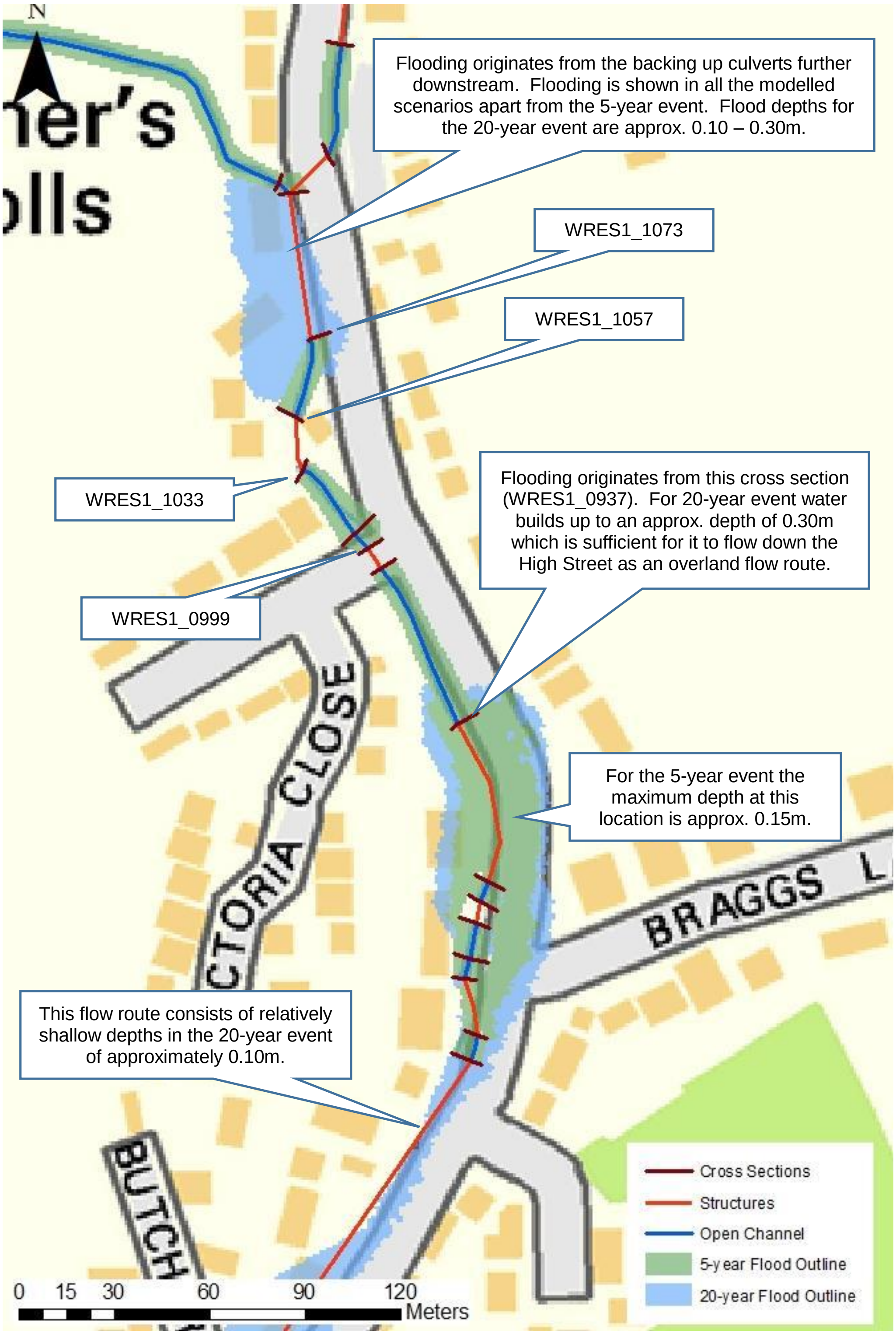


Figure 3-6 shows that for 5 and 20-year event there is flooding in the vicinity of Braggs Lane. Flooding in this location originates from WRES1_0937 where a circular culvert of 1m diameter runs for approximately 55m along the High Street. This culvert is shown to surcharge for all modelled events causing out of bank flooding. Flooding pools in this location up to a maximum depth of approximately 0.30m in the 20-year event. This is sufficient for it to flow down the High Street towards the Butchers Lane / High Street junction. Flood depths along this overflow route are shallow being a maximum of 0.10m in the 20-year event. For larger events this depth increases with the 100-year plus climate change event exhibiting maximum flood depths of approximately 0.30m.

Further upstream flooding also originates upstream of WRES1_1073 likely as a result of lack of capacity in the culverts and the backing up of flood water downstream restricting flow. This causes a peak water level during the 20-year event which is sufficient to generate out of bank flow from the right bank. Flooding follows the topography filling a depression to the north of the structure to depths of approximately 0.10-0.30m during the 20-year event. By the 100-year events the maximum water levels in this location are approximately 0.80m which is sufficient for water to spill on to the High Street and flow downstream along the road.

3.4 Summary of Flood Risk from Surface Water Drainage Investigation

A surface water drainage investigation was conducted by Plandescil Ltd in 1991. Although this is an old document it offers an insight to the flood mechanisms which have been noted in Wrestlingworth and a list of possible options which could be investigated as part of this study, in regards to flood risk.

The document identifies a number of culverts which are undersized and therefore incapable to conveying flows. The culvert located at the Butchers Lane / High Street junction (WRES1_0669) is identified as being undersized. It should be noted that at the time of this the report the culvert the dimensions of the culvert were 700mm x 1050mm brick semi-circular culvert. The area of this culvert would have been 0.77m^2 whereas the existing culvert constructed recently (600mm circular culvert) has an area of 0.28m^2. This reveals that the culvert has been further undersized since the publishing of this report. Considering that the previous 1991 report stated that the capacity of the culvert would not take flows less than the 25-year flow it seems sensible that this is the area where flooding is first exhibited in the new hydraulic model constructed as part of this study.

Further on in the report flooding is exhibited or mention for the following structures:

- Culvert E: This is WRES1_1057 within our model. The report states flooding escapes the channel at this location before flowing downstream and re-entering the channel.
- Culvert K: This is WRES1_0825 within our model. The report states that flooding was exhibited at the upstream of the culvert with water flowing down the highway.
- Watercourse between culverts L and M: Culvert L is WRES1_0669 within the new hydraulic model with M being WRES1_0562. Flooding from this location is related from overtopping of banks and also water entering the area from further upstream (e.g. Culvert E / WRES1_1057).

The following options are suggested within the report:

- Improved Maintenance of the channel.
- Upsizing of selected culverts to improve conveyance.
- Creation of off-line storage further upstream of Wrestlingworth.

Based on this report it appears that to validate a number of the flood mechanisms that have been exhibited with the hydraulic model and described in the previous sections.

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4 Flood Mitigation Options Testing

4.1 Small-scale mitigation options

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

The following options were tested:

Option	Action
Option 1	Upsizing of numerous culverts throughout Wrestlingworth. The following culverts have been identified as requiring upsizing based on the hydraulic model: • WRES1_1057C (Upstream of Victoria Close) • WRES1_0937C (Upstream of Braggs Lane) • WRES1_0853C (Opposite Braggs Lane) • WRES1_0825C (Downstream of Braggs Lane) • WRES1_0669C (Butchers Lane / High Street junction) The culverts will be tested individually to assess the impact that upsizing has at each location as well as having a scenario combining all of the upsizing options are tested together.
Option 2	Provision of off-line storage upstream of Wrestlingworth with the aim of reducing the volume of water entering the village. This storage is in the form of a two-stage channel.
Option 3	Provision of storage upstream of Wrestlingworth with the aim of reducing the volume of water entering the village. This storage feature is in the form of an embankment with a throttle (small culvert) in which out of bank flooding would back up against.

Removal of vegetation has not been tested due to most of the watercourse being in and out of culverts, except as part of model sensitivity testing in Appendix B, Section 5.

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 – Upsizing Culverts in Wrestlingworth

Figure 4-1 shows location of the culverts to be upsized. Table 4-1 shows the existing and proposed dimensions of the culverts. The hydraulic model will test each of the upsized culverts individually for the more frequently occurring events (5-year and 20-year events), with a combination of upsized culverts being tested on the 5-year, 20-year and 100-year plus climate change event to determine how such a measure would response even with a higher return period.

Figure 4-1: Option 1 Upsized culverts

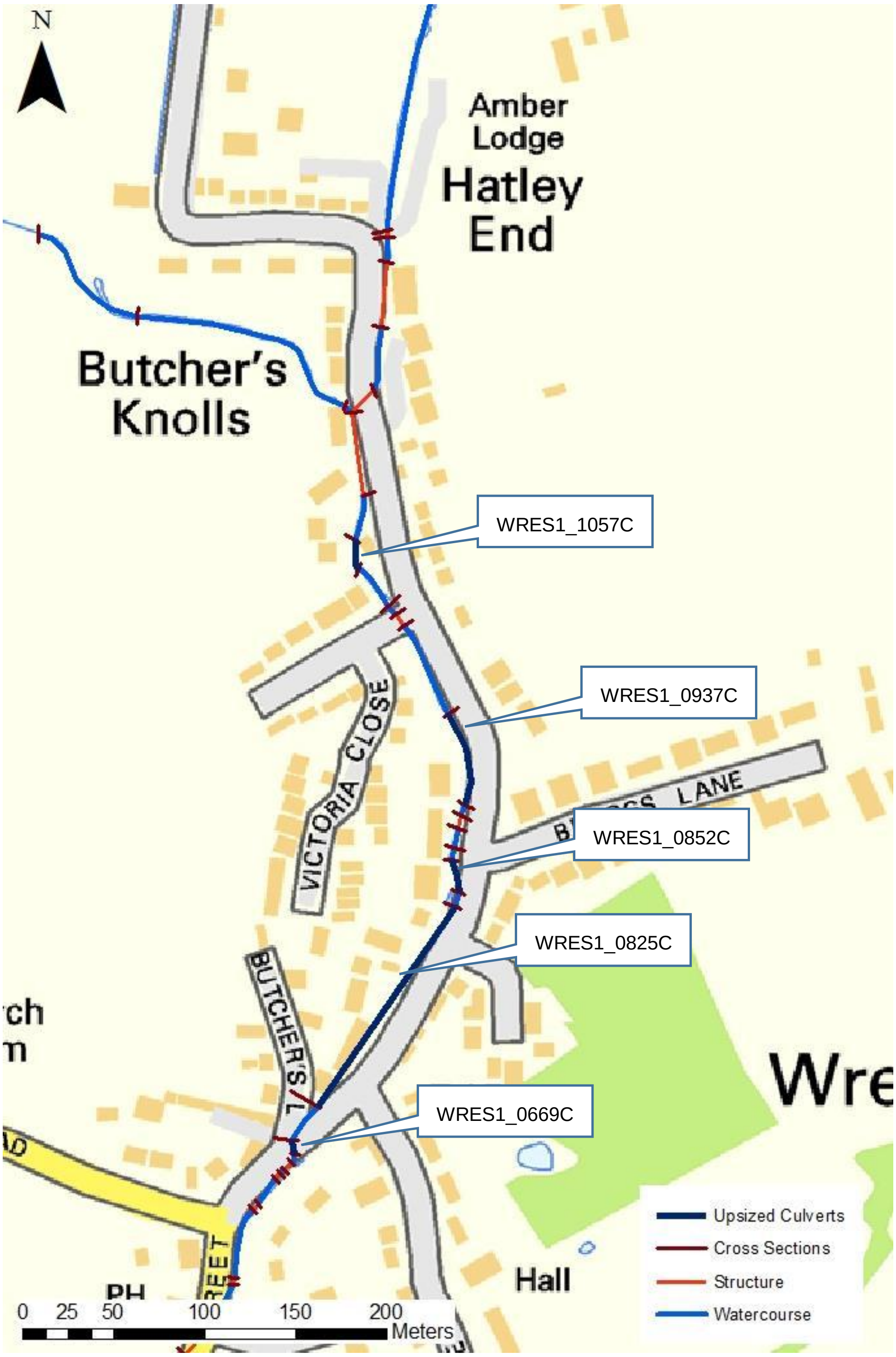


Table 4-1: Dimensions of upsized culverts

Structure Name	Existing Culvert Type	Existing Dimensions (m)	New Dimensions (m)
WRES1_1057	Circular	1.00m diameter	1.50m diameter
WRES1_0937	Circular	1.00m diameter	1.50m diameter
WRES1_0852	Circular	1.00m diameter	1.50m diameter
WRES1_0825	Circular	0.95m diameter	1.50m diameter
WRES1_0669	Circular	0.60m diameter	1.00m x 0.60m rectangular culvert.

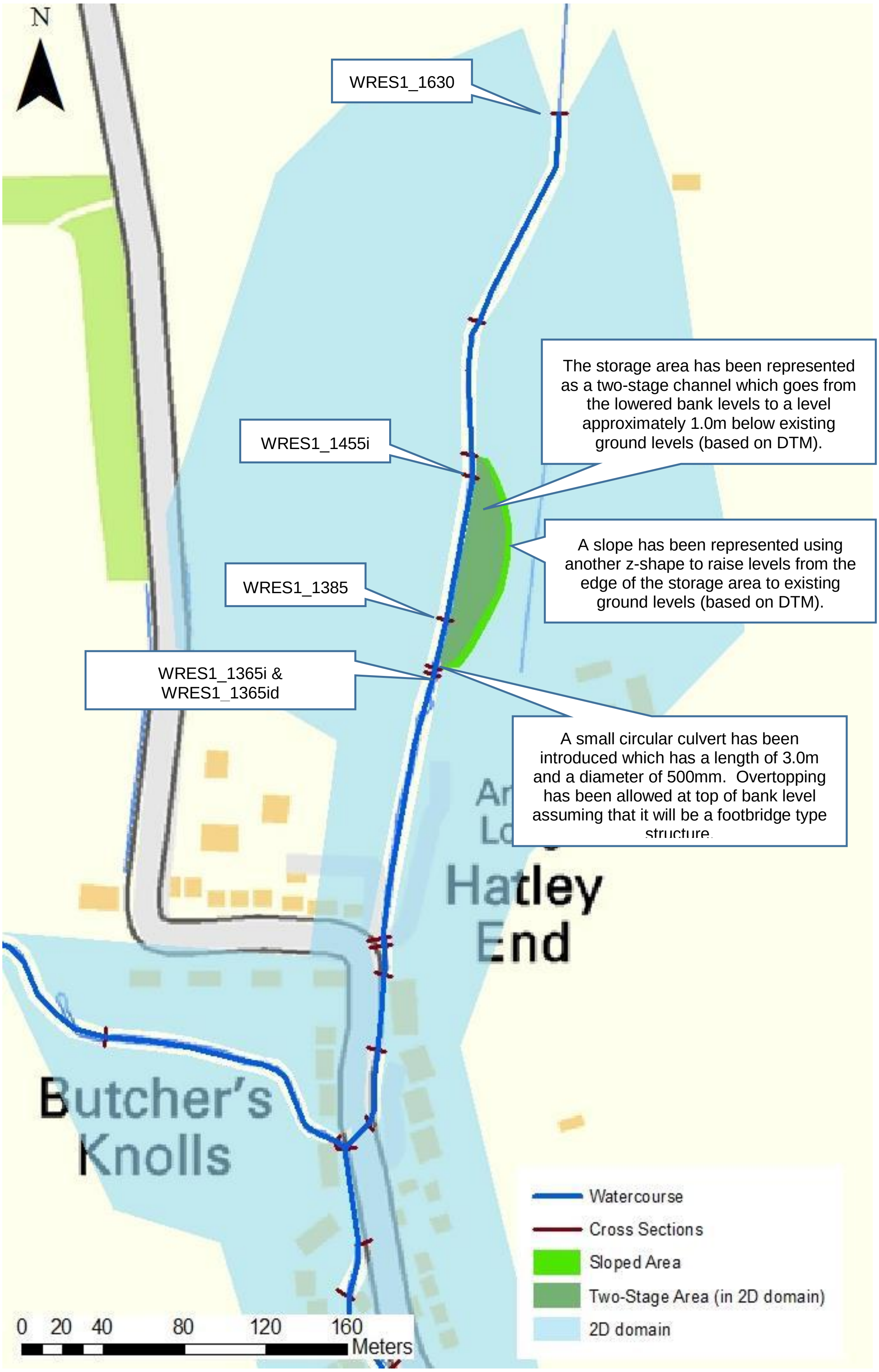
4.2.2 Option 2 – Offline Storage upstream of Wrestlingworth

Figure 4-2 shows the representation of the two-stage channel for option 2 within the hydraulic model.

A number of alterations have been made to the baseline model to model this proposed option. These changes have been summarises below:

- The hydraulic model has been extended approximately 250m upstream. As there was no survey it was assumed that the channel shape was identical to WRES1_1385 with bed and bank levels being updated based on DTM data. Although the Terrain 5 DTM showed fairly good correlation with the survey in this location it is unclear if this would be true further upstream.
- A flow control structure was introduced between WRES1_1365i and WRES1_1365id which has been used to constrict flow and make best use of the two stage channel. The flow control structure comprises of a 3.00m long circular culvert with a diameter of 0.50m.
- The flow control structure has been assumed to be a footbridge type structure with overtopping allowed at approximately the top of bank level.
- The two-stage channel has been created by lowering the left hand bank of channel between WRES1_1455 and WRES1_1385 to approximately 0.40m above the bed invert level. A z-shape has been used to alter the topography within the floodplain to provide storage. This storage extends from the lower bed levels for approximately 20m (at its widest point) to a level approximately 1m below DTM levels. It should be noted that there are already highlighted uncertainties with the DTM levels and there this should be reassessed if further work is to be conducted. Another z-shape has been used to smoothly raise ground levels to existing DTM levels over approximately 6m. This would form a slope which would allow safe access and egress.

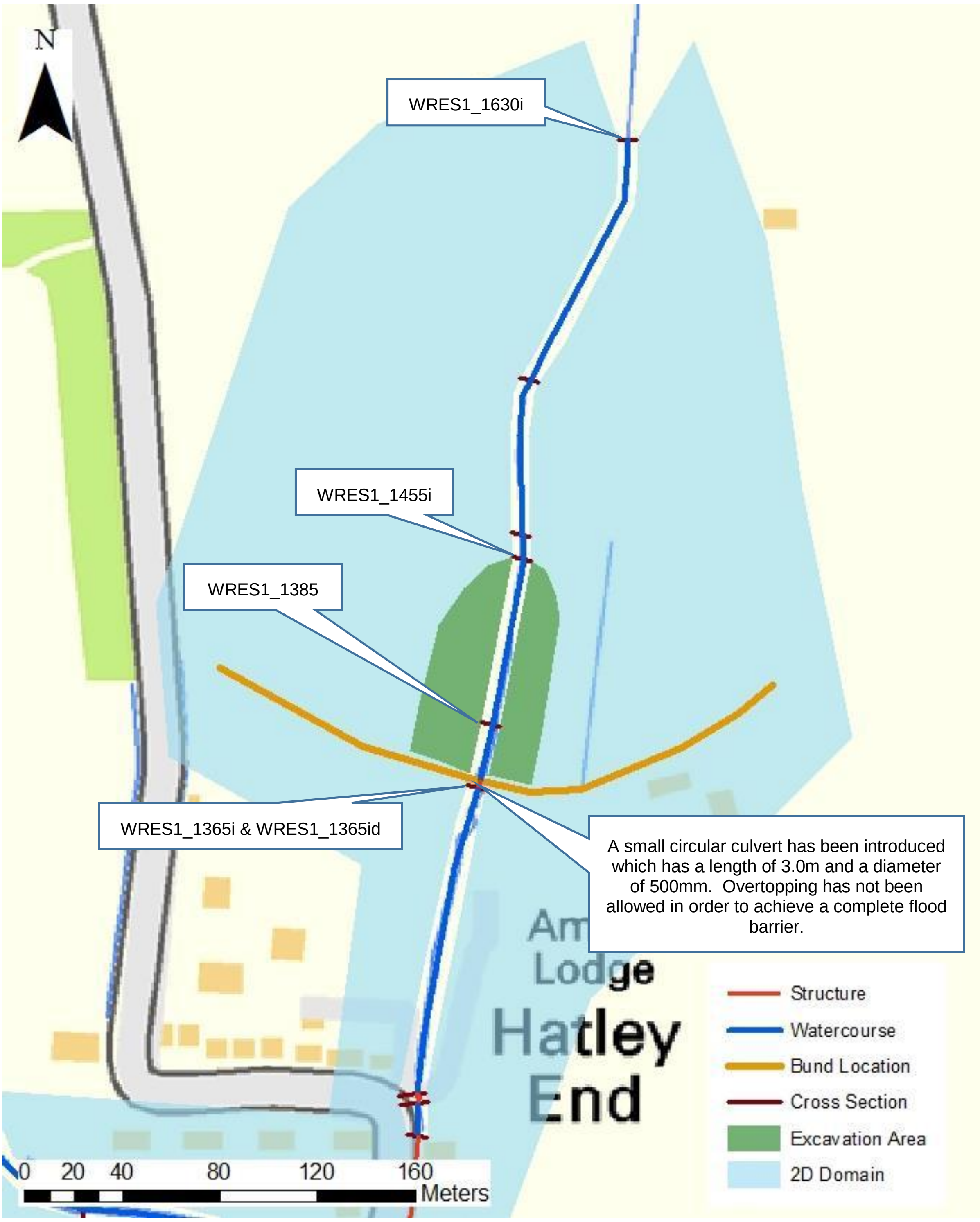
Figure 4-2: Option 2 - proposed offline storage



4.2.3 Option 3 – Flood embankment upstream of Wrestlingworth

Figure 4-3 shows the flood embankment upstream of Wrestlingworth proposed as part of Option 3.

Figure 4-3: Option 3 - Flood embankment and storage area



A number of assumptions have been made in the modelling of option 3 which are detailed below.

- Similar to option 2 the hydraulic model has been extended approximately 250m upstream. As there was no survey it was assumed that the channel shape was identical to WRES1_1385 with bed and bank levels being updated based on DTM data. Although the

Terrain 5 DTM showed fairly good correlation with the survey in this location it is unclear if this would be true further upstream.

- A flow control structure was introduced between WRES1_1365i and WRES1_1365id which has been used to constrict flow and make best use of the two stage channel. The flow control structure comprises a 3m long circular culvert with a diameter of 0.5m.
- The flow control structure has been assumed not to overtop. This was to ensure a complete barrier against flood water which might back up behind the structure.
- The bund which extends for approximately 250m has been assumed to be significantly higher than ground levels to provide a barrier which flood water shall not be capable of overtopping. An approximate height can be determined based on outline modelling results. It should be noted that any stated heights are indicative and should be reassessed with more detailed model with more accurate topographic information.
- Two areas on either bank have been excavated from bank level to approximately 0.30m of the existing ground levels to allow for more floodplain storage for higher return periods where the model does not extend further upstream.
- The location tested is the most downstream advised location, but other positions could be tested, including on the other branch of the watercourse. The aim is to show how a reduction in river flows being passed forward from a bund/ storage feature could reduce flood levels downstream.

5 Model Results - Options Testing

5.1 Options 1 – Upsizing Culverts

5.1.1 Upsizing of Culvert WRES1_1057C

Figure 5-1 shows the comparison of flood outlines for the baseline event and where culvert WRES1_1057C has been upsized for the 20-year event.

Figure 5-1: Upsized 1057C comparison with baseline scenario for the 20-year event

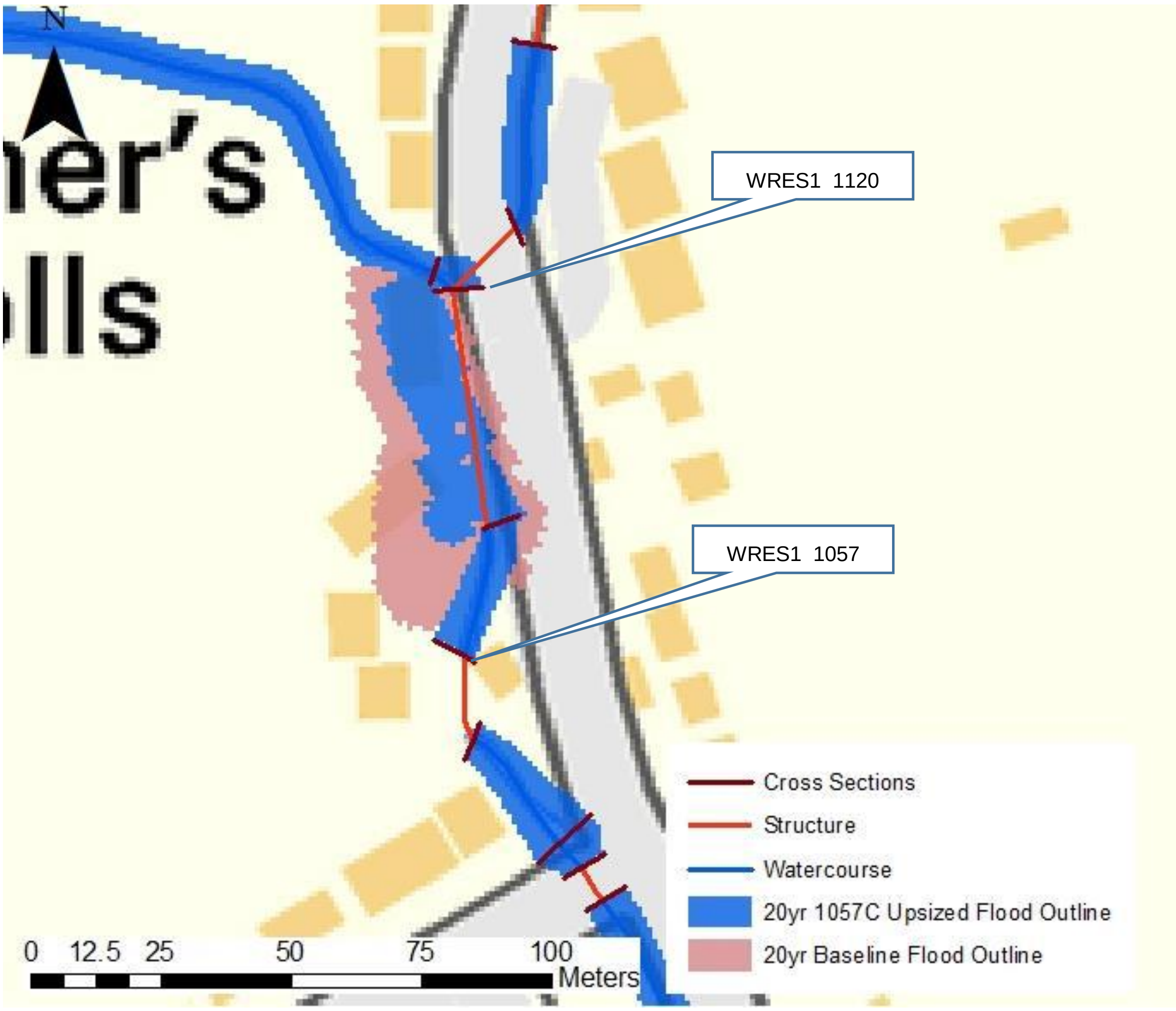


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Figure 5-1 shows that with the 20-year event, upsizing of the WRES1_1057C culvert reduces the flood extent immediately upstream. For the 20-year event there is a decrease in peak water levels of 0.50m immediately upstream at WRES1_1073 and WRES1_1073. The average decrease in peak water levels upstream of the culvert upsizing is 0.17m. There is shown to be no significant increase in peak water levels further downstream as a result of the culvert upsizing. For the smaller 5-year return period there is also a decrease in peak water levels immediately upstream of on average 0.13m. In both scenarios the newly upsized culvert becomes surcharged; however, it would be unrealistic to enlarge this culvert any further.

It is recommended that the upsizing of this culvert is further investigated in combination with other upsized culverts. Currently the modelling results show that the benefit of the increase in conveyance is reduced by the lack of capacity within the channel further downstream.

5.1.2 Upsizing of Culvert WRES1_0937C

Figure 5-2 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0937C has been upsized for the 5-year event.

Figure 5-2: Upsized 937C comparison with baseline scenario for the 5-year event

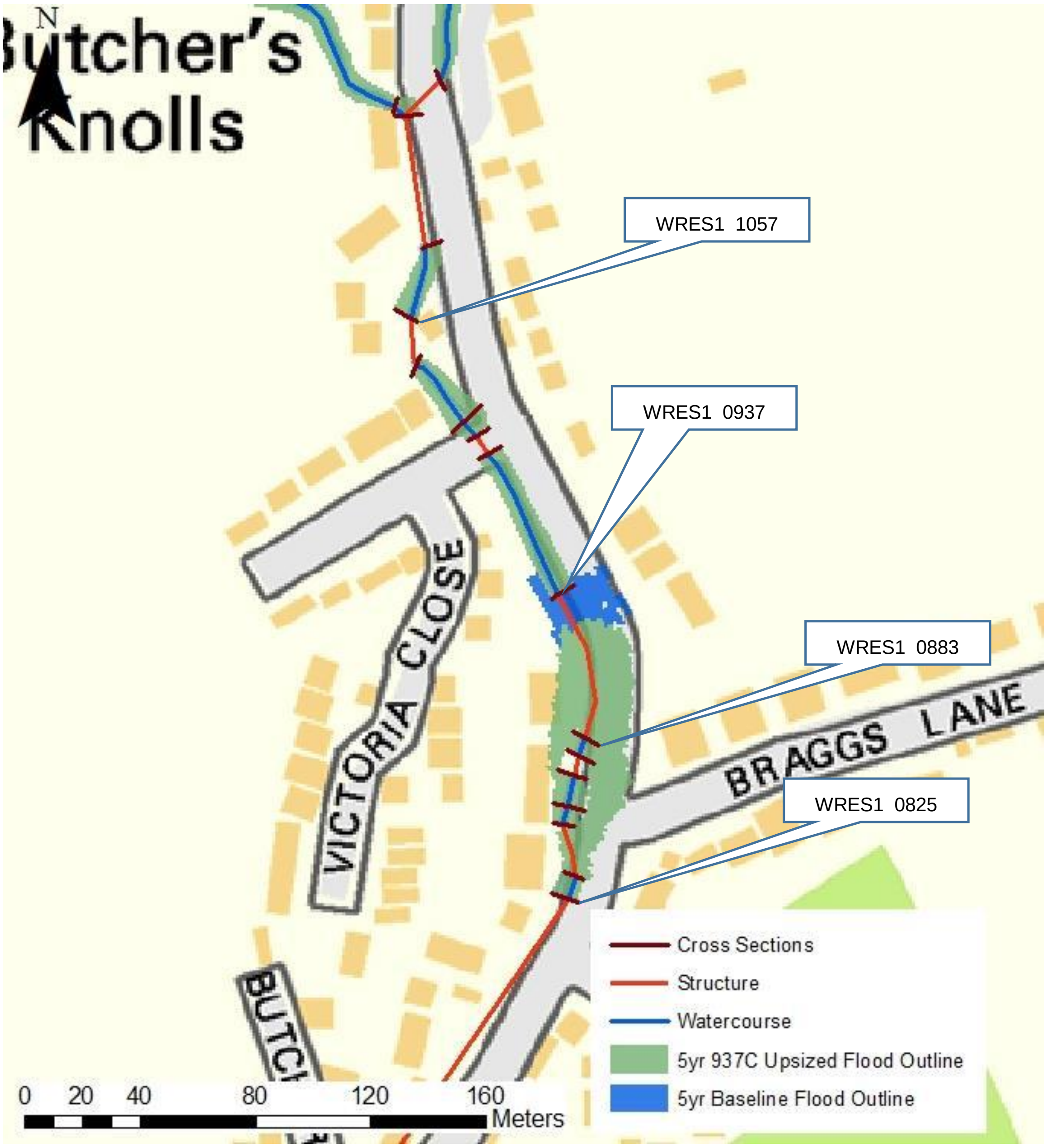

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Figure 5-2 shows with the upsizing of WRES1_0937C there is shown to be small reduction in flood extent immediately downstream of the upsized culvert. This indicates that although the upsized culvert has increased capacity and prevents flooding originating from this location, there is still insufficient capacity further downstream at the other culverts, which still results in out of bank flows flooding the vicinity to a similar extent as the baseline scenario. The maximum increase in peak water levels upstream of the upsized culvert is approximately 0.30m up to WRES1_1212. The average decrease in peak water levels upstream of the upsized culvert is 0.20m. It should be noted that the culvert still becomes surcharged during this event but water does not reach a level to overtop the banks at WRES1_0937.

Figure 5-3 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0937C has been upsized for the 20-year event.

Figure 5-3: Upsized 937C comparison with baseline scenario for the 20-year event

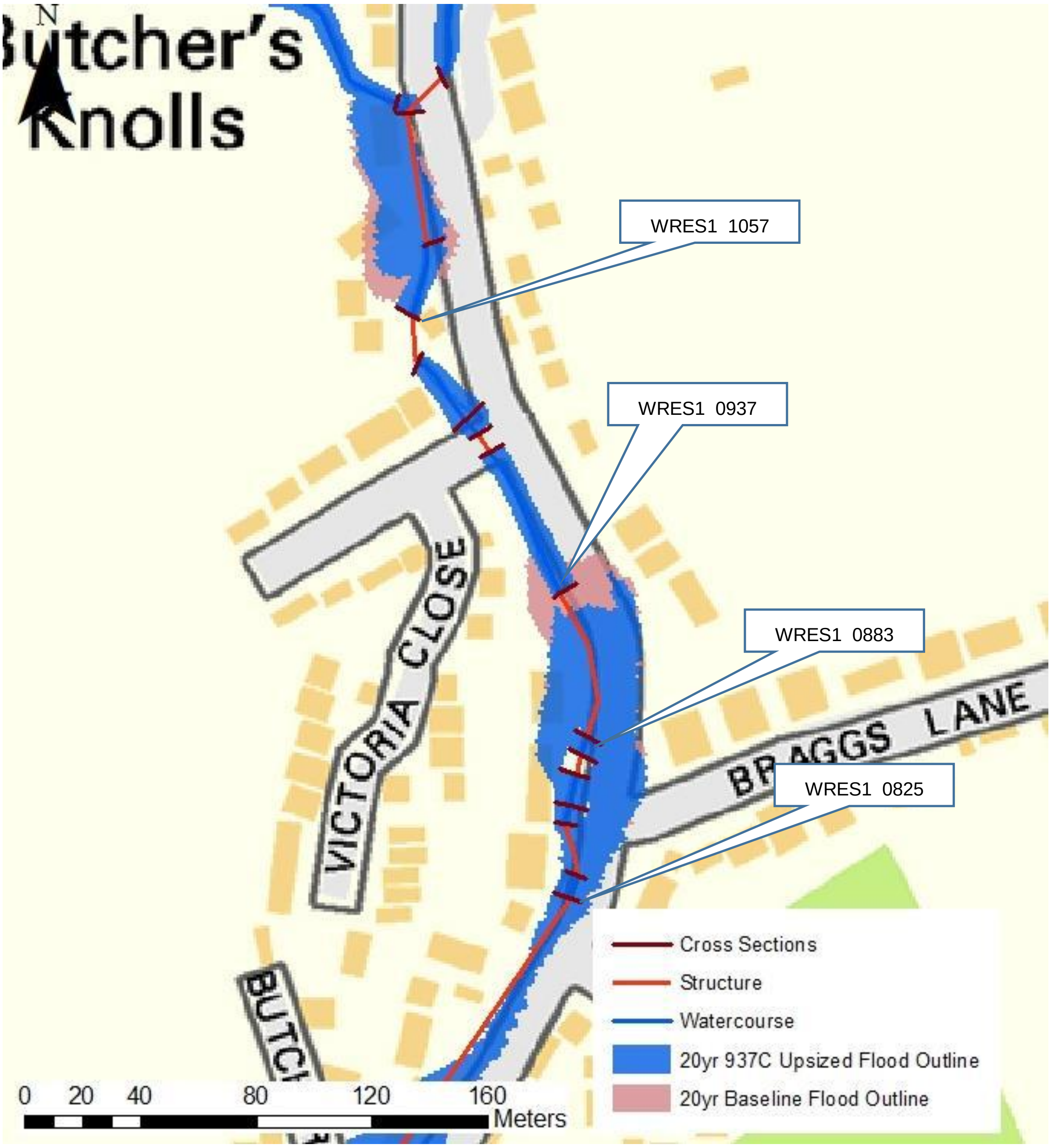

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Figure 5-3 shows that with the upsized culvert that there is a decrease in flood extent immediately downstream of WRES1_0937, similar to that exhibited with the option run with the 5-year event (see Figure 5-2). There is also a decrease in flood extent upstream of WRES1_1057. In regards to peak water levels there is shown to be a maximum decrease of 0.16m immediately upstream of the upsized culvert that extents upstream to WRES1_1057. The decrease in peak water levels upstream is approximately 0.09m.

It is recommended that the upsizing of this culvert is further investigated in combination with other upsized culverts. Currently the modelling results show that the benefit of the increase in conveyance is reduced by the lack of capacity within the channel further downstream.

5.1.3 Upsizing of Culvert WRES1_0852C

Figure 5-4 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0852C has been upsized for the 5-year event.

Figure 5-4: Upsized 852C comparison with baseline scenario for the 5-year event

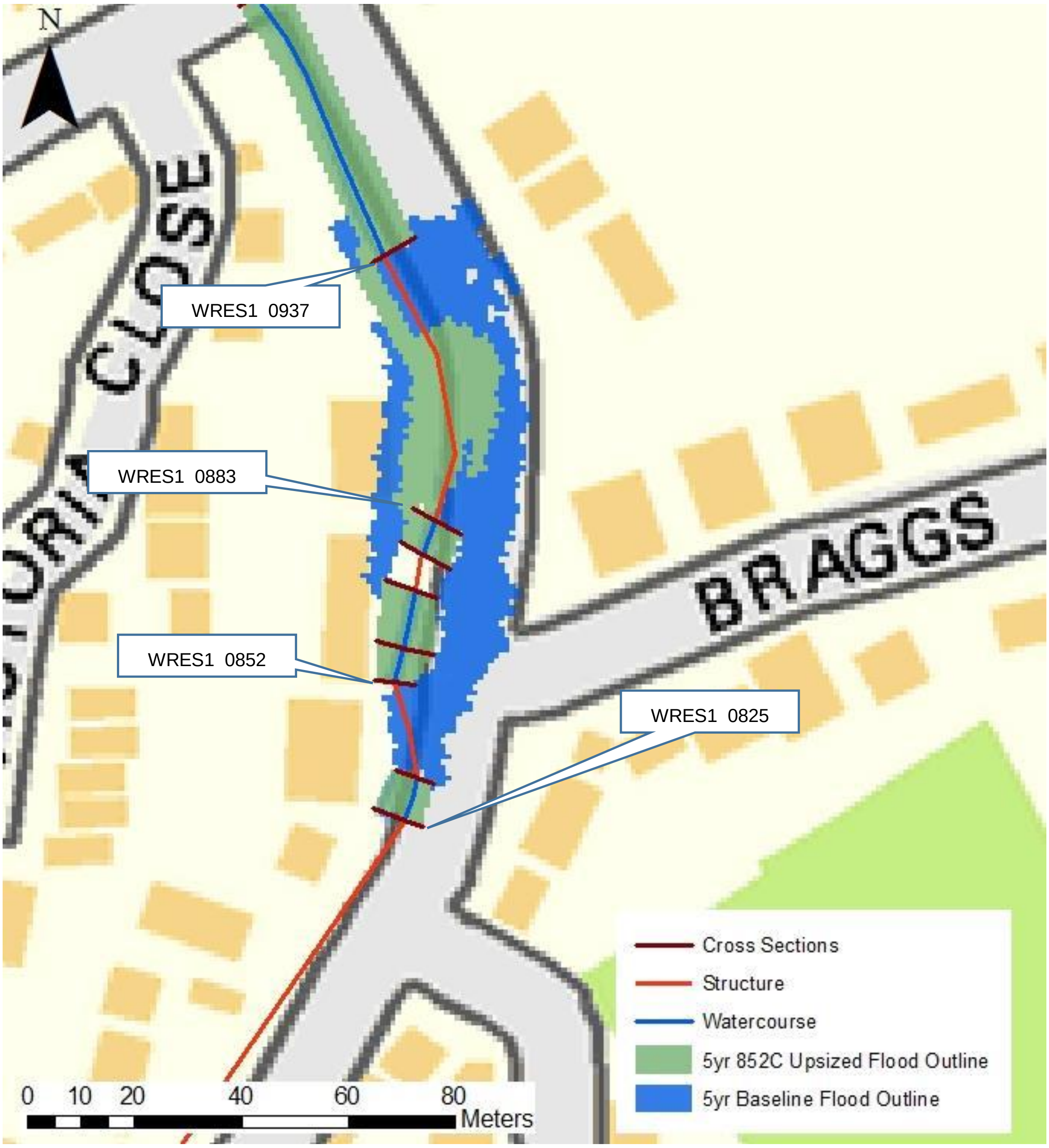

Figure 5-4 shows that for the 5-year return period that upsizing of the culvert at WRES1_0852 shows a significant reduction in flood extent. This is likely due to the increase in conveyance meaning that the culvert is no longer surcharged in this event. As a result water can be conveyed further downstream before becoming out of bank. Out of bank flooding shown in the Figure above is originating from WRES1_0937 which in this scenario has an undersized culvert. If a combination of upsized culverts was run this flow route might be mitigated. In regards to peak water levels for the 5-year event the maximum decrease is 0.25m located immediately upstream of the upsized culvert. The average decrease in peak water levels upstream of the upsized culvert is 0.09m.

For the 20-year event the upsized culvert is shown to still surcharge although peak water levels have been reduced at the upstream face of the structure by 0.17m. As a result of the surcharging of the culvert water becomes out of bank to a similar extent as the 20-year baseline scenario.

For the data above it would appear that to achieve the better results the upsizing of this culvert would need to be considered in combination with other upsizing measures.

5.1.4 Upsizing of Culvert WRES1_0825C

Figure 5-5 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0825C has been upsized for the 5-year event.

Figure 5-5: Upsized 825C comparison with baseline scenario for the 5-year event

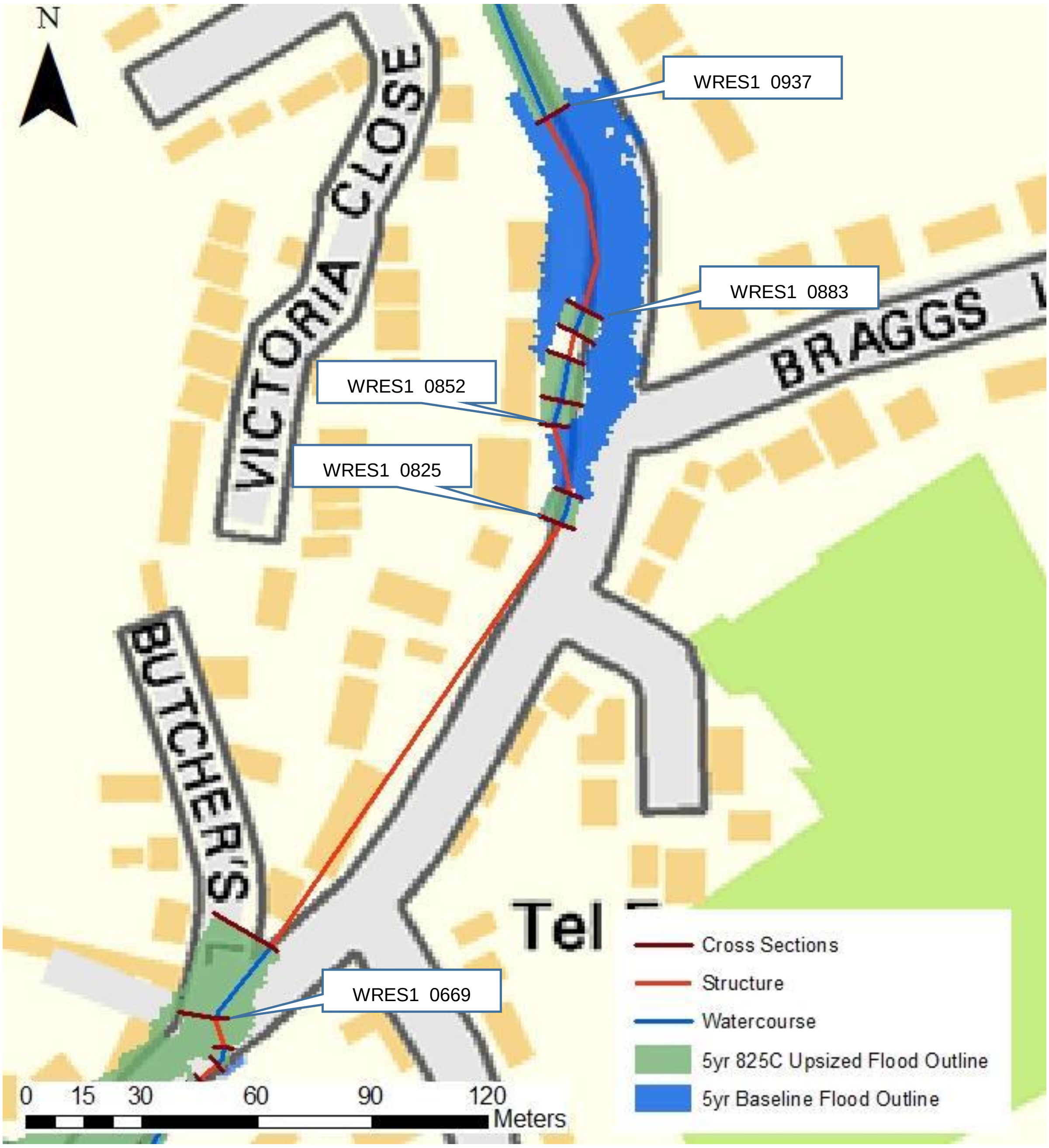

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Figure 5-5 shows as a result of upsizing the culvert at WRES1_0825 that following immediately upstream is completely reduced for the 5-year event. As a result of upsizing and increased conveyance capacity there is a maximum decrease in peak water levels of approximately 1.00m immediately upstream. The average decrease in peak water levels upstream of the upsized culvert is 0.56m.

Figure 5-6 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0825C has been upsized for the 20-year event.

Figure 5-6: Upsized 825C comparison with baseline scenario for the 20-year event

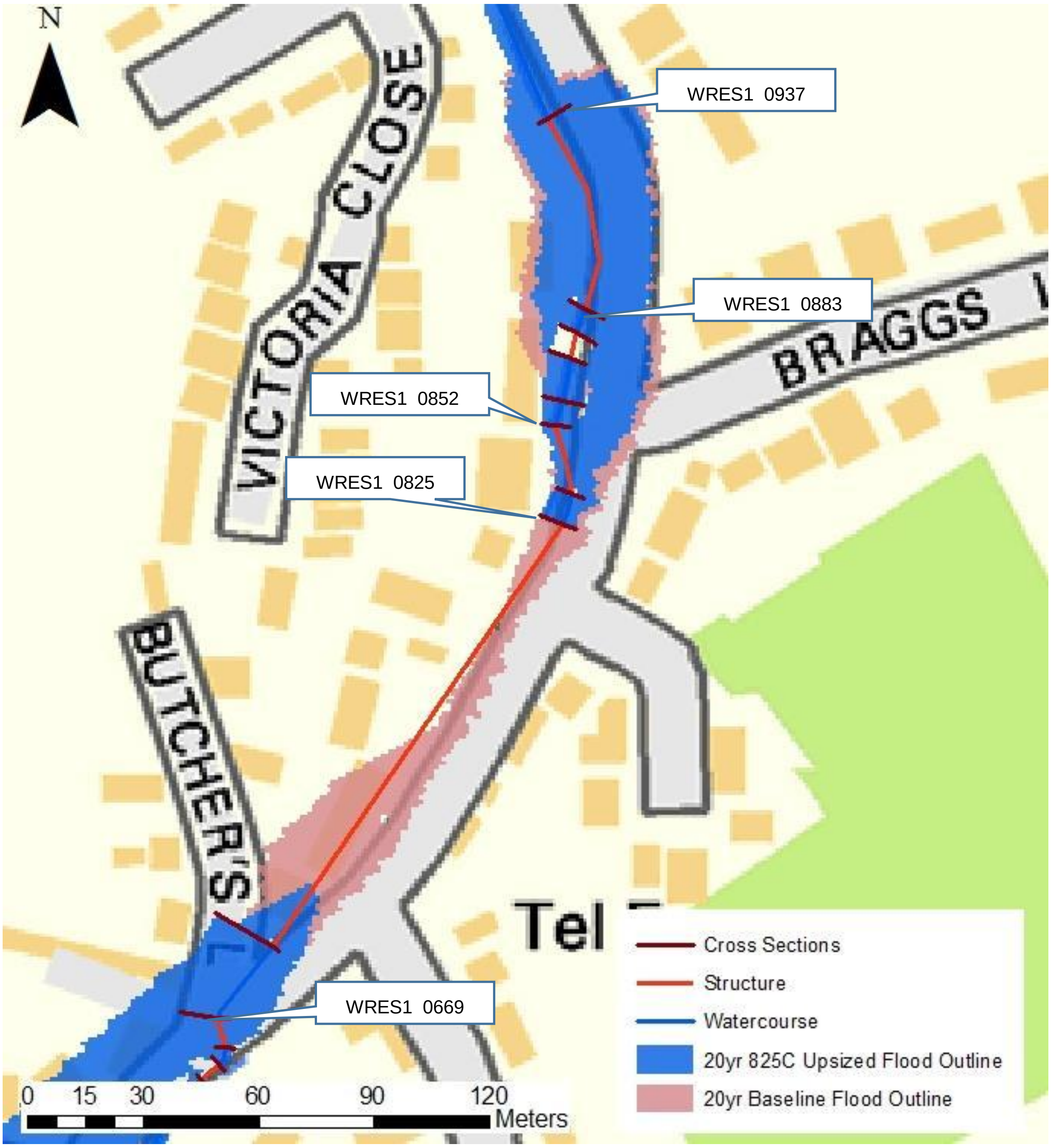

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Figure 5-6 shows for the 20-year event, upsizing of the culvert at WRES1_0825 results in a significant reduction in flood extent. Similar to the 5-year scenario reductions in peak water level are greater than 1.00m with the largest decreases being immediate upstream of the culvert. Upstream of WRES1_0883 decreases in peak water level are small being only 0.02m. The results of this scenario show that the culvert at WRES1_0825 is a key structure and that upsizing it has the potential to significantly improve flood risk.

5.1.5 Upsizing of Culvert WRES1_0669C

Figure 5-7 shows the comparison of flood outlines for the baseline event and where culvert WRES1_0669C has been upsized for the 100-year event.

Figure 5-7: Upsized 669C comparison with baseline scenario for the 5-year event

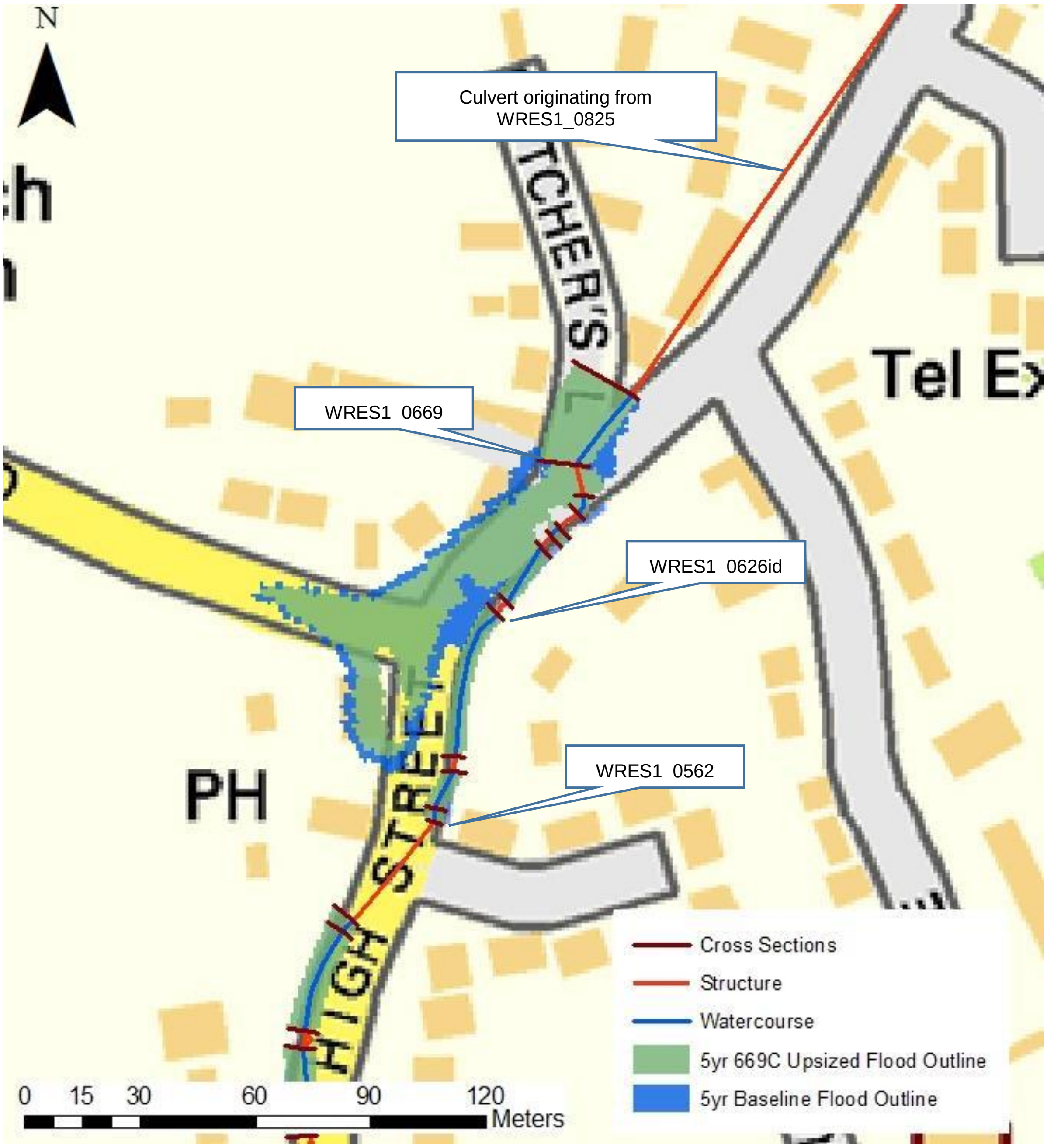

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Figure 5-7 shows that upsizing the culvert at WRES1_0669 does reduce the flood extent although a large amount of Potton Road and the High Street are still impacted by flooding. The maximum decrease in peak water levels are 0.13m at the upstream face of the culvert (WRES1_0669). A small decrease in water levels is also exhibited downstream of on average 0.01m. The upsizing of the culvert is shown to have little impact on flood extent and peak water levels for the 20-year event, however similar to the 5-year event, a small reduction (<0.03m) is shown downstream. Unfortunately due to the depth of the channel and presence of the road there is not much scope for upsizing this culvert any further without substantial highway works which are likely to be of high cost and highly disruptive.

5.1.6 Combined Upsizing of Culverts

Figure 5-8 shows the comparison of flood outlines for the baseline event and where culvert all the upsizing detailed above has been combined in one scenario for the 5-year event.

Figure 5-8: Combined Option 1 comparison with baseline scenario for the 5-year event

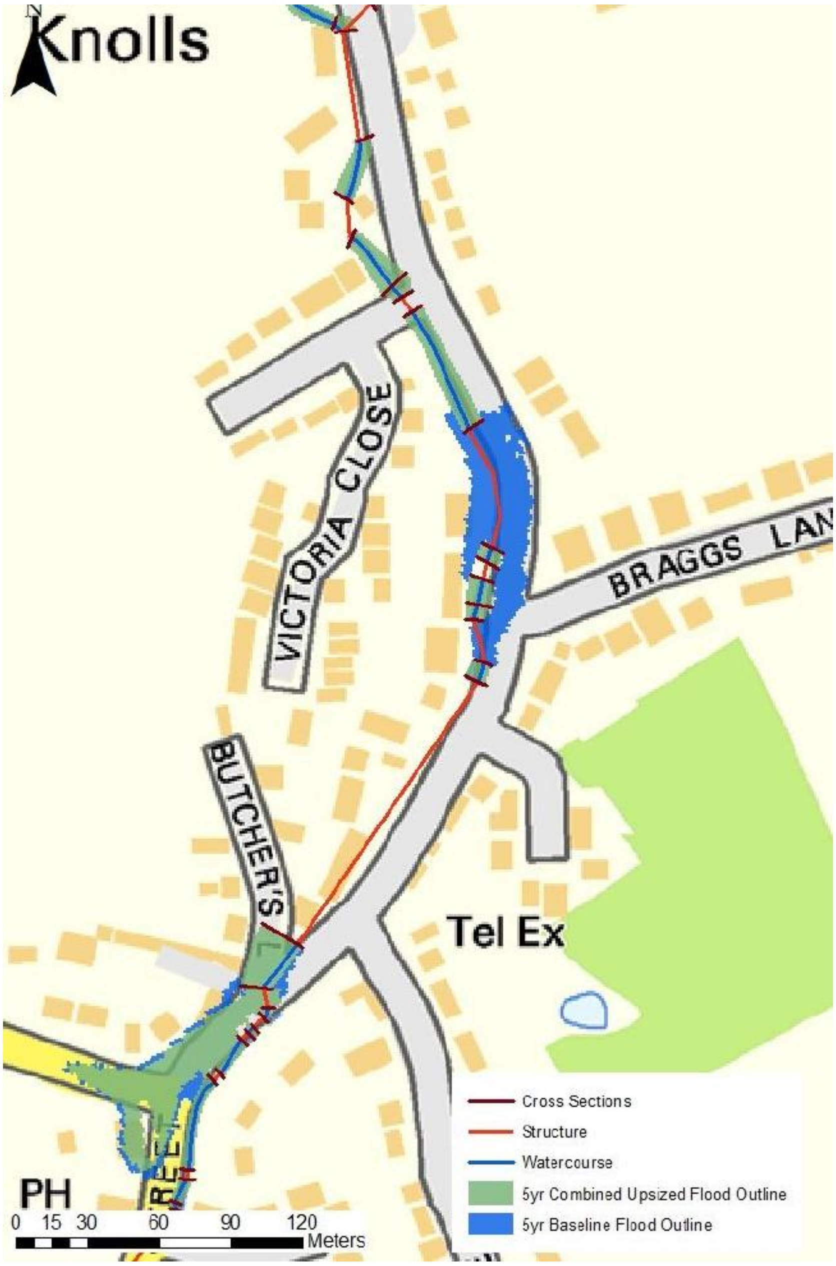

Figure 5-8 shows with all the proposed culvert upsized that for the 5-year event there is a significant decrease in flood extent. This is mainly regarding the flood in the vicinity of Braggs Lane which as a result of the upsizing has been completely reduce. In regards to peak water levels, there is a maximum decrease in peak water levels of 1.26m at WRES1_0937 and on average there is a decrease of 0.67m in peak water levels upstream of the upsizing works (upstream of WRES1_0669). Downstream of WRES1_0669 improved conveyance has resulted in an increase in peak water levels on average by 0.04m. Although this is an increase it unclear whether this would impact additional properties as property threshold levels are not available for this study. However, in regards to the flood extents there is not a significant increase in flood extents downstream. In fact there is a decrease in flood extent in the vicinity of Butchers Lane / Potton Road and the High Street. This is likely to be caused be the removal of overland flow routes along the High Street which contributed flood water to the area from further upstream.

Figure 5-9 shows the comparison of flood outlines for the baseline event and where culvert all the upsizing detailed above has been combined in one scenario for the 20-year event.

Figure 5-9: Combined Option 1 comparison with baseline scenario for the 20-year event

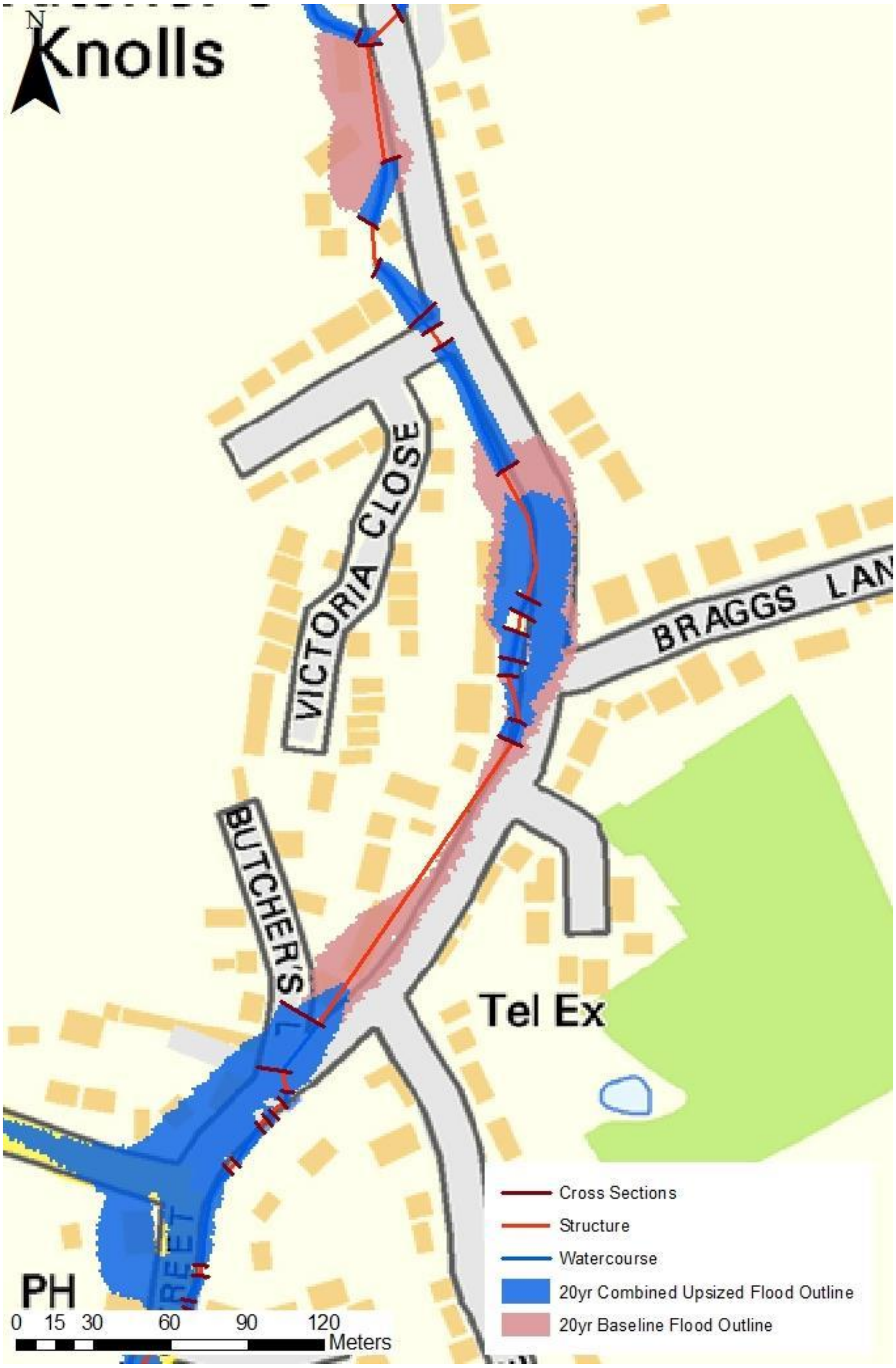

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Figure 5-9 shows with all the proposed culvert upsized that for the 20-year event there is a significant decrease in flood extent. This is mainly regarding the flooding in the vicinity of Braggs Lane which as a result of the upsizing has been reduce and the overland flow route flowing towards Butchers Lane has been removed. Further upstream (north of Victoria Close) flooding is also completely reduced as a result of culvert upsizing. In regards to peak water levels, there is a maximum decrease in peak water levels of 1.35m at WRES1_0825 and on average there is a decrease of 0.44m in peak water levels upstream of the upsizing works (upstream of WRES1_0669). Downstream of WRES1_0669 improved conveyance has resulted in an increase in peak water levels on average by 0.03m. In particular there is a maximum increase of 0.08m between WRES1_0498id and WRES1_0393. Although this is an increase it unclear whether this would impact additional properties as property threshold levels are not available for this study. However, in regards to the flood extents there is not a significant increase downstream.

Although testing of flood mitigation options have been focussed on smaller return periods to offer protection from the more common flood events the combined culvert upsizing option was still tested on the 100-year plus climate change event to ensure that there were no adverse effects during larger return periods. Figure 5-10 shows the comparison of flood outlines for the baseline event and where culvert all the upsizing detailed above has been combined in one scenario for the 100-year plus climate change event.

Figure 5-10: Combined Option 1 comparison with baseline scenario for the 100-year plus climate change event

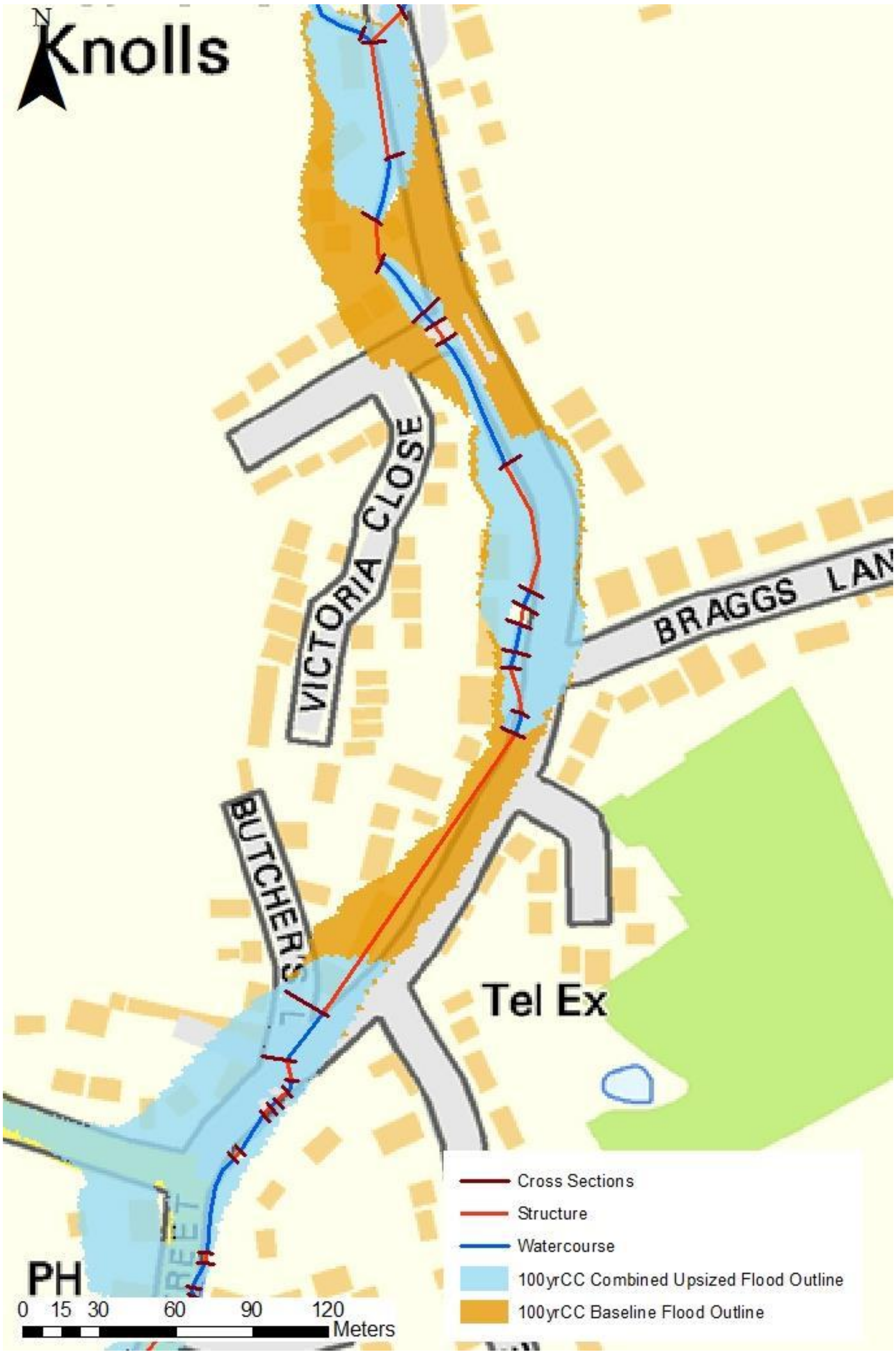

Figure 5-10 shows for the 100-year plus climate change event that upsizing of culverts still significantly reduces the flood extent compared to the baseline scenario. Overland flow routes downstream of Braggs Lane and Upstream of Victoria Close are removed, although there is still significant areas of the High Street which is still flooded. In regards to peak water levels, there is a maximum decrease in peak water levels of 0.72m at WRES1_0852 and on average there is a decrease of 0.19m in peak water levels upstream of the upsizing works (upstream of WRES1_0669). Downstream of WRES1_0669 improved conveyance has resulted in an increase in peak water levels on average by 0.01m. Although this is an increase it unclear whether this would impact additional properties as property threshold levels are not available for this study. However, in regards to the flood extents there is not a significant increase in flood extents downstream.

5.2 Option 2 – Provision of additional storage upstream of Wrestlingworth

Option 2 which includes the creation of a two-stage channel, providing addition storage within the floodplain was tested using the 5-year, 20-year and 100-year plus climate change events. Figure 5-11 shows the comparison of the baseline and the option scenario for the 5-year event.

Figure 5-11: Comparison of Option 2 against the baseline scenario for the 5-year event

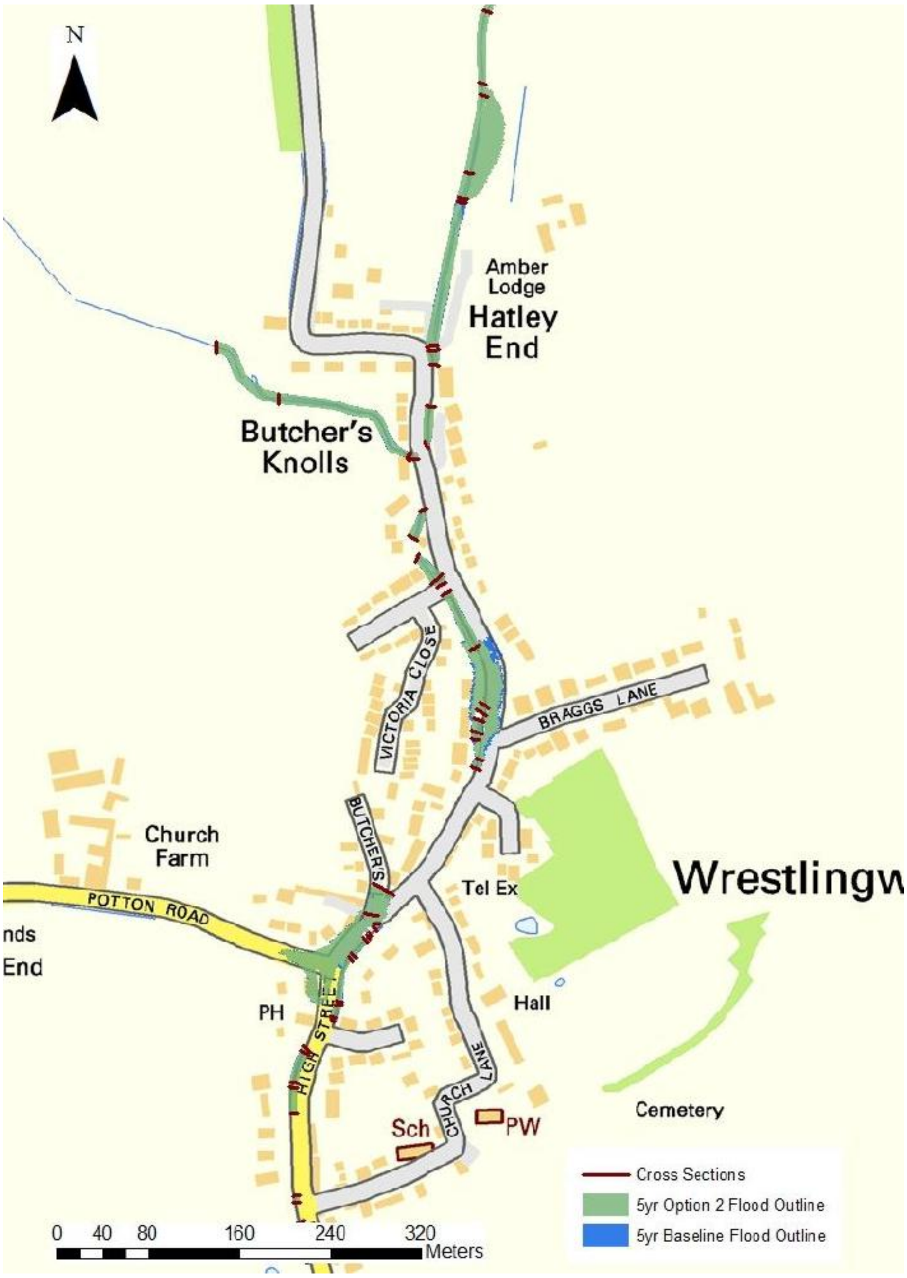

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Figure 5-11 shows that there is only a small decrease in the flood extent between the baseline and option 2. This extent is in the vicinity of Braggs Lane. For larger return periods such as the 20-year event there is no decrease in flood extent within Wrestlingworth. This implies that although additional storage and a flow control structure have been used upstream of Wrestlingworth that they do not have the capabilities to retain enough flood water to significantly influence flood extents further downstream. As such it not recommended that this option is investigated further.

5.3 Option 3 – Flood embankment upstream of Wrestlingworth

Option 2 which includes the creation of a flood embankment and creation of a storage area providing addition storage within the floodplain was tested using the 5-year, 20-year and 100-year plus climate change events. Figure 5-12 - Figure 5-14 shows the comparison of the baseline and the option scenario for the various flood events.

Figure 5-12: Comparison of Option 3 against the baseline scenario for the 5-year event

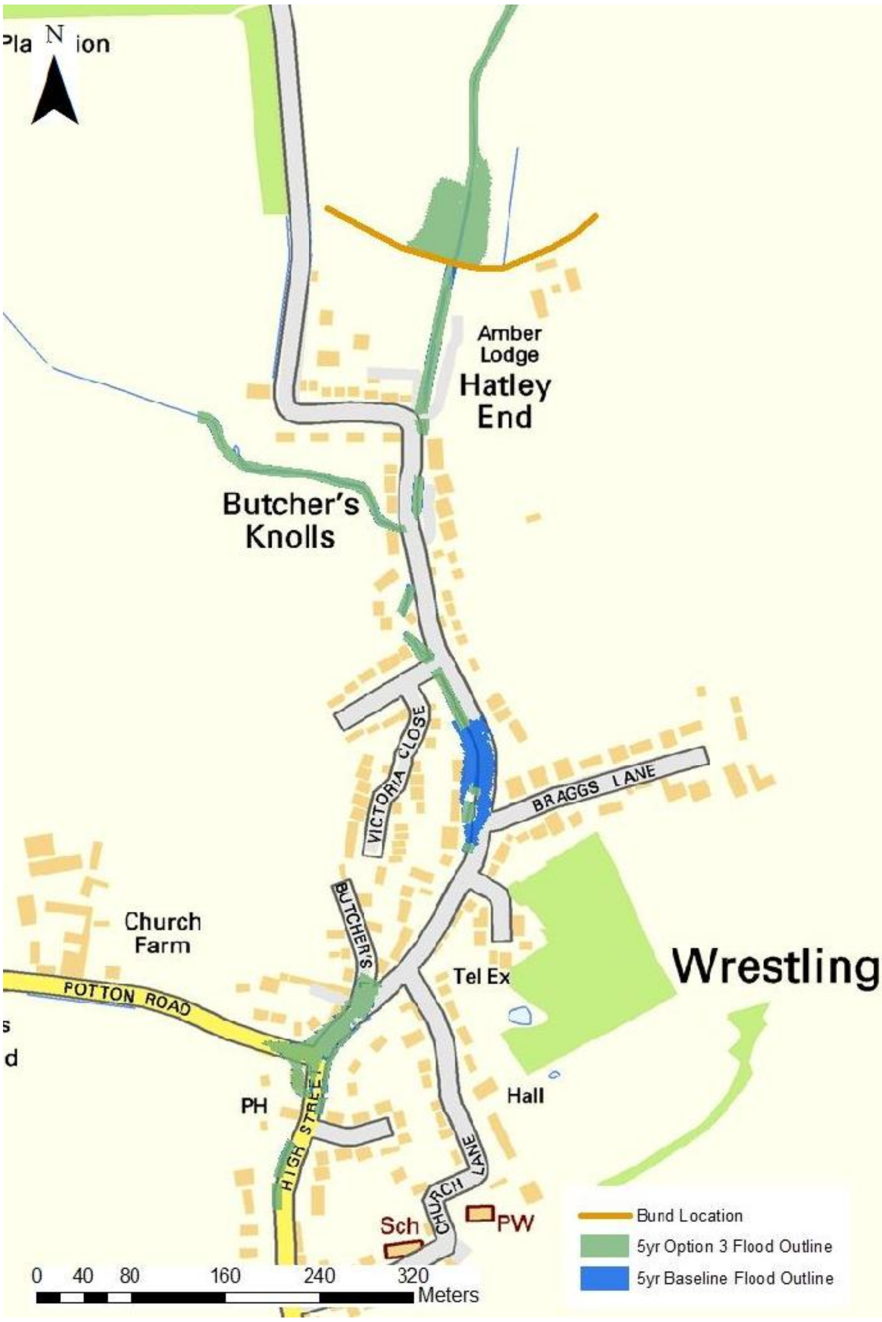

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Figure 5-12 shows that with the 5-year event that Option 3 provides a betterment in flood extents in the vicinity of Braggs Lane, completely reducing out of bank flooding in this location. In regards to peak water levels there is a decrease in peak water levels downstream of the flood embankment of on average 0.12m. The maximum decrease is 0.55m at WRES1_1140 & WRES1_1120. Downstream of the flood embankment there is an average decrease in peak water levels of 0.17m. At WRES1_1385 which is the most upstream comparable cross section between the option and baseline model there is an increase in peak water level of 1.72m. This represents where water has backed up against the flood embankment and therefore caused an increase in water level.

Figure 5-13: Comparison of Option 3 against the baseline scenario for the 20-year event

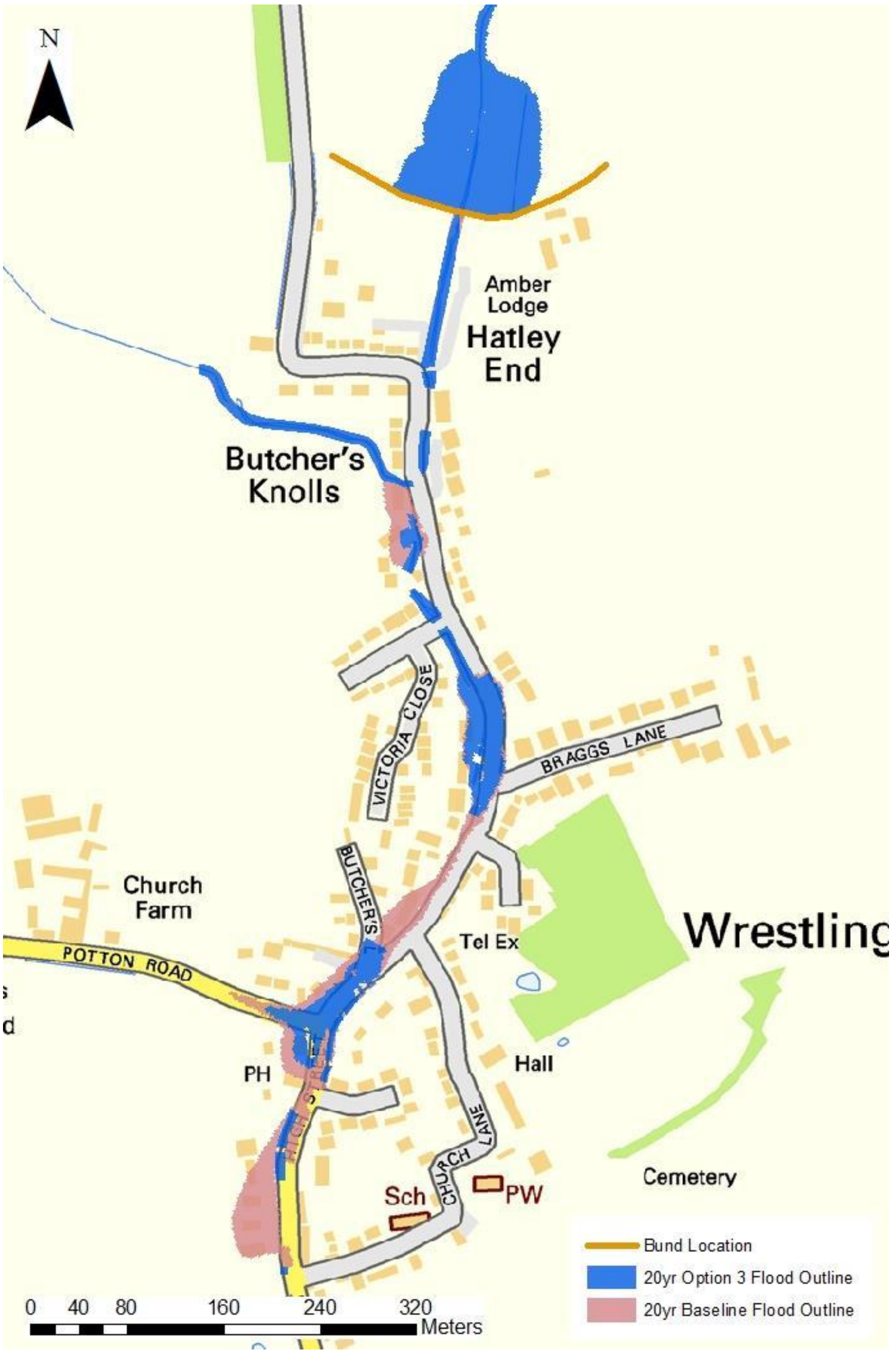

Figure 5-13 shows that in the 20-year event Option 3 provides a significant betterment in flood extent compared to the baseline scenario. Flood extents have been reduced at Butcher's Knolls and the flow route downstream of Braggs Lane, along the High Street has been removed. Flooding in the vicinity of the Butcher's Lane / High Street junction has also been reduced. Flood depths for the 20-year Option 3 scenario are shown to be approximately 0.20m less compared to the baseline scenario at Potton Road, significantly improving flood risk to the area. In regards to peak water levels decrease downstream of the flood embankment on average by 0.24m. The largest decrease in peak level is 0.31m located at WRES1_1073 & WRES1_1057. At WRES1_1385 which is the most upstream comparable cross section between the option and baseline model there is an increase in peak water level of 2.18m. This represents where water has backed up against the flood embankment and therefore caused an increase in water level.

Figure 5-14: Comparison of Option 3 against the baseline scenario for the 100-year plus climate change event

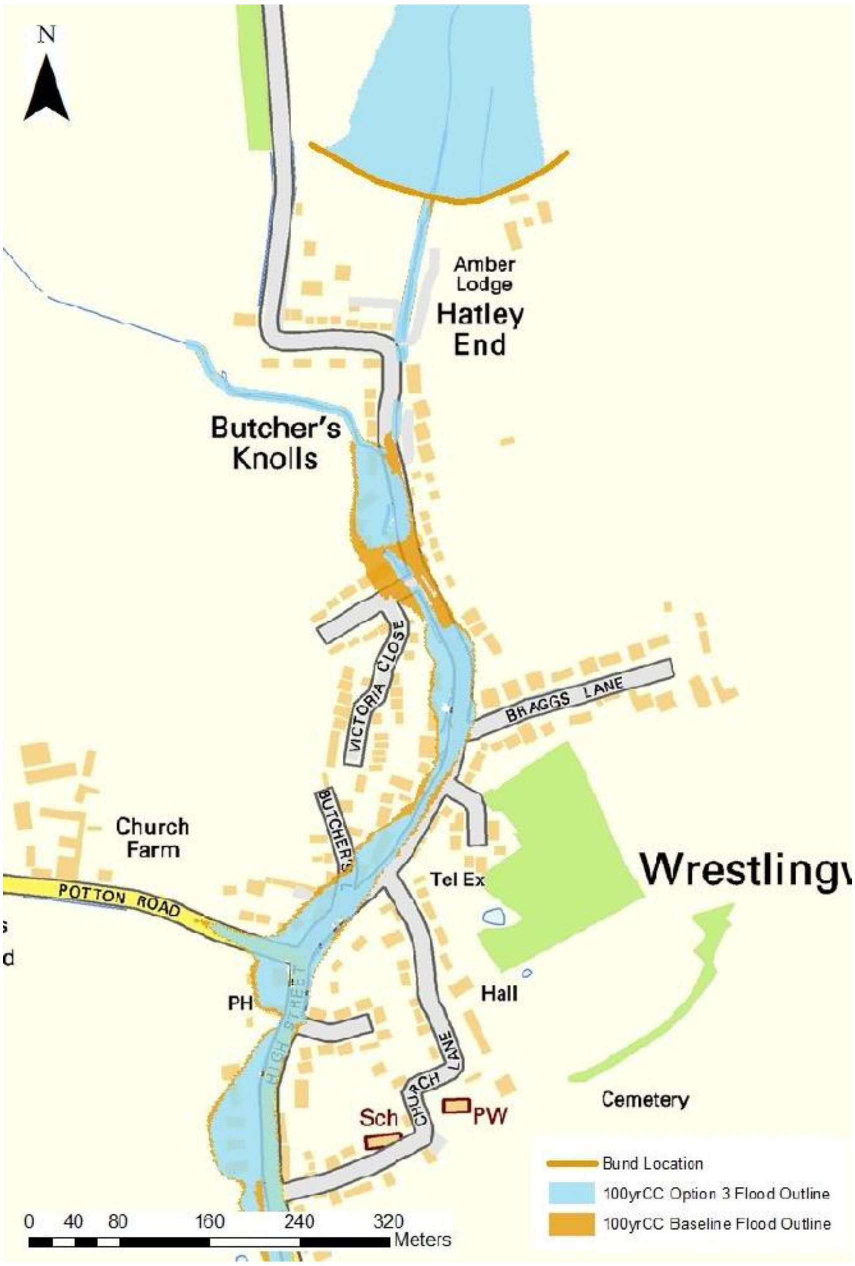

Figure 5-14 shows that in the 100-year plus climate change event Option 3 provides a small betterment in flood extent compared to the baseline scenario. In regards to peak water levels there is an average decrease of 0.17m downstream of the flood embankment. The maximum decrease in peak water levels is 0.79m at WRES1_1212. At WRES1_1385 which is the most upstream comparable cross section between the option and baseline model there is an increase in peak water level of 2.94m. This represents where water has backed up against the flood embankment and therefore caused an increase in water level.

In regards to the height of the flood embankment, it should be designed to withstand a certain standard of protection with a freeboard; in this scenario a minimum of 0.60m has been added. It should be noted that this an indicative value based on the current DTM. As previously noted this DTM is shown not to correlate to survey in some locations and therefore may not accurately represent floodplain levels. It is recommended that a more accurate DTM is used to improve confidence in the validity of this option. Also cross sections upstream of this flood embankment have been estimated; further survey would be required to determine the channel slope and capacity to more accurately represent the impact of the design of such a flood embankment. Finally OS mapping shows a small drainage ditch location behind the flood embankment. This should be investigated to determine if it exists and if so added to any modelled representation.

Storage in the 100-year plus climate change event causes a large head of water that, depending on the volume stored, could be considered a reservoir. As there is little benefit shown in the flood extents in this flood event it would be recommended to consider protecting to a lower standard of protection (i.e. a 20-30-year flood event). The feasibility is likely to be questioned if this option is taken forward due to the required bund heights and associated risks with head of water/ residual flood risk in extreme events. Also for consideration would be the potential impact of more properties flooding from residual flood risk than existing flood risk in say the 100-year plus climate change flood event, if the bund was to protect a lower flood event, in addition to breach risk.

5.4 'Do Nothing' Scenario

This additional scenario aims to give an estimate of the possible flood extents in Wrestlingworth 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 0.10 – 0.15m in peak water levels during all return periods up to the 100-year plus climate change 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 0.05m in peak water levels along the length of the model with all return periods except the 1,000-year return period. The 1,000-year event shows a general average increase but still relatively small.
- There is no significant increase in flood extent from the baseline 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.
- Approximately 1 additional property is shown to flood in this scenario for 100-year plus climate change and 1,000-year events in the vicinity of cross section WRES1_0256.

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6 Preferred Option

Based on the analysis of flood extents and peak water levels for various events, the recommended preferred option for reducing flood risk to Wrestlingworth is the following:

- Upsizing of culverts along the High Street. This considers of upsizing five culverts to increase conveyance and to prevent the watercourse from overtopping its banks as water backs up behind numerous structures.
- Development of a combination of methods north of Wrestlingworth to create a flood storage area, attenuating flows within rural land rather than within the village itself. A flow constriction structure would be used to restrict flows. For the purposes of this indicative test, this was modelled as a 3m circular culvert of 0.50m diameter. A berm which stretches for approximately 250m was used to prevent out of bank flows moving downstream, creating a flood storage area in an area of land currently used for agriculture.

The preferred option has been modelled for the 5-year, 20-year and 100-year plus climate change events. Maps showing the comparison of flood extents between the baseline and preferred option scenarios can be found in Appendix C.2. The preferred option runs have been run for a model simulation of 20hrs opposed to the baseline scenarios 16hrs to allow water levels to decrease due to the lag caused by flood storage.

To note: Storage in the 100-year plus climate change event causes a large head of water that, depending on the volume stored, could be considered a reservoir. As there is little benefit shown in the flood extents in this flood event it would be recommended to consider a lower standard of protection. The feasibility is likely to be questioned if this option is taken forward due to the required bund heights and associated risks with head of water/ residual flood risk in extreme events. Also for consideration would be the potential impact of more properties flooding from residual flood risk than existing flood risk in say the 100-year plus climate change flood event, if the bund was to protect a lower flood event, in addition to breach risk.

This is a high level assessment of the possibility of storage, which would need to be refined as part of options development.

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. This would include the following:

- Obtaining detailed topographic data to represent the floodplain. Currently an OS dataset called Terrain 5 has been used as the DTM and although there is a correlation between this data and survey points, this is not consistent throughout the model.
- Obtaining channel survey north of Wrestlingworth where the model has been extended based on copies of existing cross sections altered based on DTM data. With there being uncertainties with the DTM it is recommended that cross sections are surveyed to give a better indication of channel gradient and capacity. Extending the model further north would allow a more detailed assessment of any flood storage feasibility.
- Determining whether there is a drainage ditch located within the flood storage area. It was unclear whether this was the case from satellite imagery and should be investigated further to ensure it is not a constraint on any proposed flood storage option.
- At present a number of modelling assumptions have been made due to the accuracy of the existing data and the geometry of a number driveways crossing the watercourse. 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 other 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 Overview of Proposed Option Flood Extent

The proposed option was modelled for the 5-year, 20-year and 100-year plus climate change event to assess the impact of the proposed option on low and higher return periods, **as shown in Appendix C2**. For the 5-year event the proposed option shows a significant decrease in flood extent compared to the 5-year baseline scenario. Flooding is completely reduced on the High Street in the vicinity of Braggs Lane and there is a significant decrease in flood extent in the vicinity of the Butchers Lane / High Street junction. This is shown to be a greater reduction than either the upsizing of culverts or the creation of a flood storage area could achieve individually (See Figure 5-8 & Figure 5-12). In regards to the flooding at the location the maximum flood depths on the road are between approximately 0.05 and 0.15m. This is approximately a 0.20m reduction compared to the baseline scenario. In regards to peak water levels there is an average decrease in peak water levels of 0.39m downstream of the new flood storage area. As a result nearly all of the upsized culverts do not surcharge in this event with the exception of the culvert WRES1_669C (Butchers Lane / High Street culvert).

For the 20-year event the proposed option again shows a significant reduction in flood extent compared to the baseline scenario. The only out of bank flooding during this event with the preferred option is in the vicinity of the junction of Potton Road and the High Street. Maximum flood peak water levels at this location on the High Street have decrease by approximately 0.25m compared to the baseline scenario. The maximum observed flood depth on the road with the proposed option is 0.30m compared to 0.60m with the baseline scenario. In regards to peak water levels there is an average decrease in peak water levels of 0.53m downstream of the new flood storage area. Unlike the 5-year preferred option scenario a number of the upsized culverts do surcharge in this event however, not as significantly as with the baseline scenarios which resulted in overtopping.

For the 100-year plus climate change event the proposed option again shows a significant reduction in flood extent compared to the baseline scenario. The main reductions in flood extent are upstream of the Butcher's Lane / High Street junction where a number of overland flow routes down the High Street have been reduced or completely removed. Flooding this location is shown to be relatively shallow with the majority of flooding being less than 0.15m for only some isolated areas of higher flood depths. Downstream of the Butcher's Lane / High Street junction the proposed option scenario shows a similar flood extent to the baseline scenario however, flood depths have been reduced by approximately 0.1m. Although the betterment in this area is less significant than for smaller return periods there are a smaller number of properties that would be impacted by flooding in this location. In regards to peak water levels there is an average decrease in peak water levels of 0.34m downstream of the new flood storage area. Similar to the 20-year preferred option scenario a number of the upsized culverts are shown to surcharge in this event however, not as significantly as with the baseline scenarios resulting in less flooding.

Overall the combination of upsizing key culverts and the creation of a flood storage area north of Wrestlingworth is shown to significant improve flood risk for the more frequent lower return periods. This is achieved by retaining flood water outside of Wrestlingworth and improving conveyance so that water does not back up behind key structure and become forced out of bank. For higher return periods such as the 100-year plus climate change there is still significant flood risk although this is also shown to be reduced by the preferred option.

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 possibly requiring CCTV

Based on the modelling results and known gaps in the existing data, some culverts could be identified as potential candidates for CCTV survey. The summary below highlights some culverts which may be worth investigating for whether CCTV survey would be required, for example in relation to the condition and construction of the longer culverts, and where culverts are suspected of changing geometries. 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:

- WRES1_1120 – 40m long, 1m diameter circular culvert; WRES1_0469 and WRES1_0371 - both dual arch culverts – these culverts are constructed of brick which may require a condition check, and some look quite silted.
- WRES1_669 – culvert under the road in the centre of the town – circular culvert, which has been re-constructed since the 1991 report but to smaller dimensions. CCTV may not

be required here but further investigation into why it was made smaller than previous dimensions.

- WRES1_0562 – circular culvert entrance with a dual arch exit. Modelling assumes to be circular as this is conservative, but it would be interesting to see what is going on through its 34m length and where that changes.
- WRES1_0937 – 55m circular 1m diameter culvert, plus, WRES1_0825 – 140m long circular 0.95m diameter culvert – both of these are recommended for upsizing in this study, so CCTV may not be required.

6.2 Stakeholder engagement

A meeting was held on November 13th 2014 in Wrestlingworth with JBA Consulting, Central Bedfordshire Council and representatives from Wrestlingworth 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 Wrestlingworth, such as at Potton Lane due to runoff 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.
- Reaches of the watercourse which experience silt build up or erosion
- 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 culvert/ culvert upsizing

As part of the preferred option, a number of culverts are recommended for upsizing.

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

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

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

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

The following table presents the culverts recommended for upsizing and which indicative price bracket these would fall under.

Culvert	Existing diameter (m)	Upsized diameter (m)	Length (m)	Area (m2)	Cost per metre (£) (2010)	Total Cost (£) (2010)	Total Cost (£) (inflation to 2014)
1057C	1	1.5	16	1.77	13,500	216,000	252,655
0937C	1	1.5	55	1.77	4,700	258,500	302,367
0852C	1	1.5	18	1.77	13,500	243,000	284,237
0825C	0.95	1.5	140	1.77	3,000	420,000	491,274
0669C	0.6	1x0.6 (rectangular)	8	0.6	8,400	67,200	78,603
Total indicative cost (including inflation to 2014) for all culverts to be upsized							**£1,409,136**
Bund Pipe	-	0.5	3	0.2	8,400	25,200	29,476

6.3.2 New earth bund

In order to hold back water upstream in storage to reduce flows through Wrestlingworth, an option was tested to hold water back with a new pipe allowing water through the embankment at a reduced flow rate. The bund height would depend on the Standard of Protection able to realistically protect the town, informed by the maximum water levels plus a freeboard.

A bund length of 250m was modelled to contain the 100-year plus climate change flows.

In the 20-year flood event, the maximum water level was 44.9m AOD requiring a bund height of approximately 1.34m if a freeboard of 600mm is assumed; therefore an embankment volume of 335m^3 could be assumed when the height is multiplied by the indicative length.

The estimate in red would mean a potential cost for a 20-year standard of protection of £62,980 using 2010 prices. With inflation to 2014, this cost could be in the region of £73,667.

In the 100-year plus climate change flood event, the maximum water level was 45.89m AOD requiring a bund height of approximately 2.5m if a freeboard of 600mm is assumed, therefore an embankment volume of 625m^3 could be assumed when the height is multiplied by the indicative length.

In the 100-year plus climate change flood event, the maximum water level was 45.89m AOD requiring a bund height of approximately 2.5m if a freeboard of 600mm is assumed, therefore an embankment volume of 625m^3 could be assumed when the height is multiplied by the indicative length.

For the purposes of this assessment, both embankments have been assumed to have a rate of £188 per m^3 fill volume. Whilst the larger embankment falls into the higher bracket, using this reduced rate produces inconsistent costs for an embankment construction (i.e. the larger embankment being cheaper than the smaller embankment).

The estimate in green would mean a potential cost for a 100-year+CC standard of protection of £117,500 using 2010 prices. With inflation to 2014, this cost could be in the region of £137,440.

Important Note: The 100-year plus climate change event causes a large head of water that, depending on the volume stored, could be considered a reservoir. As there is little benefit shown in the flood extents in this flood event it would be recommended to consider a lower standard of protection. The feasibility is likely to be questioned if this option is taken forward due to the required bund heights and associated risks with head of water/ residual flood risk in extreme events. Also for consideration would be the potential impact of more properties flooding from residual flood risk than existing flood risk in say the 100-year plus climate change flood event, if the bund was to protect a lower flood event, in addition to breach risk.

This is a high level assessment of the possibility of storage, which would need to be refined as part of options development.

Table 6-3: EA (2010) Unit costs for embankments (earth bund)

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.

Higher bunds may need reinforcement with harder materials, which is not accounted for in the above costings.

6.3.3 Channel maintenance

Whilst channel maintenance has not been investigated as an option due to most of the watercourse being in and out of culverts, 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.

6.3.4 Property Level Protection

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

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

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

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

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

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

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

6.3.5 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 6-4: Indicative Costs of Further Work

Work Stage	Tasks	Guideline Total Costs
Outline Design	New LIDAR to be flown (£8-10k) Additional channel survey if proposed storage is to be taken forward (to extend the hydraulic model further upstream) £1-2k (for 1-2 days) Site Visit Services Search Refinement of Options 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)	**£~30k**
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). - Bund/pipe + upsizing culverts (Preferred Option) - Bund/ pipe (Storage-only)	**Preferred Option** **~£1,512,279** **Storage-only** **~£80-160k**
Whole scheme	**Ball-park total for whole scheme**	**£1,582,280** **(Preferred Option)** **£150-230k** **(Storage-only)**

6.3.6 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 6-5: 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.

For 20-year SoP schemes, above-scheme damages are assumed to be equivalent to the baseline.

Table 6-6: 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	**43,779**	**1,305,183**	-	-	-
Storage-Only (to a 100yrCC storage SoP*)	24,260	723,263	582,000	236,916 + 50% = **355,400**	1.6
Storage-Only (to a 20yr storage SoP)	25,616	763,690	541,500	173,143 + 50% = **259,700**	2.1

Storage + Culvert upsizing (to a 100yrCC storage SoP*)	21,167	631,052	674,000	1,626,112 + 50% = **2,439,000**	0.3
Storage + Culvert upsizing (to a 20yr storage SoP)	22,881	682,151	623,000	1,582,280 + 50% = **2,374,000**	0.3

**Costs and benefits have been derived for storage up to the 100-year+CC flood event for comparison purposes only; as discussed in Section 6, storage in the 100-year plus climate change event causes a large head of water that could be considered a reservoir, depending on the volume, and there would be additional development costs associated with such a structure.*

The above table demonstrates that the 'Preferred Option' which manages flood risk to all properties within Wrestlingworth is not cost beneficial with the estimated costs exceeding the benefits of the scheme. The most cost beneficial scheme is the storage-only scheme to the 20yr SoP with a benefit cost ratio of 2.1. The storage-only scheme doesn't prevent all flooding in Wrestlingworth as the report shows properties are still at flood risk downstream due to culverts and surface water flow routes, but it reduces the number of properties at flood risk by holding back flows coming in to Wrestlingworth from upstream. The benefit cost ratio even for this scheme is low and to qualify for funding from GiA it is likely additional contributions will need to be sourced, from the council or otherwise.

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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 Wrestlingworth.

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 1.2km, 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, including Butchers Lane/ High Street, and Victoria Close/ Braggs Lane, which allowed the identification of several small-scale flood mitigation options for the options modelling phase, to try and reduce flood risk in Wrestlingworth.

The following options were tested:

Option	Action
Option 1	Upsizing of numerous culverts throughout Wrestlingworth. The following culverts have been identified as requiring upsizing based on the hydraulic model: • WRES1_1057C (Upstream of Victoria Close) • WRES1_0937C (Upstream of Braggs Lane) • WRES1_0853C (Opposite Braggs Lane) • WRES1_0825C (Downstream of Braggs Lane) • WRES1_0669C (Butchers Lane / High Street junction) The culverts will be tested individually to assess the impact that upsizing has at each location as well as having a scenario combining all of the upsizing options are tested together.
Option 2	Provision of off-line storage upstream of Wrestlingworth with the aim of reducing the volume of watercourse entering the village. This storage is in the form of a two-stage channel.
Option 3	Provision of a storage upstream of Wrestlingworth with the aim of reducing the volume of watercourse entering the village. This storage is in the form of an embankment in which out of bank flooding would bank up against.
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 Wrestlingworth is the following:

- Upsizing of culverts along the High Street. This considers upsizing five culverts to increase conveyance and to prevent the watercourse from overtopping its banks as water backs up behind numerous structures.

Important Note: Whilst flood risk is reduced in the vicinity of each upsized culvert, the conveyance of flood water downstream is increased as a result of culvert upsizing, and hence water levels are increased water levels further downstream.

- Development of a combination of methods north of Wrestlingworth to create a flood storage area, attenuating flows within rural land rather than within the village itself. A flow constriction structure would be used to restrict flows. This was modelled as a 3m circular culvert of 0.50m diameter. A berm which stretches for approximately 250m would be used to prevent out of bank flows moving downstream and create a flood storage area in an area of land currently used for agriculture.

  Important Note: Storage in the 100-year plus climate change event causes a large head of water that, depending on the volume stored, could be considered a reservoir. There is little benefit shown in the flood extents in this flood event therefore it would be recommended to consider a lower standard of protection. The feasibility is likely to be questioned if this option is taken forward due to the required bund heights and associated risks with head of water/ breach flood risk in extreme 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 (culvert upsizing and storage option to a 20yr SoP) is in the region of £1,512,279. Approximately £1,409,136 of this would be for upsizing all five suggested culverts. 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, in terms of mitigating flood risk, is not cost-beneficial with the estimated costs exceeding the benefits of the scheme. It may therefore be appropriate to consider a partial solution, such as storage-only to a lower order SoP, which had the highest cost-benefit ratio of 2.1. The storage-only scheme doesn't prevent all flooding in Wrestlingworth as the report shows properties are still at flood risk downstream due to culverts and surface water flow routes, but it reduces the number of properties at flood risk by holding back flows coming in to Wrestlingworth from upstream. The benefit cost ratio even for this scheme is low and to qualify for funding from GiA it is likely additional contributions will need to be sourced, from the council or otherwise.

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 for certain culverts which are longer culverts or where culverts change shape through their length and assumptions in the modelling have been made as detailed in section 6.1.2.
- 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. 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.

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

- 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.
- A partial solution or phased approach to the preferred option could be considered to allow reduction (whilst not eradication) of flood risk in the short-medium term. This is based on the high-level cost-benefit appraisal indicating that the full preferred option is not cost-beneficial.
- If flood storage is to be considered further, it is recommended to gather additional cross section survey in the upper catchment to allow the model to be extended and more accurately represent storage capacity. The location tested is the most downstream advised location, but other positions could be tested, including on the other branch of the watercourse. The aim in this study is to show how a reduction in river flows being passed forward from a bund/ storage feature could reduce flood levels downstream. Landownership should be investigated in relation to the feasibility of storage in the upper catchment and implementation of a bund. Also, due to a large build-up of water behind the modelled bund in the more extreme flood events, storage should be considered for lower more frequent flood events to avoid complex issues relating to reservoirs if the volume stored is within this designation and reducing residual flood risk from breaches.
- Whilst vegetation removal to improve channel conveyance has not been modelled in Wrestlingworth, Parish Councillors have identified areas downstream near Battle Bridge where there is a build-up of silt, and erosion/ undercutting of the banks. CBC have been made aware of these issues. It is understood that there is an annual tidy-up of the culvert grills etc by residents, but more prominent siltation or debris build-up should be incorporated to improve channel conveyance in the short-medium term. 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.
- Consideration could be given to improving debris capture at culverts 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.
- In the longer term, CCTV survey to inform the upsizing of culverts could be incorporated to form the preferred option as part of a phased approach. Consideration could be given to those areas in greatest need in terms of the localised flood risk caused. **It should be recognised however that individual culvert upsizing for example, increases flood water conveyance and hence water levels downstream.**
- Property level protection (PLP) could be considered if preferred options are unviable, 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.
- 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.
- Asset and riparian ownership should be established in Wrestlingworth to allow CBC to identify where works are necessary and who has responsibilities for these works. The 1991 report suggests maintenance of the watercourse is the responsibility of the riparian owners, with some occasional maintenance previously being carried out by the District Council, charged to the riparian owner concerned. Investigation and co-ordination of riparian ownership could provide improvements to channel conveyance by the removal of vegetation through Wrestlingworth.
- 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

Baseline Events	Wrestlingworth Properties affected by flood outlines	Properties benefited
5yr	11	-
20yr	27	-
30yr	33	-
100yr	43	-
100yrCC	49	-
1000yr	63	-
Preferred Option		
5yr	7	4
20yr	8	19
100yrCC	31	18
Option 1 (Combined upsizing of all proposed culverts)		
5yr	7	4
20yr	23	4
100yrCC	35	14
Option 2		
5yr	9	2
20yr	27	0
100yrCC	48	1
Option 3		
5yr	7	4
20yr	13	14
100yrCC	37	12
Options		
Option 1: Upsizing of various culverts through Wrestlingworth. The figures shown above are the modelled combined upsizing of all 5 proposed culverts.		
Option 2: Creation of a two-stage channel upstream of Wrestlingworth to provide additional storage.		
Option 3: Creation of a flood storage area using a berm upstream of Wrestlingworth to provide additional storage.		
Preferred Option: A combination of Option 1 and Option 3.		

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E Appendix – ‘Do Nothing’ Scenario

Offices at

Coleshill
Doncaster
Dublin
Edinburgh
Exeter
Haywards Heath
Limerick
Newcastle upon Tyne
Newport
Saltaire
Skipton
Tadcaster
Thirsk
Wallingford
Warrington

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