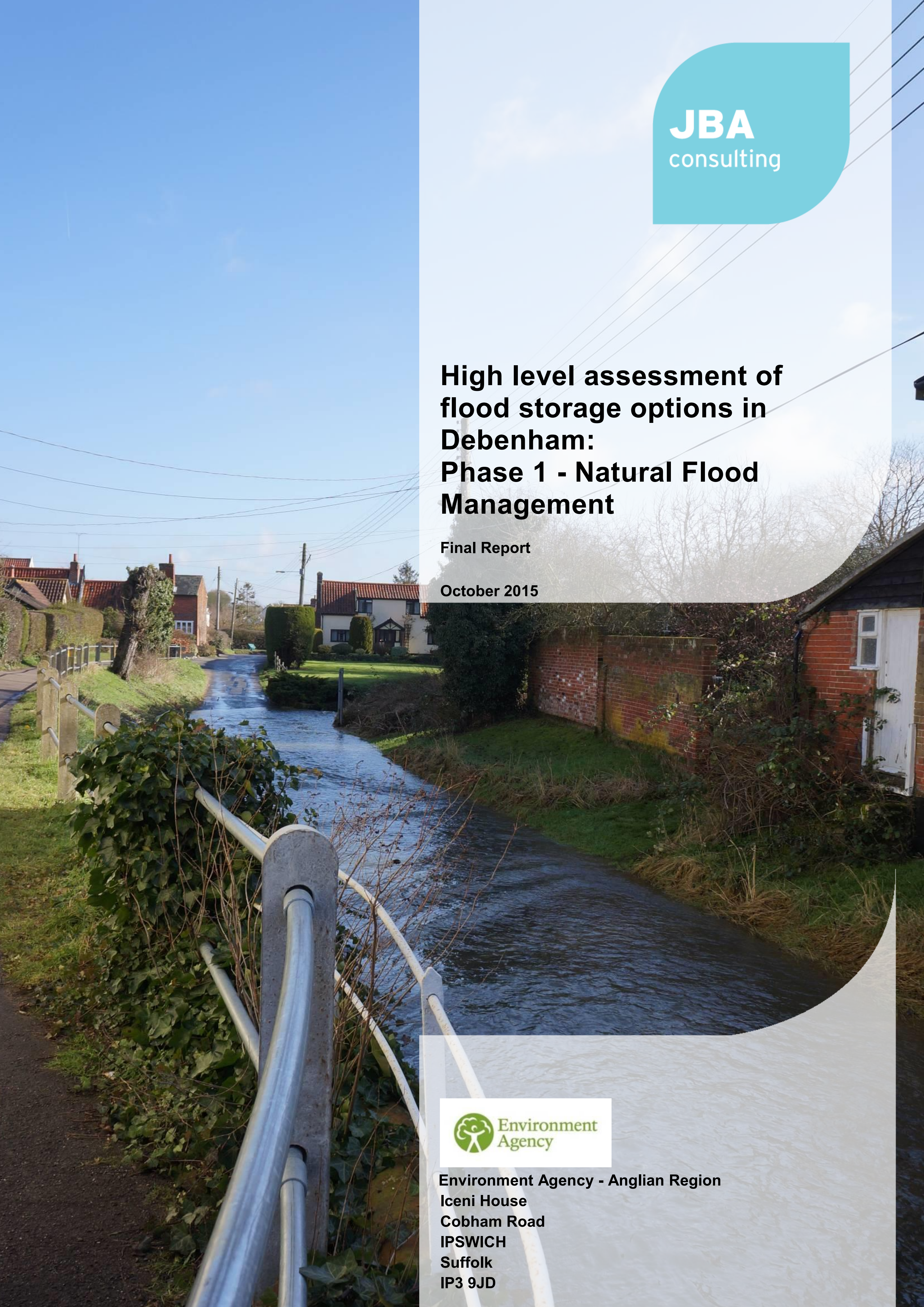

High level assessment of flood storage options in Debenham: Phase 1 - Natural Flood Management

Final Report

October 2015

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Revision History

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Contract

This report describes work commissioned by the Environment Agency as a follow on to the project referenced AN169. The Environment Agency's representative for the contract was Rebecca Brown. Alex Siddaway, Colin Riggs and Kevin Haseldine of JBA Consulting carried out this work.

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Purpose

This document was prepared as a report for the Environment Agency. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

Acknowledgements

We are indebted to many people associated with Debenham for the help provided in completion of this project.

Firstly we would like to acknowledge the guidance provided by Rebecca Brown and Will Todd at the Environment Agency in Ipswich. Further thanks go to Suffolk County Council and Paul Bradford, of the River Deben Holistic Water Management Project, who was involved in the discussions in July 2015.

Evidence of past flooding in Debenham was vital in the calibration of the hydrological estimates and the hydraulic model, much of which was provided by residents of Debenham. Peter Carter provided a detailed photographic record of major flood events dating back to the 1930s, without which it would have been challenging to ensure results matched the historical record.

Further thanks go to local landowners for their contributions concerning the location and dimensions of Natural Flood Management features, and information on local hydrology, which greatly aided the modelling process.

Carbon Footprint

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JBA is aiming to reduce its per capita carbon emissions.

Executive summary

JBA Consulting was commissioned by the Environment Agency to undertake a flood mapping study of the River Deben and its tributaries, in and around Debenham, Suffolk, in early 2014. A subsequent project saw the hydraulic model extended further upstream. Both projects undertook a high level cost benefit analysis of a range of possible flood mitigation measures. The findings from this analysis highlighted the effectiveness of catchment storage options. This study examines the impact of Natural Flood Management features on flood risk and associated economic damages in Debenham. The modelling approach involved a direct rainfall JFlow+ model to assess the impact of the NFM features on flows within each sub-catchment, and a modified version of the detailed hydraulic model to evaluate the change in flood risk and economic damages in the village.

Economic damages were assessed for the baseline scenario and a NFM scenario, with an analysis of the changes in damages to property and other land uses. However, a full cost benefit analysis was not carried out for this phase of work. The NFM features were shown to reduce flood risk and economic damages throughout Debenham, but especially areas affected by flooding from Cherry Tree Brook.

Contents

List of Figures

List of Tables

Abbreviations

1D .... One Dimensional (modelling)
2D .... Two Dimensional (modelling)
AAD .... Annual Average Damage
AEP .... Annual Exceedance Probability
DTM .... Digital Terrain Model
FRISM .... Flood Risk Metrics software
GIS .... Geographical Information System
HR .... Hydraulic Research, Wallingford
IDB .... Internal Drainage Board
ISIS .... Hydrology and hydraulic modelling software
JFlow+ .... JBA in-house 2D hydraulic modelling software
LIDAR .... Light Detection and Ranging
mAOD .... metres Above Ordnance Datum
M-CM .... Multi-Coloured Manual
NFM .... Natural Flood Management
NRD .... National Receptor Dataset
OS .... Ordnance Survey
Q100 .... Flow at the 100-year return period
QMED .... Median Annual Flood (with return period 2-years)
ReFH .... Revitalised Flood Hydrograph method
TUFLOW .... Two-dimensional Unsteady FLOW (a hydraulic model)
SCC .... Suffolk County Council

1 Introduction

JBA Consulting was commissioned by the Environment Agency to undertake a flood mapping study of the River Deben and its tributaries, in and around Debenham, Suffolk, in early 2014[1]. This project involved the development of a detailed 1D-2D hydraulic model of the three main river channels flowing through the village; the model was then used to inform a high level cost benefit analysis of a range of possible flood mitigation measures. A subsequent project (late 2014[2]) saw the hydraulic model extended further upstream to fully test the effects of one of the proposed options, a flood storage area (FSA) on The Gulls tributary.

The previous projects demonstrated that a significant flood risk benefit could be attained by developing a FSA in both The Gulls and Cherry Tree Brook catchments. This finding highlighted the benefit upstream storage could bring to the village, and following delivery of the previous projects, the Environment Agency and Suffolk County Council asked that the potential for Natural Flood Management (NFM) features in the upper catchments was also analysed. The use of many smaller scale storage features would likely be cheaper to implement than major mitigation schemes, assist in the attenuation of flood flows and also create surface water features in the catchments in and around Debenham, delivering a wider range of ecological and environmental benefits to the area. These include improvements in water quality required by the Water Framework Directive (2000/60/EC) through management of diffuse pollution pathways.

This report outlines the approaches adopted by JBA to assess the impact of the proposed NFM features on flood risk and the associated economic damages in and around Debenham.

2 Catchment NFM feature assessment

Following a period of consultation between the Environment Agency, Suffolk County Council and local landowners, a teleconference was held on 2nd July 2015 to discuss potential locations and dimensions of both NFM and larger scale storage features within the catchments upstream of Debenham. Owing to the programme constraints affecting the assessment of NFM features we proposed a phased approach to the study. During the first phase we would assess only the lower cost NFM type features (which had potential to be implemented later in the year) and in the second phase we would provide and initial assessment of potential larger scale online storage features (on the Gulls and Derry Brook tributaries). This report provides a summary of the work undertaken during phase one of this study. The phase two work will consider larger online storage features on The Gulls and Derry Brook, in conjunction with the NFM features modelled in this phase.

The NFM features described below were modelled using different approaches depending on the purpose of each feature. Those features designed to intercept surface water directly were modelled in a catchment wide JFlow+ model (JBA's in house 2D hydrodynamic modelling software). Features intended to interact with and store fluvial flows were included in an updated version of the 2014 ISIS-TUFLOW model (developed by JBA). The JFlow+ model was used to quantify the impact of the surface water NFM features on peak flows further down the catchment, by modelling the catchment response to rainfall before and after the implementation of NFM features. The changes in peak flows were incorporated into the ISIS-TUFLOW model assess the impact of the NFM features on flood risk within Debenham.

2.1 Feature design

During the preceding consultation period, a number of local landowners have expressed support for potential NFM features on their land. Table 2-1 summarises each of these features along with some indicative dimensions. These dimensions have been used to inform subsequent hydraulic modelling but remain provisional, subject to future discussions with landowners and other stakeholders. In a number of cases we understand retained water levels will be required within the NFM features. Where this is the case, it is assumed (for the purposes of flood risk modelling) that this is in addition to the capacities outlined below. This is because any storage capacity designed to be permanently filled with water will not be available to attenuate flood flows.

[1] Environment Agency, 2014. Debenham Village, Flood Mapping Project. Prepared by JBA Consulting May 2014.

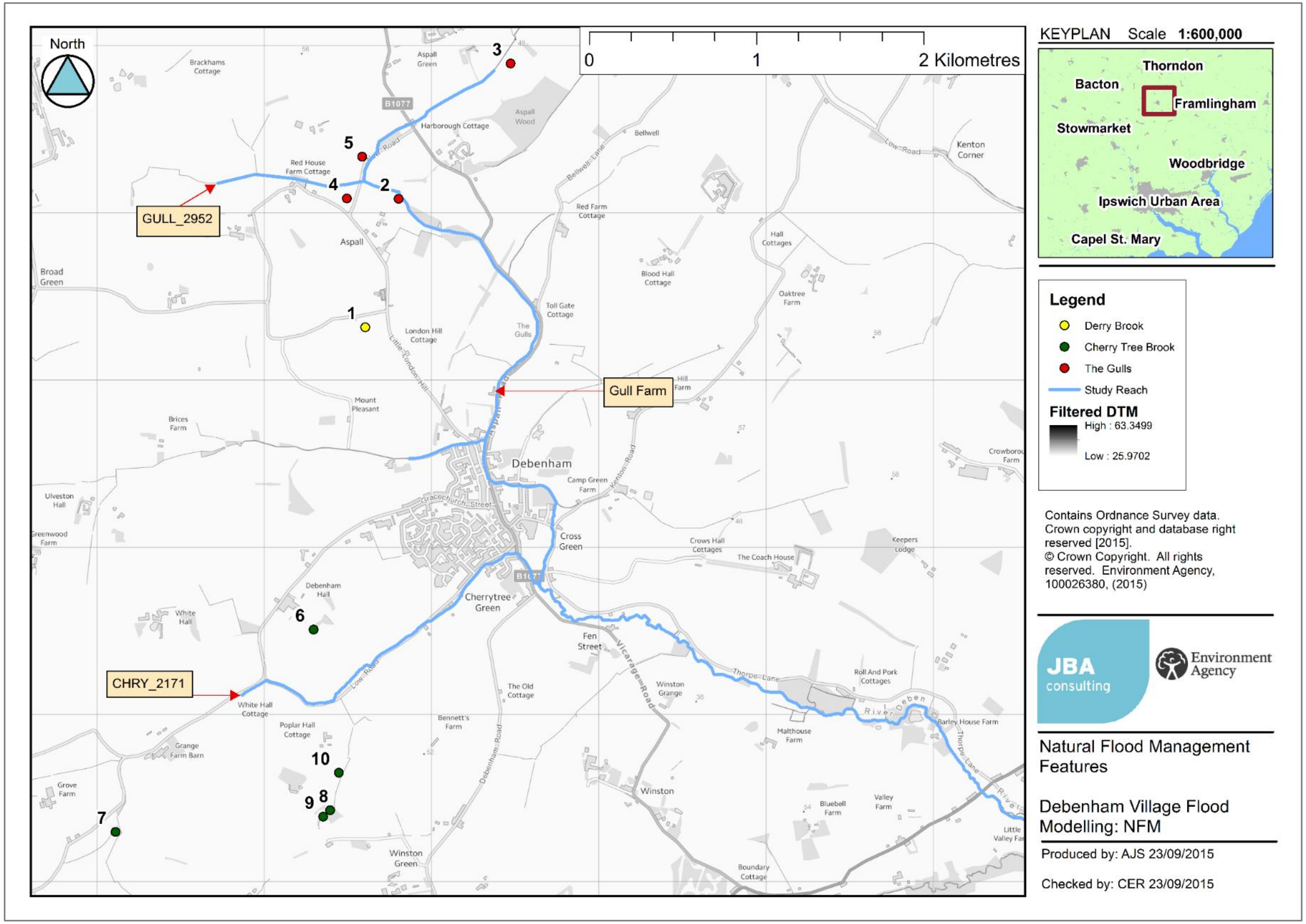
[2] Environment Agency, 2014. Debenham Village, Flood Mapping Extension Project. Prepared by JBA Consulting November 2014.

Table 2-1: Modelled NFM features						
Location	**Feature**	**Modelled storage volume (m^3)**	**Indicative dimensions (from landowner discussions)**			**Modelling Software**
			Length (m)	Width (m)	Depth (m)	
Derry Brook	1	2,500	50	50	1	JFlow+
N.B. feature 1 was initially specified as being in The Gulls catchment, but further analysis of the catchment watersheds indicated the feature lies in the Derry Brook catchment.						
The Gulls	2	450	20	15	1.5	ISIS-TUFLOW
	3	6,000	200	20	1.5	JFlow+
	4	5,000	50	50	2	JFlow+
	5	1,000	50	20	1	JFlow+
Cherry Tree Brook	6	100 x 2*	10	10	1	JFlow+
	7	15,000	300	50	1	JFlow+
	8	1,000	40	25	1	JFlow+
	9	600	20	20	1.5	JFlow+
	10	2,500	100	25	1	JFlow+
*Feature 6 consists of two separate swales.						

The dimensions in Table 2-1 correspond to the available storage volume in each feature. Any water levels to be retained in features are considered below the modelled bed levels, as this volume is not available for storing flood water.

The locations of these features are detailed in Figure 2-1.

Figure 2-1: Potential location of NFM features



In some locations, the positioning of the feature was modified slightly in order to increase its effectiveness. For example, features 1 and 3 were adjusted to intercept nearby surface water flow paths.

2.2 Surface water modelling

The JFlow+ modelling included catchment wide direct rainfall inputs applied to The Gulls, Derry Brook and Cherry Tree Brook catchments, as well as Debenham village and an area of the River Deben downstream of the village, to allow full routing and drainage of floodwaters. These inputs were routed over the ground model (informed by LIDAR data) to generate an outflow into each watercourse. For reference, the gross rainfall accumulations which correspond to particular flood return periods in Debenham are provided in Table 2-2.

Table 2-2: Rainfall accumulations and flood return period

Flood return period	Design rainfall total (mm)*	
	The Gulls catchment	Cherry Tree Brook catchment
2	14.4	14.5
5	19.3	19.5
10	23.5	23.7
20	28.4	28.6
75	40.4	40.7
100	43.6	43.9
1000	79.7	80.4
*Rainfall totals occur over a 7.75 hour duration storm.		

2.2.1 Baseline modelling

Prior to representing NFM features within the JFlow+ model, it was first necessary to confirm flows produced from the JFlow+ model were an acceptable match to inflows used in the latest ISIS-TUFLOW model and previously verified against local flood history and available hydrometric data. This gives some confidence that the 2D hydraulic model is providing a reasonable representation of the current catchment response.

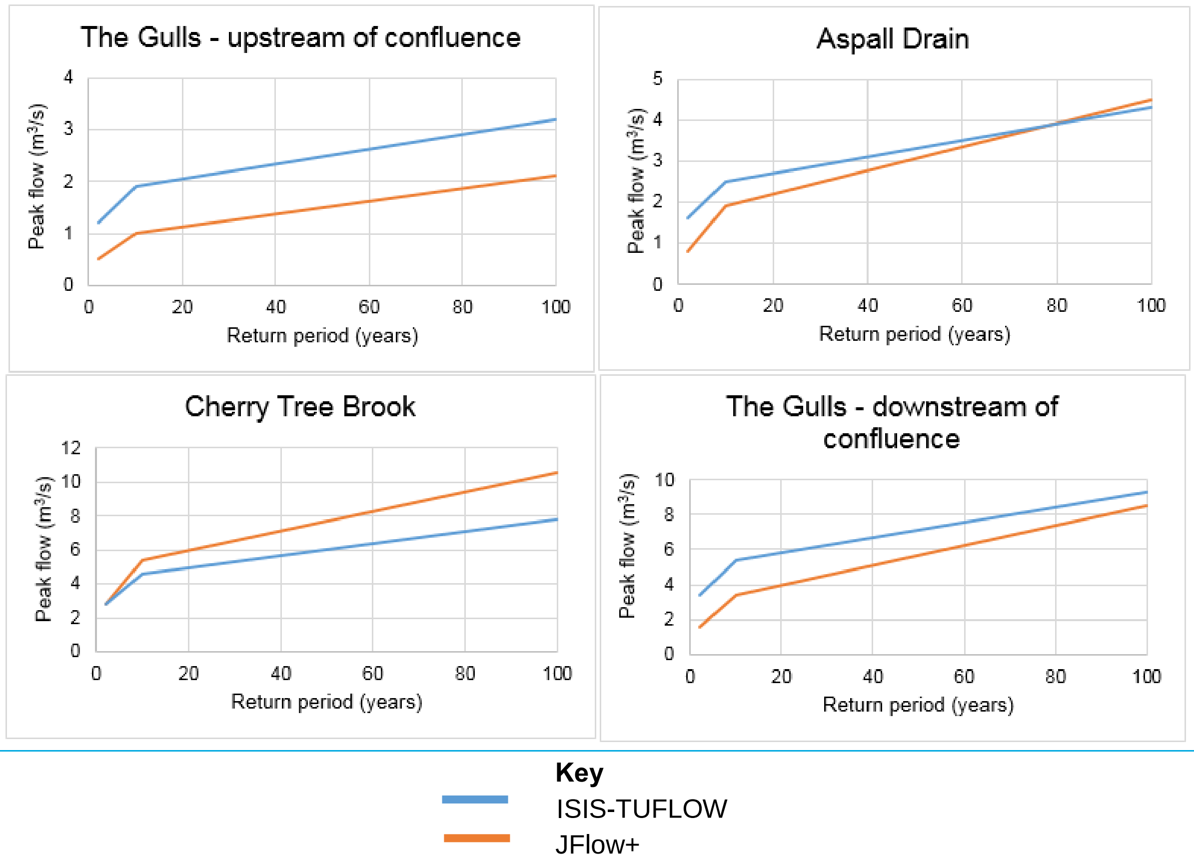
An important consideration for our modelling of the upper catchment (and ultimately the proposed NFM features) is the manner in which hydrological losses are accounted for. Broadly there are two available options:

a. Apply total rainfall to the hydraulic model and attempt to represent all significant hydrological losses within the model. In some respects this is the more elegant solution as it provides a realistic distribution of losses across the catchment. However, hydraulic models are not designed for this purpose and the lack of sub-surface and sub-grid scale flows paths can significantly impact model performance.
b. Use a separate hydrological loss model to estimate net rainfall (i.e. the proportion of rainfall which generates runoff) and apply this to hydraulic model. In this case, no further losses should be represented within the hydraulic model.

In the previous Debenham flood modelling projects design flood flows were estimated using the ReFH model (the parameters of which were improved as far as possible using local data and the resulting modelled flood extents were verified against extensive records of local flood history). By using the ReFH model to derive net rainfall, and adopting the same storm profiles, we were able to promote consistency with these studies.

Net rainfall was applied to the 2m resolution Digital Terrain Model (DTM) used in the Updated Flood Map for Surface Water modelling. In order to avoid double counting the hydrological losses resulting from natural storage within topographic depressions we modified the DTM to fill these sinks. Figure 2-2 compares the peak flows derived from the ReFH model and the JFlow+ models at the upstream boundaries of the ISIS-TUFLOW model.

Figure 2-2: Comparison of peak flows – JFlow+ and ISIS-TUFLOW



The results in Figure 2-2 show that there is generally a good correlation between the results of the two models. However, they also demonstrate differences between study catchments. In Cherry Tree Brook, a very good match is achieved for the 2-year event. However, at longer return periods, flows in the JFlow+ model are higher than the ISIS-TUFLOW model. The converse situation occurs for the Aspall drain catchment, where JFlow+ flows are lower for smaller magnitude events, with values converging at longer return periods. The results for The Gulls catchment reflect the topographic losses highlighted above – the flows in the JFlow+ model are consistently lower than in the ISIS-TUFLOW model. This situation is partially rectified downstream of the Gulls-Aspall Drain confluence, with peak flows converging with increasing return period.

The timing of the peaks compared favourably between the JFlow+ and ISIS-TUFLOW models, validating the modifications made to the ReFH model in the previous projects. This also suggests that distributing all losses across the catchment (by including them in the JFlow+ model) would have offered little benefit. The receding limbs of the hydrographs were also found to be comparable between the two models.

The rising limbs of the hydrographs differed between the JFlow+ and ISIS-TUFLOW models. Catchment response in the JFlow+ model was initially slower, resulting in a steeper secondary section of the rising limb, creating a slight disparity in the volume at this point of the hydrograph.

While the JFlow+ model does not replicate the flow in the ISIS-TUFLOW model in all situations, the results above are considered acceptable for the purposes of this study. Additionally, the similar and independent response of the JFlow+ model and ReFH model for some aspects of the catchment response provides confidence in the approach. The JFlow+ model will be used to determine the total volume stored by NFM features, and the absolute effect on flows (rather than a percentage reduction), and this can be assessed adequately between the baseline and NFM JFlow+ models, despite the inconsistencies between the JFlow+ and ISIS-TUFLOW models.

2.2.2 NFM modelling

The NFM features were 'stamped in' to the DTM. Bed levels within the feature outline were lowered to the minimum ground elevation with a bund created around the feature to provide the necessary storage depth (where features were specified as a swale storage volume was created only through excavation). However, in some locations the slope gradient was sufficiently shallow that this method did not provide the required storage volume. In these cases, further reductions to the bed level were made. This equated to a greater extraction of earth than the storage volume of each feature. However, the economic viability of earthworks were not evaluated at this stage. NFM features are often designed to store water for a temporary period, releasing it slowly after the flood peak to prevent long term inundation of agricultural land. Culverts, 300mm in diameter, were placed through the bunds of each structure to allow drainage of water from these features. The design of the culverts and drainage time of features were not reviewed in detail as part of this study.

2.3 Fluvial modelling

2.3.1 Hydraulic model inflow modification

Flows in the baseline and NFM models were compared at locations corresponding to the inflows in the ISIS-TUFLOW model. The inflows into the ISIS-TUFLOW model were then scaled to represent the absolute reduction (see section 2.2.1) in peak flow at each point within the JFlow+ model. The scaling of hydrographs was based on the change in peak flow. Lateral inflows to the ISIS-TUFLOW model were also modified, where appropriate, to ensure the effects of all NFM features were reflected. In general, the reduction in flow was greater on Cherry Tree Brook than The Gulls, reflecting the differing sizes and locations of the proposed features on each catchment.

2.3.2 Fluvial flood storage

Feature 2 was included as an offline storage reservoir in the ISIS domain of the hydraulic model, to store fluvial flows exceeding bank full water levels. The feature was not designed to intercept and store surface water.

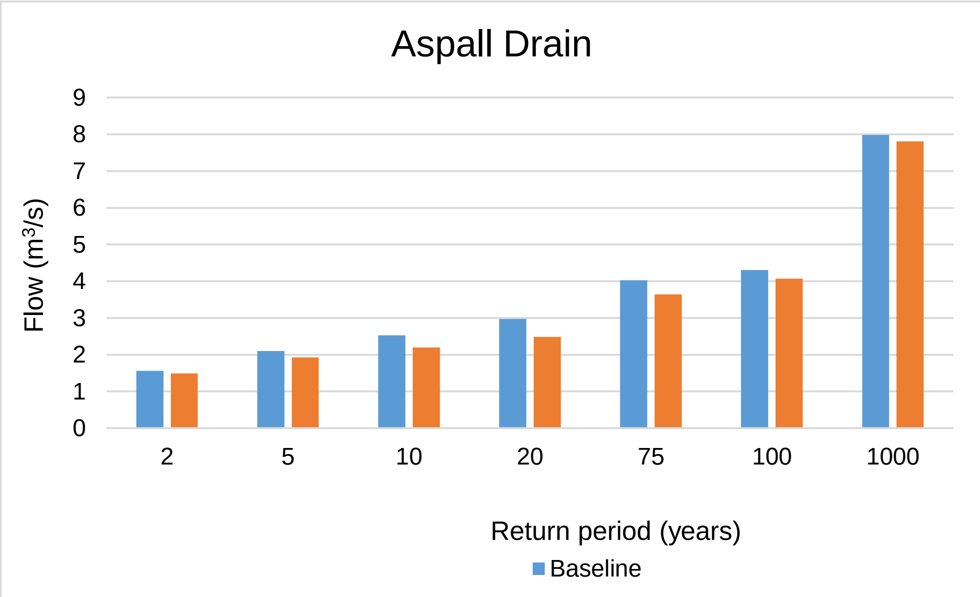
3 Fluvial results

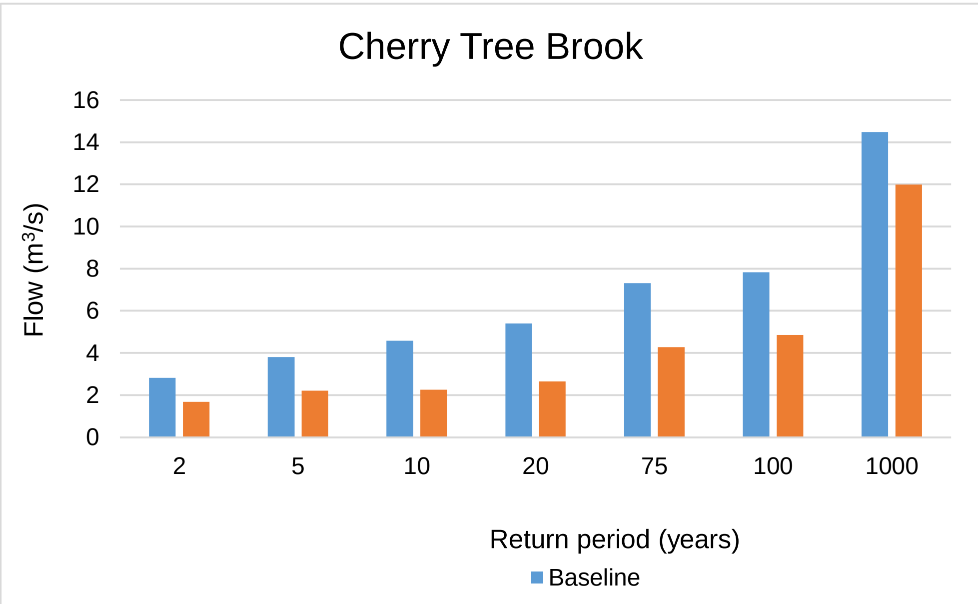
The impact of NFM features on fluvial flows and water levels in Debenham are presented in this section.

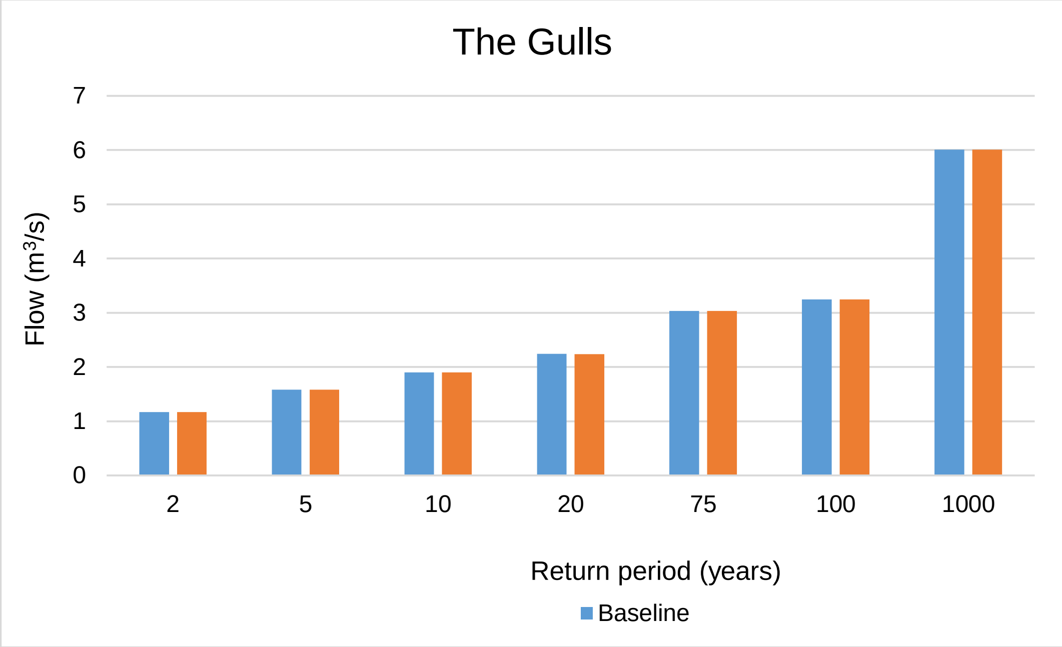
3.1 Peak flows and water levels

Figure 3-1 and Figure 3-2 demonstrate the effect of NFM features on flows and water levels at various key locations in and around Debenham.

Figure 3-1: Impact of NFM features on peak flows – hydraulic model inflows







NFM features reduce peak inflows to the hydraulic model. However, this is spatially variable, with the features on Cherry Tree Brook proving most effective. Aspall Drain shows a lesser reduction in peak inflows. It should be noted that there are no NFM features upstream of GULL_2952 (for location see Figure 2-1).

Figure 3-2: Impact of NFM features on peak water levels - Debenham

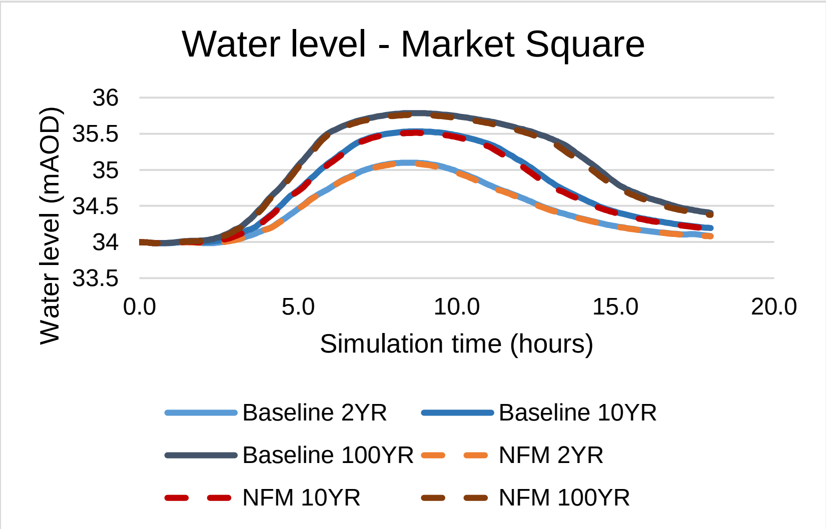
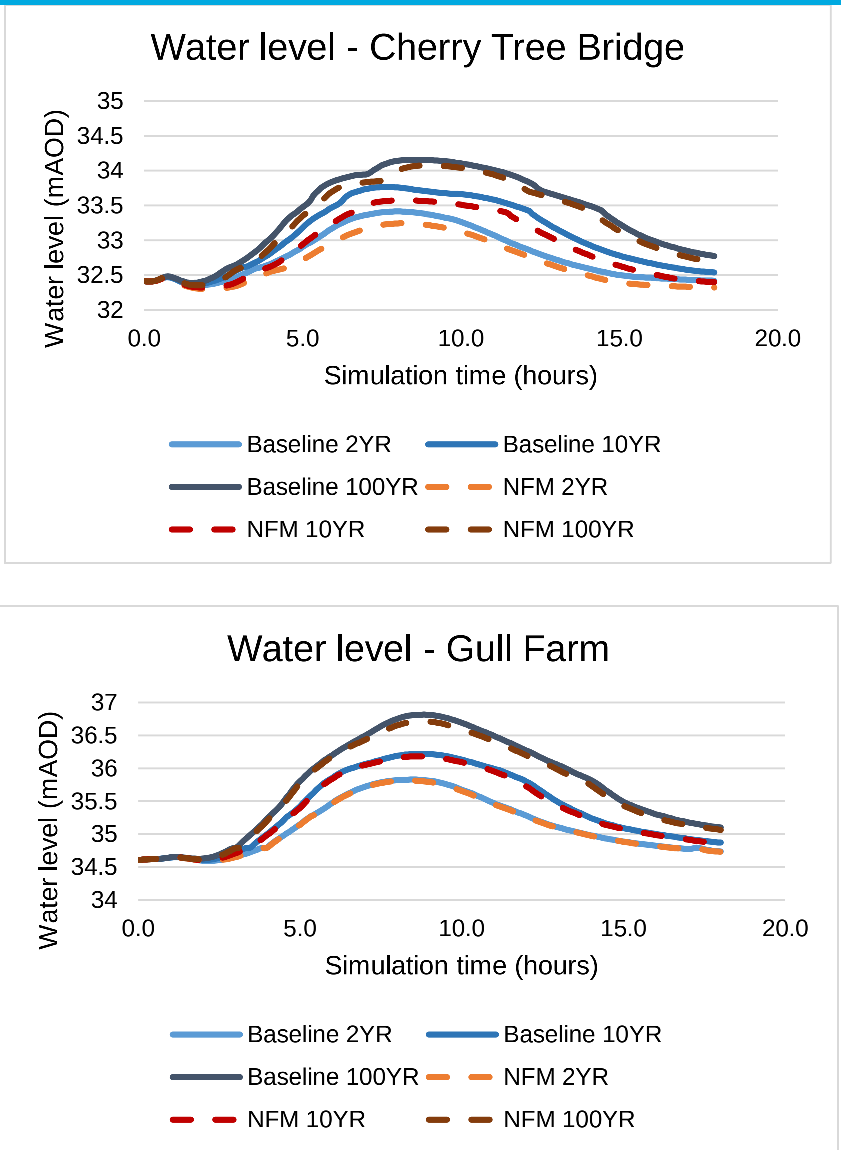


Figure 3-2: Impact of NFM features on peak water levels - Debenham



The reduction in water levels in Debenham is most pronounced on the downstream reach of Cherry Tree Brook. Reductions in water level are seen on The Gulls upstream of the village, but these are much less significant in the village itself around Market Square; probably a result both of the local rating (relationship between stage and flow) and the influence of un-attenuated tributary inflows (most notably from Derry Brook).

The reduction in water levels at Gull Farm are greater at the 100-year event compared to the 2-year as certain NFM features, such as feature 3, intercept flow pathways which become active at higher return periods.

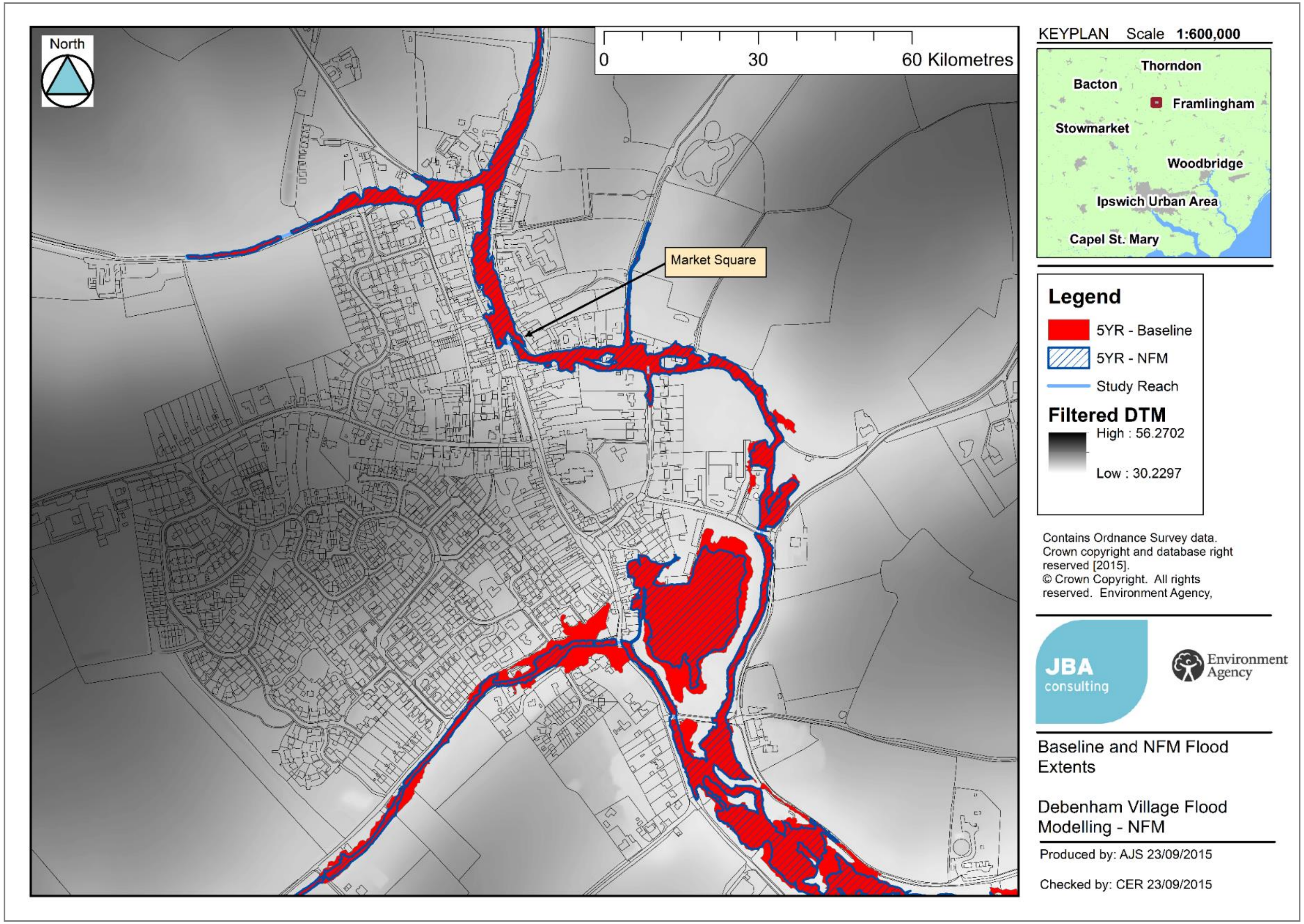
In general, the NFM features have the effect of reducing flood peaks. There are also minor delays in the timing of peaks, due to the attenuating function of storage areas. While these changes are not thought to synchronise flood peaks in Debenham, there is insufficient hydrometric data to determine the exact effect of the NFM features on relative flood peak timings and synchronisation.

3.2 Flood extents

Figure 3-3 contains an example of the reduction in flood extents resulting from implementation of NFM features.

The reduction in flood extents is greatest around the confluence of the River Deben and Cherry Tree Brook, for example at Cherry Tree Bridge. Flood extents are also reduced in other key areas of flood risk such as Market Square (albeit to a lesser degree), as well as downstream of the confluence.

Figure 3-3: Impact of NFM features on flood extents



4 Economic damages methodology

To assess the economic impact of the NFM features in Debenham, damages were compared between the baseline scenario – using the November 2014 hydraulic model results – and the NFM scenario. To achieve this, JBA's Flood Risk Metrics (FRISM) toolkit was used; a GIS based impact analysis software that computes a range of flood risk metrics, including property damages, based on the techniques outlined in the Multi-Coloured Manual (MCM)[3] (2013).

The final estimated damages per property are provided alongside this report in shapefile format.

4.1 Methodology

The method used for estimating economic damages to property is broadly consistent with that used in the Flood Mapping Extension Project 2014 JBA report[2], although since this analysis an updated version of FRISM was released. Damage values are assigned to a property when the flood outline intersects the building boundary, calculated as a function of the depth of water, type of property and floor area. Building polygons were obtained from the National Receptor Dataset (version NRD 2011 - the latest available from the Environment Agency's Geostore datasets). Any changes to properties which post-date this dataset are therefore not accounted for in damage calculations. The damage estimates undertaken for this study use the current NRD (2011) dataset; this is consistent with damage estates undertaken for previous studies but could underestimate damage if recent development has increased financial exposure to flood risk. It is therefore recommended that subsequent analysis of economic damages in Debenham would benefit from updating this to include any recent developments (for example the conversion of a vehicle repair garage at the junction of Low Road and the B1077 to residential dwellings). Any revised threshold data should also be included incorporated at this stage so that the implications both to the onset of flooding and property type are updated in unison.

In addition to providing costs per flood event, we have also estimated average annual damages (AADs), the estimated damage incurred per year. The damages associated with each return period are simply multiplied by the probability of this event occurring and summed together to obtain this value. For further details on the calculation of damages please see the previous reporting.

Table 4-1 illustrates the baseline flooded property counts between the current study and the November 2014 study. It is evident that fewer properties are counted as flooded in the updated calculations, due to the improved manner in which FRISM queries non-residential buildings.

Table 4-1: Changes to FRISM: flooded property counts

	Baseline flooded property count	
Return period (years)	**November 2014**	**Current study**
2	9	5
5	35	27
10	63	52
20	83	76
75	117	112
100	124	117
1,000	183	177

4.2 Accounting for other damages

As well as damages to property in Debenham itself, the potential cost of flooding to both roads and agricultural land has also been considered; in both cases the methods employed are proportional to type of study.

[3] Penning-Rowsell, E. *et al.*, 2013. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal (The Multi-Coloured Manual)*. Flood Hazard Research Centre.

The MCM provides sufficient detail to undertake detailed damage analysis for various other land uses and infrastructure, but highlights the need for proportionality (Chapter 6). In order to assess the losses associated with utilities, telecommunications, hospitals, schools, rail services etc., a prioritised approach is recommended:

1. Identify those assets at risk of flooding
2. Determine the likelihood of flooding
3. Determine the criticality of assets to flooding
4. Utilise a risk matrix
5. Assess the impact of resistance and resilience

A similar approach is required for assessing agricultural damage, as outlined below:

1. At a broad scale, appraisals will at least require information of categories of land use, and the extent to which they may be affected by floods
2. At a detailed scale, there is a need to collect primary data associated with farming systems.

Much of the information required to undertake such detailed analysis was not available for the current study, such as the number of properties impacted by failure of a water treatment works, the cost of alternative classroom accommodation for schools or the repair costs for given infrastructure. However, the analysis undertaken here does address the first two points from the above list, in addition to providing an indicative damage cost based on depth-damage curves (see Table 5-3).

4.2.1 Roads

The total length of road flooded was calculated from hydraulic modelling results. The MCM highlights the costs of road reconstruction following flooding, with variable costs incurred depending on the type of road; typically £15/m^2 for local, quiet roads and £50/m^2 for more major, busy roads. However, assuming all roads require re-surfacing after every flood event is unrealistic.

Relatively frequent flooding of some roads in Debenham does occur, including areas of Water Lane, High Street and Low Road. However, in order to provide a more detailed assessment of economic damage associated with roads, further information such as traffic data and potential diversion routes is required. Moreover, flood durations are typically short and it is not anticipated that major diversion routes would be required. These considerations, along with a lack of traffic survey data, makes estimation of damages associated with road flooding outside of the current scope. If further data are made available from Suffolk County Council, economic damages can be estimated. This is recommended for future work.

As such, results for flooding of roads are presented as flooded lengths of carriageway only. For the purposes of analysing the results of this study, flooded road length can be used as a proxy for damages to roads.

4.2.2 Emergency services

The MCM highlights research undertaken by Penning-Roswell et al. (2002)[4] that identified the UK flooding experienced in 2000 was accompanied by significant emergency costs, including those associated with police, fire and ambulance call outs, Local Authority costs and Environment Agency costs. These costs were quantified at 10.7% of all property damages and therefore it is recommended total economic damages are multiplied by 1.107 for a given study. This approach was followed in Debenham.

4.2.3 Agriculture

With no detailed information available regarding local agricultural processes, economic damages to agricultural land were derived simply based on the area of land flooded with no consideration of depth of water. The MCM (Table 9.20) categorises agricultural land into grassland (pastoral) and arable types, and by the intensity of the activity. Local drainage conditions are also taken into account. Based on the combination of these factors a single flood cost per hectare is produced, which can be combined from the area of flooded land estimated by FRISM. These categories are detailed in Table 4-2.

[4] Penning-Rowsell, E. *et al*., 2002. *Autumn 2000 flood in England and Wales: Assessment of national economic and financial losses*. Flood Hazard Research Centre.

Table 4-2: Damage estimation – agriculture		
Agriculture type	**Drainage**	**Single flood cost (£/ha)**
Extensive Arable	Good	650
	Bad	478
Intensive Grassland	Good	180
	Bad	50
Extensive Grassland	Good	100
	Bad	80
	Very Bad	50
Intensive Arable	Good	1,150

Agricultural land around Debenham was broadly classed as either extensive arable, intensive grassland or intensive arable. Upland sheep farming, an example of extensive grassland farming, is not a likely type of agriculture in this area of Suffolk and this category was therefore discarded. The remaining agricultural land use types were informed by aerial photography and local knowledge. Where ploughed fields were observed, the agricultural type was designated extensive arable, and intensive grassland used for grassed fields, as these are likely to represent high quality grazing land.

Drainage was considered as 'good' for the purposes of the damage calculations, assuming there is no impediment to drainage within the soil (as recreated below from Table 9.2 of the MCMC Handbook[3]). This approach is conservative and was therefore adopted in the absence of any further information of local drainage characteristics.

Table 4-3: Drainage conditions from MCM Table 9.2	
Drainage condition	**Productivity class**
Good: "rarely wet"	Normal, no impediment to drainage.
Bad: "occasionally wet"	Low, reduced yields, reduced field access and grazing season.
Very bad: "commonly or permanently wet"	Very low, severe constraints on land use, much reduced yields, field access and grazing season, mainly wet grassland.

Damages could increase or decrease depending on the crop type and seasonality of flooding. For example, economic damage to a cereal crop is likely to be greatest in the summer months. The seasonality of flooding is considered in section 5.2.

5 Results

This section outlines the economic damages to each flood receptor type, comparing baseline and NFM scenarios. These results quantify the benefits of reductions in flood risk to Debenham. The damage calculations and analysis are only available for the extent of the ISIS-TUFLOW model domain developed for the previous Debenham projects, and therefore benefits from NFM features in the upper catchment areas, and areas downstream of the model domain, cannot be quantified. In the upper catchment areas especially, there is likely to be little change in property damage with NFM features due to the low number and sparse distribution of property. It is probable, however, that a decrease in agricultural damages would occur upstream and downstream of the ISIS-TUFLOW model domain due to reduction of flood extents in these areas.

NFM features also provide wider environmental benefits, such as water quality improvement (through management of diffuse nutrient and suspended sediment pollution pathways), habitat provision and other ecosystem services. These functions may also provide an additional economic benefit which has not been quantified by this study.

5.1 Property

Table 5-1 contains the flooded property counts for both model scenarios, as well as a consideration of the magnitude of change.

Table 5-1: Impact of NFM features on cumulative flooded property counts

	Cumulative flooded property counts			
Return period (years)	Baseline	NFM	Change	Change (%)
2	5	3	-2	40
5	27	15	-12	44
10	52	28	-24	35
20	76	53	-23	30
75	112	97	-15	13
100	117	110	-7	6
1,000	177	172	-5	3

The change in flood extents (section 3.2) results in reduced numbers of flooded properties at all return periods. This is most noticeable at shorter return periods, where the impact of NFM features on flood extents is most pronounced. At longer return periods these features are mostly at capacity, reducing their impact in reducing flood flows.

The change in total property damages for each modelled return period are presented in Table 5-2.

Table 5-2: Impact of NFM features on total property damages

	Total damages			
Return period (years)	Baseline (£k)	NFM (£k)	Change (£k)	Change (%)
2	45.9	29.7	-16.2	35
5	191.3	105.0	-86.3	45
10	385.0	219.6	-165.4	43
20	751.8	473.2	-278.6	37
75	1,763.8	1,342.4	-421.4	24
100	2,006.0	1,631.9	-374.1	19

1,000	4,977.8	4,671.5	-306.4	6

The NFM features result in a significant reduction in property damages, especially at short and medium return periods. This reflects the design characteristics of NFM structures; capacities are small, and filled during the rising stage of larger return period flood events, reducing the impact on peak flows. The effect of NFM features on economic damages relates to reductions in both spatial flood extent (number of flooded properties) and flood depths (damage within each property flooded).

Figure 5-1 illustrates the AADs for each property within Debenham if the NFM features are implemented, and is directly comparable to Figure 5-4 in the November 2014 flood mapping report (see Appendix A). Figure 5-2 shows the reduction in economic damage at each property whilst Figure 5-3 highlights the removal of property from flooding at each return period.

Figure 5-1: Property damages with NFM features implemented

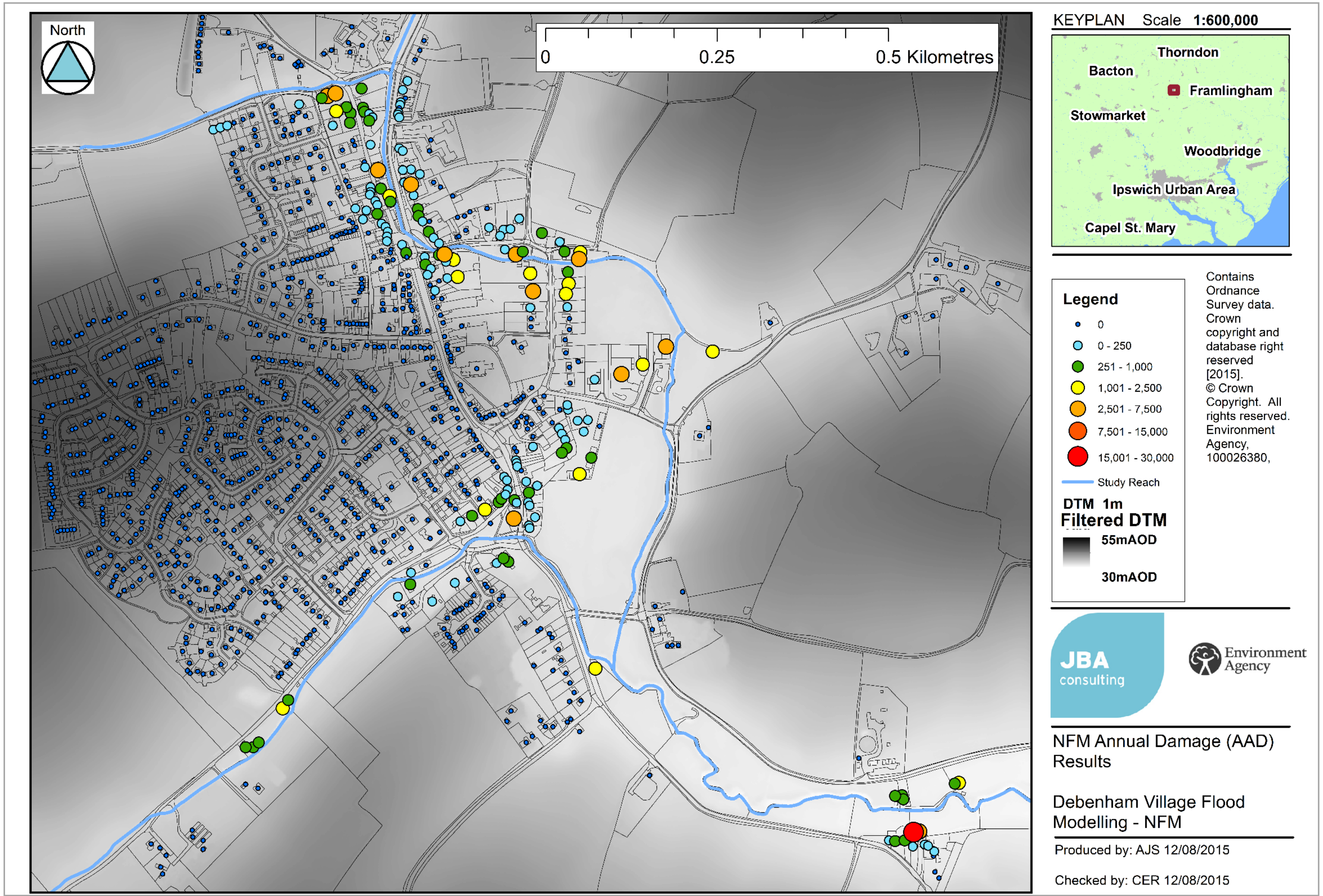


Figure 5-2: Reductions in property damages

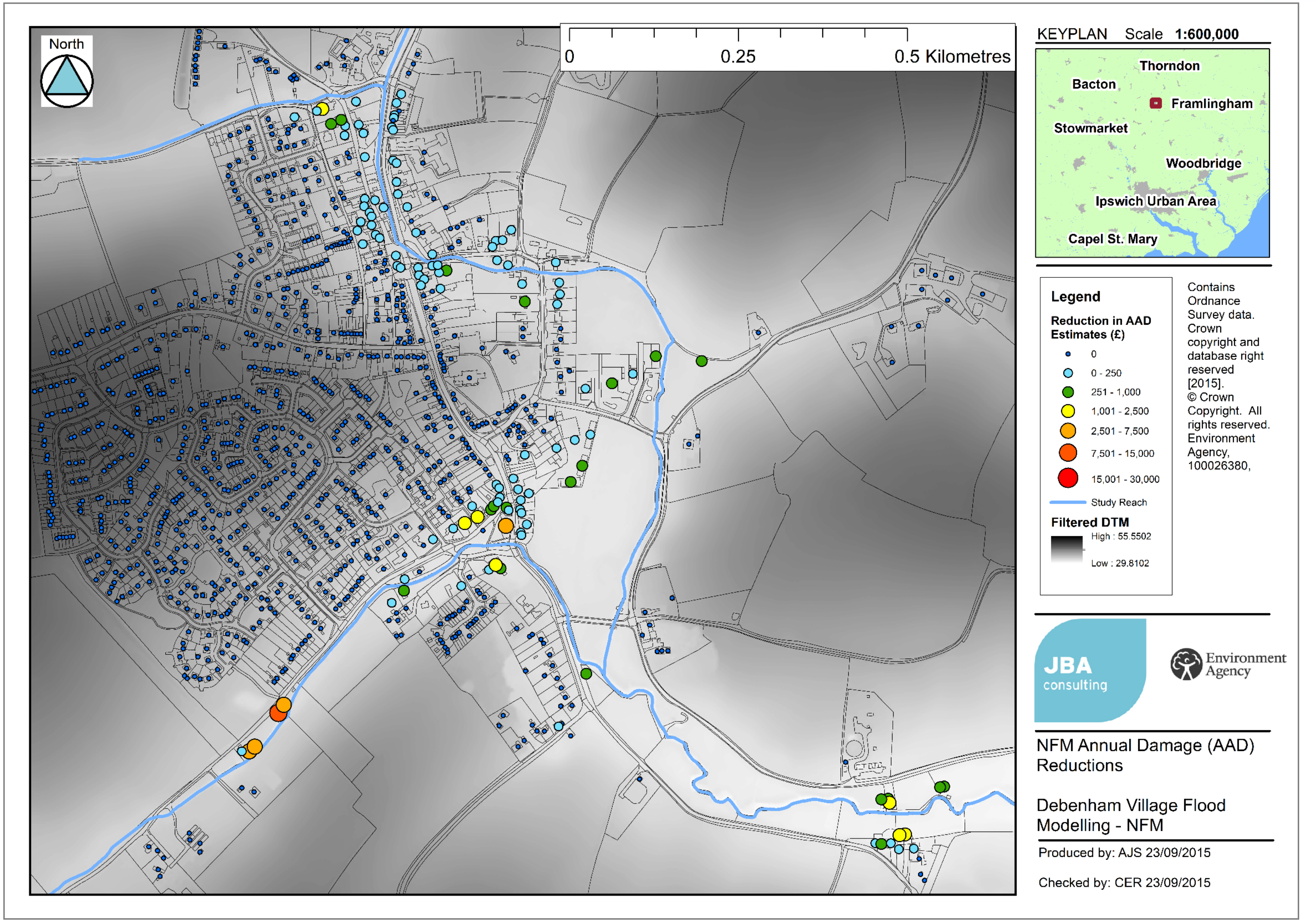
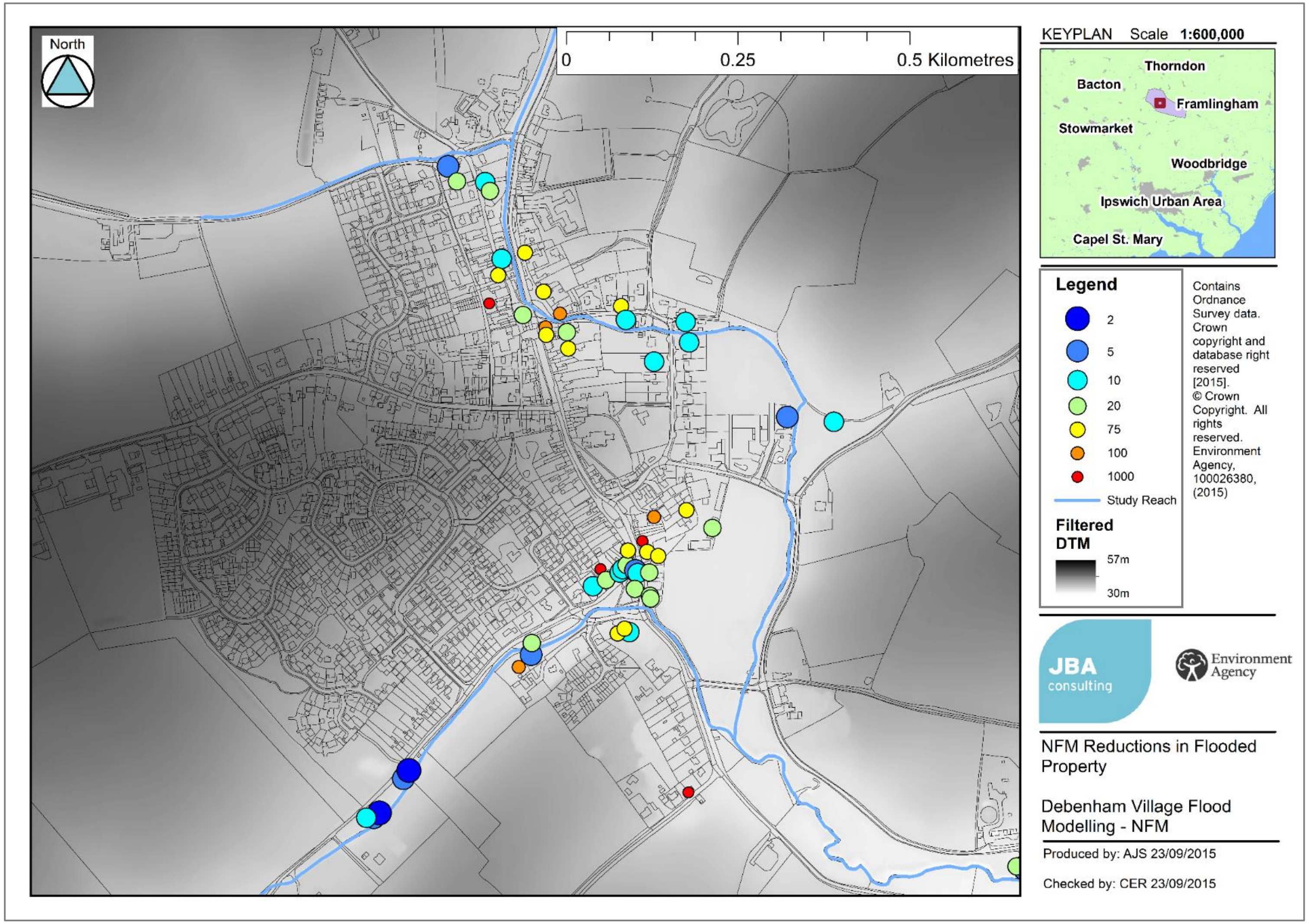


Figure 5-3: Reductions in flooded property counts



There is noticeable change in property damages and flooded property counts to the south of the village along Cherry Tree Brook. There are also minor reductions in property damage and flooded property counts around the Market Square area.

In addition to simply assessing overall property damage, Table 5-3 below provides a breakdown of total AADs for a number of different property types throughout Debenham (based on the Ordnance Survey feature class); only those properties with associated damages are included below.

Table 5-3: AAD breakdown for property types				
Property type	**AADs**			
	Baseline (£k)	**NFM (£k)**	**Change (£k)**	**Change (%)**
Dwelling	92.4	70.3	-22.1	23.9
Fire Station	2.3	1.0	-1.3	56.1
Factory/Works	11.2	8.8	-2.4	21.0
Garage	59.1	32.4	-26.8	45.3
Police Station	0.08	0.07	-0.01	12.6

From the above figures it is clear that much of the economic damage in Debenham is accounted for in residential properties and garages (these include both domestic and commercial premises).

5.2 Agriculture

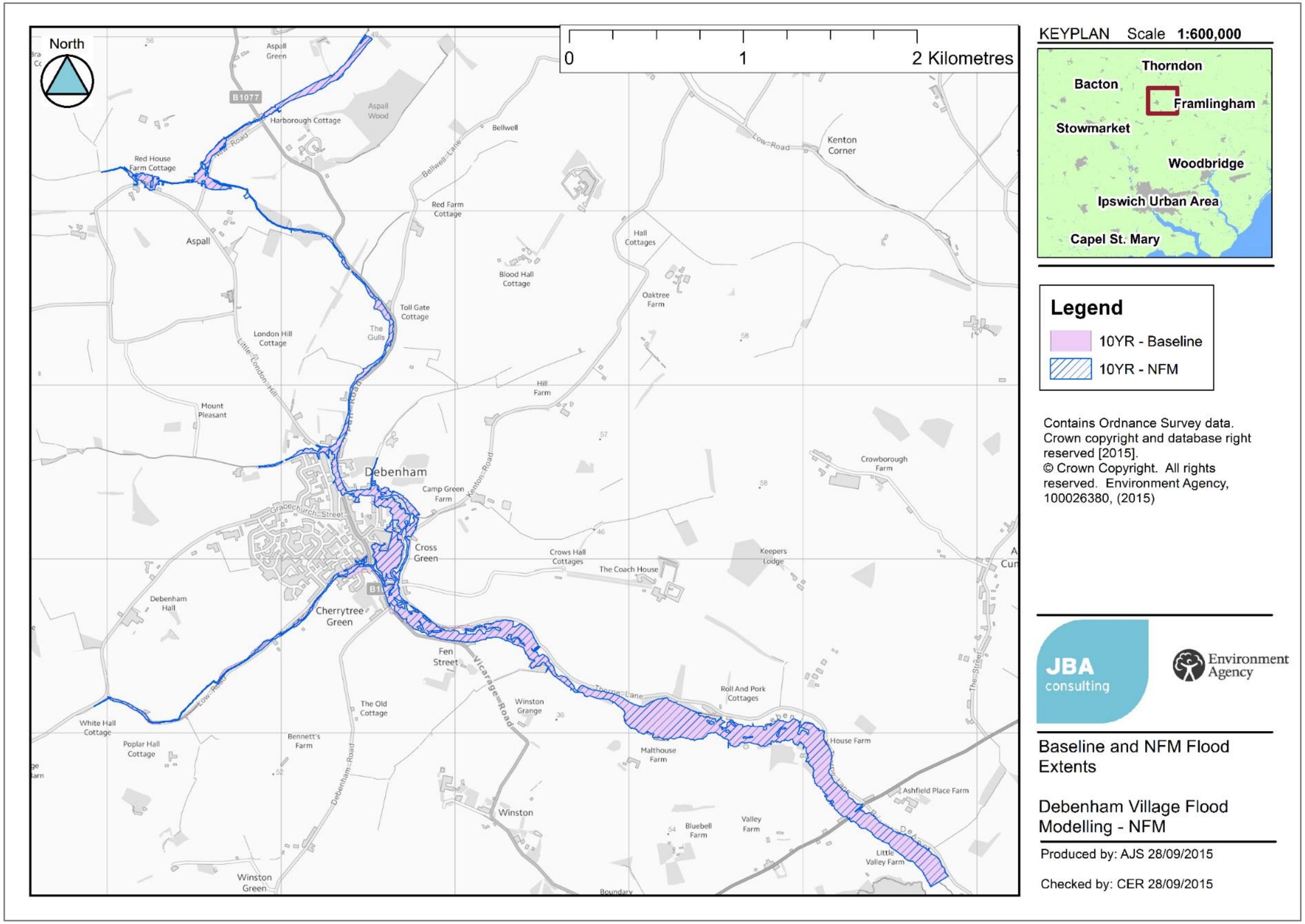
Agricultural damages occur throughout the area surrounding Debenham.

The change in total agricultural damages are presented in Table 5-4.

Table 5-4: Impact of NFM features on total agriculture damages				
Return period (years)	**Total damages**			
	Baseline (£k)	**NFM (£k)**	**Change (£k)**	**Change (%)**
2	2.6	2.3	-0.3	10.9
5	3.0	2.8	-0.2	7.9
10	3.4	2.9	-0.6	16.4
20	3.7	3.4	-0.3	9.4
75	4.4	4.2	-0.2	5.5
100	4.5	4.3	-0.2	4.6
1,000	6.0	5.8	-0.2	2.5

Agricultural damages are closely related to changes in flood extents, as the analysis of damage is based on flooded area rather than the additional consideration of flood depth. Figure 5-4 shows the reduction in flood extent at the 10-year return period as a result of implementing NFM features. From this map, changes in agricultural damages can be inferred from the reduction in flooded area. The significant reduction in damages at short and medium return periods is once again pronounced. Crop type was not considered in Debenham for the reasons outlined in section 4.2.3. Flooding in Debenham is most likely during the autumn and winter months (see Appendix A, section 1.7, of the November 2014 report).

Figure 5-4: Reduction in flooded area - agricultural damages



5.3 Roads

Table 5-5 contains the change in total flooded road length.

Table 5-5: Impact of NFM features on total road damages

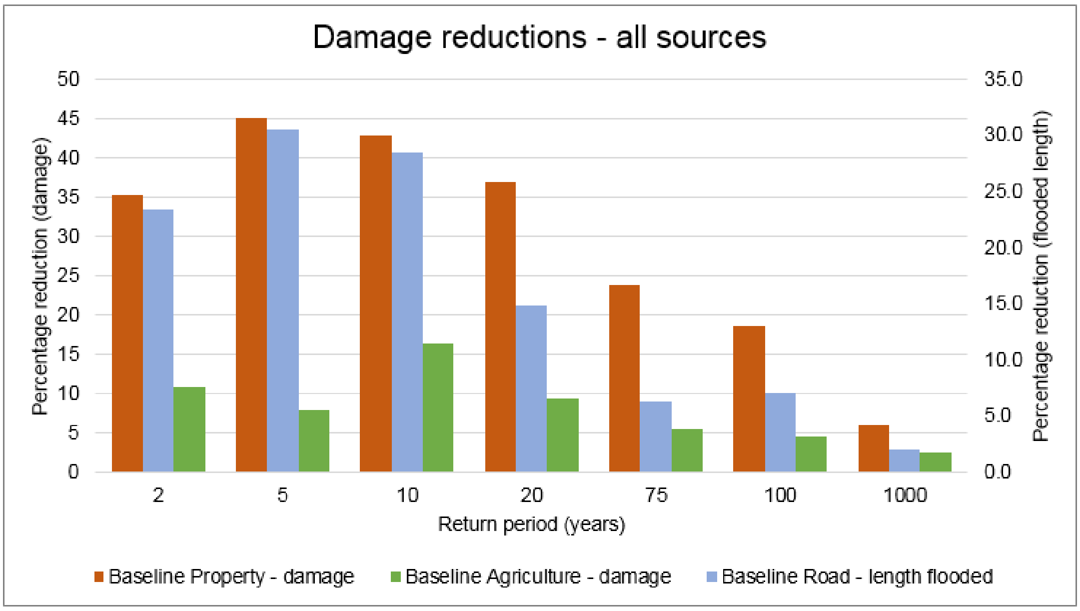
Return period (years)	Total flooded road length			
	Baseline (m)	NFM (m)	Change (m)	Change (%)
2	1,377	1,054	-323	23.4
5	2,656	1,845	-811	30.5
10	3,868	2,766	-1,103	28.5
20	4,503	3,832	-671	14.9
75	5,574	5,218	-355	6.4
100	5,870	5,450	-421	7.2
1,000	8,429	8,260	-168	2.0

Length of flooded roads is reduced across the full range of return periods, but this is particularly significant for medium return periods. This is because these return periods represent the threshold where the location of flood extent margins and the impact of NFM features on these extents combine to take entire reaches of road out of flood risk.

5.4 Combined economic damages

Figure 5-5 presents the percentage reduction in economic damages for each land use by return period.

Figure 5-5: Damage reductions – proportion of baseline



NFM features in the river catchments draining to Debenham would have the greatest proportional reduction on property damages and damage to roads. Agricultural land uses would experience a smaller proportional reduction in damages. This relates to the spatially distributed nature of this land use (areas of agriculture are less likely to be removed from flooding completely than discrete properties or linear roads), and the fact that damage to agricultural land does not take account of flood depth i.e. there is currently no reduction in damage for a field flooded to the same extent but a lower depth.

Damages to property and agriculture as a proportion of total damage cost are displayed in Figure 5-6.

Figure 5-6: Damage reductions – proportion of total cost

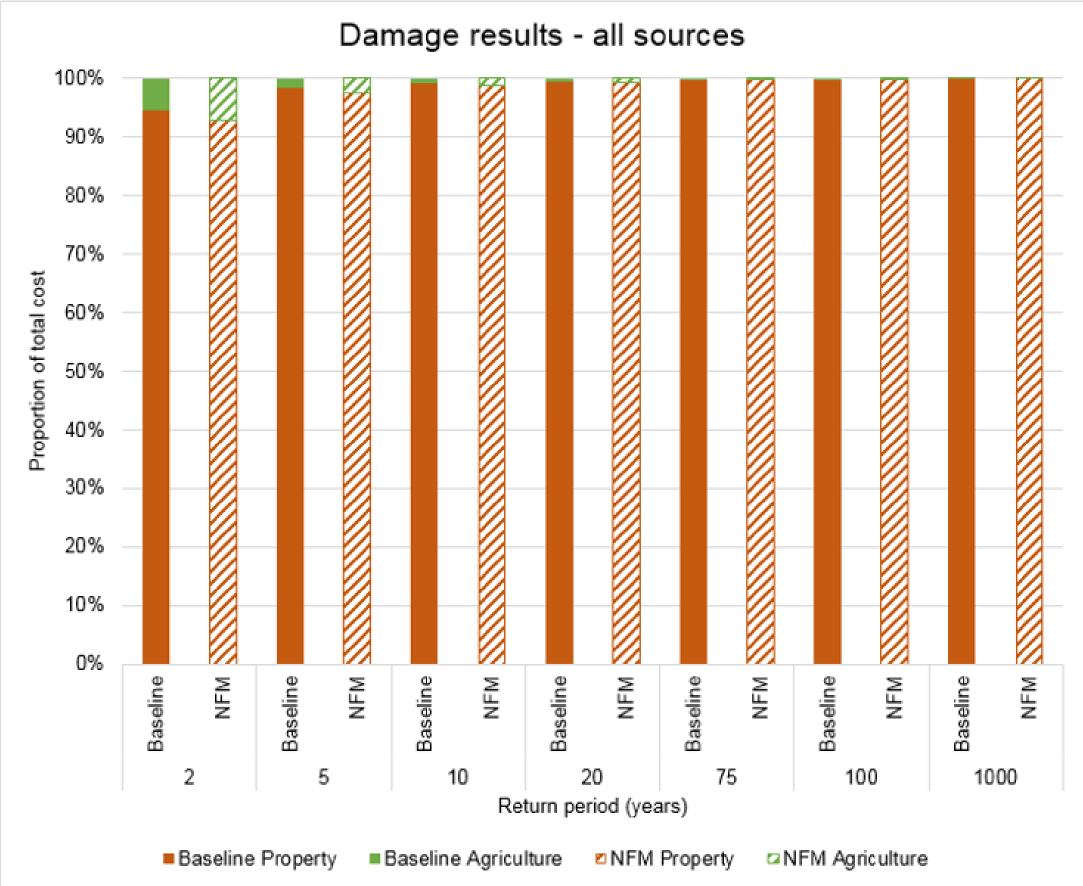


Figure 5-6 indicates that property damages are dominant in Debenham. Agriculture damages are more significant at shorter return periods, accounting for a larger proportion of total damages. Property damages gradually increase in significance; at longer return periods these costs account for almost all damages. Moreover, property damages decrease in significance as a result of NFM features in the catchment. This is important in demonstrating the potential change in flood impacts on the Debenham community, and could have implications for the distribution of post-flood efforts and resources.

5.5 Annual average damages

The impact on AADs is summarised in Table 5-6.

Table 5-6: Impact of NFM features on annual average damages

Type	Annual average damages			
	Baseline (£k)	NFM (£k)	Change (£k)	Change (%)
Property	193.1	132.5	60.6	30.8
Agriculture	2.2	2.0	0.2	10.2
Combined	195.3	134.5	60.8	31.1

The baseline total AAD for Debenham is £195,300 compared to a total of £134,500 when the NFM features are in place, a reduction of £60,800.

The 31% reduction in AADs is significant. This is a reflection of the effectiveness of NFM features in attenuating flows at shorter return periods, reducing the occurrence of economic damages associated with higher frequency, lower magnitude flood events. Moreover, the results in Table 5-6 highlight the dominance of property damages in overall costs incurred due to flood events in Debenham. Table 5-7 contains details on the annual average road length flooded.

Table 5-7: Impact of NFM features on annual average road length flooded				
Type	**Annual average length flooded**			
	Baseline (m)	**NFM (m)**	**Change (m)**	**Change (%)**
Roads	1,761	1,348	414	23

While Table 5-7 does not provide explicit information on the reduction in damages related to road flooding, a 23% reduction in the length of flooded roads is likely to cause a significant decrease in cost, through both direct damage and disruption to the road network as a whole.

6 Conclusions

This study uses a combination of hydrological and hydraulic modelling tools to assess the potential benefit of proposed NFM features. Each of these methods incorporates some degree of uncertainty and we recommend that the results of this study are interpreted with this in mind. Our understanding of the baseline flood risk and the associated uncertainties has been addressed in the previous studies and whilst we have demonstrated that these results are consistent with observed flood history limited hydrometric data does increase uncertainty in the results. For this study the key source of uncertainty is the ability of the JFlow+ 2D hydraulic model to replicate the complex hydrological response of the catchment and the impact on this of the proposed NFM features. Whilst we have made every effort to limit uncertainty (for example by retaining existing design flows and modifying the parameterisation and schematisation of the JFlow+ models to represent a realistic catchment response) we acknowledge this this is a relatively new application of 2D hydraulic modelling and there is little data available to quantify this uncertainty.

This study has explored the impact of NFM features, in the river catchments draining to Debenham, on flood risk and economic damages in the village. NFM features are very effective at reducing both flood extents and depths, as well as economic damages. Using the features specified by local landowners and the Environment Agency, a 31% decrease in annual average damages could be achieved. Most of this figure is attributable to reductions in property damages at all modelled return periods. At any given return period, this is a result of both removing properties from flooding entirely, or reducing the flood depth in a particular property. Damages to agricultural land are also reduced due to the reduction in flood extents when the NFM are incorporated; damages would likely decrease as a result of reduced flood depths as well, although the effect of flood depth on damage to agricultural land has not been assessed here. While economic damages to roads could not be assessed within the scope of this work, annual average flooded road lengths are decreased by 23% through NFM features, with associated reductions in damage and disruption.

The NFM features cause the largest reduction in peak flows, flood extents and economic damages on Cherry Tree Brook. This is the only sub-catchment in which there will be no additional storage capacity considered for phase 2. Therefore, there is potential to further increase the economic benefit of catchment storage for Debenham by providing flood storage on Derry Brook and The Gulls in phase 2. A greater proportion of the available storage was filled in Cherry Tree Brook, suggesting the features were more appropriate for the scale and nature of the surface water catchment. The features were generally situated 'online', and further down in the river catchment where accumulation of surface water flows is greater. Similarly, those features which were effective in The Gulls catchment were those intercepting key surface water flow paths. As such, to be most effective, NFM features require targeted design following analysis of surface water flow paths. If features are to be located offline and further up in a catchment, a greater number of NFM features are required to provide the cumulative attenuation of surface water flows necessary to reduce the peak flow in a downstream area.

There are several opportunities for further studies to expand the hydraulic modelling and economic analysis conducted:

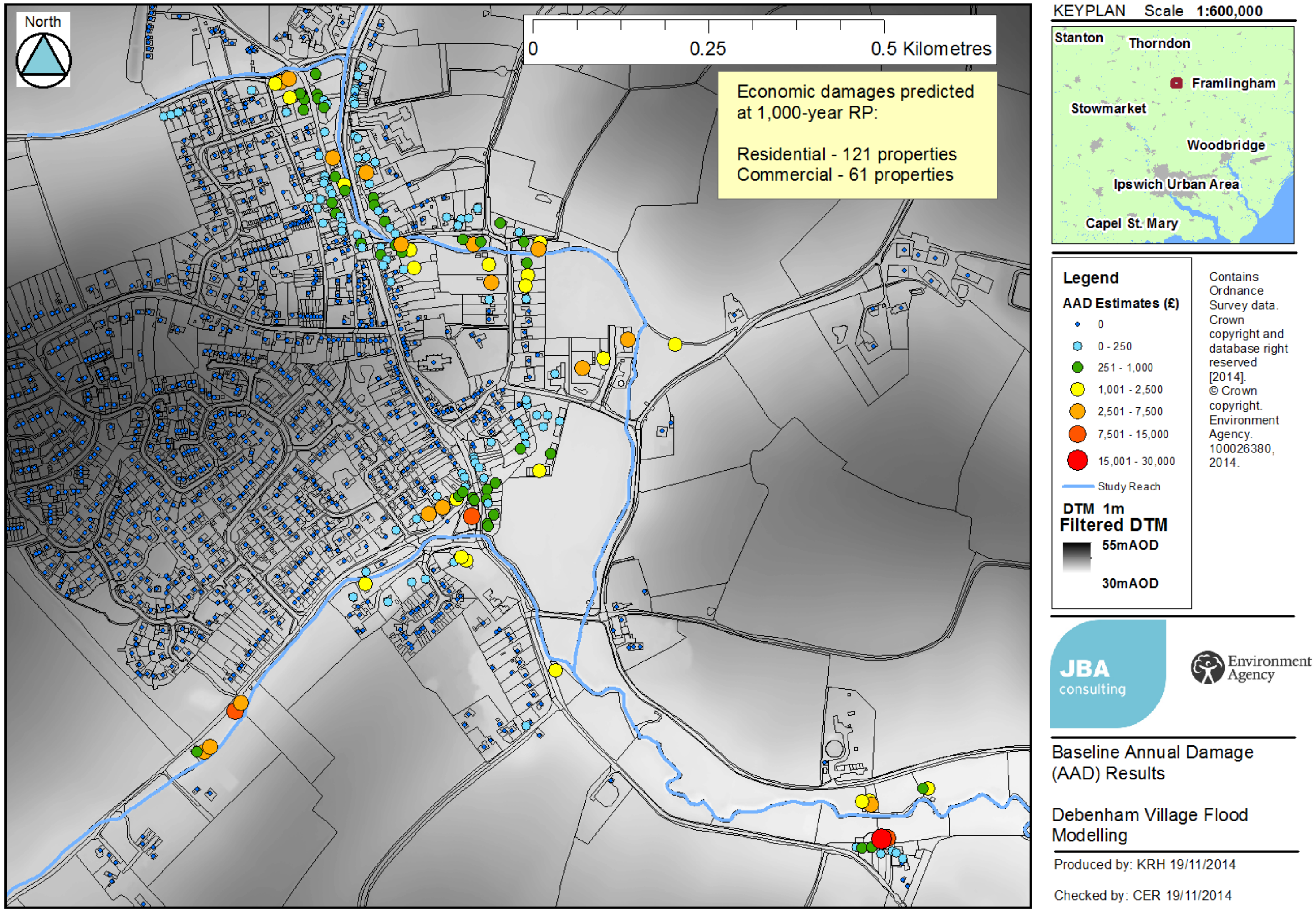
- Every effort has been made to reconcile the performance of the JFlow+ direct rainfall model and the ISIS-TUFLOW model. Further improvements in this area could be made with gauged flow data which is currently not available.

- The inflow hydrographs to the ISIS-TUFLOW model were scaled based on the difference in peak flows between scenarios in the JFlow+ model. This does not fully account for the differences in hydrograph volume. A more detailed analysis on each sub-catchment and group of NFM features could develop this approach, potentially adjusting only a portion of the hydrograph to represent the effect of the NFM features on the full flow hydrograph more closely.
- In some locations the design and extent of the proposed NFM features were modified slightly to improve performance; however, there remains scope for the design of these features to be optimised to further improve flood risk benefit.
- The economic damage analysis could be expanded with further information including traffic data, crop types and infrastructure. This would provide results for a greater variety of receptor types.

Appendices

A November 2014 flood mapping project - flooded property counts

Figure 6-1: Property AAD results at Debenham based on the depth and frequency of flooding



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