Newmarket Surface Water Management Plan - Model Update

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Synopsis: This report details the Newmarket Surface Water Management Plan (SWMP) modelling update. The SWMP model has been updated to improve the estimation of surface water flood risk. Flood mitigation options have been identified and a cost benefit analysis carried out.

REVISION/CHECKING HISTORY

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001	11/04/2019	J. Pickering		R. Jensen	
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Executive Summary

BMT have been commissioned by Suffolk County Council (SCC) as a part of their role as Lead Local Flood Authority to update the Surface Water Management Plan (SWMP) modelling for Newmarket.

The existing Newmarket SWMP was detailed by AECOM (*Newmarket Surface Water Management Plan* in April 2015. In 2017, BMT were commissioned to review the model developed as part of the SWMP. This study addresses limitations in the previous modelling, presents concept mitigation options and outline benefit costs analysis.

This report details the findings of the SWMP model update and mitigation assessments. In summary:

- An Integrated Urban Drainage (IUD) model has been developed for the Newmarket catchment.
- Infiltration and structure blockage have a substantial impact on flood risk in Newmarket.
- The model has been validated to the May 2012 historic event and shows a good correlation
- The updated flood risk is more substantial than shown in previous studies, typically due to more complete representation of infiltration and the entire contributing upper catchment.
- Key flood risk areas lie along Newmarket Brook and Newmarket Drain
- Four mitigation options have been developed with SCC to reduce flood risk. Three of these target the upper catchment source flow, and one option targets vulnerable receptors.
- Inundated property and total catchment damages have been estimated across the catchment and highlight at risk receptors. The total catchment present value estimated damage is £106,071,800.
- A 'Do Nothing' Scenario has been assessed, simulating if Council and the EA cease all but statutory duties. This has been compared to the baseline ('Do Minimum') Scenario.
- The finalised benefit cost ratios of the proposed schemes, compared to the baseline ('Do Minimum' secnario) are shown below. Benefit Cost ratios have also been prepared against the 'Do Nothing' scenario.

Scenario	Present Value total cost	Present Value Total Benefit	Benefit Cost Ratio
Mitigation 1 – South West	£255,200	-£4,823,000	**18.90**
Mitigation 2 – South East	£1,559,300	-£8,345,100	**5.35**
Mitigation 3 – Frampton Close	£616,000	-£31,500	**0.05**
Mitigation 4 – Combined South	£1,817,000	-£13,217,300	**7.27**

- BMT recommends that both mitigation option 1, South West, and mitigation option 4, combined south, are appropriate to proceed to further detailed design or forward to funding calculation. This would further assess the feasibility of the designs and provide more certainty as the options progress to implementation.

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1 Introduction

The existing Newmarket SWMP was detailed by AECOM (*Newmarket Surface Water Management Plan* in April 2015. In 2017, BMT were commissioned to review the model developed as part of the SWMP. The findings of the review are summarised in section 1.1 and inform the key changes instigated as part of this modelling update.

The purpose of this study is to develop an updated model to resolve outstanding gaps in the 2015 modelling, include recently available data, develop concept flood risk mitigation options and provide outline cost benefit assessments. The updated model results includes additional data such as a catchment based approach, updated watercourse information and a more complete representation of the sewer network. It will provide Suffolk County Council (SCC) with a more accurate understanding of the current surface water flood risk to Newmarket

1.1 BMT SWMP Model review findings

The current InfoWorks ICM model was developed in April 2015. The model was reviewed by BMT for Quality Assurance purposes. The review assessed whether:

- The modelling software has been applied appropriately;
- The modelling methodology represents current best practice; and
- The assumptions and limitations are suitable and proportionate, such that the model can be used with confidence to support flood risk management decisions.

The predicted surface water flood risk was presented, and a low confidence rating and several recommendations made for updating the hydraulic model, including new datasets (e.g. terrain, landuse, etc.) and current best practice methodologies (e.g. climate change, integrated urban drainage, infiltration, etc.).

The final review recommendations included:

- Design Rainfall Events – Only three (3) design rainfall events were previously modelled. Five (5) design rainfall events have been modelled in this update, as required for SCC to complete an Outline Business Case (OBC). These include the 5%, 3.33%, 1.33%, 1% and 0.1% Annual Exceedance Probability storm events.
- Critical Duration Analysis - All storm events were previously simulated for a single storm duration of 16 hours. No justification was given for selecting the storm duration. We have analysed the critical storm duration that produces the greatest flood extents and depths for the 1% AEP event.
- Climate Change – A 20% allowance for climate change was previously applied to the 1% AEP storm event. In February 2016, the Environment Agency updated their guidance on climate change allowances to inform flood risk and strategic flood risk assessments. The latest guidance has been used to select the peak rainfall intensity allowance for small and urban catchments.
- Surface run-off had been modelled in the upper catchment by multiplying the rainfall by 30% and assuming 70% of the rainfall is lost through infiltration. The infiltration process is not explicitly

modelled. Consequently, when the rainfall stops, so does the loss / infiltration. We have modelled infiltration dynamically, varying the rate of infiltration over time based on the soil's characteristics.

- Pipe network – There are large parts of the previous Newmarket SWMP model with no stormwater sewer network. The model has been updated to include the sewer network based on latest Anglian Water datasets.
- Manholes and Gullies – The previous SWMP model transferred surface water from the surface into the sewer via manholes. The discharge was controlled by assuming a standard weir equation where the manhole circumference is taken as the weir width. In the updated modelling, surface water transfer is via the highways gullies, where the discharge is controlled by the gully grate configuration and depth of surface water. Where the pipe network data is available, the highways gullies are linked to the stormwater sewer, such that water can discharge from the road surface into the sewer, as well as surcharge from the sewer onto the road surface. If there is no sewer pipe data, the Virtual Pipes feature in TUFLOW has been used.
- Sub-Catchments – in the previous modelling sub-catchments have been digitised to define those parts of the urban area that drain into the stormwater sewer network. The spatial coverage of the sub-catchments does not include all urban areas of Newmarket. In areas where the sewer network is missing, 70% of the rainfall is assumed to infiltrate (section 1.3.3). The sub-catchments have been removed and the rainfall hyetograph applied everywhere.
- A large portion of the Newmarket catchment boundary has not been included in the previous model. Specifically, the southern (upper) part of the catchment and, to a lesser degree, part of the northern (downstream) catchment towards Chippenham. The model extent has been be updated to include all the contributing catchment area influencing surface water flood risk within Newmarket.
- A single roughness value of 0.013, equivalent to a manmade road, had been used for the entire previous SWMP modelled area. The updated model uses Ordinance Survey (OS) MasterMap data to classify different land uses, and Manning's *n* coefficient values applied to each of these land uses.

1.2 Catchment Overview

Newmarket is located in west Suffolk, 20km north east of Cambridge. The urban areas are located within Suffolk and the rural upper catchment extends into Cambridgeshire (Figure 1-1).

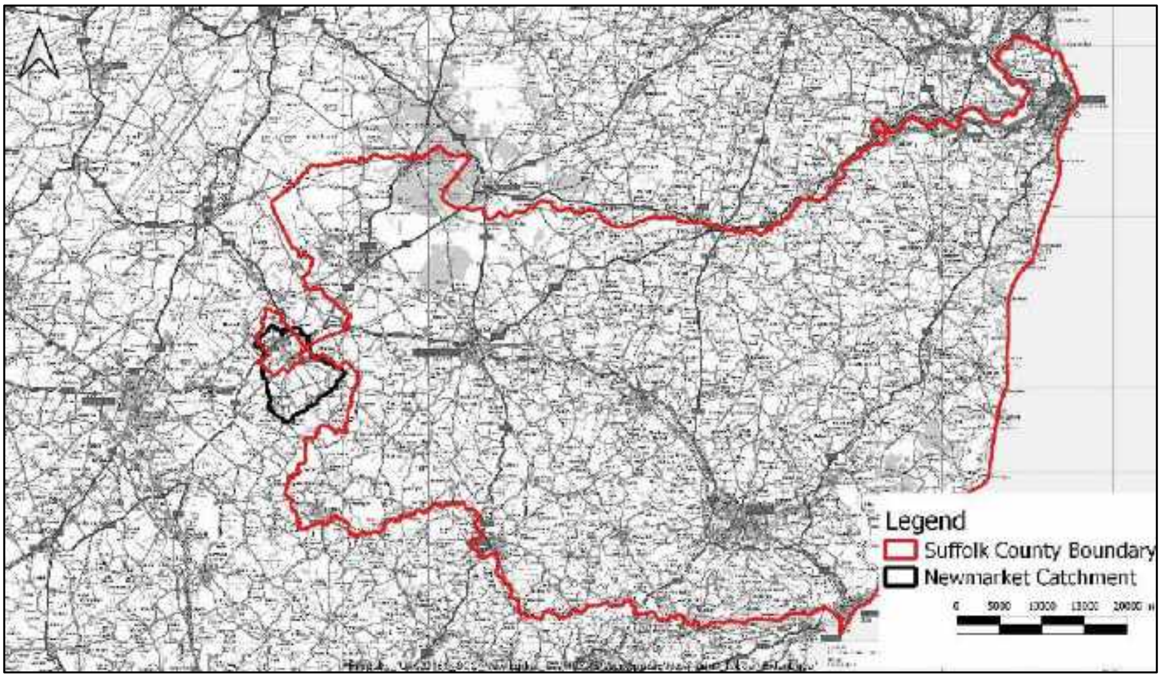


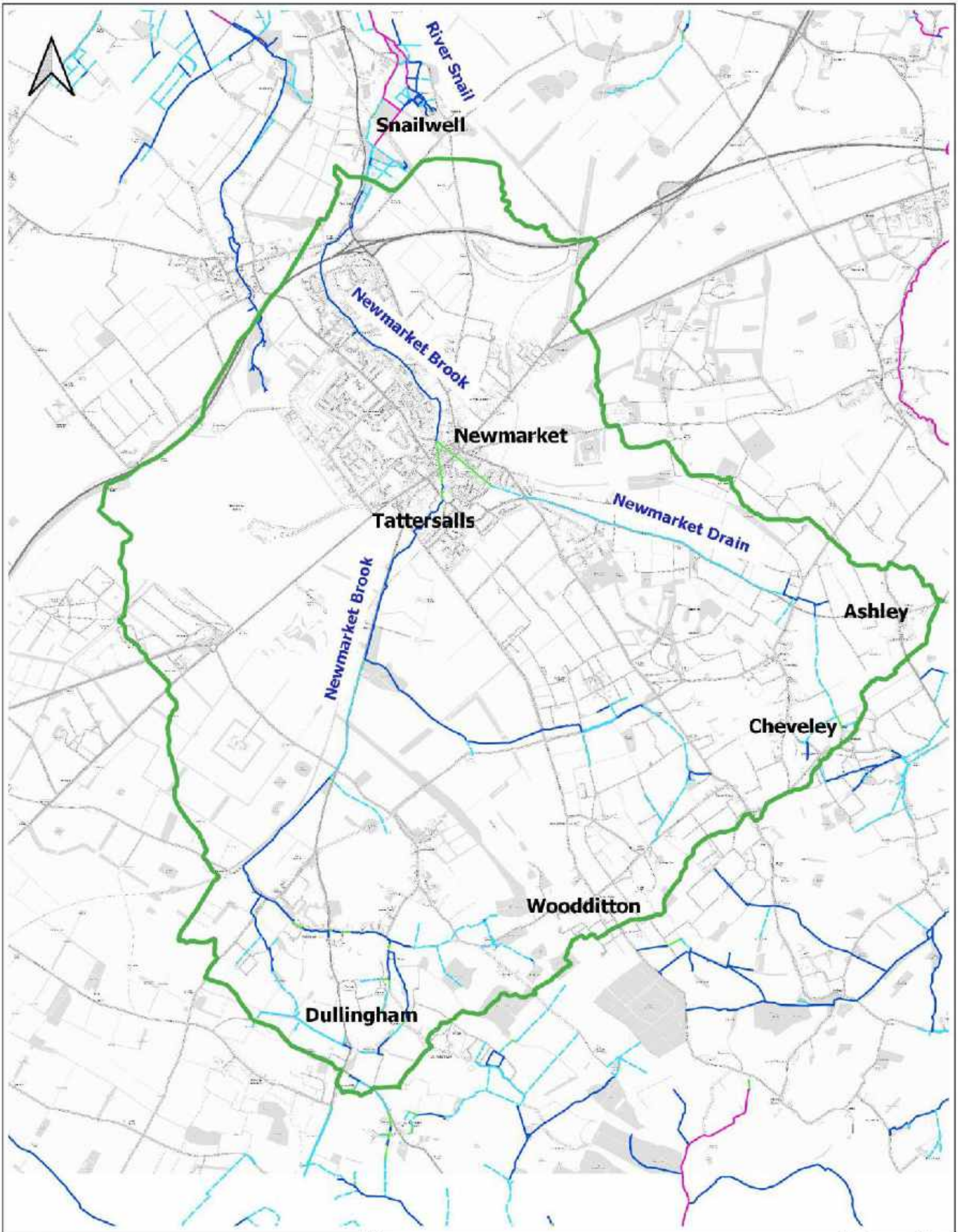
Figure 1-1 Study Area

The Newmarket Brook, an ordinary watercourse, runs through the town of Newmarket (Figure 1-2). The Brook's headwaters are located in the upper reaches of the catchment around Dullingham and Woodditton. From Dullingham the Brook flows as open watercourse approximately 7km north towards Tattersalls before becoming a culverted watercourse from 'The Avenue' to its outfall at Exeter Road. The contributing catchment of the Newmarket Brook, upstream of Exeter Road, is approximately 40km^2.

A significant amount of this contributing catchment (approximately 11km^2) is sourced from the Newmarket Drain which originates near the township of Ashley and flows in a westerly direction along Ashley Road towards the Allotments. This drain becomes culverted at Willow Crescent and joins the Newmarket Brook upstream of Exeter Road. From the Exeter Road outfall, the Brook continues in open channel north, through Newmarket and under the A14 Bypass before merging into the River Snails around the Wastewater Treatment Plant along Fordham Road.

Newmarket has been subject to a number of flood events, most recently in 2012 and with a major event in 1968. Areas such as Sassoon Close and Tattersalls are reported to be at key risk.

The risk management authority for all Main Rivers is the Environment Agency. Ordinary Watercourses, both designated watercourses and drains, are maintained by staturoty requirement by the lead local flood authority. In the Newmarket catchment, this is Suffolk County Council.



Legend
Model Boundary Extent
Model Output Zone
Detailed River Network
Main River
Culvert
Lake
Ordinary Watercourse - Drain
Ordinary Watercourse - Open Channel

Title:
Newmarket Catchment Watercourses

Drawing: 1-2
Rev: A

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2 Hydrology

2.1 Rainfall

Design rainfall events were developed for inclusion in the hydraulic model as inflow boundaries. The direct rainfall method was selected for assessing flood risk from surface water. It enables the dynamic modelling of rainfall hyetographs which vary in duration and storm frequency.

Total rainfall depths were extracted at two locations across the catchment from the Flood Estimation Handbook (FEH) Web Service Depth Duration Frequency (DDF) model, one in the centre of Newmarket (NGR: TL 63000 65000) and one in the upper catchment.

A comparison of the rainfall depths showed typically 1% variation across the catchment. A single 1km grid point in the upper catchment (NGR: TL 63000 65000) was selected to represent the catchment rainfall as it is slightly more conservative than the other locations. Total rainfall depths were extracted for the following five storm events:

- 5% AEP (1 in 20 year);
- 3.33% AEP (1 in 30 year);
- 1.33% AEP (1 in 75 year);
- 1% AEP (1 in 100 year); and
- 0.1% AEP (1 in 1000 year).

Hyetographs were generated for the three storm durations discussed in Section 2.2. The final rainfall depths and hyetographs are shown in Section 3.2.9.1.

2.2 Rainfall Depth Adjustments

2.2.1 Areal Reduction Factor

The Areal Reduction Factor (ARF) is used to reduce the depth of rain in synthetic storms to convert from a typical point rainfall to a rainfall across a catchment area. Based on the drainage catchments within the study area, the ARF ranged between 0.980 for short duration storms (1 hour) to 0.990 for long duration storms (6 hours).

2.2.2 Storm Profile and Seasonal Correction Factor

The storm profile describes the hyetograph of the rainfall event. FEH storm profiles are symmetric and single peaked. The storms analysed to generate the FEH profiles were split into summer and winter events, centred on the most intense part of the storm and averaged. A summer storm profile presents a shorter duration but higher intensity storm and is generally recommended for application to urban catchments due to the higher rates of runoff and therefore worse case scenario. A catchment should be more than 25% urbanised to be considered urban.

Rainfall depth outputs from the FEH DDF model are based on annual data. As the maximum rainfall depths tend to be in the summer periods, this can lead to an over-prediction of rainfall depths in winter periods. The seasonal correction factor (SCF) is a function of the standard annual average rainfall for the catchment, the storm duration and the selected season (summer/ winter).

The level of urbanisation in the study area has been estimated using URBEX at approximately 10%, between the thresholds for a summer or winter storm profile and SCF is recommended. The SCF has been scaled linearly based on the estimated level of urbanisation and applied with the winter storm profile. This assumption has been sensitivity tested to assess the impact on the modelled results. The final scaled SCF ranges from 0.535 for short duration storms (1 hour) and 0.659 for long duration storms (6 hours).

2.3 Critical Storm Duration

The critical storm duration is defined as the storm duration that produces the greatest flood extent and flood depth. Even within a small area, the critical duration can vary due to several factors including topography, land use, size of the upstream catchment and nature of the drainage systems.

In the previous AECOM modelling, all storm events were simulated for a single storm duration of 16 hours. No justification was given for selecting the storm duration.

Three storm durations were simulated in the model for the 1% AEP event to determine the critical duration. The three durations tested were the 1 hour, 3 hour and 6 hour. Following simulation of the hydraulic models, the predicted maximum depth results were processed for each storm duration. This was then processed into a classified grid which highlights the source storm duration which has produced the maximum flood depth at locations across the study area (Figure 2-1).

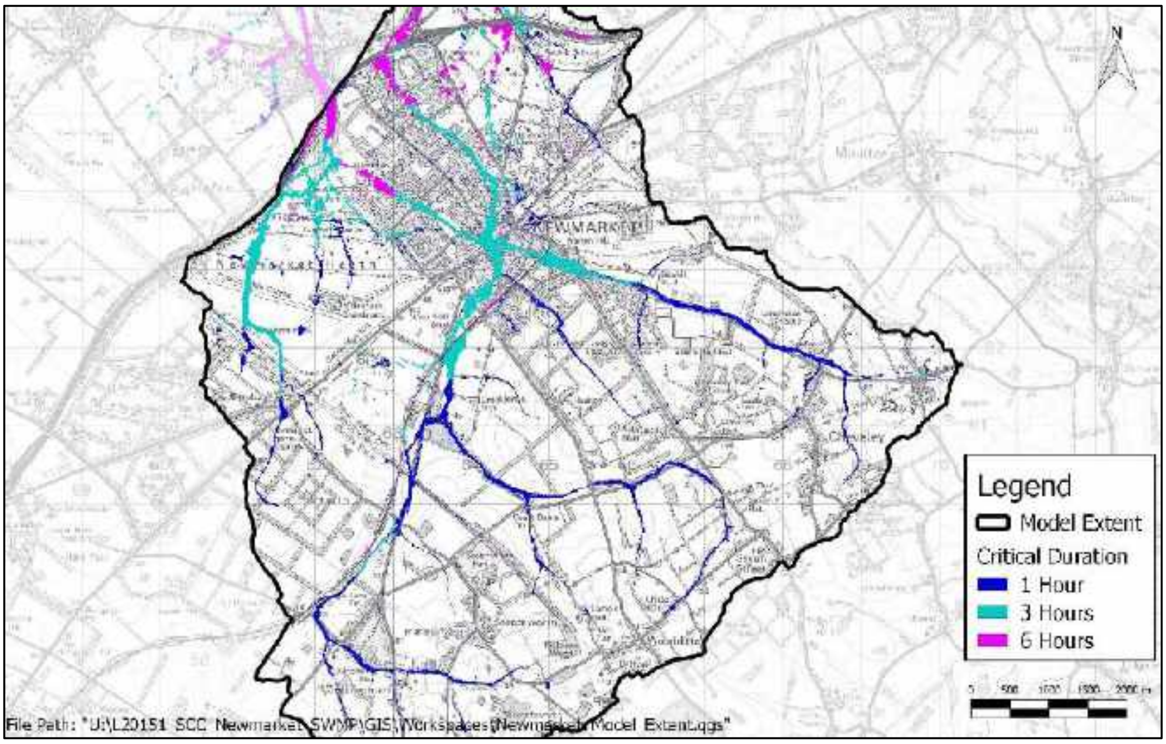


Figure 2-1 Critical Storm Duration Assessment for the 1% AEP Storm Event

Figure 2-1 shows the 1 hour event has the greatest flood depths for the upper catchment, the 3 hour through the mid catchment and Newmarket centre and the 6 hour in the downstream extent. When excluding areas of shallow depth (<0.1m) from the critical duration assessment, the 3 hour event has the greatest flood depth and fluvial flood extent within the township of Newmarket, which has the greatest number of receptors. The 3 hour event was therefore chosen as the critical duration for this study.

The selected 3 hour duration was tested against the previously modelled 16 hour duration. The 16 hour duration was found to substantially under-predict the peak flood depths and extents compared to the 3 hour duration.

2.4 Climate Change

The Environment Agency (EA) updated their guidance on climate change allowances to inform flood risk and strategic flood risk assessments in February 2016[1]. Table 4 of the guidance provides peak rainfall intensity allowances in small and urban catchments and is reproduced below (Table 2-1).

Table 2-1 Peak Rainfall Intensity Allowance in Small and Urban Catchments[1]

Allowance Category	Total potential change anticipated for 2010 to 2039	Total potential change anticipated for 2040 to 2059	Total potential change anticipated for 2060 to 2115
Upper End	10%	20%	40%
Central	5%	10%	20%

The Environment Agency guidance recommends assessing both the central and upper end allowances to provide a range of the potential impacts of climate change. The ‘central’ (20%) and ‘upper’ (40%) allowances have been applied to the 1% AEP event.

[1] ‘Adaption to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities’ (Environment Agency, 2016)

3 Model Methodology

3.1 Software Selection

TUFLOW HPC was selected as the software of choice for constructing a hydraulic model for the Newmarket study. TUFLOW HPC is a mass conserving finite volumes solver which provides greater model stability than the finite difference solver previously used. This means that the model can represent smaller scale features that may have resulted in un-resolvable stability issues in other software packages.

TUFLOW HPC uses the power of Graphical Processing Units (GPU) and can simulate large models at a high resolution. It is therefore suitable for assessing surface water flood risk in urbanised areas where micro-topographic features influence flooding mechanisms.

The TUFLOW suite of products were benchmarked by the EA[2] in 2010 and 2013. It represents industry standard software and is determined to be suitable for assessing surface water flood risk.

3.2 Model Build

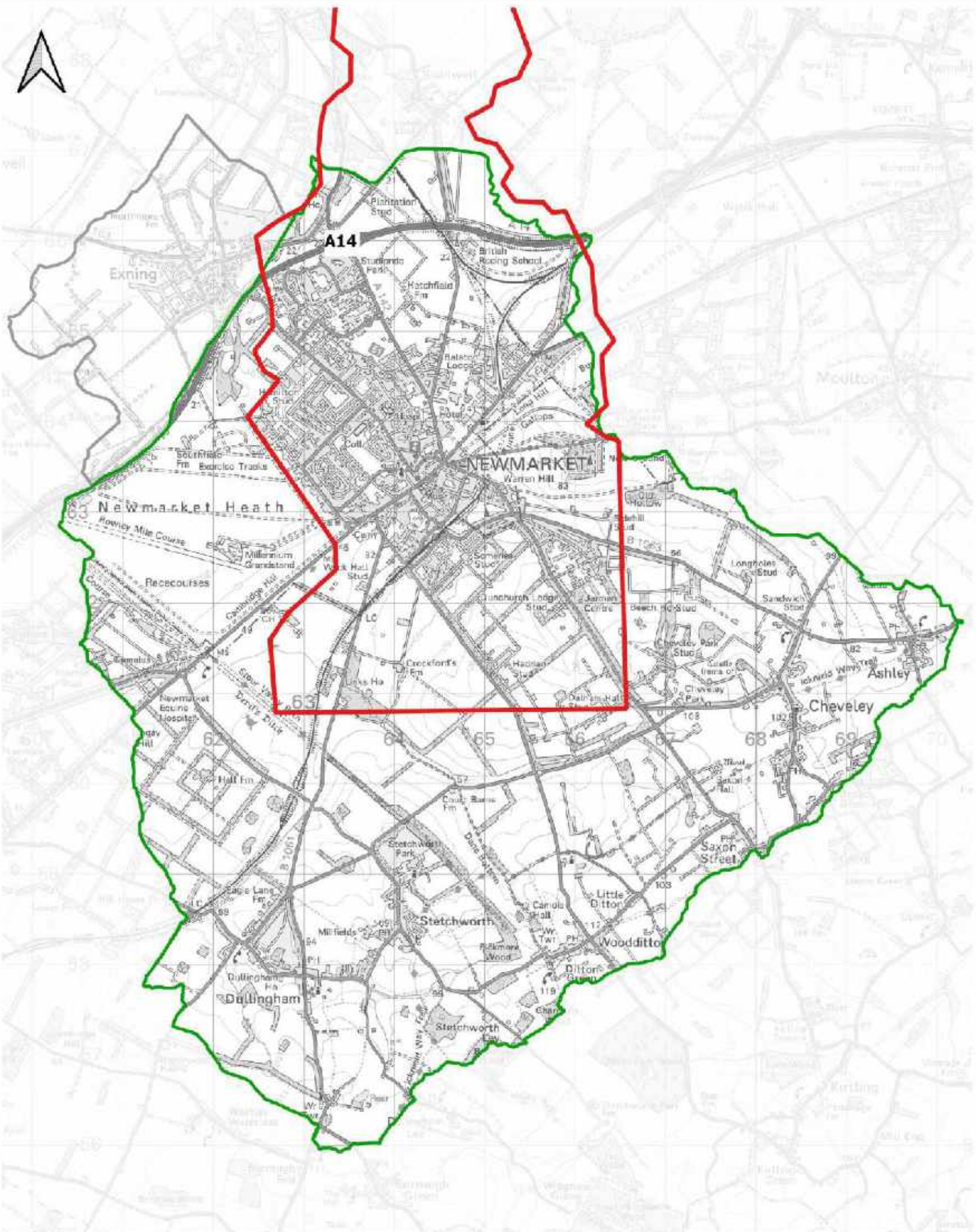
3.2.1 Model Extent

A rolling ball analysis based on the Risk of Flooding from Surface Water (RoFfSW) digital terrain model (DTM) was undertaken to determine the topographic sub-catchments in an area of interest. These sub-catchments represent the overland drainage areas which have the potential to contribute to surface water flooding. The model extent incorporates all sub-catchments including rural catchments to the south of Newmarket, covering much of Cheveley, Ashley and Dullingham (Figure 3-1).

This differs to the previous ICM SWMP model which excludes a large proportion of the upper catchment in the hydraulic model extent (Figure 3-1). The inclusion of this upper catchment in the updated SWMP model extent provides greater understanding of the sources and mechanisms of flooding in the township of Newmarket. This has provided key insights for optioneering flood mitigation measures discussed in Section 6.

The updated SWMP model area extends approximately 1.2km downstream of the A14 to minimise the influence that the modelled boundary conditions would have on the hydraulic behaviour in the area of interest. Exning has been included within the modelled extent to capture the downstream flood behaviour. However, as this is not the area of interest, it has not been modelled in detail. As such, results have only been produced in the model ‘output zone’. It is this model output zone which will remain the focus of the study.

[2] Benchmarking the Latest Generation of 2D Hydraulic Modelling Packages SC120002 (Environment Agency, August 2013)



Legend

Previous (2015) model extent

Updated Model Extent

Updated Model Output Zone

Title:
Newmarket Catchment Model Extent

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3.2.2 Topography

The EA RoFfSW DTM dataset was used as the base topography defining ground elevations within the model. This topography was then supplemented by watercourse survey and fences and walls where data was available.

The RoFfSW dataset (Figure 3-2) is a composite DTM comprising of both LiDAR data (0.25m up to 2m resolution) and NEXTMap (5m resolution), that has been sampled to a common 2m resolution. The DTM includes the following topographic amendments:

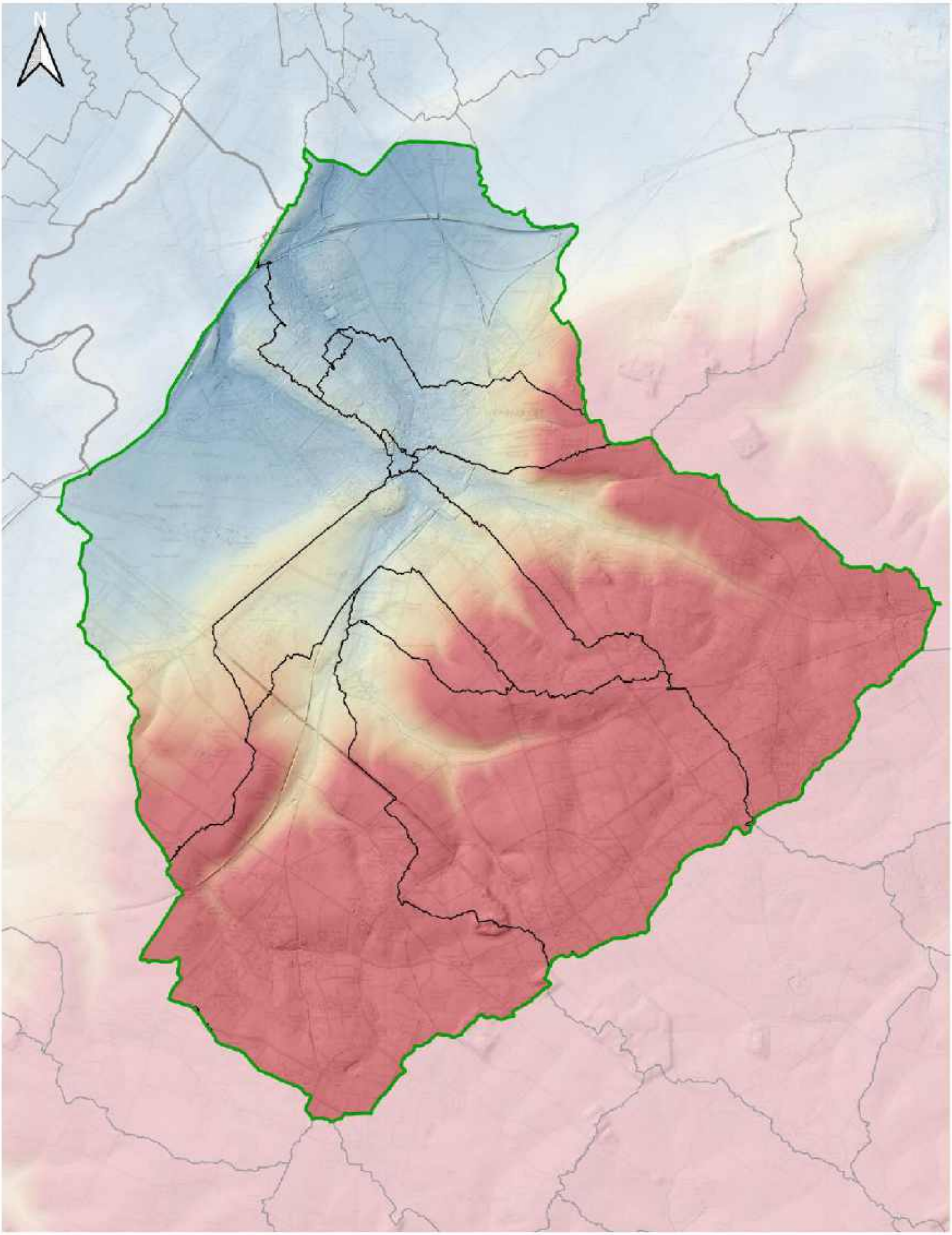
- 0.3m building upstands representing the depth at which any damp-proof course would be exceeded; and
- Road levels lowered by 0.125m - the height of a British Standard kerb.

The incorporation of building upstands and road lowering is to more accurately represent the conveyance of surface water through urban areas, including exceedance along roads and deflection around buildings. This is in line with current best practice and modelling guidelines.

Channel survey was obtained in 2019 by SCC for this study to provide greater definition in the open bank sections of watercourse. This is further discussed in Section 3.2.7.

Topographic amendments were included to represent urban features located on the key flow paths through the study area. A site visit was undertaken by BMT to verify the urban features, building thresholds and kerb heights initially identified via online mapping. Data was collected on embankments, garden fences and solid walls and added to the modelled representation of the urban environment. The location of the topographical features implemented in the model are shown below in Figure 3-3. 11 property threshold levels were obtained in the SCC survey. These property levels, located on Sassoon Close, have been used instead of the standard 0.3m upstand.

Fences inspected on site were typically found to be wooden property boundary fences. They have been represented within the model to have an assumed height of 1.8m with 40% permeability. The 40% permeability represents the assumption of fences permitting flow through slats and underneath. Solid walls (such as flood defences) causing an obstruction along key flow routes have also been included within the model as completely impermeable.



Legend

- Model Extent
- Model Output Zone
- Hydraulic Sub-Catchments

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Newmarket Hydraulic Sub-Catchments			3-2	A
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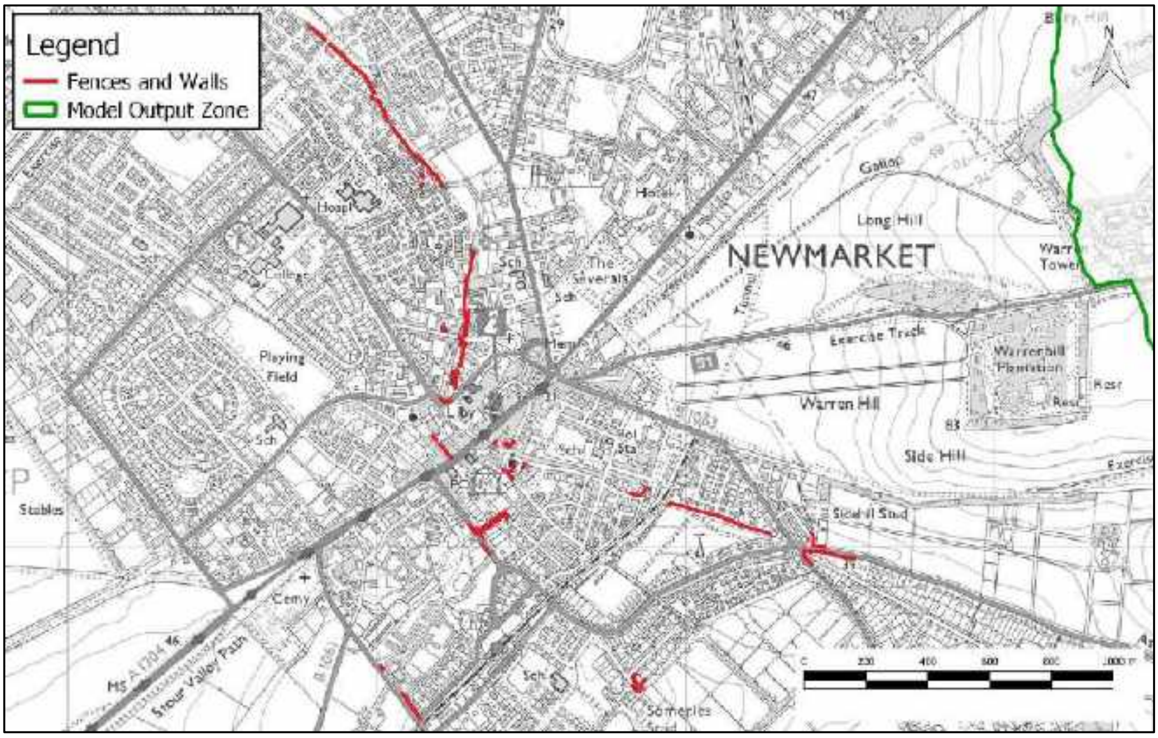


Figure 3-3 Additional fences and walls

3.2.3 Cell Size

The flood hazard predictions in urban environments with complex flow paths can be sensitive to model grid resolution. Three to five metre grid cells resolutions are typically required across key flow paths (i.e. a road or channel) to provide suitable representation of hydraulic features. The Newmarket hydraulic model domain covers an area of approximately 66km² and comprises a uniform grid of 2m resolution square cells.

This resolution was used to best define the finer scale urban features and open channels that existed in this catchment, while maintaining appropriate model run times and data output sizes. Each grid cell contains information on ground topography sampled from the DEM at 1.0m spacing, the surface resistance to flow (Manning's '*n*' value), the rainfall applied at that cell and soil infiltration.

3.2.4 Landuse

Flow velocity depends on the amount of friction (resistance) between the water and the underlying surface. Smoother surfaces will have less friction and therefore, faster flow. Surface roughness contributes to turbulence, which dissipates energy and reduces flow velocity. The Manning's *n* coefficient represents the roughness of the land surface, or river channel, in the hydraulic model. Ordinance Survey (OS) MasterMap data was used to classify different land-uses (Figure 3-4). Manning's *n* coefficient values were then applied to each of these land-uses as per Table 3-1.

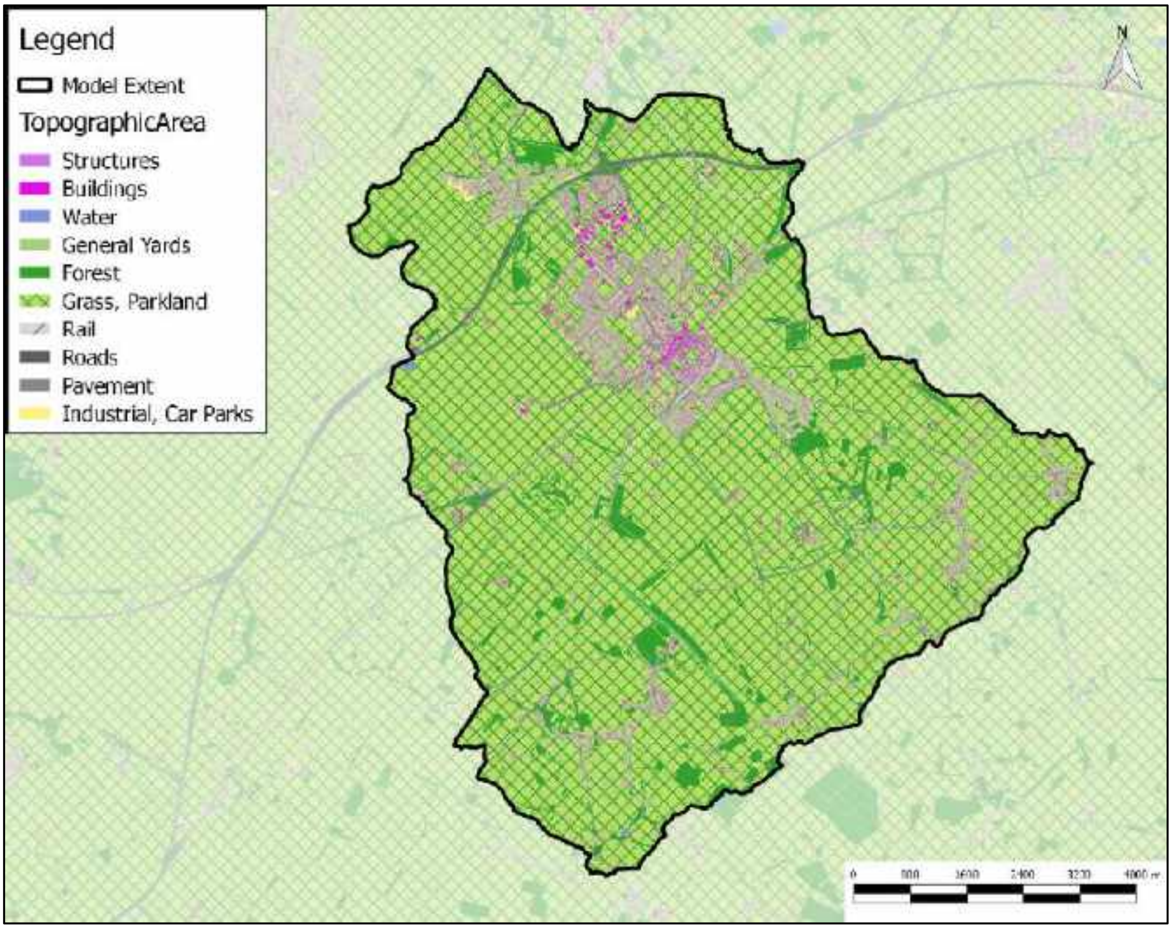


Figure 3-4 Land Use Classifications

A depth varying Manning's *n* coefficient was applied to buildings. The coefficient value is reduced at shallow depths so that rain falling on the building can flow away, to represent roof drainage. The coefficient value is increased at greater depths to represent the likelihood of water to pond within buildings.

Table 3-1 Land Use Roughness Coefficients

OSMasterMap Code	OSMasterMap Description	Manning's *n* Coefficient
10021	Buildings	0.015 – 0.5
10053	General Surface (Residential Yards)	0.04
10054	General Surface (Step)	0.025
10056	General Surface (Grass Parkland)	0.03
10062	Buildings, Glasshouse	0.015 – 0.5
10076	Land - Heritage and Antiques	0.5
10089, 10210	Water (Inland)	0.035
10099, 10111	Natural Environment (Coniferous/Non-Coniferous Trees)	0.1

OSMasterMap Code	OSMasterMap Description	Manning's *n* Coefficient
10119	Roads Tracks and Paths (Manmade)	0.02
10123	Roads Tracks and Paths (Dirt Tracks)	0.025
10167	Rail	0.05
10172, 10183	Roads Tracks and Paths	0.02
10096	Roadside structure	0.03
10185, 10193	Structures	0.03
10187	Structures (Generally on top of Buildings)	0.5
10203	Water (Foreshore)	0.04
10217	Land (Unclassified)	0.035

3.2.5 Infiltration

UK Soil Observatory (UKSO) data, catchment inspection and anecdotal reports highlight that soil infiltration and groundwater is a key parameter within the Newmarket catchment. Local soil testing results were provided for the Newmarket catchment. These have been discussed in the below Chapter 3.2.5.1.

In the previous modelling, surface run-off had been modelled by multiplying the rainfall by 30% and assuming 70% of the rainfall is lost through infiltration. The infiltration process was not explicitly modelled. Consequently, when the rainfall stops, so does the loss / infiltration. There is uncertainty that a 70% reduction in rainfall is an appropriate representation of the amount of water lost to infiltration.

In the updated modelling, infiltration losses have been applied to all permeable land uses within the modelled extent. The underlying soil types across the modelled extent were determined from data identified from mySoil from the British Geological Survey (Figure 3-5). This dataset provides a broad scale summary of the soil landscapes for England and Wales.

The Horton approach has been selected as it dynamically varies the rate of infiltration based on soil class and is suitable to adapt to local infiltration test results. Infiltration parameters for each soil class have been derived from Akan, (1993[3]).

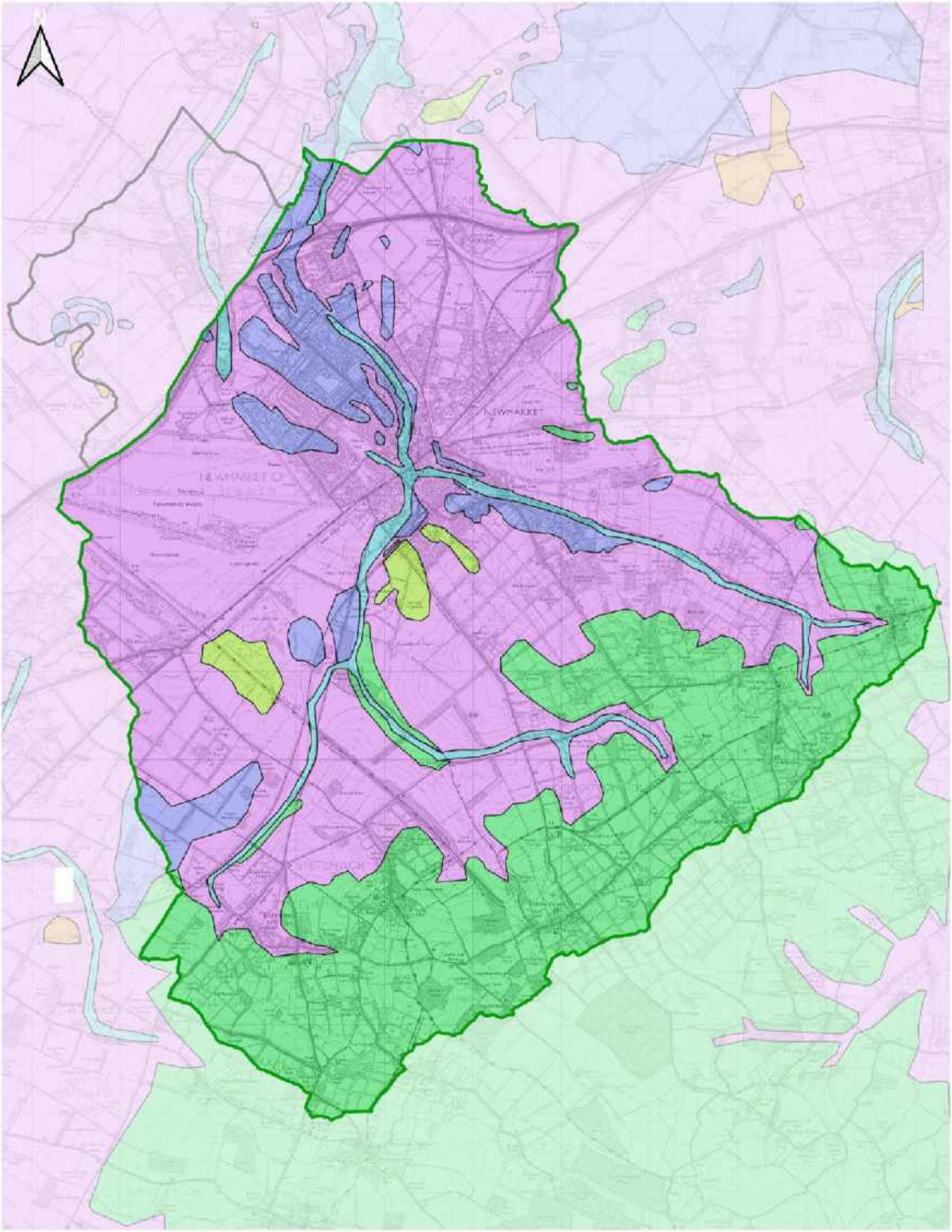
The catchment is underlain by the soils detailed in Table 3-2 below. The majority of the catchment is classed as chalky, silty loam, with Newmarket town centre classed as Sand to Sandy Loam. Table 3-2 also details the corresponding soils parameters specified in Akan, (1993) and used in the model. A Horton decay factor (k) of 4.14 has been used.

[3] Akan, Osman (1993). *Urban Stormwater Hydrology*, CRC Press.

Table 3-2 Soils Classification and Parameters

Soil Class	Initial Infiltration Rate (mm)	Final Infiltration Rate (mm)
Clay to Sandy Loam	18	0
Clayey Loam to Sandy Loam	25	1.3
Loam to Clayey Loam	25	0
Loam to Sandy Loam	25	3.8
Peat	7.6	0
Sand to sandy Loam	43	7.6
Chalky, silty Loam	25	3.8

The soil parameters above are based on the lower threshold values presented by Akan, representing impeded infiltration, potentially through moist catchment initial conditions or conservative estimation of soil porosity. This assumption has been sensitivity tested to measure the impact on the prediction of flood risk (Section 4.5.1). The lower infiltration condition inhibits both the initial and final infiltration rates. This results in greater predicted peak flood depths and extents due to reduced infiltration. The lower infiltration assumption has been selected for the baseline modelled scenario as it presents a more conservative risk profile and historic flood events have previously occurred after prolonged rainfall.



Legend

- Newmarket Hydrualic Model Extent
- Newmarket Model Output zone

Soil Classification

- Clay to Sandy Loam
- Clayey Loam to Sandy Loam
- Loam to Clayey Loam
- Loam to Sandy Loam
- Peat
- Sand to Sandy Loam
- Chalky, Silty Loam

Title: **Newmarket Soil Classification**			Drawing: **3-5**	Rev: **A**
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3.2.5.1 Local Soil Testing Results

Local soil type and infiltration testing within the Newmarket catchment was provided by SCC for two sites; Willie Snaith Road and Exning Road.

Both locations are within the 'Sand to Sandy Loam' soil type. The soil classification results at both sites correlates with the UKSO data and states that the soil types is sand. Two test pits were assessed at each site. Soils testing is spatially limited and does not capture a substantial cross section of the Newmarket catchment. Test results are also limited to the sand soil type and it is not appropriate to extrapolated to other soil types.

The derived infiltration results for the test sites have been compared to literature values for the sand soil type. Akan (1993) states that sand infiltration rates are highly variable and often substantially higher than averages stated. Figure 3-6 below displays values recommended in the ranging from moist to dry infiltration rates for the sand soil type and the measured infiltration rates for the assessed sites.

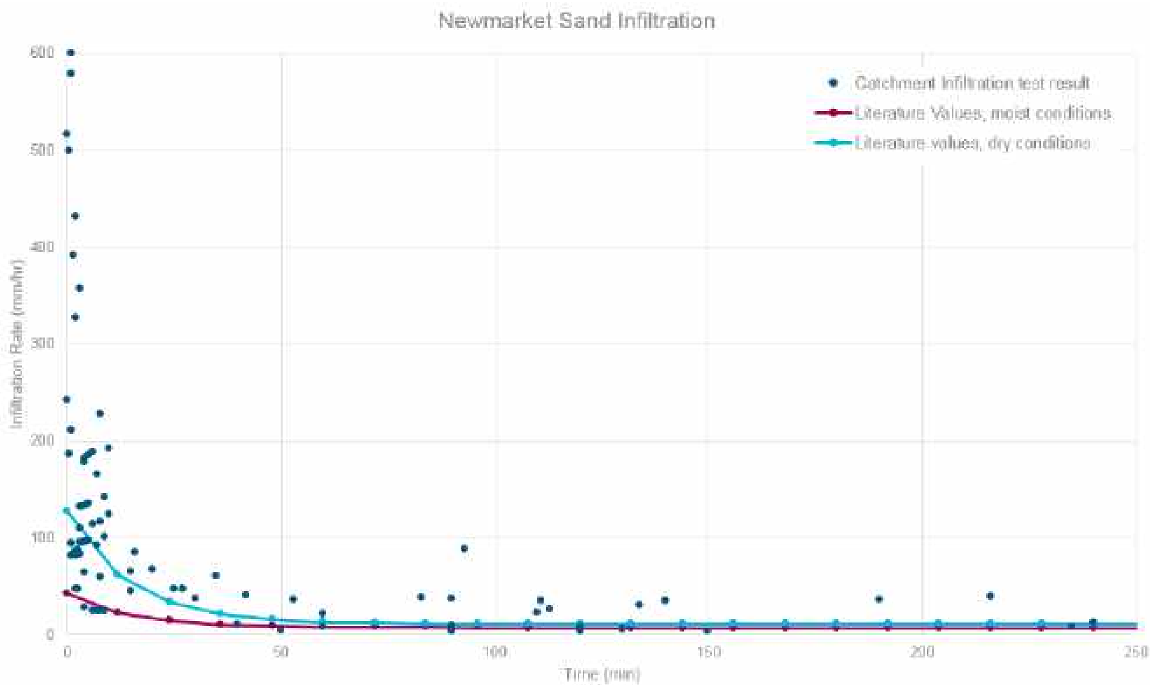


Figure 3-6 Sand Infiltration rates, literature and local testing

Test results are highly variable across the test sites. Results for the initial inundation rate vary from 1718mm/hr to 186mm/hr. Values from Akan (1993) correlate with the catchment infiltration rate, however test results appear to indicate that infiltration rates in Newmarket may be substantially higher.

Due to the highly variable results and spatially restricted nature of the testing, the values in the local soil testing have not been carried forward to modelling. Should further soil infiltration testing across the Newmarket catchment become available, it is recommended that the impact on flood risk is investigated further.

3.2.6 Drainage Network

3.2.6.1 Piped network

Four primary datasets were provided to describe the underlying drainage network:

- Anglian Water (AW) ICM Live model (2018),
- AW GIS dataset (date unknown),
- layer showing soakaways from SCC (date unknown),
- Previous SWMP ICM model (2015)

The report for the previous SWMP model states the representation of the drainage network was based on data provided by AW. Anglian Water confirmed that the ICM Live model is the most up-to-date and complete dataset for surface water modelling.

The BMT review of the previous SWMP model showed that there are large parts of the previous model with no stormwater sewer network. Comparing the previous SWMP model pipe network to the latest available AW dataset shows that they were largely similar and that there are substantial gaps within the AW dataset.

Using the latest AW dataset, a substantial portion of the town is shown as not connected to the surface water system. Most of these locations are shown as located within a Soakaway, as per the layer provided by SCC highways team (Figure 3-7). No further details are available on these soakaways, including capacity, function or connectivity. The soakaway dataset covers a large part of where there are gaps in the AW dataset, however there are also substantial areas of overlap. The existence of soakaways in Newmarket has been confirmed by SCC, however, no details of capacity or mechanism have been confirmed.

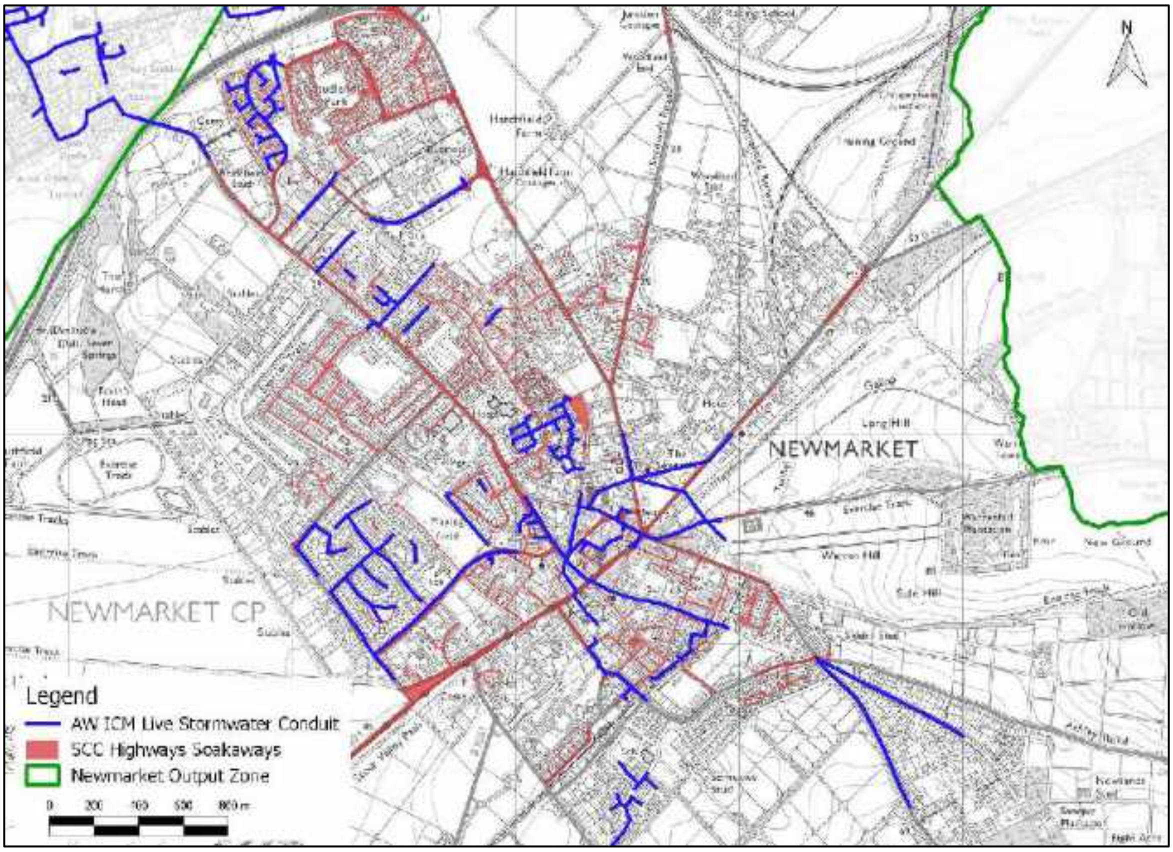


Figure 3-7 Soakaways and piped drainage

The AW pipe data has been modelled explicitly as 1D pipe sections connected to the surface via gullies.

For the soakaways, it has been assumed that surface water runoff enters the gully pits and is capable of being infiltrated or stored offline and does not re-enter the drainage network. Given the lack of information on the capacity of the soakaways, it has been assumed that the limiting factor in volume entering the soakaways is the gully grate and not the total system capacity (Figure 3-8). This is a reasonable assumption in lower order events, however may over estimate the total drainage in higher order events.

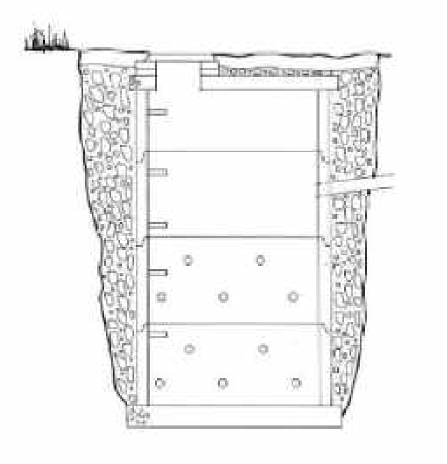


Figure 3-8 Typical Soakaway Cross Section[4]

Given that there is no further information on the soakaway function, these locations have been modelled using the TUFLOW 'Virtual Pipes' feature. This has been applied to where gullies fall within the soakaways layer and are not reasonably adjacent to AW storm sewer.

The 'Virtual Pipes' feature uses the gully data supplied by SCC where flow through each gully is represented using a depth-discharge curve. The 'Virtual Pipes' feature assumes that the limiting factor in the drainage network is the inlet capacity of the grating/pot and not the associated pipe network. The removal of surface water into the stormwater drainage system is limited to represent the maximum flow around the gully pot trap.

3.2.6.2 Gullies

In the previous SWMP model, surface water was transferred from the surface into the sewer via manholes. The discharge was controlled by assuming a standard weir equation where the manhole circumference is taken as the weir width. In the updated modelling, surface water transfer is via the highways gullies, where the discharge is controlled by the gully grate configuration and depth of surface water. This change allows a more realistic representation of the flow into the sub-surface system, including volume and spatial distribution.

Gully data was provided by SCC and neighbouring Cambridge County Council (CCC). The gully locations were sense checked against OS MasterMap and the RoFfSW DTM to ensure they were located on roads and intersections. A comparison to Google StreetView has been carried out in key areas to check the approximate location and number of gullies correlated with photos. Some areas are missing gully information; however, most cases show a good correlation. Typically, missing data areas are on the periphery of Newmarket or are suspected private drainage, such as stables on Hamilton Road. Where the SCC and CCC data overlapped, the SCC data has been chosen, due to its better correlation with StreetView. Figure 3-9 shows the location of modelled gullies and the connectivity to either the drainage network or soakaway.

[4] Kent County Council, 2000, *The Soakaway Design Guide,* https://www.kent.gov.uk/__data/assets/pdf_file/0014/13037/Making-it-Happen-Soakaway-design-guide-July-2000.pdf

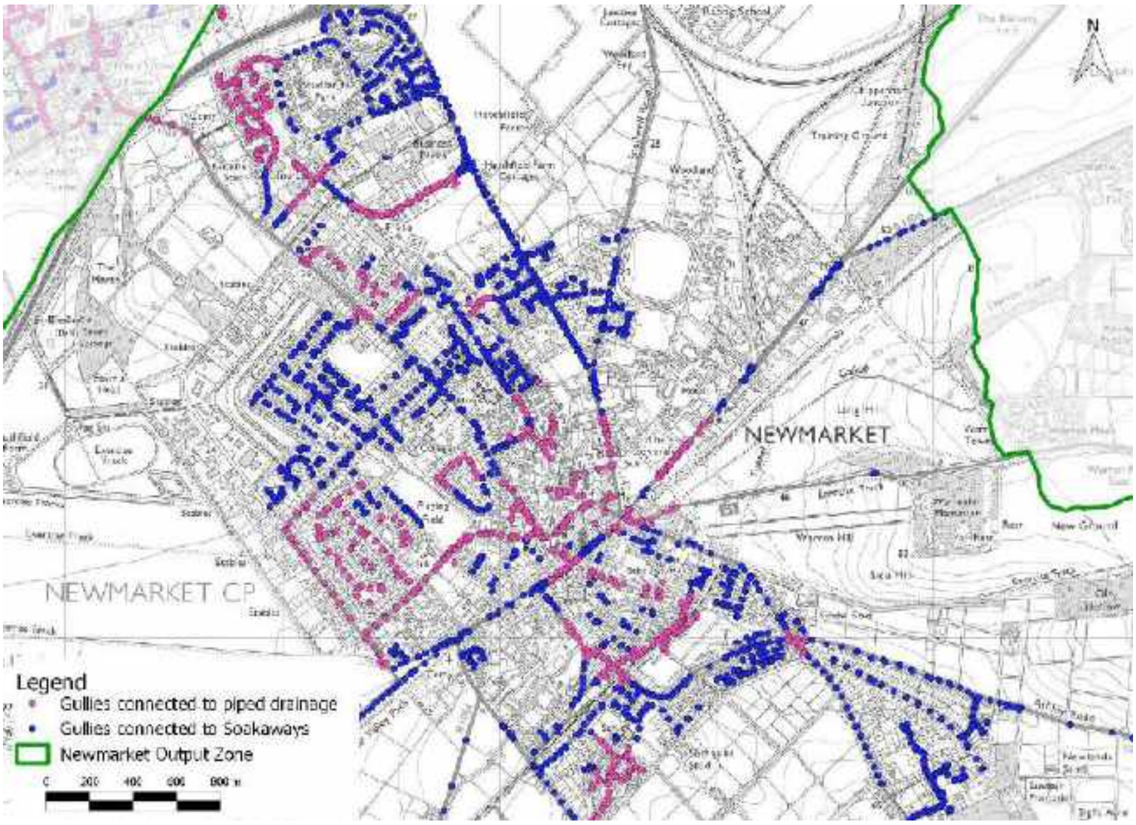


Figure 3-9 Newmarket Gully Connectivity

Most of the study area is listed as having a gully type of ‘grate’, however no further information on the specific British gully type as defined within the Design Manual for Roads and Bridges[5] has been provided. Based on observations on site and StreetView photos, gullies have been assumed to be ‘Type S’. ‘Curb Inlet’ and ‘Side Entry’ type gullies have been assumed to be standard British kerb inlets at 0.3m wide.

Figure 3-10 Type S and Kerb gullies

[5] Design Manual for Roads and Bridges, Volume 4: Geotechnics and Drainage, Section 2: Drainage, Part 3: HA 102/17 Spacing of Road Gullies. (Highways England, February 2018)

3.2.7 Watercourses

The Newmarket watercourses have been schematised in both 1D and 2D components throughout the model. A 1D model representation is the preferred channel schematisation where possible, as it provides greater detail of the channel conveyance and hydraulic features. The decision to use a 1D or 2D schematisation for different reaches of the watercourse was based on the requirements of channel conveyance, model stability and data availability. Data availability was a key driver in this decision process.

Three sources of data were identified for representing the Newmarket watercourses, these were; the SWMP ICM model, survey obtained in 2018 by SCC and the RoFfSW DTM.

The 2018 survey data was provided for the regions between Cheveley Rd to Willow Crescent and Exeter Road to Fordham Road (north of the A14 bypass) as shown in teal in Figure 3-11. The survey was obtained by SCC for this study. The origin of the ICM SWMP model data is unknown. Where there were overlaps with the survey and ICM data, the survey was used due to its recent collection and clear origin. Typically, the agreement between the ICM and survey was reasonable.

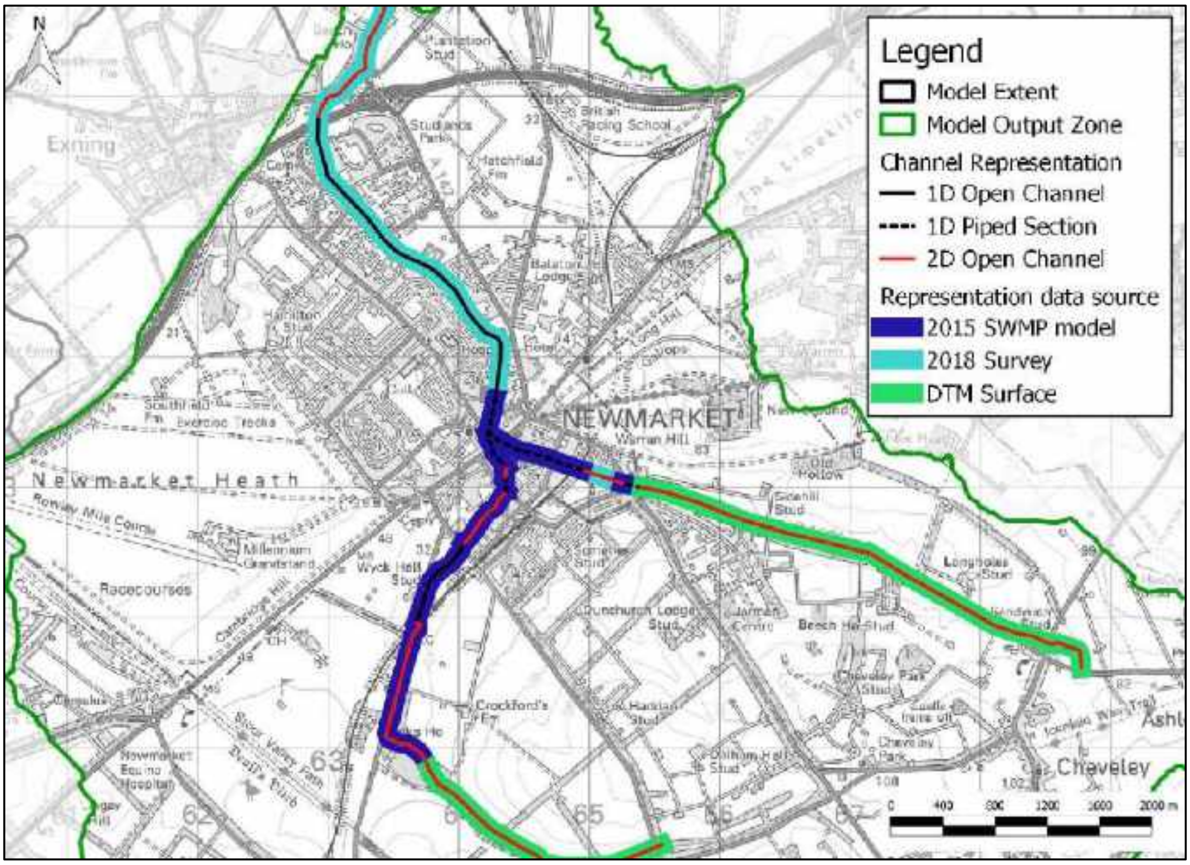


Figure 3-11 Channel Representation and Data Source

Where survey data and ICM 1D data were available, a 1D representation of the watercourse channel was implemented. In some locations the implementation of a 1D schematisation was not feasible due to channel conveyance limitations and instabilities. Stability issues in the 1D, required a 2D representation of the channel between Woodditton Road and The Avenue, as well as between the

A14 and Fordham Road. In these locations the survey and ICM data were used to reinforce the channel features into the 2D representation of the watercourse.

The channel reach adjacent to the allotments was also modelled in 2D and the survey data was used to reinforce the channel thalweg and banks. The width of this channel ranged from 1m – 3m wide and resulted in laterally adjoined 1D/2D boundary cells. This is not a stable or suitable model configuration and a 2D representation was therefore implemented. The channel conveyance in this location small in comparison to the total flow and the channel geometry is uniform, suiting a 2D schematisation.

In the absence of survey data or existing 1D data from the ICM SWMP model, the RoFfSW DTM was used to represent 2D channels in the model. This representation was applied in the upper (south-east) region of the modelled catchment (Figure 3-8).

A Manning's *n* roughness of 0.04 was used for the channel bed and 0.06 for the river banks. This was based on observations on-site as well as survey photos.

A key area of interest in the Newmarket Brook catchment is the stretch of watercourse between Exeter Road and Noel Murless Drive. This was highlighted after the site visit identified several bends and structures in this area. Bend losses were therefore important to represent in this region of the model and the bend angles were estimated using the QGIS angle tool and the Cowan method (Cowan, 1956[6]) was adopted to determine the bend loss coefficients for channels identified with a bend angle of 45 degrees or greater. The Cowan method applies a Manning's *n* multiplication factor as outlined in Table 3-2 to represent the losses associated to channel bends

Table 3-3 1D channel and bend loss multiplier

Channel Section	Cumulative Bend Angle	Multiplication Factor
Sew001	50	1.15
Sew005	90	1.3
Sew012	120	1.3
Sew015	90	1.3
NMK071	80	1.3
NMK061	50	1.15
NMK015	65	1.2
NMK012	55	1.15

[6] Cowan, W.L.m 1956, *Estimating Hydraulic Roughness Coefficients: Agricultural Engineering*, v. 37, no.7

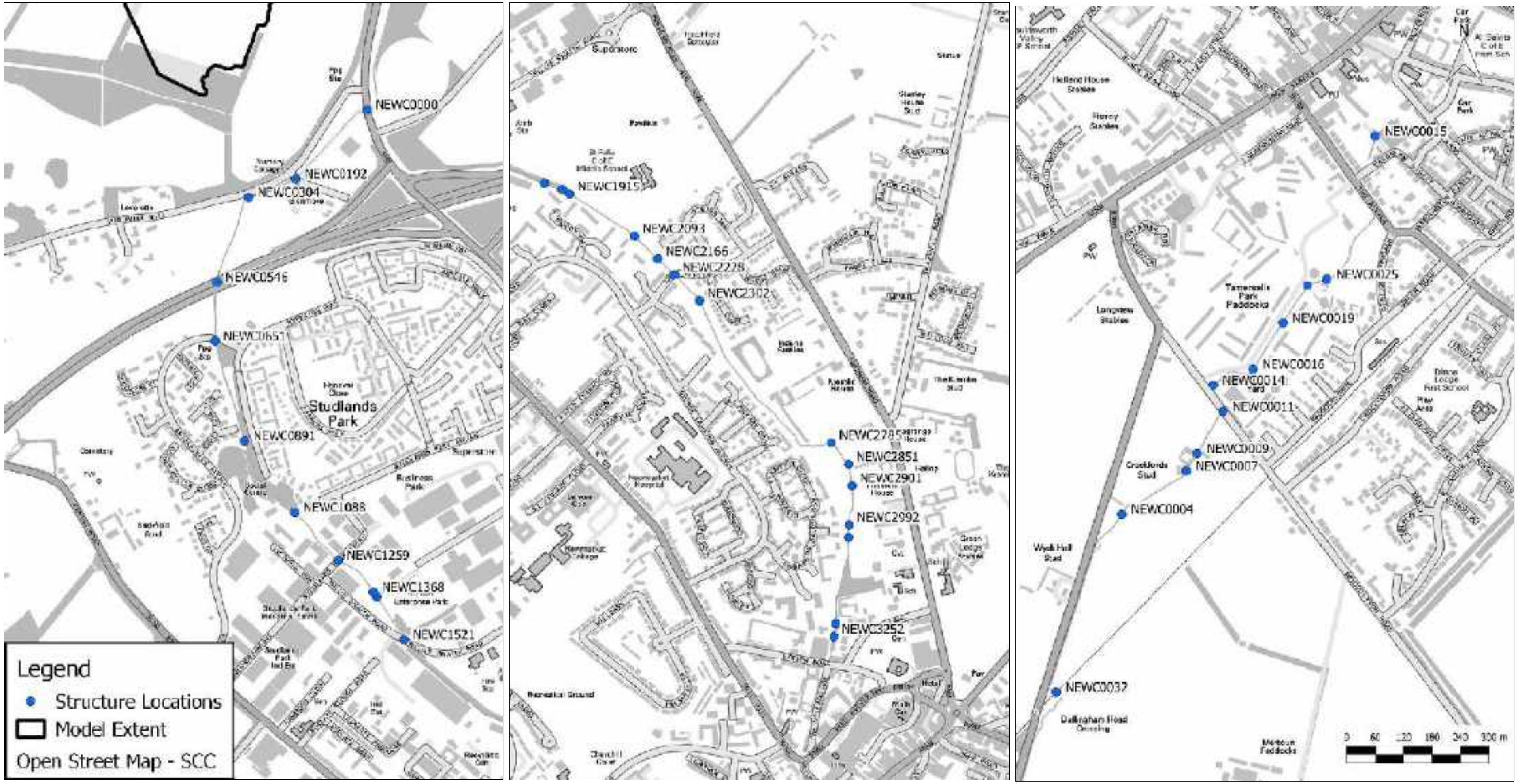
Channel Section	Cumulative Bend Angle	Multiplication Factor
NMK010	55	1.15

3.2.8 Hydraulic Structures

Through a review of the provided data, aerial imagery and site visit, 39 key hydraulic structures including bridges, culverts and weirs were identified within the Newmarket catchment. A number of these structures were excluded from the model as they were not deemed to have a significant impact to the hydraulic behaviour and flood risk to the area of interest. As a result, 31 structures, presented in Figure 3-12 below, were represented in the final Newmarket surface water model.

Individual structure sheets, detailing modelling method, results and structure geometry, are shown in Appendix C

Figure 3-12 Structures identified within Newmarket Catchment



Most structures represented in the updated SWMP model are based on 2018 survey data. This includes all the structures from NEWC3252 to NEWC0000 shown in the left and middle image of Figure 3-9 above. The remaining structures along the southern channel shown in the right image of Figure 3-9 were sourced from the existing ICM model. These structures were modelled using three different TUFLOW schematisation approaches including culvert, B bridge and BB bridge, depending on the structure features.

A structure has been represented as a culvert when the length of the structure is five times greater than the width of the structure. This is because the ‘minor’ hydraulic losses that occur through the culvert become more significant than the ‘major’ expansion and contraction losses of the bridge structure. Standard culvert loss values were applied as per Section 5.7.1 of the TUFLOW Manual (BMT, 2016). Where the length to width ratio of a structure was less than 5, the obstructive capacity of the structure was assessed to determine whether a B or BB bridge type was most appropriate.

B bridges require the modeller to specify an energy loss versus elevation table (LC table) derived from the loss coefficient tables in the “Hydraulics of Bridge Waterways” (Bradely, 1978). The BB bridge type is a new TUFLOW feature that automatically calculates the form losses associated with deck obstruction and the approach and departure flows at the structure. BB bridges are suitable for simple structures with minimal obstruction, such as a flat road deck crossing. The B bridge is necessary for more complex and obstructive structures such as arch bridges, commonly found in the Newmarket catchment.

BMT undertook an assessment of all structures and identified 13 arch bridge structures (as seen in Appendix B) which were modelled using a B bridge and LC table approach. All other bridge structures were modelled using the BB approach. It is also important to consider the representation of the flow overtopping the structure. This can be modelled using a 1D or 2D approach depending on the length of the structure. Typically structures with a length less than 4 metres (2 cells) were modelled using a 1D weir, which has no length component in the weir function. All other structures were modelled using a 2D weir schematisation.

A detailed summary of each structure including schematisation approach, conveyance and data source is provided for in Appendix B.

3.2.9 Boundaries

To simulate the dynamic hydraulic processes in the catchment, the model requires time-varying boundary conditions. For the Newmarket model this included a rain on grid approach and downstream outflow boundaries.

3.2.9.1 Rainfall

The rainfall generation process is described in Section 2.1. The rain-on-grid (direct rainfall) method has been used, which applies the rainfall directly onto the entire catchment land surface. This approach is particularly beneficial for catchment-based studies and the impact of dry and saturated ground conditions can be assessed. The direct rainfall is assumed to be spatially uniform across the entirety of the model extent. This approach differs to the ICM SWMP model which provided upstream source inflows derived from a hydrological model assessment.

A hydraulically routed model, used in the updated SWMP model, provides a more detailed representation of the runoff routing process than a hydrological model, which requires assumptions around the topography, soil and landuse to calibrate the routing coefficients. An example of the 1% AEP rainfall event is shown below in Figure 3-13 and the total rainfall depths for each event are shown in Table 3-4.

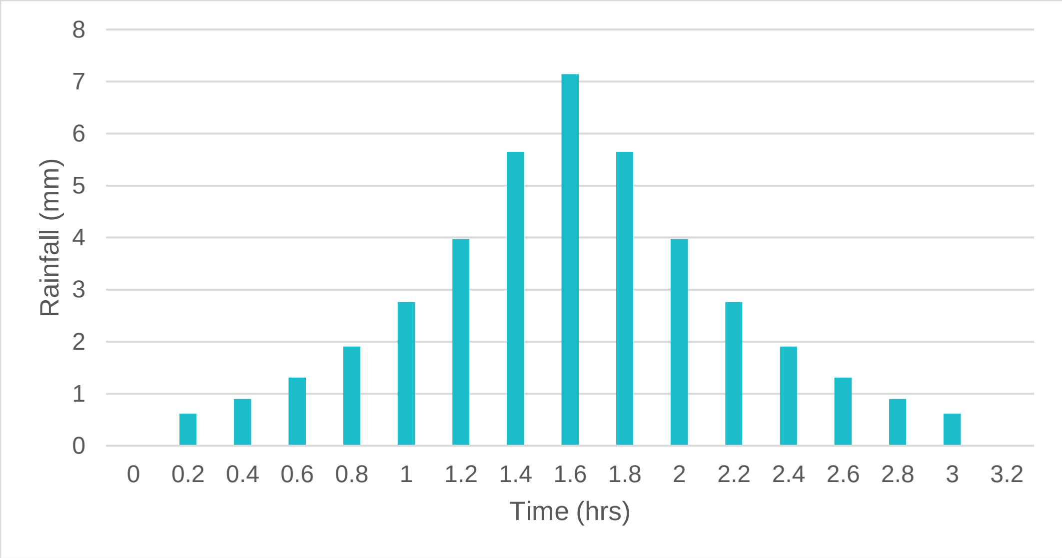


Figure 3-13 1% AEP rainfall hyetograph

Table 3-4 Total Rainfall Depths

Rainfall Event	Total Rainfall Depth (mm)
5% AEP (1 in 20 year)	26.11
3.33% AEP (1 in 30 year)	29.35
1.33% AEP (1 in 75 year)	38.15
1% AEP (1 in 100 year)	41.4
0.1% AEP (1 in 1000 year)	79.48

3.2.9.2 Outflow

A 2D stage discharge (HQ) boundary was used in three of the downstream boundary locations as shown in Figure 3-14. These locations were chosen where predicted flow routes continued outside of the defined model extent. They allow for the removal of water from the model preventing artificially elevated water levels within the areas of interest. The impacts of downstream flow constrictions are not considered when using HQ boundaries.

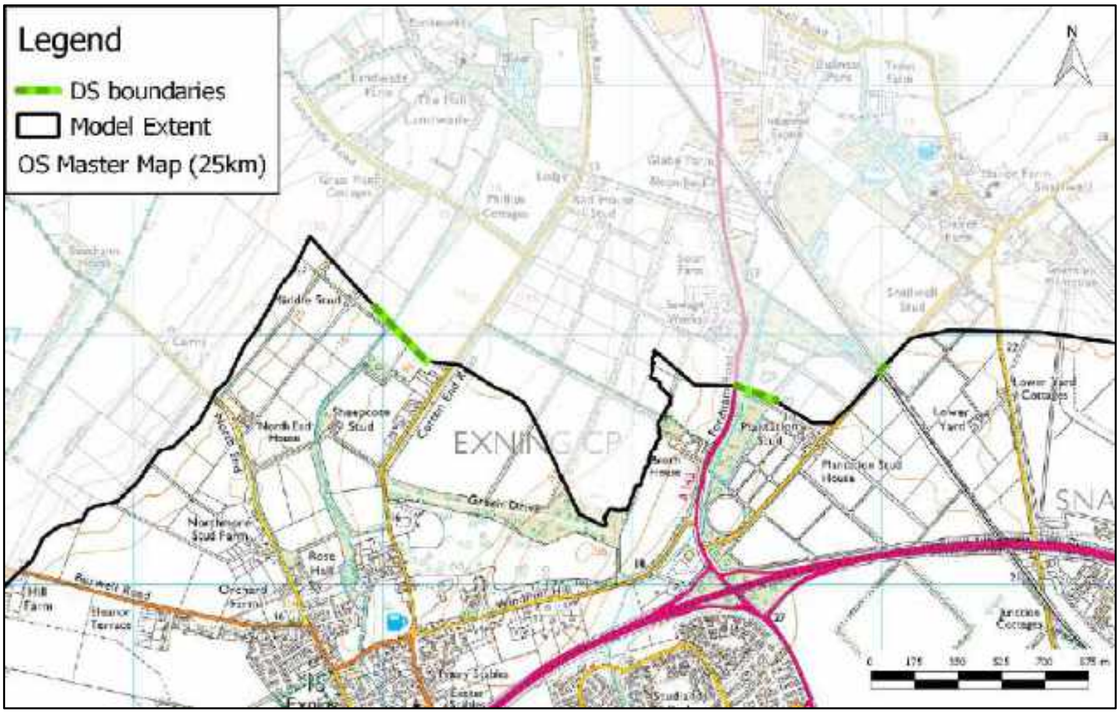


Figure 3-14 Downstream Model Boundaries

The HQ boundary uses the slope of the ground (m/m) to calculate a stage-discharge curve. Based on the upstream water level, the corresponding flow within the stage-discharge curve is used to determine the volume of water leaving the model from each boundary cell. Boundaries are located away from the area of interest, to reduce the impact of the stage-discharge assumption on the model results in key locations.

An additional outflow boundary was modelled at the railway underpass at Old Station Road to represent water leaving the modelled area and entering the underpass. A normal flow boundary (Type ‘HT’) was used. This boundary type assumes uniform flow based on the ground slope of adjoining cells. It assumes constant water depth where flow leaves the model downhill and was found to provide a more stable solution than the HQ boundary in this location.

4 Model Simulation

4.1 Model Run Parameters

The hydraulic model was simulated using the HPC Solver for TUFLOW build 2018-03-AB-iSP. The only change to default parameters was to reduce the Cell Wet/Dry Depth in line with recommendations within the TUFLOW Manual[7] for direct rainfall modelling. The model naming convention is outlined in Table 4-1.

Table 4-1 Model Naming Convention

SCC_NMK_~s1~_~e1~_~e2~_039.tcf			
~e1~	Rainfall Event	0020R	5% AEP event
		0030R	3.33% AEP event
		0075R	1.33% AEP event
		0100R	1% AEP event
		1000R	0.1% AEP event
		0100RCCL	1% AEP event with 'central' climate change allowance
		0100RCCU	1% AEP event with 'upper end' climate change allowance
		May2012	May 3rd, 2012 rainfall event
~e2~	Storm Duration	01HR	1-hour storm duration
		03HR	3-hour storm duration
		06HR	6-hour storm duration
~s1~	Scenario	WET	Baseline Model
		DRY	Sensitivity Test 1, increased soil infiltration to represent greater infiltration catchment conditions
		BLOCK01	Sensitivity Test 2, blockage of key structures

The baseline model was simulated for the storm events listed within Section 2.1 for the 3 hour storm duration. In addition, two climate change event scenarios were simulated for the 1% AEP event; 'lower' (20%) allowances and 'upper' (40%) allowances (Section 2.4).

4.2 Model Validation

The ICM SWMP model was calibrated to the Fordham stream gauge station situated 3 km downstream of Newmarket. Several limitations in this calibration exercise were raised in the BMT SWMP model review, including the link between the fluvial Fordham gauge and the upstream pluvial Newmarket catchment. Because of this review, the Fordham gauge was not included in the model domain of the update and has not been used in this validation exercise. In the absence of this gauge data, the updated model has been validated against historical event data.

Historical flooding events within the Newmarket catchment were reviewed and the quality and availability of observed data for each event was assessed. A major flood event in September 1968

[7] Page A-5 TUFLOW User Manual Build 2016-03-AA (BMT WBM)

resulted in much of the town becoming inundated. This event was omitted from the validation exercise due to a lack of available data and appropriate baseline reference point, as significant hydraulic changes to the town and been implemented over time. Events in 2013 and 2016 were also excluded as there was very limited flood mark information available. Due to the availability of flood marks (community photos provided by SCC) and rainfall data (provided by EA), the May 2012 event was the only flooding event that the Newmarket Catchment model was validated against.

Rainfall events from 2008 to 2010 that were used in the ICM SWMP model did not result in widespread inundation of properties in Newmarket and were not assessed in this validation. In addition, rainfall events in April 2013 and January 2016 which led to isolated locations of flooding, were not widespread enough and did not possess sufficient evidence to be considered for validation.

Rainfall gauge records closest to Newmarket were sought to capture the most accurate record of the 2012 event. Available sources are listed below in Table 4-2 and shown in Figure 4-1.

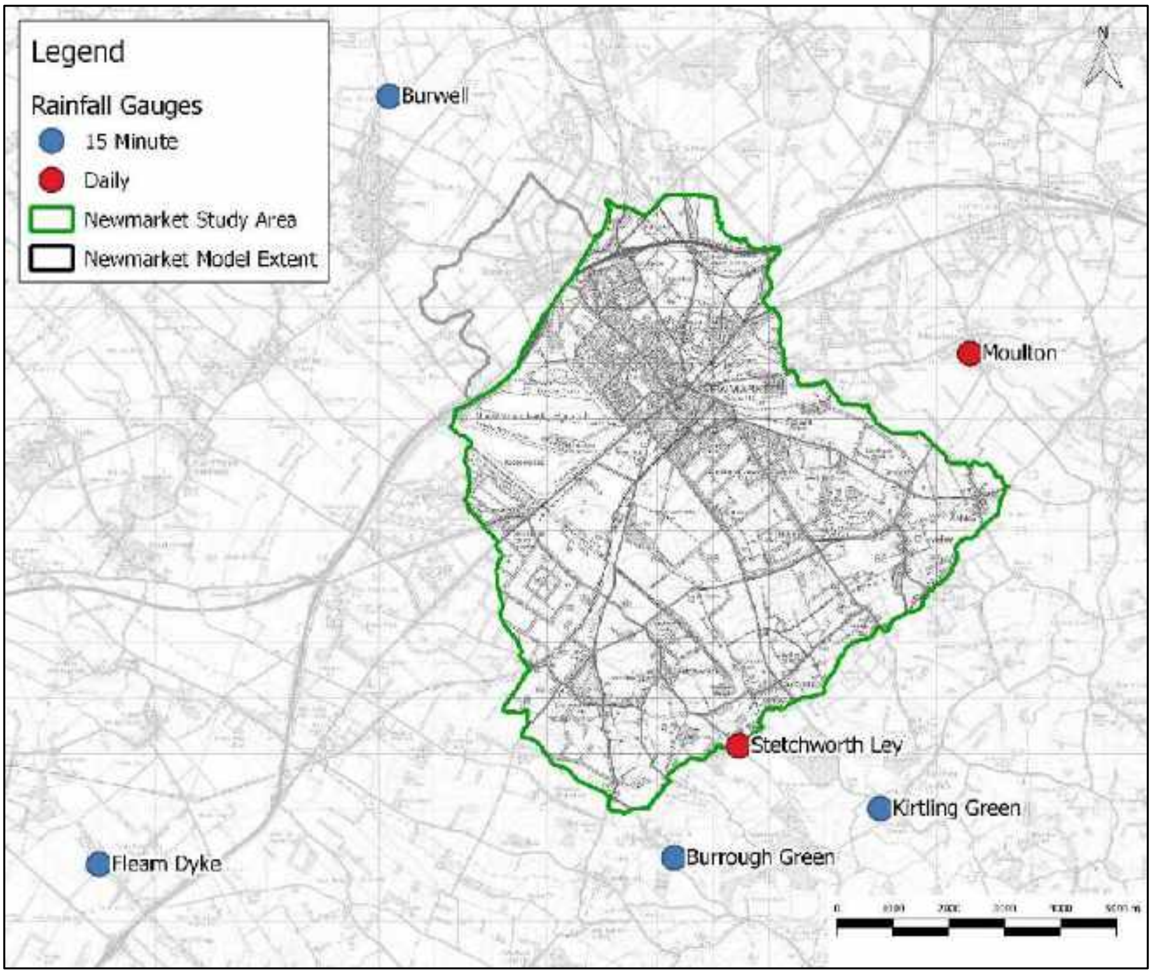


Figure 4-1 Rainfall Gauge Locations

Table 4-2 Rainfall Gauge Data Summary

Gauge Station	Distance to Newmarket town centre (km)	Data Owner	Data Frequency
Burwell	7.5	EA	15 minute
Kirtling Green	8.1	EA	15 minute
Burrough Green	8.1	EA	15 minute
Fleam Dyke	13.3	EA	15 minute
Moulton	5.1	EA	Daily
Stetchworth Ley	6.1	EA	Daily

Figure 4-1 shows that the rainfall gauges identified are all situated outside the catchment extent. This is a limitation of the validation data, as the spatial variation of the rainfall event within the Newmarket catchment may not be reflected accurately in the gauge record. The Moulton and Stetchworth Ley gauges have not been used as daily rainfall measurements are not appropriate for modelling short duration storms due to the low resolution of the recording time interval.

The four 15-minute gauges listed in Table 4-2, are tipping bucket rainfall gauges. This frequency of recorded rainfall provides a suitable representation of the temporal rainfall pattern for the validation model. A data quality check confirmed that there was no missing or anomalous data in the recorded dataset; all gauge quality flags have been classes as 'Good'. The correlation of total rainfall recorded in each gauge for the May 2012 event is reasonable, therefore all four 15-minute gauges were used in the validation assessment.

The data from the 15 minute gauges has been spatially interpolated to estimate the rainfall in the Newmarket catchment for the May 2012 flood event. The 'Inverse Depth Weighting' (IDW) spatial interpolation approach has been used.

The rainfall gauge data indicates that the May 2012 flood event was the result of rainfall that fell on the catchment from approximately 7.30pm on the 2nd May 2012 to 6.30am on the 3rd May 2012 (Figure 4-2). In the 48 hours preceding this event there was 9.6mm of rainfall recorded at the Burrough Green gauge. Similar totals were recorded in the 3 other gauges used. Due to this volume of rainfall leading up to the rainfall event on the 2nd May, antecedent conditions were added to validation event. This was represented in the model by assuming the soil is in a moist state prior to the main rainfall burst on the 2nd May. For further information on soil antecedent conditions, refer to Section 4.5.1

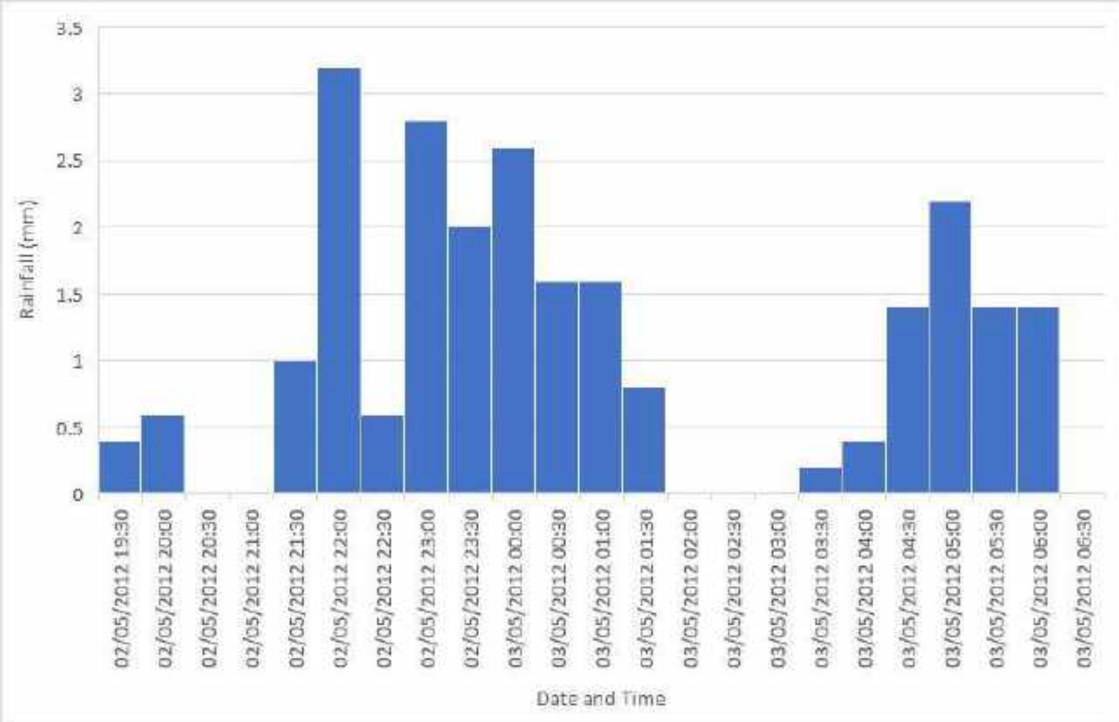


Figure 4-2 Burwell Gauge Rainfall Record

The peak modelled depths were compared to anecdotal evidence of the event in the form of photos (Appendix F). The exact time at which the photographic evidence was taken is not captured and the depths of ponded water were not measured. Therefore, this validation is limited to confirming locations of predicted inundation and a comparison of estimated depth of ponding. In addition, the photographed locations are limited to a single area of known flooding in Newmarket and do not have spatial coverage across other aspects of the flow path (Figure 4-3). Locations such as the ponding along Ashley Road, Heathbell Road, Woodditton Road and The Avenue cannot be validated using the anecdotal dataset.

There are anecdotal reports that structures in Newmarket Brook were severely blocked in this event. As such, structure NEWC3020, located adjacent Sassoon Close has been completely blocked for the validation event.

Figure 4-3 May 2012 validation photo locations

The comparision of the validation model to the photos are presented in Appendix F.

In conclusion, the validation shows that the model represents the conditions of the May 2012 storm event and corresponding flooding reasonably well. Depth, extent and flooding mechanisms correlate with the images provided.

The validation exercise highlights several key sensitivities in the modelling, including the impact on out of bank flooding from blockages and key bank levels.

There are several key limitations to the validation exercise carried out. These include:

- Rainfall gauges not within the Newmarket catchment may not reflect the spatiality of rainfall.
- Photo evidence is restricted to Sassoon Close. Validation has not been carried out in other areas of the model.
- The validation event as modelled shows flooding in areas such as the Allotments and Healthbell Road, for which there is no anecdotal evidence.
- Validation has not been carried out across a number of events of differing magnitudes, restricting the robustness of the validation.

4.3 'Do Minimum' Scenario

The 'Do Minimum' Scenario is often required for Outline Business Case (OBC) assessments with the EA. The 'Do Minimum' scenario is defined *'as the minimum action or intervention needed to ensure that the legal requirements or the performance of the asset as set out in the Asset Management Plan (AMP) is met'*. Furthermore, *'Do Minimum' is appropriate where there is a minimum legal requirement that has to be met. Similarly, where action is required under Health & Safety legislation, it would again be appropriate to use do-minimum.'*[8]

The 'Do Minimum' scenario in the case of the Newmarket SWMP, is defined as the baseline flood risk. This scenario represents stakeholders carrying out their minimum duties, including watercourse and drainage asset management. The assumptions within the baseline scenario are detailed in Section 3.

4.4 'Do Nothing' Scenario

A 'Do Nothing' scenario has been considered to inform a future outline business case. The Do-Nothing option is based on a 'walk-away' scenario, the premise that *'action, maintenance and repair ceases'*[9] on the floodplain assets. In a catchment, this may include waterway and channel maintenance, gully clearing or blockage removal.

The 'Do Nothing' scenario results can be used to approximate the influence of routine maintenance and ongoing catchment management.

4.4.1 Methodology

The specific methodology requirements in a do-nothing scenario are not defined by the EA or the treasury. In consultation with SCC, the following changes have been made to the baseline model to assess a scenario in which no further action on floodplain assets was undertaken:

- 50% increase in channel roughness,
- 50% blockage of channel structures (identified in Figure 3-12), and
- 100% blockage of gully pits.

Additional form losses at blocked structures have not been applied.

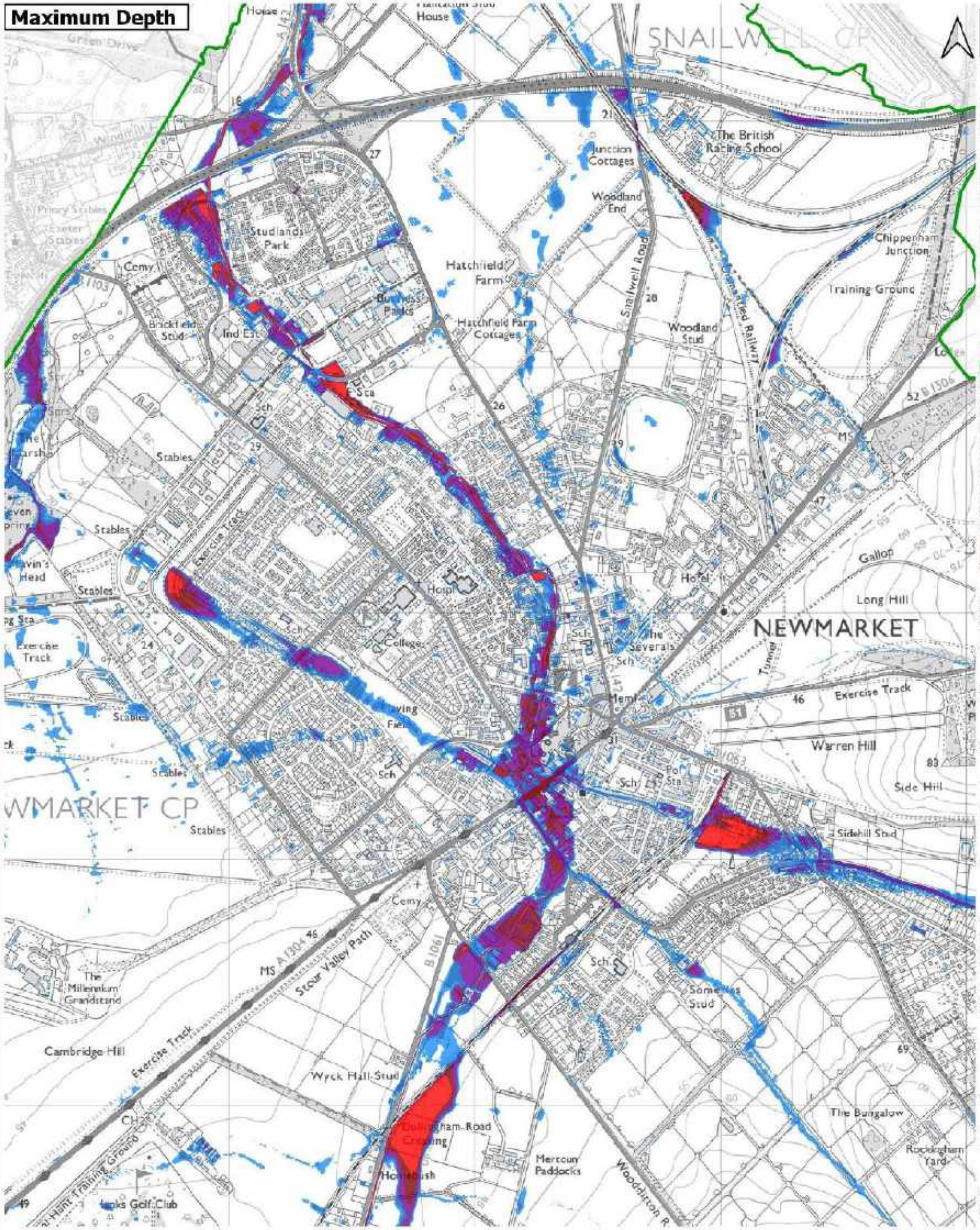
[8] Environment Agency, March 2010, *Flood and Coastal Erosion Risk Management Appraisal Guidance*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/481768/LIT_4909.pdf
[9] Environment Agency, May 2018, *RMA Short Form Business Case Template*, https://www.gov.uk/guidance/flood-and-coastal-defence-appraisal-of-projects

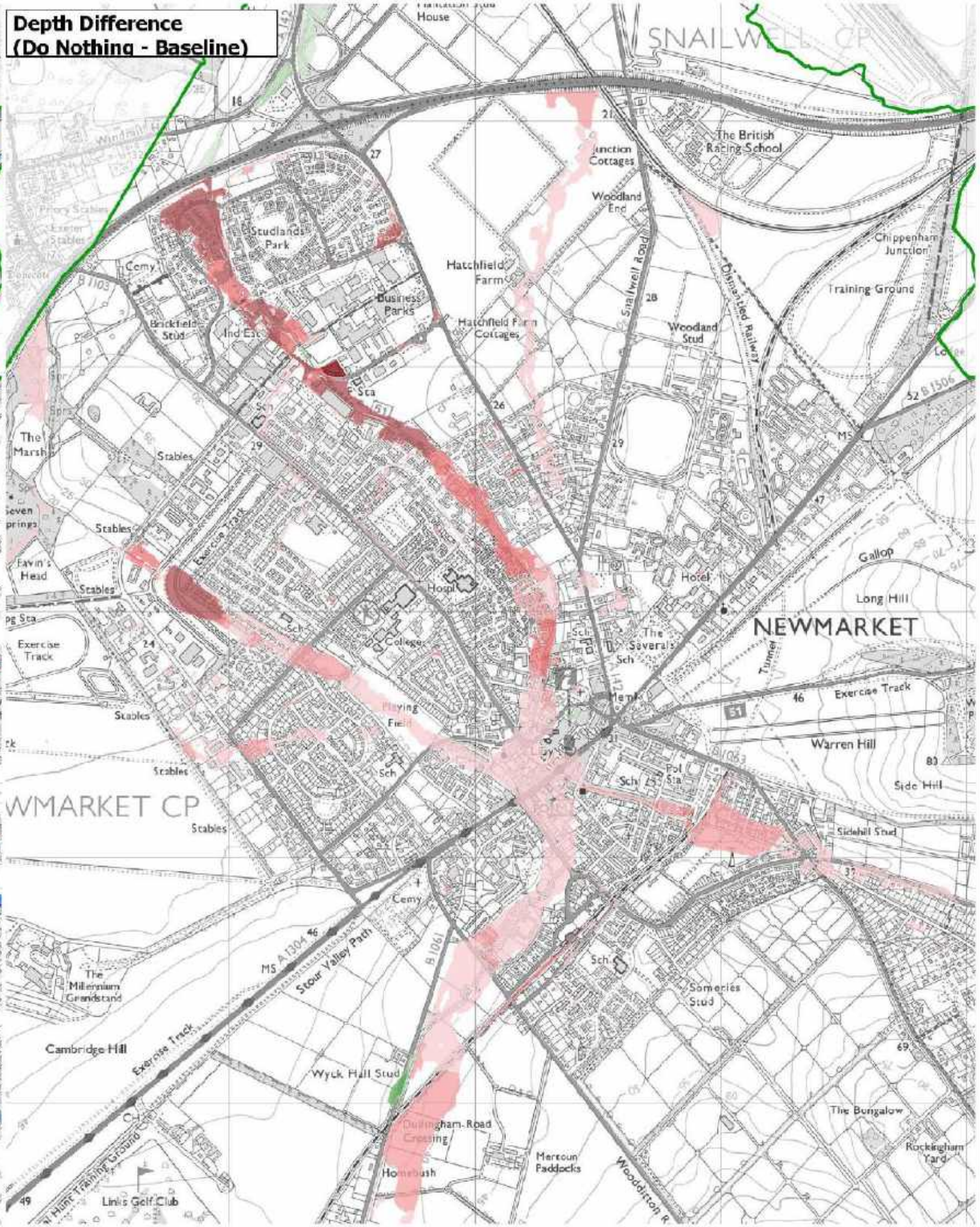
4.4.2 Results

The ‘Do Nothing’ Scenario typically represents an increase in flood depth throughout the Newmarket catchment (Figure 4-4 and Figure 4-5).

Throughout most of the catchment, there is moderate increase in depth (0.05m to 0.10m) in both the 1% and 3.33% AEP events. Isolated locations show a decrease in flood depth. These locations are typically downstream of major structures, which are modelled as 50% blocked, or dominated by flooding caused by outfalls of the drainage network, which is reduced as the gullies are blocked.

The increase in flood depth is exacerbated moving downstream. This is due to the increasing influence of blocked structures and reduced channel capacity.





Model Output Zone

Maximum Depth (m)	Difference in Peak Depth (m)	
0.10 - 0.25	<-0.5	-0.01 to 0.01
0.25 - 0.50	-0.5 to -0.2	0.01 - 0.05
0.50 - 1.00	-0.2 to -0.1	0.05 - 0.1
1.00 - 1.50	-0.1 to -0.05	0.1 - 0.2
> 1.50	-0.05 to -0.01	0.2 - 0.5
		>0.5

Title:
Newmarket SWMP Model Update
'Do Nothing' Scenario, 3.33% AEP, Maximum Depth and Difference to Baseline

Drawing: **4-4** Rev: **A**

Drawn/Check: REJ
Date of Issue: 02/04/2019
Scale: 0 100 200 300 400 500 m

BMT

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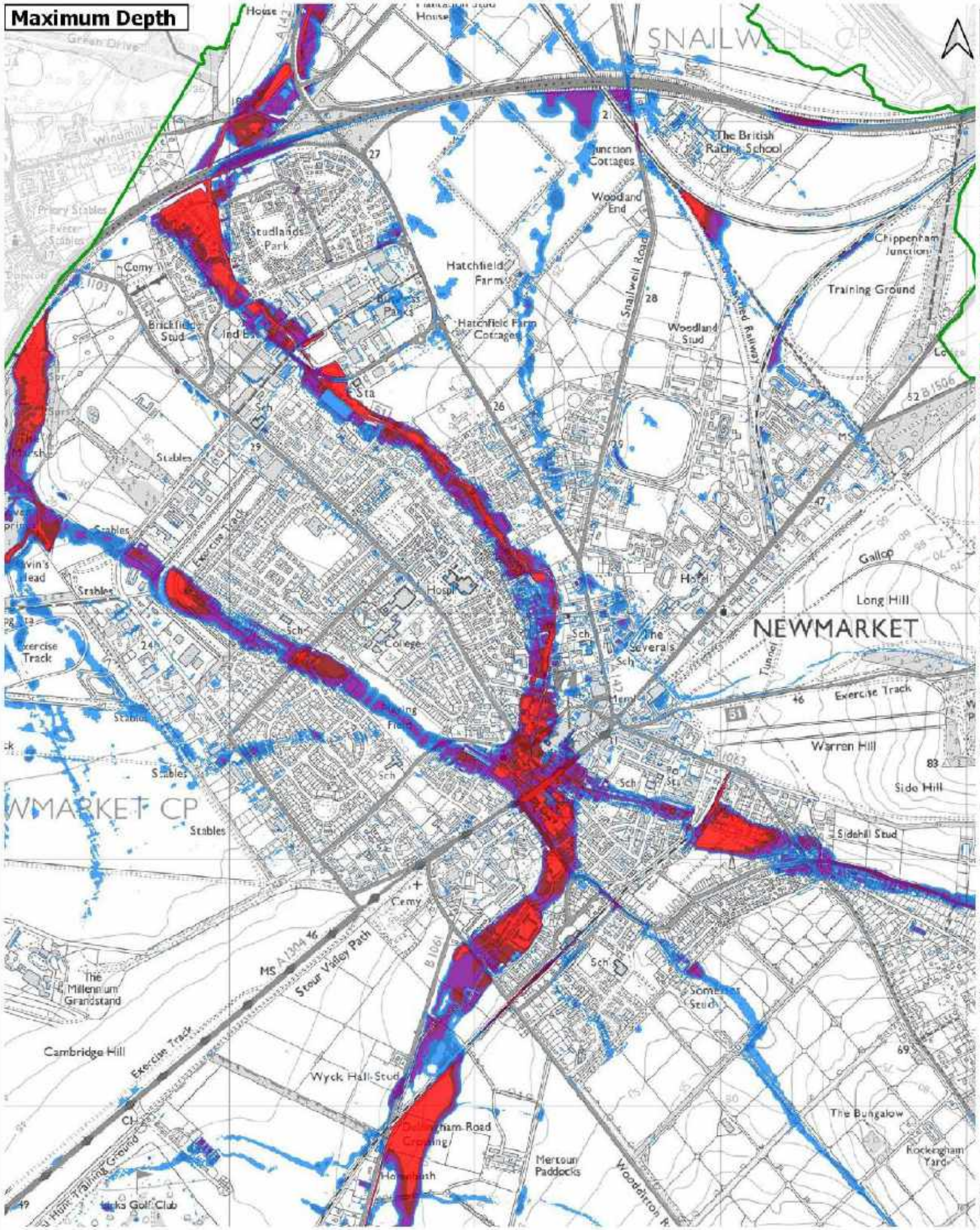

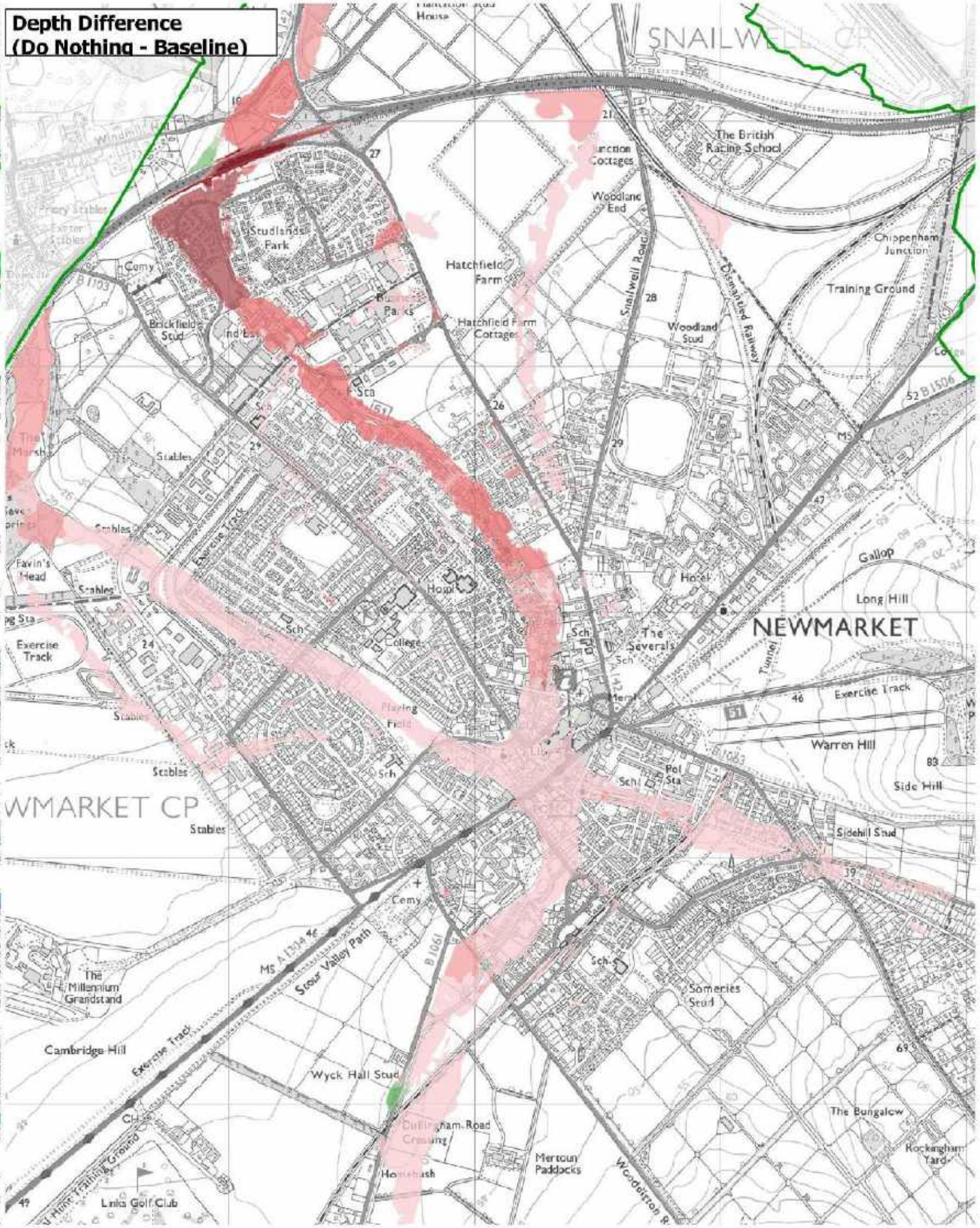

Model Output Zone

Maximum Depth (m)
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Difference in Peak Depth (m)
- <-0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title:
Newmarket SWMP Model Update
'Do Nothing' Scenario, 1% AEP, Maximum Depth and Difference to Baseline

Drawing: 4-5
Rev: A

Drawn/Check: REJ
Date of issue: 02/04/2019
Scale: 0 100 200 300 400 500 m

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4.5 Sensitivity Testing

Sensitivity analysis is the study of how the variation in the output of a model (depth, velocity, hazard, etc.) can be apportioned, qualitatively and quantitatively, to different changes in the model inputs (model variables, boundary conditions and parameters).

Sensitivity analysis has been used to identify:

- The factors that have the most influence on model outputs;
- The factors that need further investigation to improve confidence in the model; and
- Regions in space of inputs where the variation in the model output is maximum.

The change in maximum flood depth has been plotted for each sensitivity test in each below section. Areas of green indicate a decrease in flood risk and red areas indicate an increase in flood risk when compared against the baseline scenario.

4.5.1 Infiltration

Infiltration has been highlighted as a key mechanism in the Newmarket catchment. The catchment is underlain by sandy soil, which has a large range of infiltration coefficients, ranging from very high infiltration to quite impeded. Thus, the range of infiltration values in Newmarket catchment have been sensitivity tested.

Sensitivity testing has been carried out to test the impact of infiltration rates on flood risk in Newmarket. The baseline model uses Horton infiltration rates, chosen at the lower threshold of the ranges presented in Akan (1993). This models impeded infiltration rates, representing soil types at the lower band of infiltration.

The sensitivity test carried out uses Horton infiltration rates at the upper end of the range presented in Akan (1993). This represents the least conservative scenario; soil types highly prone to infiltrate or very dry conditions.

The Horton infiltration parameters for each scenario are detailed in Table 4-3 below. The standard Horton decay rate remains the same at 4.14.

Table 4-3 Sensitivity Testing; Horton Infiltration Parameters

Soil Class	Baseline (low infiltration condition)		High infiltration condition	
	Initial Infiltration Rate (mm)	Final Infiltration Rate (mm)	Initial Infiltration Rate (mm)	Final Infiltration Rate (mm)
Clay to Sandy Loam	18.0	0.0	51.0	1.3
Clayey Loam to Sandy Loam	25.0	1.3	76.2	3.8
Loam to Clayey Loam	25.0	0.0	76.2	1.3

Soil Class	Baseline (low infiltration condition)		High infiltration condition	
	Initial Infiltration Rate (mm)	Final Infiltration Rate (mm)	Initial Infiltration Rate (mm)	Final Infiltration Rate (mm)
Loam to Sandy Loam	25.0	3.8	76.2	7.6
Peat	7.6	0.0	25.4	1.3
Sand to sandy Loam	43.0	7.6	127.0	11.4
Chalky, silty Loam	25.0	3.8	76.2	7.6

The results show that the catchment is highly sensitive to changes in the initial soil moisture content and soil infiltration. The difference in maximum water depth is presented in Figure 4-7.

When comparing low and high infiltration conditions (Figure 4-7), there are substantial changes in extent and depth across the entire catchment. A number of maximum depths and depth differences are shown at key points across the catchment in Figure 4-7. The change results in widespread reductions in flood depths, a result of the increased infiltration. The cumulative infiltration over the duration of the event at The Avenue at Tattersalls Gate is shown in Figure 4-6 for the 3.33% AEP event.

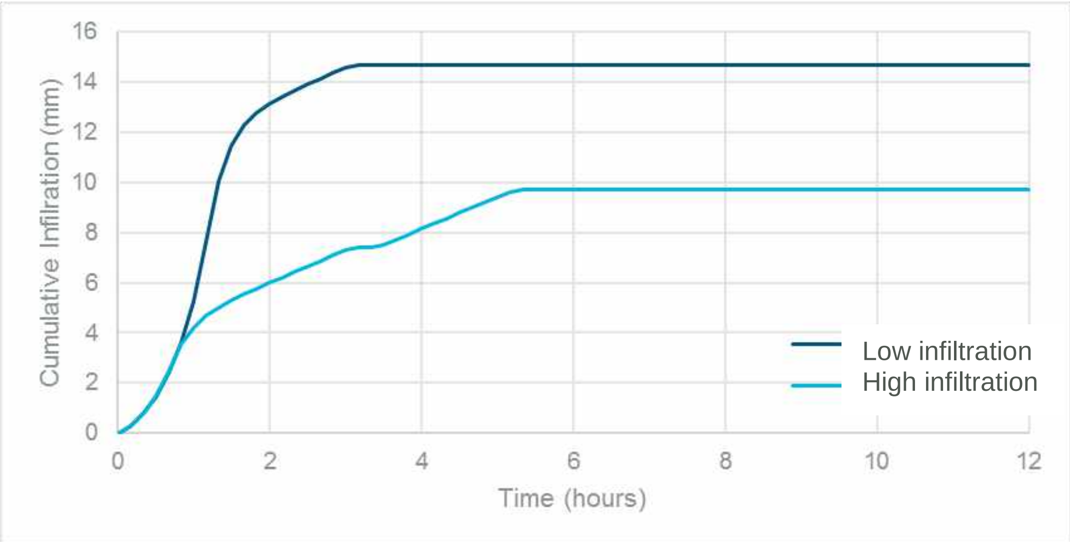
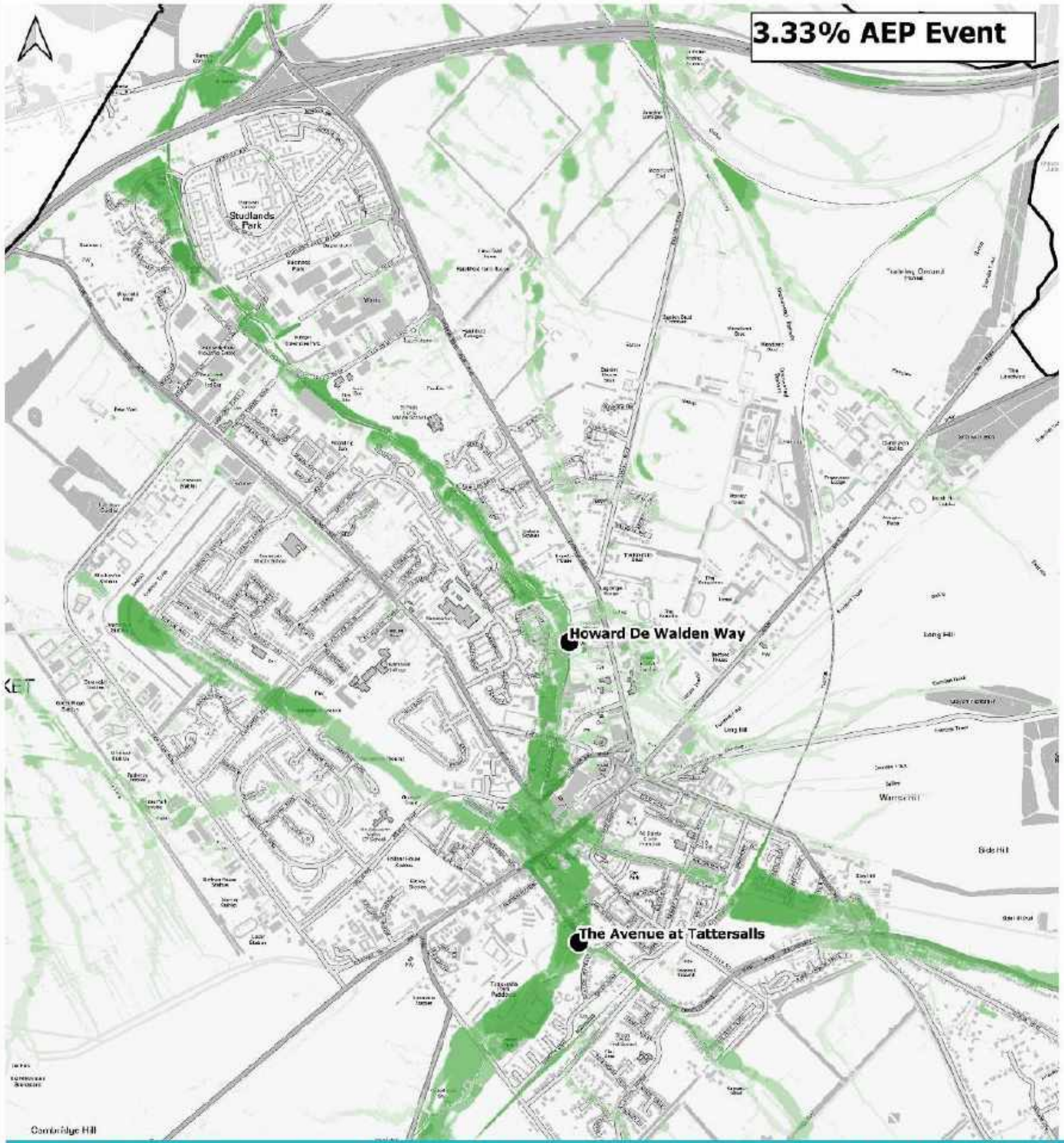
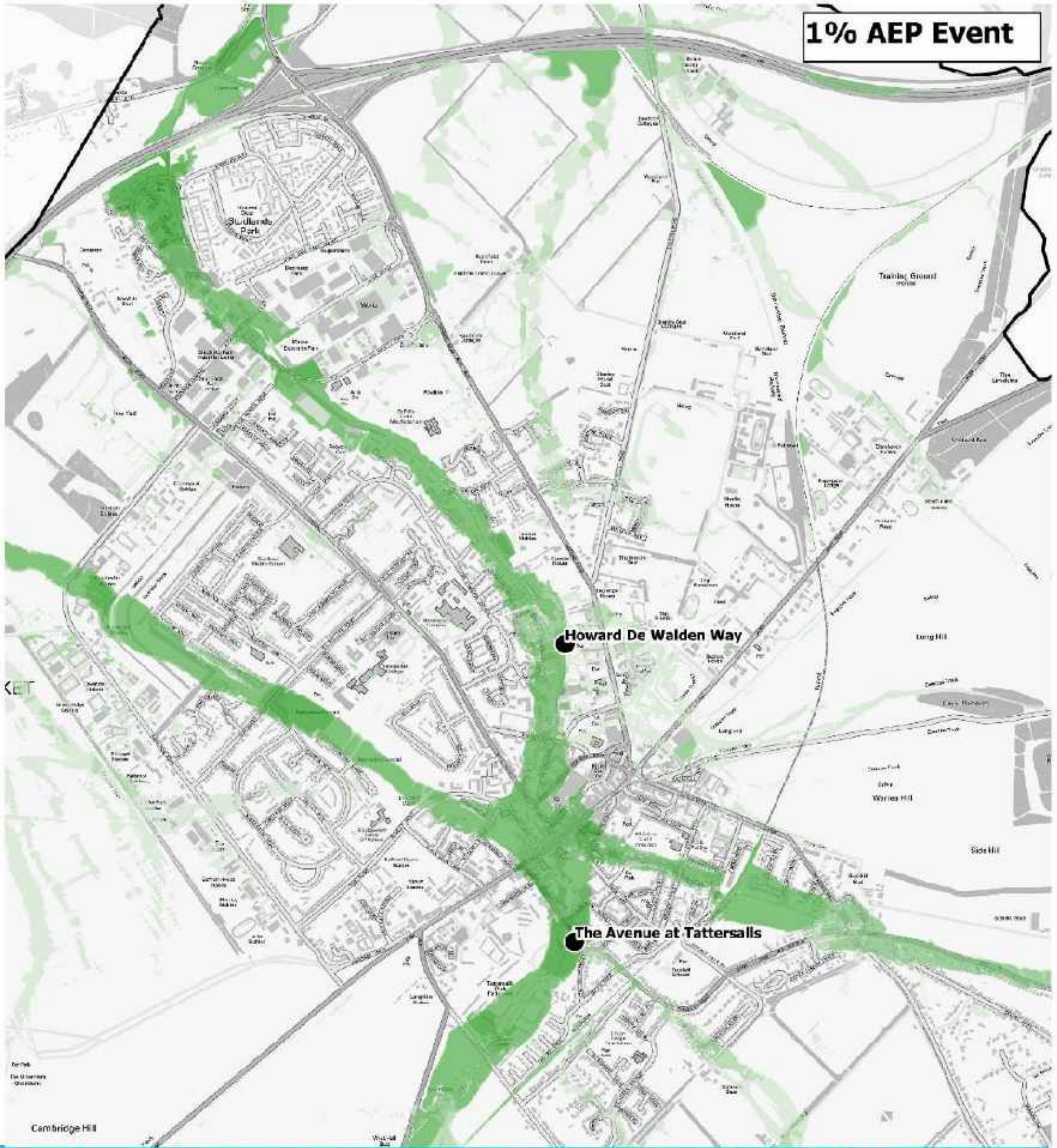


Figure 4-6 Cumulative Infiltration over time, Low and high infiltration conditions, 3.33% AEP

In addition to the increased infiltration, the time to peak flood depth in the impeded infiltration catchment is greatly increased, as the flood wave is slowed through the upper catchment and more of the initial rainfall is infiltrated. An example of this is at The Avenue near Tattersalls gate (point 1, Figure 4-7) where in the 3.33% AEP event, the time to peak in low infiltration conditions is 3hrs, 53mins after the onset of rain, and the time to peak in high infiltration conditions is 7hrs, 5 mins, a delay of 3hrs and 12 minutes.

In conclusion, the assumption of a low or high infiltration capacity has a very significant impact on flood risk in Newmarket. This assumption impacts flood depth, extent and time to peak. It is strongly recommended that should further detailed modelling be carried out; additional soils and moisture content testing is carried out. The baseline assumption of a low infiltration catchment presents the most conservative assessment of flood risk.





Location ID	Location Name	Dry Conditions, Maximum Depth (m), 3.33% AEP	Local Testing, Maximum Depth (m), 3.33% AEP	Depth Difference (m)	Dry Conditions, Maximum Depth (m), 1% AEP	Local Testing, Maximum Depth (m), 1% AEP	Depth Difference (m)
1	The Avenue at Tattersalls gate	0.37	0.36	0	1.1	1.1	-0.01
2	Heathbell Road at the Allotments	0.65	0.61	-0.03	1.68	1.66	-0.02
3	High Street at the Jockey Club	0.61	0.61	0	1.39	1.39	-0.01
4	Frampton Close FAS Basin	1.53	1.52	0	1.92	1.9	-0.02
6	Brickfields Road near Waterloo Close	1.63	1.61	-0.01	2.44	2.41	-0.02
5	Willie Snaith Road at Fire Station	1.63	1.61	-0.01	3	2.99	-0.01

Model Extent
Depth Inspection Points

Change in Peak Depth (m)
- <-0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title:
Sensitivity Testing - Infiltration
Low minus High Infiltration Conditions

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Rev: A

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4.5.2 Channel Blockage

Anecdotal evidence suggests that flood risk in Newmarket is exacerbated by excessive channel blockage. The baseline assessment of flood risk assumes that the channel is unblocked. To assess how sensitive the modelled flood risk is to blockage, two structures have been selected for blockage testing. The nature of structure blockage often provides an increase in flood risk upstream and a corresponding decrease downstream. Structure blockage in series can often distort results and overlook the impact of blockage at each discrete location. Thus, only two structures have been assessed individually against the baseline results.

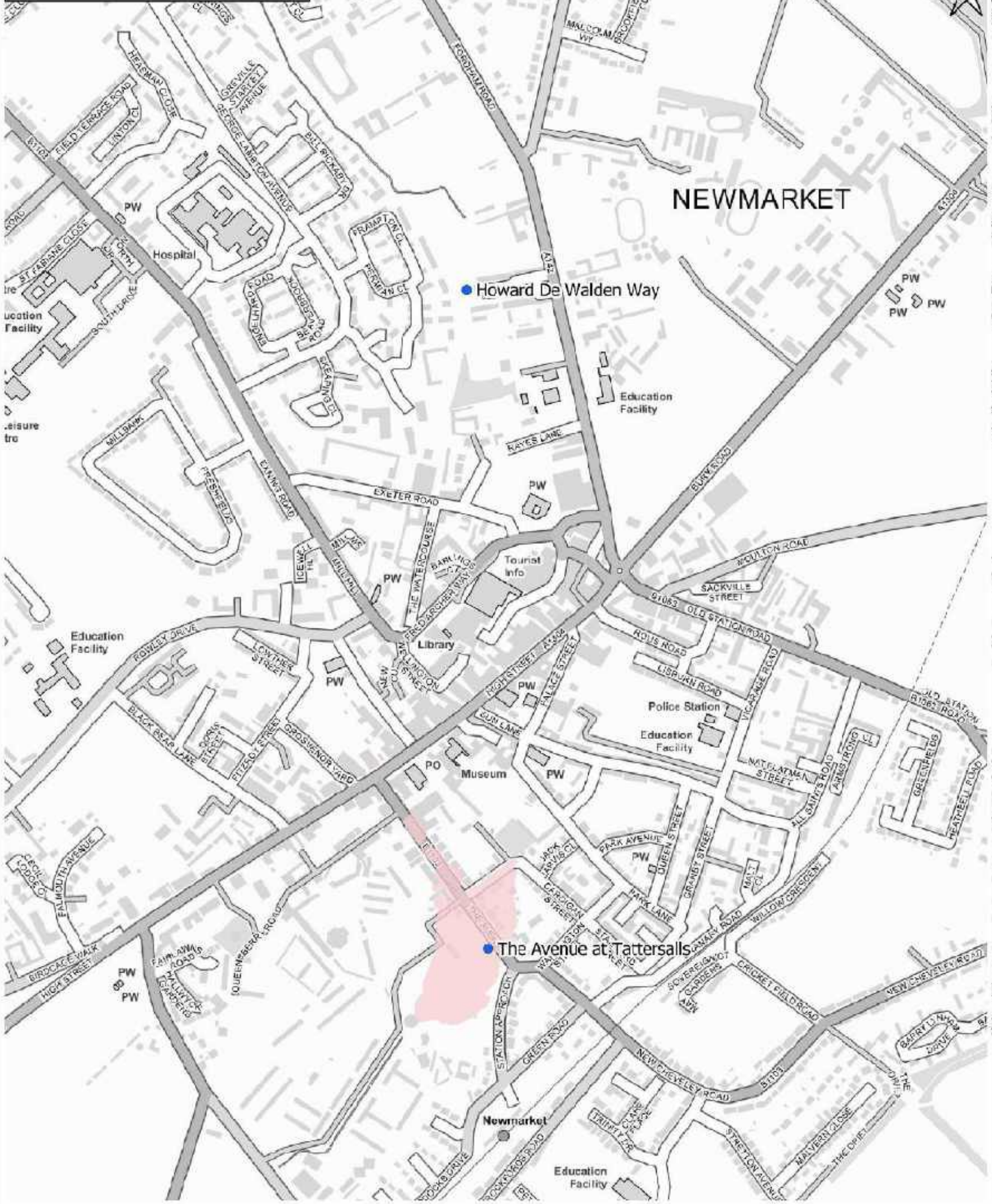
The structures chosen, in consultation with SCC, are shown below in Figure 4-8 and include the large trash screen at The Avenue near Tattersalls and an unnamed crossing near Howard De Walden Way. A 50% blockage has been tested on each of the structures for the 3.33% AEP and 1% AEP storm events.

Figure 4-8 Sensitivity Testing: Blocked Structures

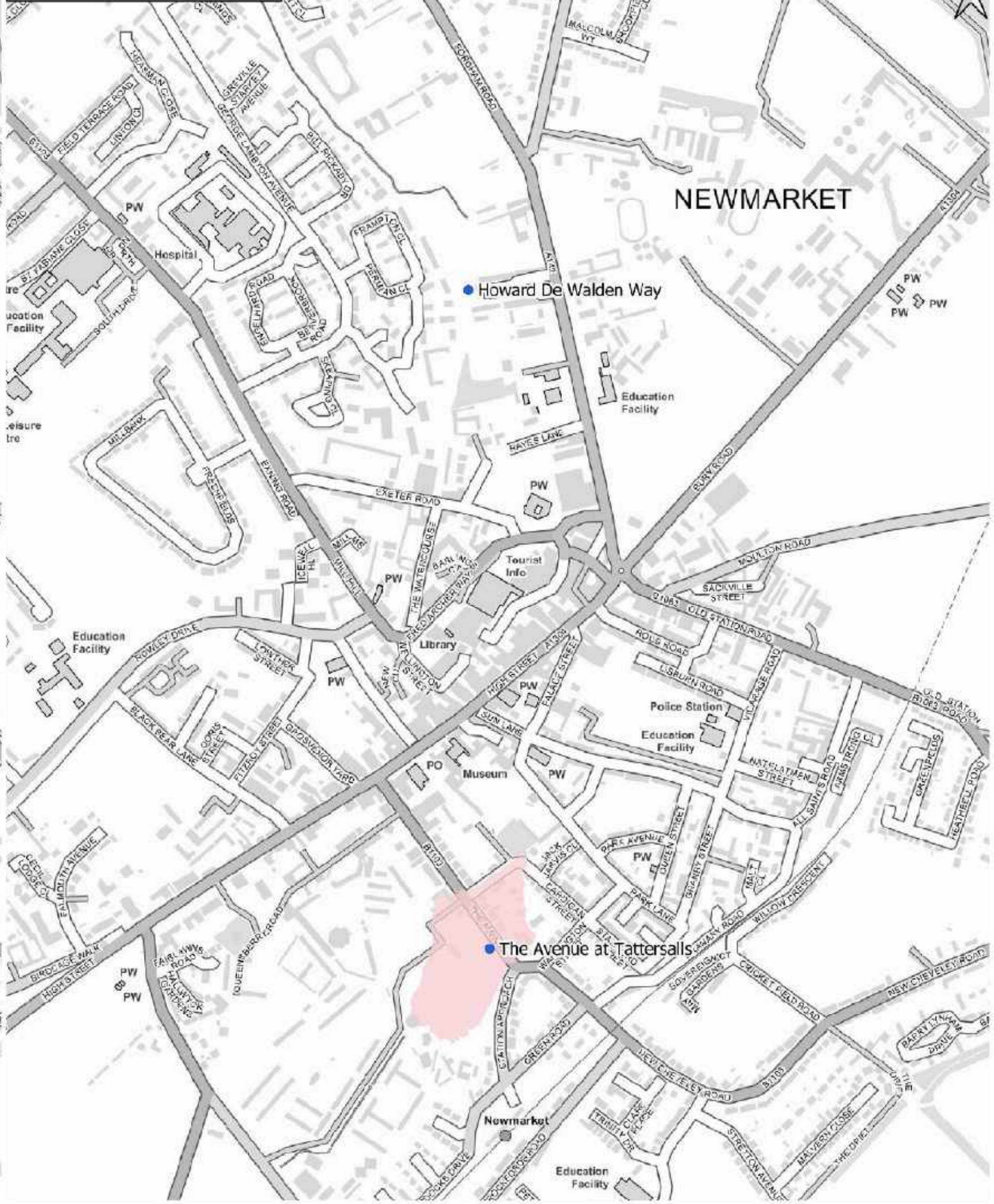
The modelled depth differences for the sensitivity blockage test against the baseline model results for the 3.33% and 1% AEP rainfall events are shown in Figure 4-9. The depth difference results indicate the peak flood depth is sensitive to the blockage of the Tattersalls structure under ‘The Avenue’. The impact of this structure being 50% blocked during a flood event may result in increases of up to 0.04m and 0.02m in the 3.33% and 1% AEP rainfall events respectively.

The structure at Howard De Walden Way does not appear to have any notable impact on the peak flood depth for the 3.33% and 1% AEP rainfall events. This is due to the face that in the events modelled, the structure is not the constricting factor in the channel, compared to the channel capacity and adjacent structures. Modelling at lower order events or higher percentage blockage would change the flood risk impacts of these structures.

3.33% AEP Rainfall Event



1% AEP Rainfall Event



Model Output Zone
Blocked Structures

Difference in Peak Depth (m)

<-0.5	0.01 - 0.05
-0.5 to -0.2	0.05 - 0.1
-0.2 to -0.1	0.1 - 0.2
-0.1 to -0.05	0.2 - 0.5
-0.05 to -0.01	>0.5
-0.01 to 0.01	

Title:
Newmarket SWMP Model Update
Sensitivity Test 2 (Blockage)- Maximum Depth Difference to Baseline Results

Drawing: 4-9
Rev: A

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5 Flood Risk Appraisal

The updated model has been used to assess the baseline flood risk in Newmarket. The below section presents the key flow routes and properties identified to be at risk of flooding in the baseline scenario.

5.1 Model Results

Newmarket lies at the confluence of the Newmarket Brook and the Newmarket Drain. Figure 5-1 shows the time varying depth across the catchment for the 3.33% AEP storm event.

There are four distinct quadrants of flood risk in Newmarket:

- Newmarket Drain (South East) upper catchment; Cheveley to the Allotments
- Newmarket Brook (South West) upper catchment; Stetchworth to Tattersalls
- Newmarket Brook (North East) downstream catchment; Exeter Road to Snailwell
- Unnamed flow route (North West) downstream catchment, Rowley Drive to A14 near Exning

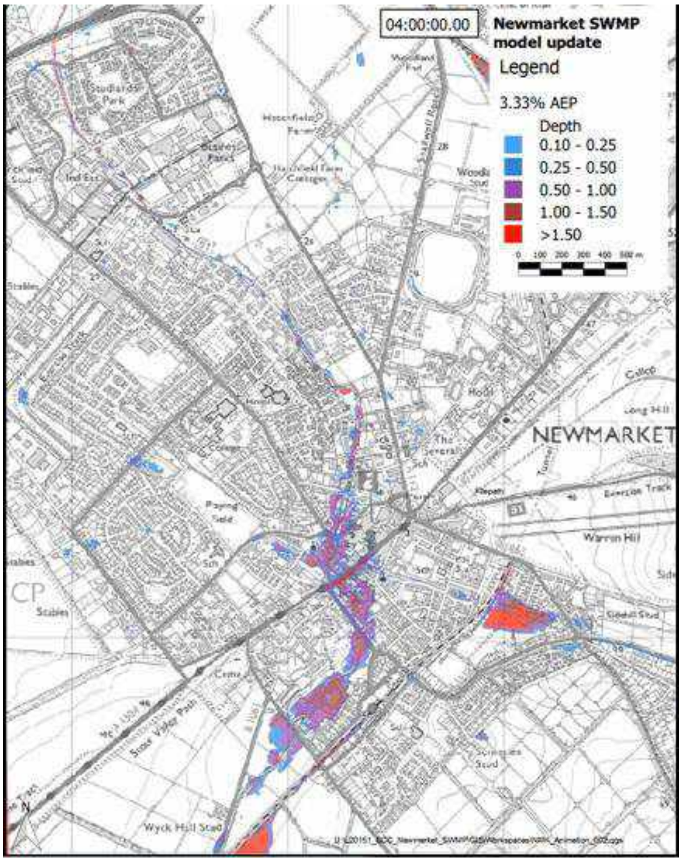


Figure 5-1 3.33% AEP Storm Event, Depth (m), Animation

Each of these quadrants have been assessed using the ‘Source-Pathway-Receptor’ model below.

Newmarket Drain (South East) Upper catchment; Cheveley to the Allotments

Source

The Newmarket drain originates in the upper rural catchment including Cheveley and Ashley. It is fed by overland flow runoff over pasture. The majority of the upper catchment lies in Cambridgeshire and is underlain by loamy soil.

Pathway

Minor flow routes from Ashley, Broad Green and Cheveley converge directly downstream of Cheveley, at the junction of Newmarket Road, Hight Street and Moulton Road. The hydrological timing of convergence is identical and results in a 'flashy' and sharp flood peak. From Cheveley, flood water flows downstream along Newmarket road, with high flows meandering across the roadway. The pathway enters Newmarket at the Ashley Road and Stanley Road junction. Flow travels through a pipe to the allotment gardens. When flow exceeds the pipe capacity, flow moves through residential properties on Cheveley Road and Stanley Road. Flood water ponds behind the railway embankment in the allotments before moving through pipes to join the Newmarket Brook and outfall to Exeter Road.

Receptor

Receptors impacted along this route are primarily located near the Allotments; including Ashley Road, Stanley Road, Heathbell Road and Whitegates. In addition, a small number of isolated properties are impacted in Cheveley. The properties in the allotments are typically impacted by direct surface water runoff, occurring around the time of peak rainfall, and then heavily impacted by the combined fluvial flow moving down Ashley Road. This fluvial flow has a sudden onset and inundates properties and key transport junctions.

Downstream of the railway embankment, a number of receptors between All Saints Road and Nat Flatman Street are impacted by surface water runoff. The main flow route is piped under this area and limited gully drainage is shown.

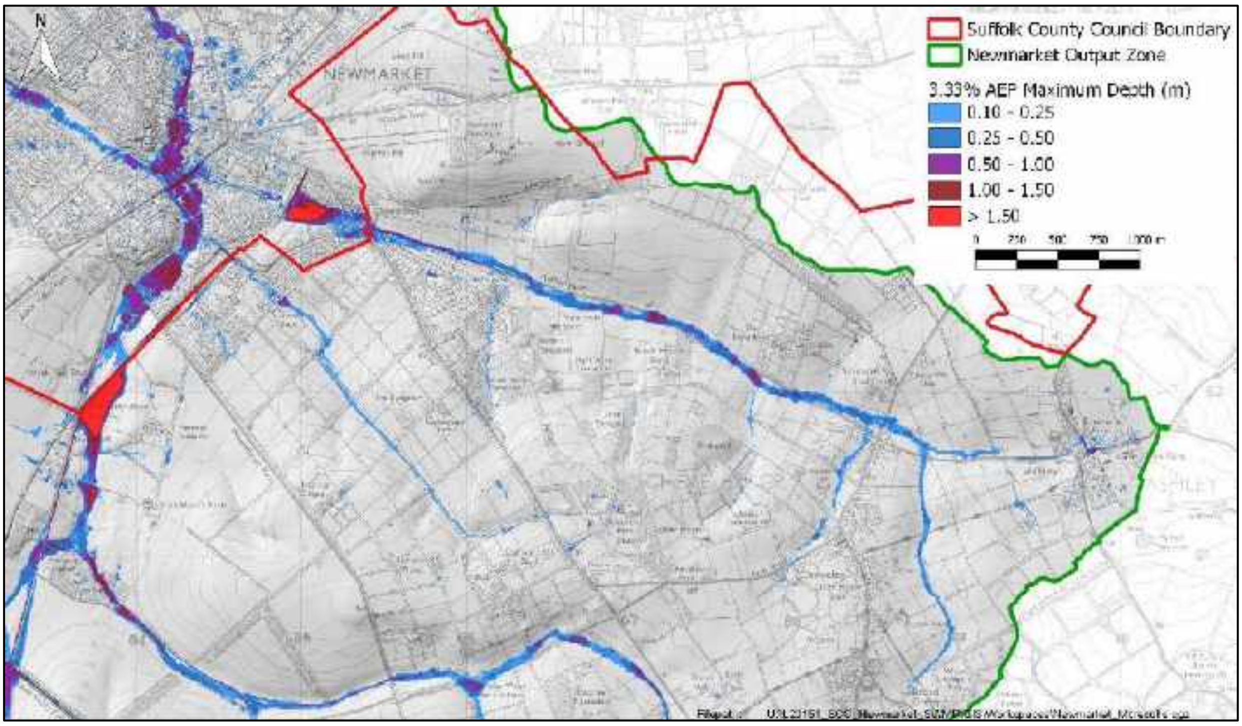


Figure 5-2 Newmarket Drain (South East) Catchment

Newmarket Brook (South West) Upper Catchment; Stetchworth to Tattersalls
Source
The headwaters of the Newmarket brook comprise of two major subcatchments, Stetchworth and Woodditton (Figure 5-3). Both subcatchments are predominately rural pasture. The majority of the upper catchment lies in Cambridgeshire and is underlain by loamy soil.
Pathway
The main upstream sub-catchments are approximately the same size and converge at The Links. In the upper catchment flow moves, largely unimpeded, through field drains and over pasture. The flow pathway is substantially attenuated at the rail crossing at Dullingham Road. Flow moves through the railway culvert (1.7x1.0m) and into Crockfords Stud. This is location collects both surface water catchment runoff as well as the attenuated fluvial flows. Flood water moves through Tattersalls, overland in higher order events, to meet the Avenue. There is a large grated pipe inlet at the Avenue which carries flow to the confluence with Newmarket Drain and the outfall at Exeter Road. Larger order events cause flow to move overland from the Avenue, through the Jockey Club and High Street before joining the main downstream Newmarket Brook flowpath.
Receptor
Key receptors along this route are Tattersalls, the Jockey Club and properties along the Avenue and the High Street. In addition, a small number of isolated properties are impacted in Dullingham. Due to the attenuation behind the railway line, properties are typically impacted by surface water from the local catchment, and then are larger runoff from the upper catchment. This fluvial flow has a sudden onset and inundates property and key transport junctions. Downstream of Tattersalls, receptors are impacted as flow moves through Newmarket centre and towards the Exeter Road outfall.

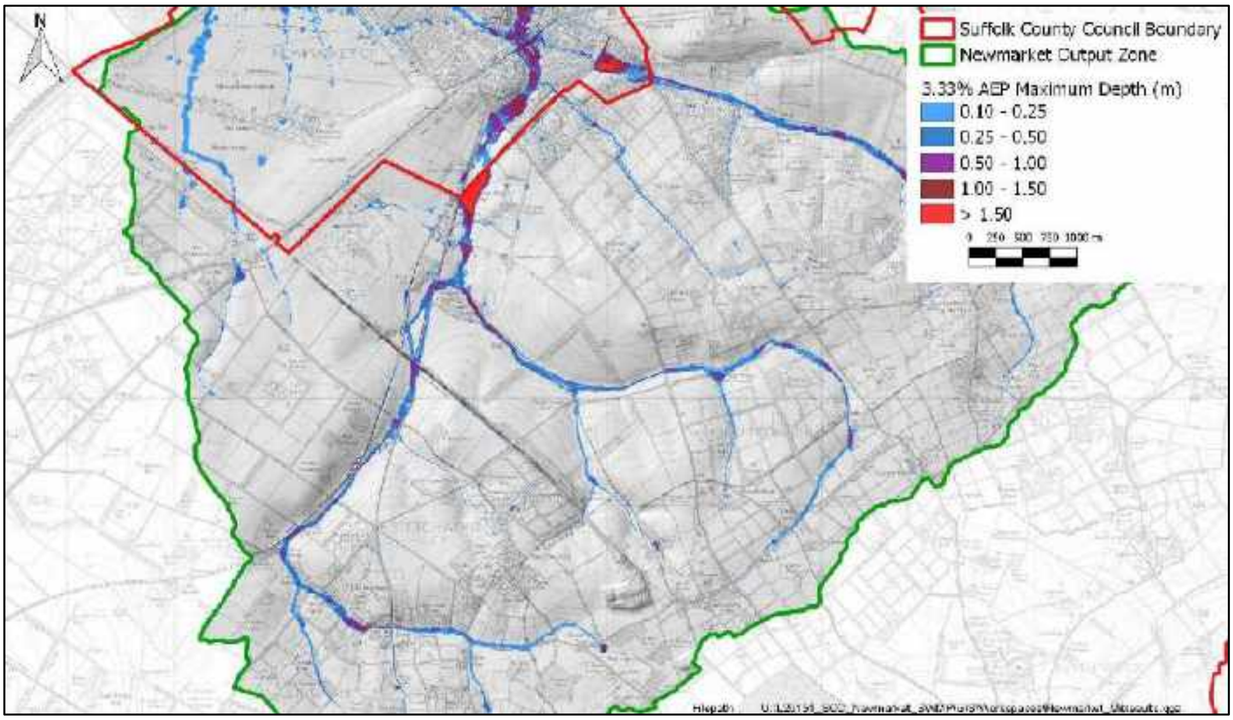


Figure 5-3 Newmarket Brook (South West) Catchment

Newmarket Brook (North East) downstream catchment; Exeter Road to Snailwell
Source
The downstream catchment of the Newmarket Brook is driven by the two southern flow paths in the upper catchment. These two upper catchments (described above) confluence in the underground network upstream of the Exeter Road outfall. The upper catchments hydrology has synchronicity, producing peak flows in the brook at very similar times. This results in a rapid rise in flood water. Compared to the upper catchment, there is little increase in contributing area along the length of the channel as the lower catchment is bounded by the B1103
Pathway
The upstream contributing flow paths are culverted near the confluences forming the Newmarket Brook. The culvert outfalls near to Exeter Road and continues as an open channel. The open channel is crossed by a number of road bridges, foot bridges and the horse walk, before passing under the A14 and discharging south of Fordham Road. There is a flood alleviation scheme located along the pathway, designed to capture surface water runoff from nearby developments and attenuate flow joining the main open channel.
Receptor
Receptors along this route are primarily located along the main open channel. A number of non-residential properties near the Watercourse are expected to be inundated in the 5% AEP event. Residential properties expected to be impacted are primarily located near Frampton Close, Bill Rickaby Drive and in the estate near Brickfields Avenue. Properties along this flow route are typically impacted minorly in with initial surface water runoff then by the larger fluvial flow from the open channel

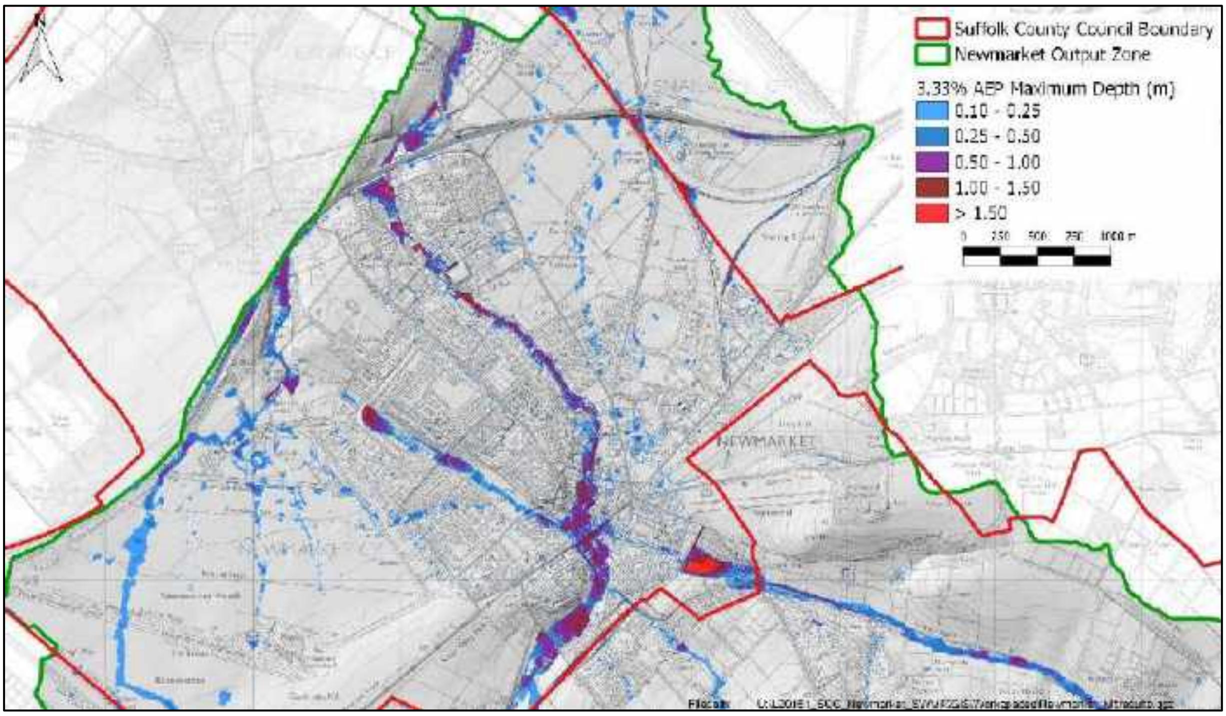


Figure 5-4 Newmarket Brook (North East) Catchment

Unnamed flow route (North West) downstream catchment; Rowley Drive to A14 near Exning
Source
The unnamed flow route is driven by both surface water runoff from the adjacent direct catchment and a portion of the fluvial runoff from the south west catchment. In larger order events, flow from the south west catchment travels along the Newmarket Brook as well as spilling into the unnamed flow route near Fitzroy Street. There is anecdotal evidence of groundwater emergence in the downstream areas of this flow path, near Seven Springs and the Marsh upstream of the A14 and Exning.
Pathway
The flow route travels overland from Fitzroy Street and Rowley Drive north west through recreation grounds near the colour box Montessori School and Newmarket Academy. The flow route moves through recreational areas at Edinburgh Road, Leader's Way and Sefton Way. The DTM shows a large raised obstruction of the horse gallop near Amberdue Stables. Site inspection and aerial photography review shows no through drainage in this structure. Flood water ponds upstream of this obstruction and impacted the horse exercise track and properties on Churchill Avenue. Downstream of the obstruction, pluvial runoff from the broader catchment of Newmarket heath and Cambridge Hill meets near Seven Springs. Downstream of Seven Springs, flow moves through culverts under the A14 and towards Exning.
Receptor
Receptors along this flow route are located primarily in the non-residential area near Fitzroy Street and Rowley Drive. A cluster of residential properties are impacted on Edinburgh Road and Leaders Way, in events larger than the 5% AEP. Receptors in upstream of the obstruction in on the Horse Gallop are predicted to be impacted for a number of hours, as water ponds,

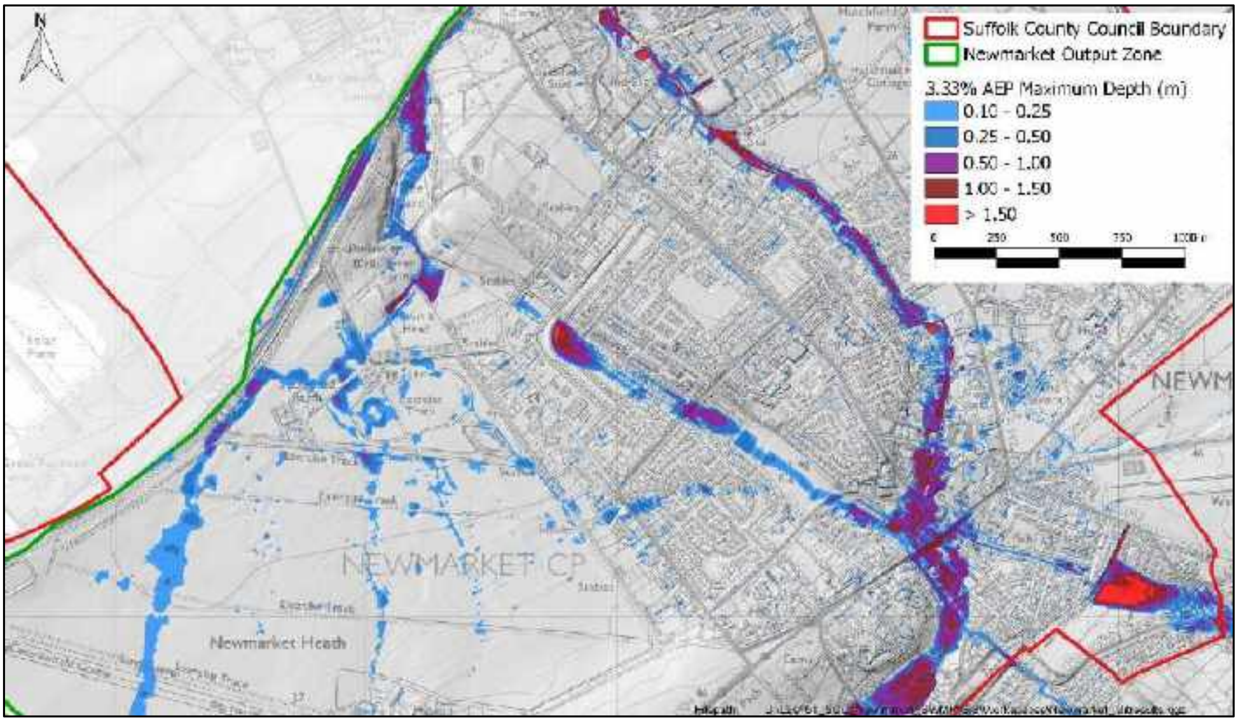


Figure 5-5 Unnamed Flowpath (North West)

5.2 Properties at Risk

The number of properties at risk in Newmarket have been estimated using the latest EA guidance on Property at Risk estimation[10]. The methodology used to calculate the number of properties as risk is detailed in Appendix Section **Error! Reference source not found.**.

5.2.1 Baseline Scenario

The number of properties estimated to be impacted in each event for the baseline scenario is shown below in Table 5-1.

Table 5-1 Properties at Risk, Baseline Scenario.

AEP	Residential	Non-Residential	Critical Services	TOTAL
5%	420	152	1	573
3.33%	550	184	1	735
1.33%	1013	290	1	1304
1%	1128	312	1	1441
0.1%	1757	471	4	2232
1% Central Climate Change	1296	371	1	1668
1% Upper Climate Change	1466	410	2	1878

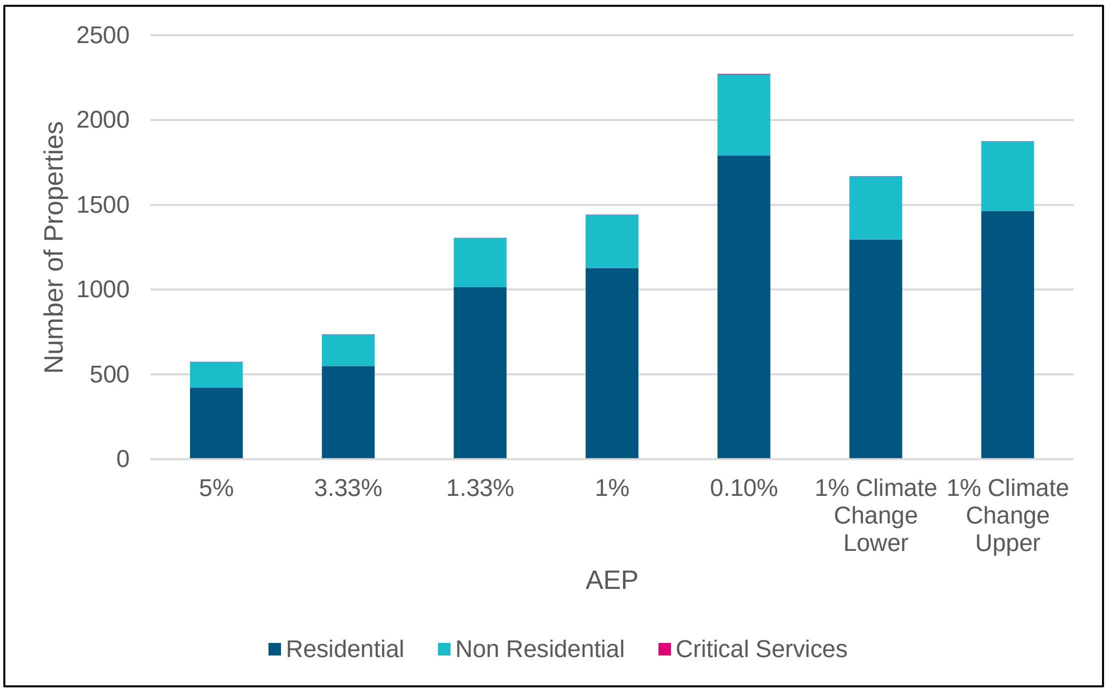


Figure 5-6 Properties at Risk, Baseline Scenario, Bar Chart

[10] EA (2014), The updated Flood Map for Surface Water (uFMfSW) Property Points Dataset

The properties expected to be impacted are typically restricted to the four main flood risk quadrants, as described in section 5.1. The receptors impacted are typically residential, reflecting the nature of Newmarket town.

The 5% AEP event is expected to impact 573 properties, shown in red on Figure 5-7. They are primarily located near the High Street, Tattersalls and upstream of the allotments. One critical infrastructure property is expected to be inundated, a childcare centre near the Exeter Road culvert outfall.

The number of properties expected to be inundated increases substantially from the 3.33% to the 1.33% AEP events. This highlights that the catchment and receptors are sensitive to events of this size.

5.2.2 'Do Nothing; Scenario

The number of properties estimated to be impacted in each event for the 'Do Nothing' scenario is shown below in Table 5-2.

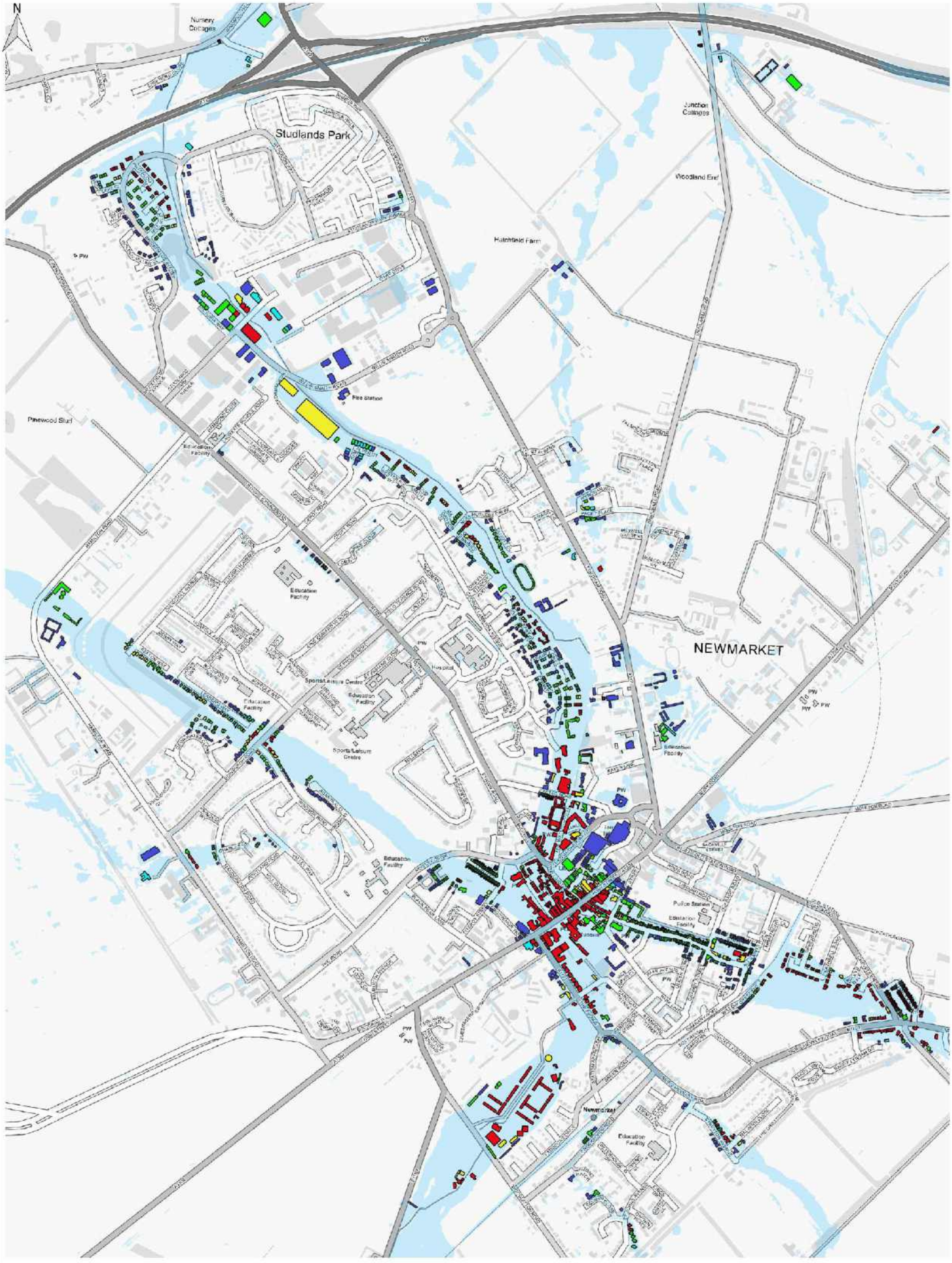
The properties impacted in the 'Do Nothing' scenario are shown spatially in Figure 5-8.

Table 5-2 Properties at Risk, 'Do Nothing' Scenario

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference from Baseline
5%	491	163	1	655	82
3.33%	671	211	1	883	148
1.33%	1105	306	1	1412	108
1%	1193	326	1	1520	79
0.1%	1802	483	4	2289	57
1% Central Climate Change	1352	376	1	1729	61
1% Upper Climate Change	1512	423	2	1937	59

All events in the 'Do Nothing' scenario show an increase in the estimated impacted properties from the 'Do Minimum'. The increase is largest in the 3.33% and 1.33% AEP events. The difference is apparent in these events as they are typically where factors such as structure blockage and channel roughness have critical impacts. In larger events, these factors dictate less of the major floodplain mechanics as structures become overtopped when their capacity is exceeded, and therefore there is less difference in expected property inundation.

Similar to the baseline scenario, there is a substantial step in expected property impacts between the 3.33% and 1.33% AEP events.



Legend

1% AEP, Maximum extent

Event of First Inundation

- 5% AEP
- 3.33% AEP
- 1.33% AEP
- 1% AEP
- 0.1% AEP

Title:
Newmarket SWMP model update
Estimated Property Impacts, Baseline Scenario

Drawing: 5-7 | Rev: A

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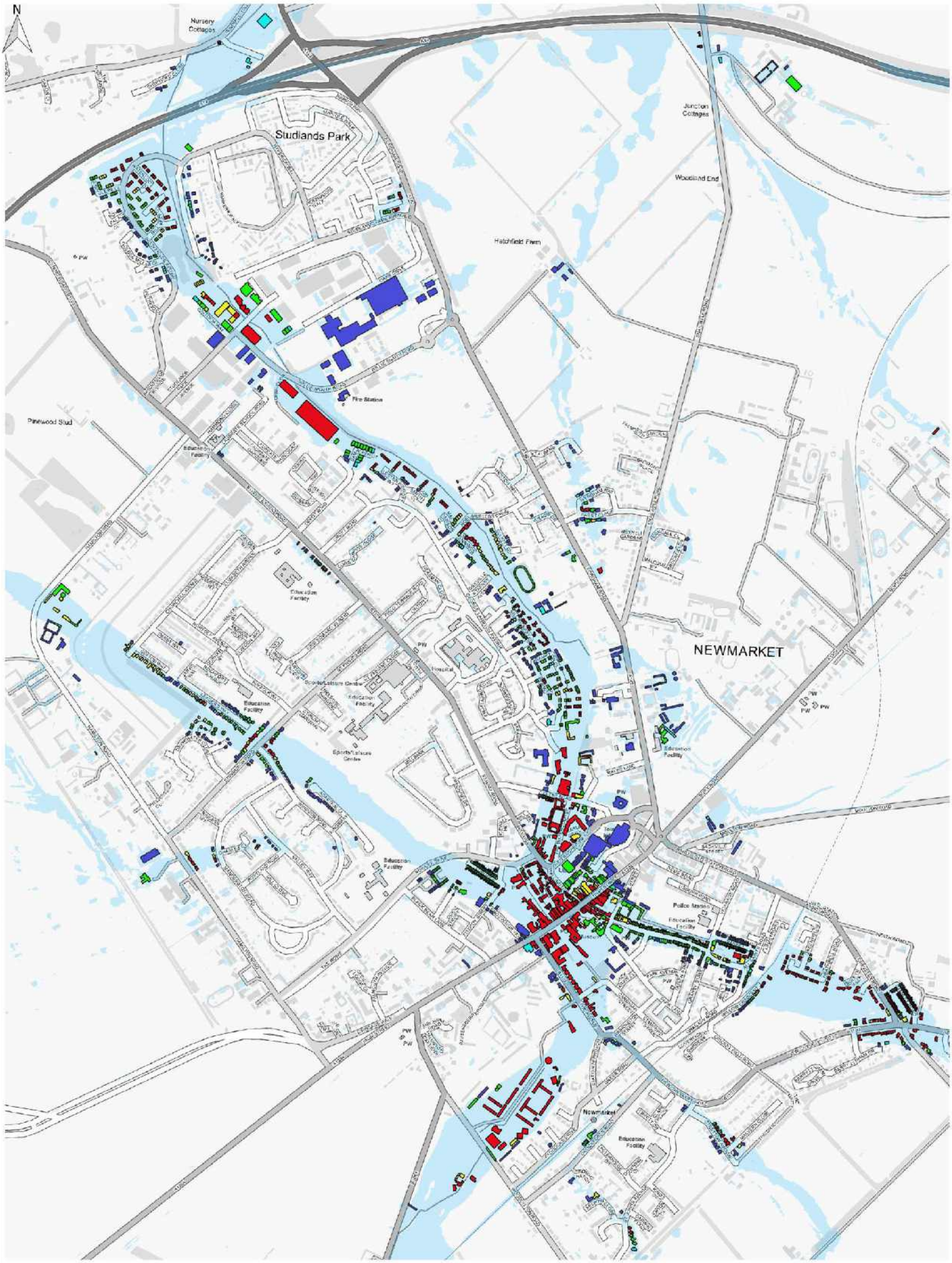

Legend

1% AEP, Maximum extent

Event of First Inundation

- 5% AEP
- 3.33% AEP
- 1.33% AEP
- 1% AEP
- 0.1% AEP

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Newmarket SWMP model update
Estimated Property Impacts, 'Do Nothing' Scenario

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6 Mitigation Assessment

As part of this study, BMT have undertaken a mitigation assessment to identify potential options that could be utilised to reduce the risk of flooding to Newmarket.

BMT started with an assessment of the existing mitigation optioneering presented in the Newmarket Surface Water Management Plan (AECOM, 2014). The mitigation measures outlined in the existing Newmarket SWMP were found to predominately target locations closer to the town centre and ignored much of the wider catchment. This approach was likely adopted due to the reduced hydraulic model extent in the 2014 study which limited surface water modelling to Wyck Hall Stud Farm to the south and McCalmont Way to the east.

As part of the SWMP update, BMT has extended the hydraulic model boundary to include Dullingham and Woodditton to the south and Ashley and Cheveley to the east. This has allowed for a much greater area of the catchment to be considered when considering mitigation options.

As discussed in Section 5.1, there are two key upstream flow paths causing inundation of properties in Newmarket. BMT considered several storage and attenuation solutions along these flow paths to minimise the impact that these flood waters had in Newmarket. The final mitigation options and considerations are considered in sections 6.1 through 6.3 below.

6.1 Existing SWMP Mitigation Assessment

The existing Newmarket Surface Water Management Plan (AECOM, 2014), outlined nine mitigation measures for further assessment. These mitigation measures are outlined in Table 6-1 below and locations shown in Figure 6-1.

As a part of this study, BMT have reviewed this proposed list of mitigation options, with a view to carrying forward options with a high likelihood of achieving widespread mitigation benefits.

Table 6-1 Existing SWMP mitigation measures

Option	Measure	Comment	Carried Forward?
A	Property Level Protection (PLP) for properties adjacent the Newmarket Brook around Sassoon Close.	This mitigation measure aims to alter existing structures and make them less susceptible to water damage through leakage protection or raising the property. PLP would protect individual properties, however carries residual risk of not being in place at the time of an event. In addition, raising the properties in this location will displace additional water and likely result in adverse impacts to other properties not raised.	No
B	Raising a section of the Newmarket Brook embankment adjacent Ian Trethowan House.	This mitigation measure aims to reduce the volume of water escaping the Newmarket Brook and flooding properties in lower order events. This measure may provide benefit in lower order flooding events but has the potential to cause adverse impacts to properties. This area has substantial surface water and fluvial	Tested. Not carried forward.

Option	Measure	Comment	Carried Forward?
		interactions and a wall for fluvial defence is likely to have adverse impacts on surface water drainage	
C	Raising of the Newmarket Brook embankment from Ian Trethowan House to Periman Close. Increase storage in the existing greenspace adjacent Frampton Close.	This mitigation measure has two components. The first is to raise the embankment and therefore water level needed to overtop the bank and flood properties. This provides greater flood immunity to the fluvial flood risk but increases property risk to surface water flooding. The second aspect of this mitigation measure is to increase the flood storage in an existing greenspace. This can be modelled and may provide some local flood benefits without causing any adverse impacts.	Yes
D	Re-profiling of pedestrian pathway along the western bank of Newmarket Brook near Manny Mercer Court.	This measure provides additional storage in the confined space between properties and the Newmarket Brook. There is potential for additional water to drain into the greenspace storage area and overtop sooner as a result of this augmentation.	Tested. Not carried forward.
E	Increase floodplain storage in greenfield space around Cockfords Stud (Tattersalls).	This measure proposes several detention basins and potentially a wetland around the existing Cockfords Stud between Woodditton Road and Dullingham Road. The additional flood storage should reduce the volume of floodwater reaching the town and reduce flood risk to Newmarket properties downstream Woodditton Road.	Tested. Not carried forward.
F	Maintenance of the culvert screen at the inlet under 'The Avenue'.	This measure aims to ensure the effectiveness of existing drainage assets. It is assumed in baseline modelling that structures are kept clear, though it is acknowledged this is difficult to achieve in the reality of a significant flood event. The 'Sensitivity testing presented in section 4.4, demonstrates the impacts of this structure not operating efficiently.	Sensitivity tested. Not carried forward as mitigation
G	Maintenance of the culvert screen at the downstream end of the 'Allotments' under the railway embankment.	This measure aims to ensure the effectiveness of existing drainage assets. It is assumed in baseline modelling that structures are kept clear, though it is acknowledged this is difficult to achieve in the reality of a significant flood event.	No
H	Remove usage of sand or other sediment material along horse tracks to prevent sedimentation build up within the Newmarket drainage network.	Sedimentation is known to reduce the conveyance and integrity of drainage structures. Removing unnecessary sediment transfer may benefit the asset lifespan and flow conveyance. Unlikely to provide widespread benefits to flood risk. Water trace and morphological modelling could be conducted to better estimate the impact of the horse trails on the drainage network.	No

Option	Measure	Comment	Carried Forward?
I	Debris management and removal at key structures along the Newmarket Brook, downstream of Exeter Road.	This measure aims to ensure the effectiveness of existing drainage assets. It is assumed in baseline modelling that structures are kept clear, though it is acknowledged this is difficult to achieve in the reality of a significant flood event. The 'Sensitivity testing presented in section 4.4, demonstrates the impacts of this structure not operating efficiently.	No

Mitigation option C was carried forward to the mitigation short listing. The development and impact on flood risk is discussed in Section 6.4. Other options, such as re-profiling around Sassoon Close were tested and found to provide widespread catchment benefit.

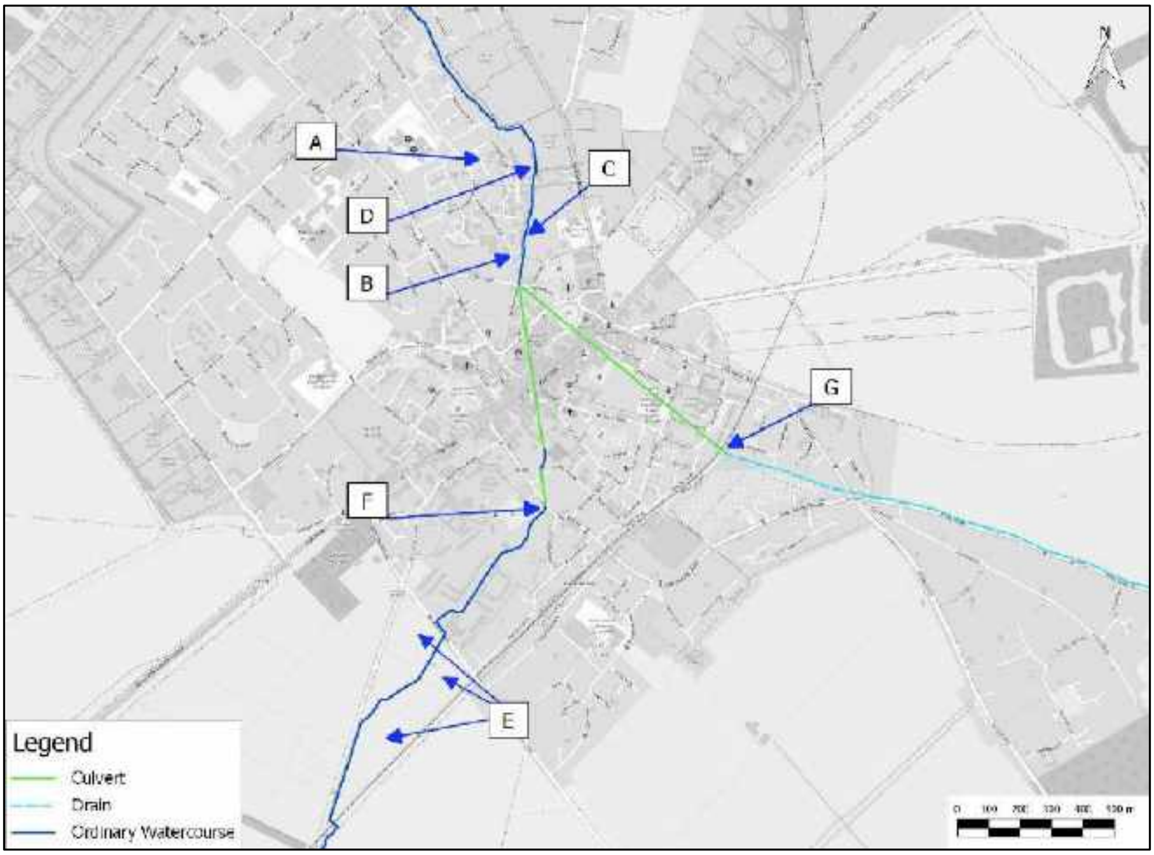


Figure 6-1 Existing SWMP mitigation locations

6.2 Mitigation Option 1 – South West

6.2.1 Optioneering

The South West mitigation option was designed to reduce the flood risk associated with the southern flow path, which enters Newmarket via Tattersalls and results in significant inundation.

Two key flow routes were identified in the upper catchment for attenuation bunds; Dane Bottom and Moorley Plantation (Figure 6-2).

Bund 1 located at Dane Bottom was modelled to a height of 74.9mAOD, with a maximum bunded wall height of 1.65m. The bund is approximately 149m wide and provides a storage volume of 19,410m^3 during flood conditions. Bund 2 is situated at Moorley Plantation and was modelled to a height of 88.9mAOD, with a maximum bunded wall height of 1.20m. The bund is approximately 118m wide and provides a storage volume of 16,420m^3 under flood conditions. The design details of each bund are summarised in Table 6-2.

Table 6-2 South West Mitigation: Bund Details

Mitigation Measure	Minimum Bund Height (mAOD)	Maximum Storage Depth (m)	Total Water Storage (m^3)
Bund 1 – Dane Bottom	74.90	1.90	19,410
Bund 2 – Moorley Plantation	88.90	1.70	16,420

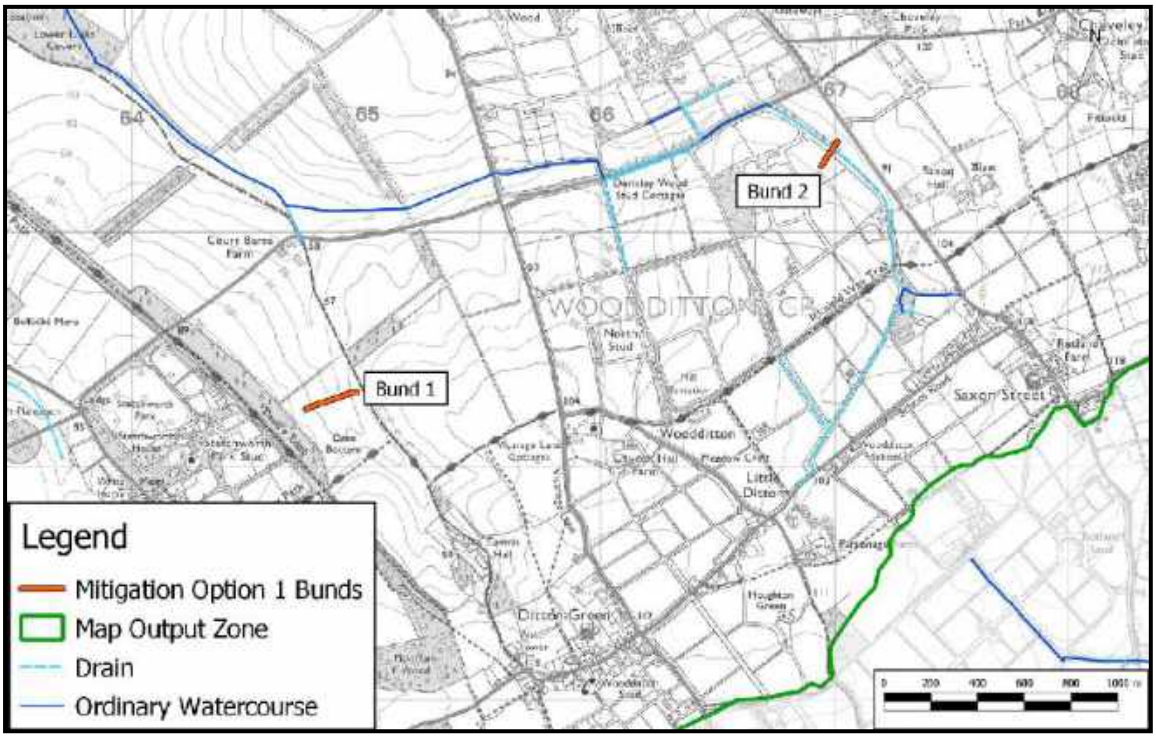


Figure 6-2 South West Mitigation Option Configuration

Several existing storage and attenuation features along this flow path were also investigated and tested. These are shown in Figure 6-3 and included:

- Woodditton Road
- The railway line embankment upstream of Wyck Hall Stud
- Devils Ditch across Dullingham Road

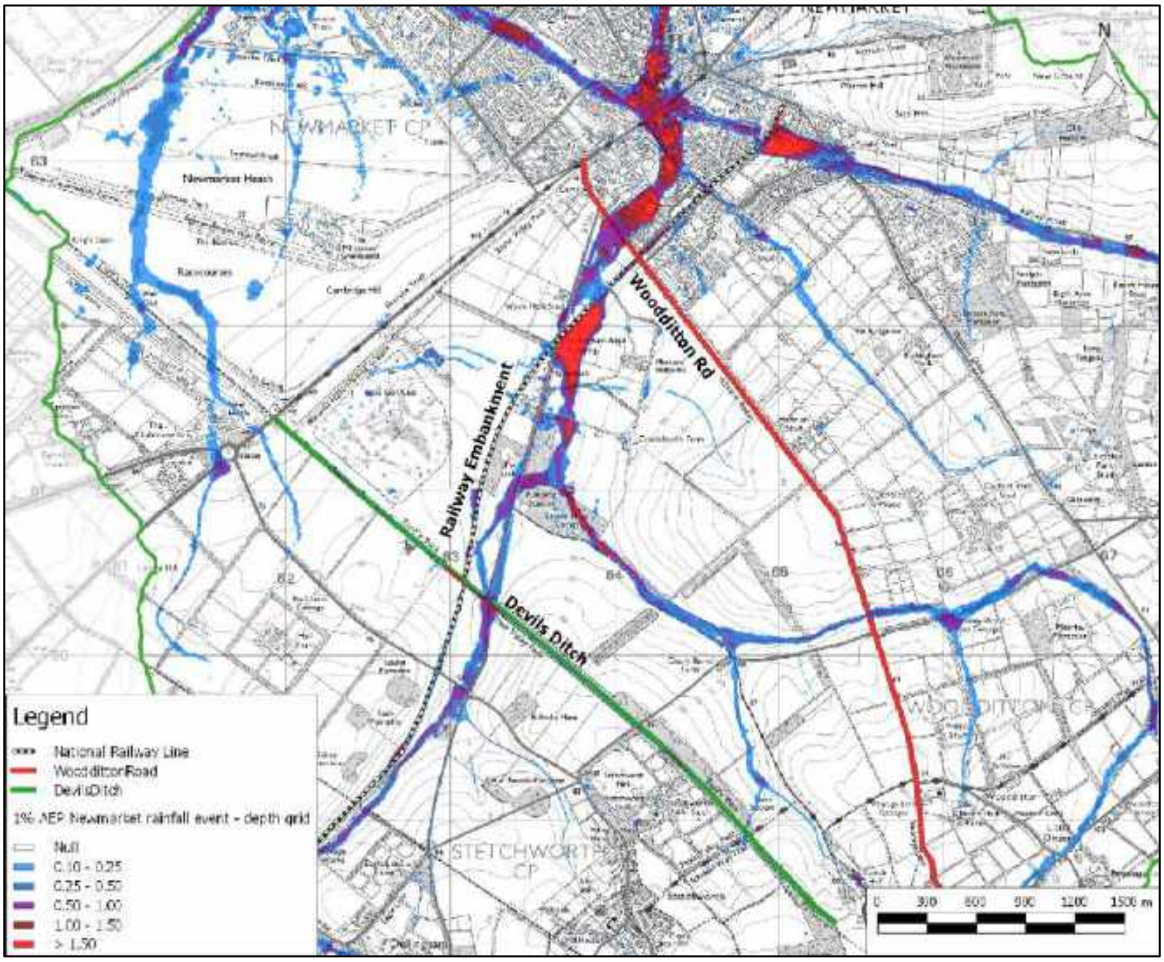


Figure 6-3 South West Mitigation, existing storage

Enhancing the storage of each of these existing attenuation measures was considered and, in some cases, modelled as part of the optioneering process. However, none of these options were advanced to final modelling due to adverse property impacts, inadequate benefit or feasibility. For example, the Woodditton Road embankment could not be raised without increasing flood risk to some nearby properties. Preliminary modelling indicated that additional storage in the form of a detention basin in this location provided little benefit to the downstream catchment.

The railway embankment stores a large volume of water (approximately 122,200m^3) upstream of Tattersalls, however it is overtopped in the 3.33% AEP rainfall events and larger. The water that overtops this railway embankment causes significant flooding. Raising this railway embankment or restricting the culvert size to increase the upstream storage and attenuation of floodwaters was ruled out for final modelling in conjunction with SCC. The increase in residual risk to the railway line or major works required to rail assets was not deemed feasible to achieve cost benefit requirements.

Finally, the existing ‘Devils Ditch’ flood attenuation was considered to be highly effective in its current state and that minimal work could be done to improve this existing attenuation. Flood waters in events up to the 0.1% AEP rainfall event did not overtop this dyke and water escapes through an existing channel and Dullingham Road itself.

Thus, the final mitigation configuration for the South West flow route is two bunds, located in Dane Bottom and Moorley Plantation.

6.2.2 Mitigation Results

The south west bunds show an effective reduction in flood depth for all modelled rainfall events. The 3.33% AEP and 1 % AEP events are shown in Figure 6-5 and Figure 6-6. Modelling shows widespread benefits and no adverse downstream impacts. Impact mapping for all mitigation measures are shown in Appendix B.

The depth difference results indicate that the south west mitigation provides substantial betterment of flood risk throughout most of the Newmarket catchment, from Tattersalls to Fordham. The greatest benefits are located around The Avenue where the peak modelled depth is reduced by 0.11m and 0.06m for the 3.33% and 1% AEP rainfall events, respectively. Importantly the modelled depth of inundation in the centre of town, where there is a greater number of receptors, shows a reduction of up to 0.09 and 0.06m in the 3.33% and 1% AEP rainfall events respectively.

Figures 6-5 and 6-6 indicate that the south west mitigation provides benefits further downstream to properties situated near the banks of the Newmarket Brook from Exeter Road to the A14 Bypass. The modelled results indicate that properties around Waterloo Close may benefit from 0.09m and 0.07m reductions in the 3.33% and 1% AEP rainfall events.

6.2.2.1 Properties at Risk

The number of estimated properties at risk in the baseline and south west mitigation scenarios are shown below in Table 6-3. The greatest reduction in property inundation occurs in more frequent events such as the 5% and 3.33% AEP rainfall events. The total properties impacted for all mitigation options is summarised in Appendix D. The counts presented in Appendix D are aimed at Partnership Funding calculations and are split by areas of deprivation; differences to both the Baseline and ‘Do Nothing’ are shown.

Table 6-3 Properties at Risk, South West Mitigation Scenario

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference to Baseline
5%	366	128	1	495	-78
3.33%	514	168	1	683	-52
1.33%	982	279	1	1262	-42
1%	1106	303	1	1410	-31

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference to Baseline
0.1%	1754	470	4	2228	-4
1% Central Climate Change	1281	353	1	1635	-33
1% Upper Climate Change	1459	406	2	1867	-11

Majority of the properties removed from flood risk in the 5% AEP rainfall event are situated around the centre of town along High Street (Figure 6-4). The south west mitigation also removes a number of properties along Bill Rickaby Drive and Lester Piggott Way from flood risk in the 5% AEP rainfall event.

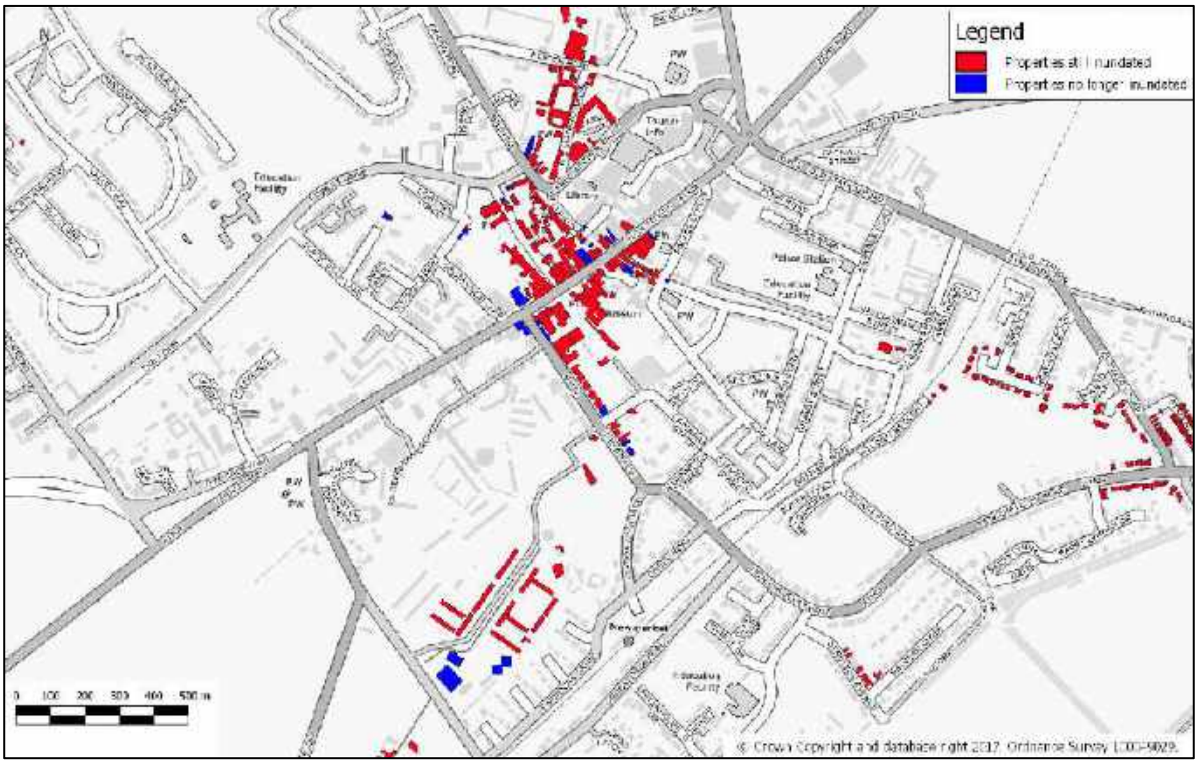
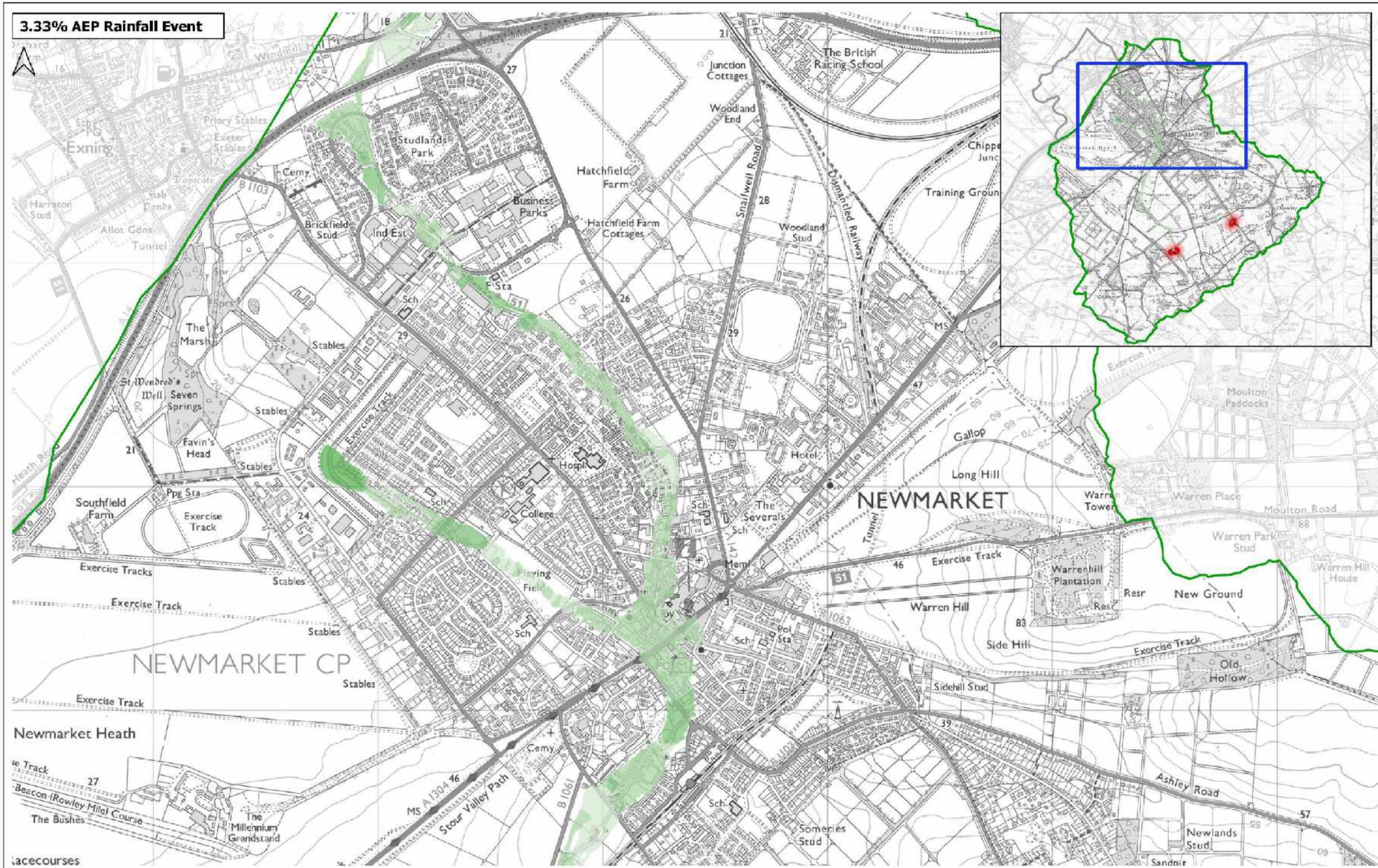


Figure 6-4 South West Mitigation, 5% AEP, change in property at risk



Title:
Newmarket SWMP Model Update
Mitigation Option 1 - Maximum Depth Difference to Baseline Results

Drawing: 6-5
Rev: A

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Date of issue: 09/04/2019
Scale: 0 80 160 240 320 400 m

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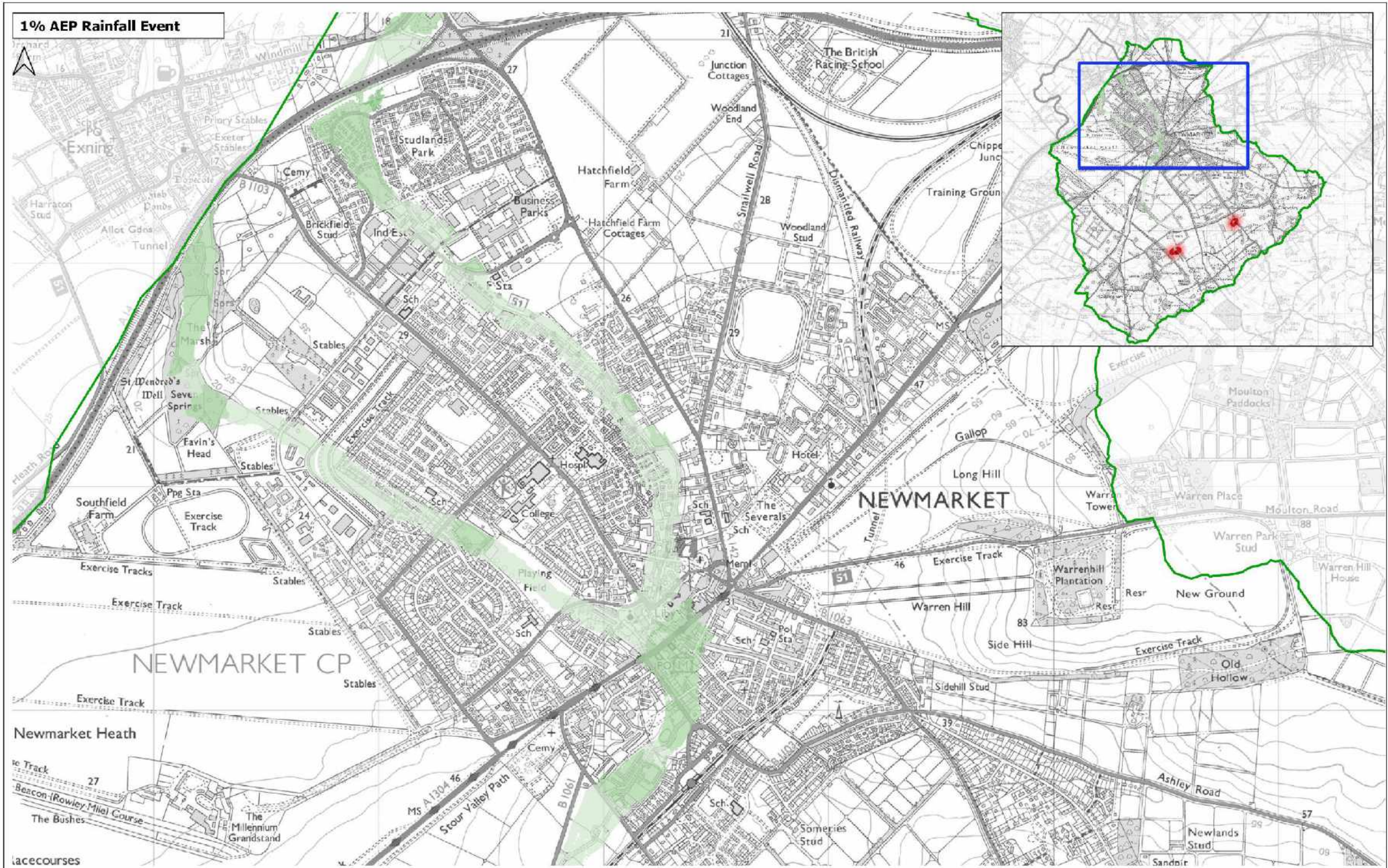
1% AEP Rainfall Event



- Model Output Zone
- Mitigation Location

Difference in Peak Depth (m)

<-0.5	0.01 - 0.05
-0.5 to -0.2	0.05 - 0.1
-0.2 to -0.1	0.1 - 0.2
-0.1 to -0.05	0.2 - 0.5
-0.05 to -0.01	>0.5
-0.01 to 0.01	

Title:
Newmarket SWMP Model Update

Mitigation Option 1 - Maximum Depth Difference to Baseline Results

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6.3 Mitigation Option 2 – South East

6.3.1 Optioneering

The south east mitigation option was designed to reduce the flood risk associated with the south eastern flow path which begins around the township of Ashley and flows along Ashley Road, before entering the Newmarket Allotments. This flow path results in significant flooding of properties along Cheveley Road, Heathbell Road and Whitegates before its confluence with the south west flow route. The confluence of the southern and eastern flow paths results in increased flooding of the town centre and further downstream.

Figure 6-7 indicates that there is a large amount of grassed and undeveloped land which could be utilised for storage and attenuation measures along the eastern flow path. BMT focused on specific sections of the flow path which aligned with the following criteria so as to ensure the feasibility and maximise the effectiveness of any proposed mitigation measures.

- Avoid causing additional ponding to roads or properties;
- Ensure detention basins could be designed so that they remain dry when not activated as a Flood Alleviation Scheme (FAS);
- Maximise storage by utilising reaches of the flow path with flatter gradients; and
- Utilise any existing natural depressions in topography.

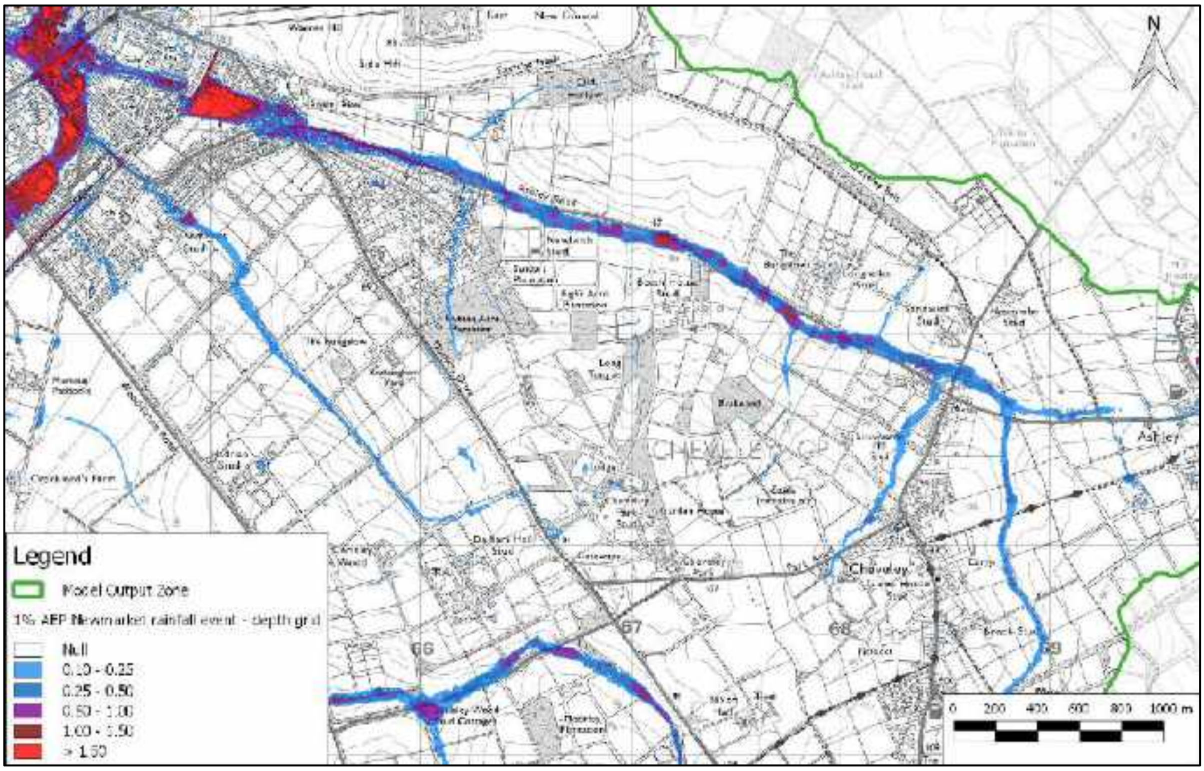

Figure 6-7 Baseline flood results, 1% AEP event, maximum depth (m)

After assessing the DTM, OSMM and aerial data provided, BMT identified three locations that met all of the criteria outlined above. These locations are presented in Figure 6-8 below.

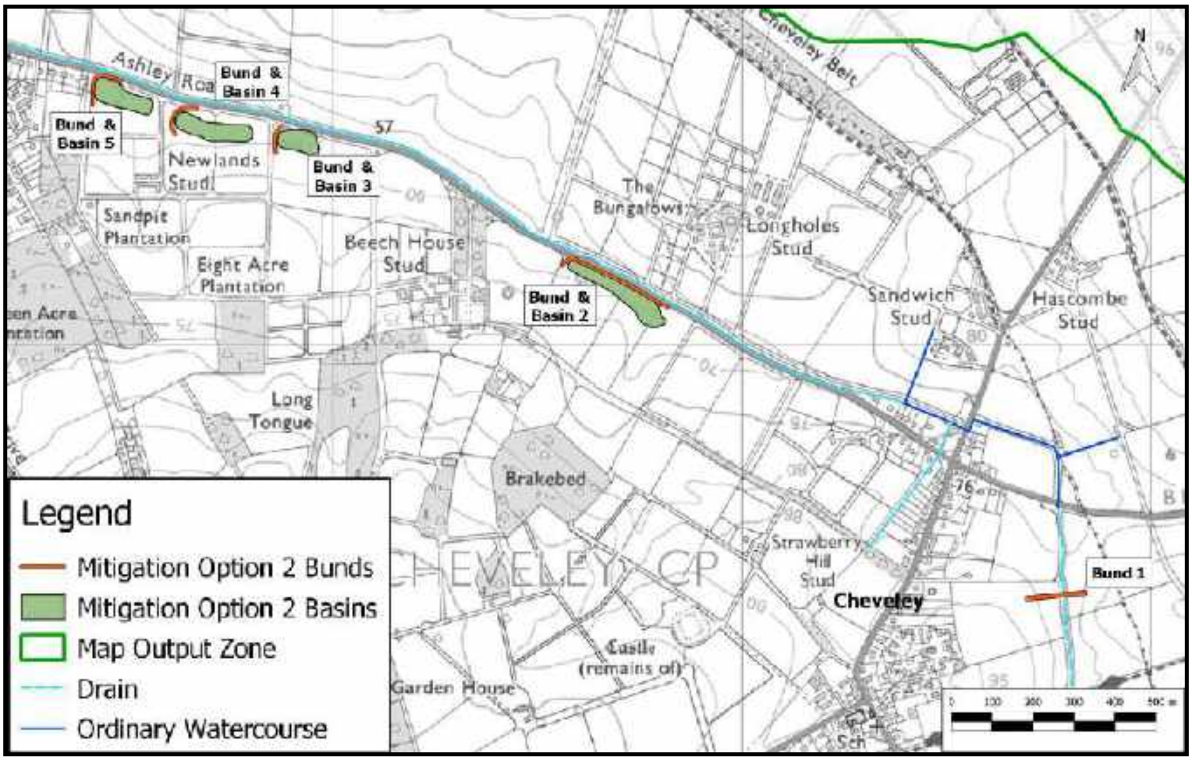

Figure 6-8 South East Mitigation Configuration

The design details for each mitigation measure along this eastern flow path are summarised in Table 6-4.

Table 6-4 South East Mitigation, Basin and Bund details

Mitigation Measure	Minimum Bund Height (mAOD)	Maximum Storage Depth (m)	Total Water Storage (m3)
Bund 1	84.50m	1.50m	5,680
Bund and Basin 2	65.60m	1.90m	11,160
Bund and Basin 3	56.00m	1.50m	5,350
Bund and Basin 4	53.70m	1.45m	6,700
Bund and Basin 5	51.10m	1.70m	7,340

6.3.2 Mitigation Results

A comparison of the modelled flood depths for the south east mitigation against the baseline results shows that the terraced bund and basin configuration along Ashley Rd is effective for all modelled rainfall events (5% - 0.1% AEP). The depth difference results are presented in Figure 6-10 and Figure 6-11 for the 3.33% and 1% AEP rainfall events. Impact mapping for all mitigation measures are shown in Appendix B.

There are minor adverse impacts presented in the modelled results to a few properties downstream of bund 5 in the 0.1% and upper climate change rainfall events. from the additional detriment is caused by overtopping of the southern section of the western bund wall. Adverse impacts could be avoided at detail design, through a lower weir elevation along the northern facing section of the bund and raising the height of the eastern bund crest. There are no adverse impacts to properties found in any of the smaller magnitude rainfall events modelled.

The depth difference results indicate that mitigation option 2 could provide substantial betterment of flood risk to residents of Newmarket upstream of Exeter Road. Modelled results suggest as many as 63 properties in the 3.33% AEP event, which are situated between Cheveley Rd and the Allotments, may benefit from up to 0.31m reductions in peak flood levels for the 3.33% event and up to 0.1m in the 1% AEP event. Unlike the south west mitigation option, these larger benefits do not extend across the entire downstream catchment but may provide flood level reduction of up to 0.05m to properties downstream of Exeter Road for the 1% AEP rainfall event or similar.

6.3.2.1 Properties at Risk

Table 6-5 shows the number of properties estimated to be inundated in the modelled results, for a given AEP rainfall event. The south east mitigation scheme is expected to remove a large number of properties from flood risk in varying rainfall event magnitudes. The scheme appears most beneficial to moderate and less frequent events, with the greatest reduction in flooded properties (86 properties) expected to occur in the 1.33% AEP rainfall event.

The total properties impacted for all mitigation options is summarised in Appendix D. The counts presented in Appendix D are aimed at Partnership Funding calculations and are split by areas of deprivation; differences to both the Baseline and 'Do Nothing' are shown.

Table 6-5 Properties at Risk, South East Mitigation Scenario

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference to Baseline
5%	386	151	1	538	-35
3.33%	492	179	1	672	-63
1.33%	936	281	1	1218	-86
1%	1074	302	1	1377	-64
0.1%	1754	471	4	2229	-3
1% Central Climate Change	1276	353	1	1630	-38
1% Upper Climate Change	1453	407	2	1862	-16

Figure 6-9 indicates that the properties most likely to be removed from flood risk in the 1.33% AEP rainfall event occur along All Saints Road. The south east mitigation option may also remove a number of properties along Ashley Road and Stanley Road from flood risk in the 1.33% AEP rainfall event.

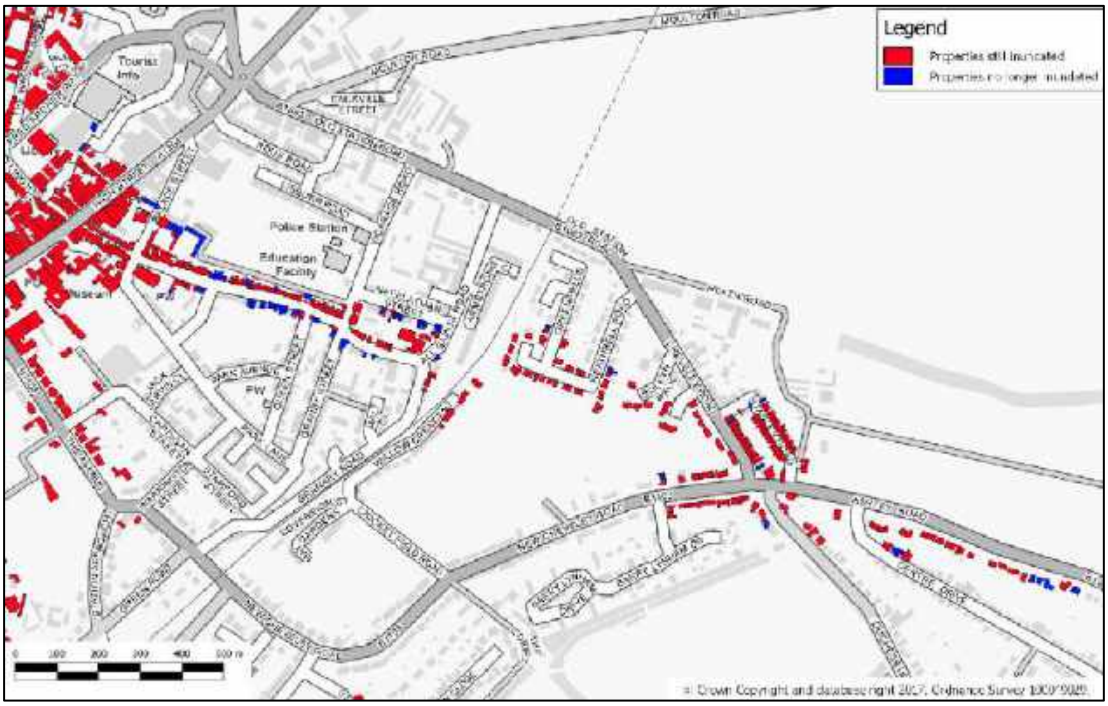

Figure 6-9 South East Mitigation, 1.33% AEP, change in property at risk

3.33% AEP Rainfall Event

Model Output Zone
Mitigation Location

Difference in Peak Depth (m)

- <-0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title: Newmarket SWMP Model Update Mitigation Option 2 - Maximum Depth Difference to Baseline Results			Drawing: 6-10	Rev: A
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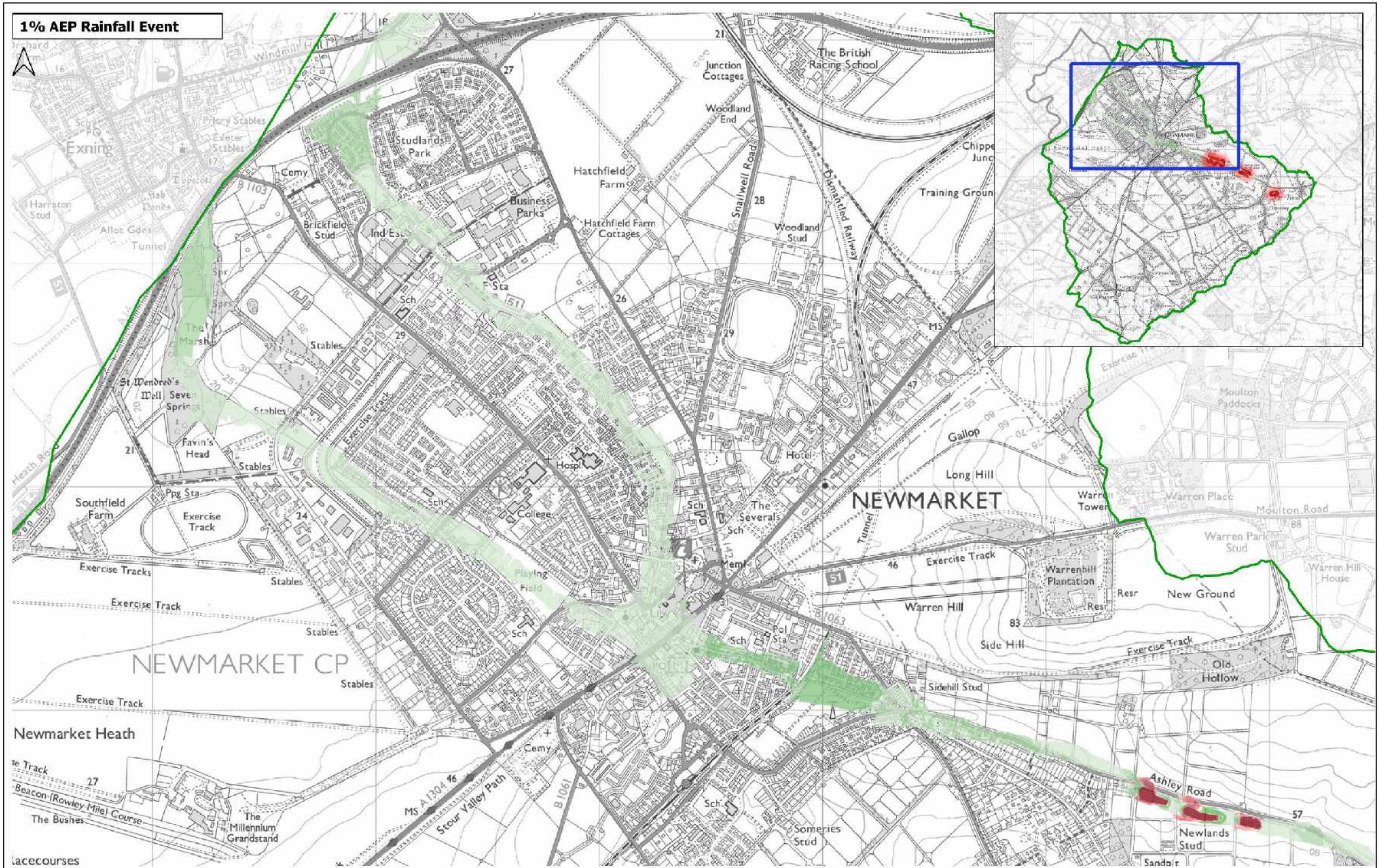

Model Output Zone
Mitigation Location

Difference in Peak Depth (m)

- <-0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title:
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Drawing: 6-11
Rev: A

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6.4 Mitigation Option 3 – Frampton Close

6.4.1 Optioneering

The Frampton Close mitigation option was designed and modelled to address local flooding issues in the vicinity of Manny Mercer Court and Sassoon Close. Anecdotal data indicates that properties in this area are regularly inundated properties and have been identified as in a critical area of investigation by SCC. The greenspace between Frampton close and the Newmarket Brook provides a large and accessible space for additional flood storage. BMT has modelled a 9,460m^3 detention basin in this location (Figure 6-12) to capture surface water runoff and out of bank flow from the Newmarket Brook. The details of the modelled detention basin are provided in Table 6-6 below:

Table 6-6 Frampton Close Mitigation Option Detail

Mitigation Measure	Minimum Bund Height (mAOD)	Maximum Storage Depth (m)	Total Water Storage (m^3)
Basin 1	24.50	1.60	9,460

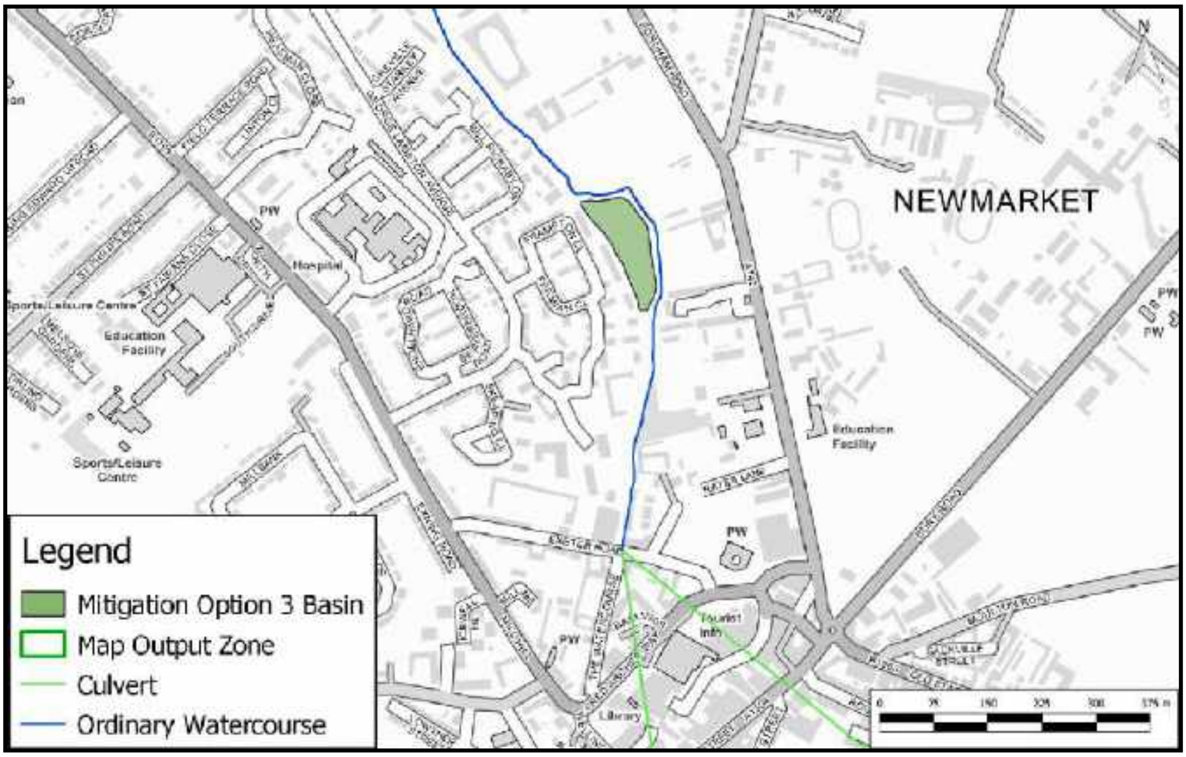


Figure 6-12 Frampton Close Mitigation Option Configuration

The 2014 SWMP study proposed several other localised mitigation measures that were targeted at reducing the frequency of inundation to these properties. The mitigation measures identified included:

a) Re-profiling of pathway between properties and Newmarket Brook

b) Raising of the west bank of Newmarket Brook channel

c) Provide a detention basin in the greenspace adjacent to Frampton Close

d) Raising of property floor levels through the use of ‘air bricks’

BMT modelled the mitigation measures A, B and C outlined above as part of the Frampton Close mitigation measure, to help identify whether localised mitigation measures could improve the localised flood risk. Measure C (Frampton Close detention basin) was the only measure which was progressed to final modelling.

The re-profiling and raising of the west bank of the Newmarket Brook were not considered as viable mitigation options, as the implementation of these measures resulted in an increase in the flood risk to a number of properties. Figure 6-13 shows the depth difference results for one of these earlier iterations, where the west bank was raised, and the pathway was reprofiled to increase storage and protect properties from fluvial flooding.

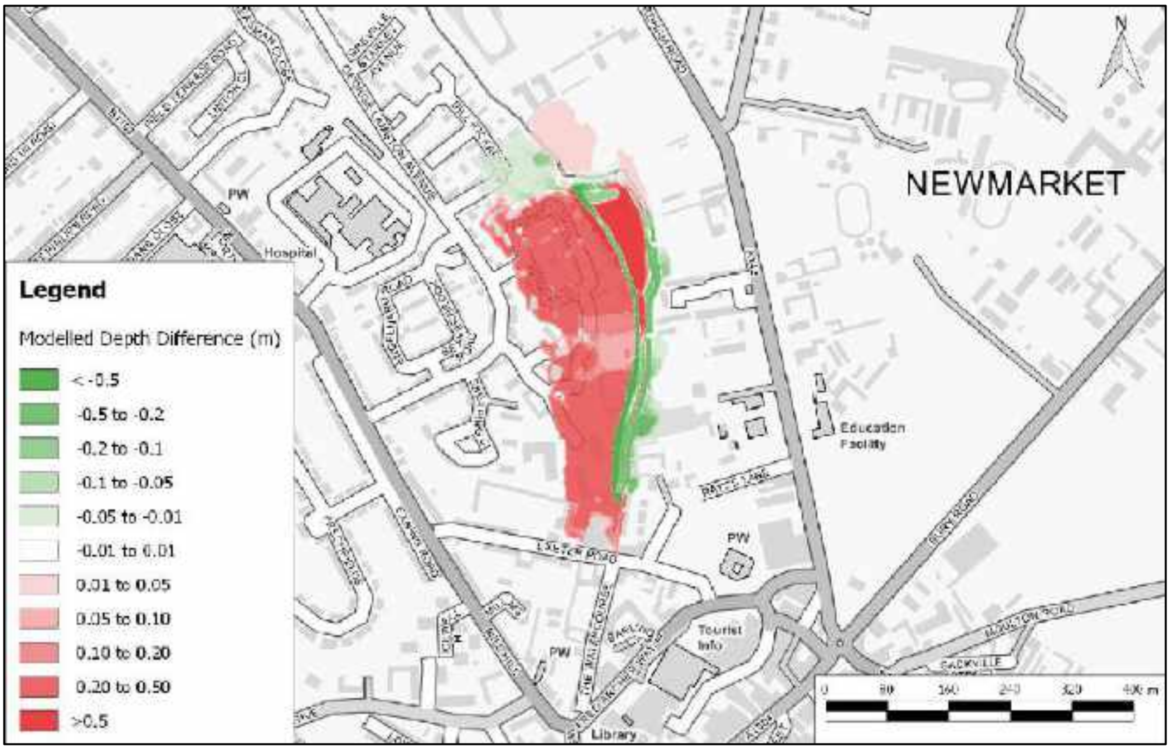


Figure 6-13 Frampton Close Mitigation, 1% AEP Event, Preliminary Design

The results show a large increase in the flood risk to properties along Manny Mercer Court and Frampton Close. An assessment of the hydraulic behaviour indicates that this is due to surface water runoff from the west, becoming impeded by the raised banks along the Newmarket Brook. The surface water in this preliminary mitigation modelling ponded behind the bank and resulted in greater flooding of these properties. As such, BMT progressed with the modelling of increased flood storage within the greenspace adjacent to Frampton Court (shown in Figure 6-12) with no pathway and bank reprofiling.

6.4.2 Mitigation Results

A comparison of the modelled flood depths for the Frampton Close mitigation option against the baseline results indicated that a detention basin is likely to provide localised benefits for all modelled rainfall events (5% - 0.1% AEP). The depth difference in the 3.33% and 1% AEP rainfall events are presented in Figure 6-15. Impact mapping for all mitigation measures are shown in Appendix B.

The depth difference results indicate that the Frampton Close option is unlikely to provide any benefit to properties in the 3.33% AEP event, but may reduce the peak flood depth on the horse trail (adjacent the detention basin) by up to 0.12m. The modelled results indicate that minor (0.02m) reductions in the peak flood depth may be achieved for the 1% AEP rainfall event, however, small (up to 0.02m) adverse impacts are shown along Bill Rickaby Drive for the 1% AEP rainfall events and greater.

6.4.2.1 Properties at Risk

Table 6-7 shows the number of properties inundated in the modelled results for the Frampton Close option for a given AEP rainfall event. The Frampton Close storage scheme is not expected to prevent the inundation of many properties for any rainfall event size. The scheme appears most beneficial in the 1 % AEP rainfall event, with the potential to remove 6 properties from flooding.

The total properties impacted for all mitigation options is summarised in Appendix D. The counts presented in Appendix D are aimed at Partnership Funding calculations and are split by areas of deprivation; differences to both the Baseline and 'Do Nothing' are shown.

Table 6-7 Properties at Risk, Frampton Close Mitigation Scenario

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference to Baseline
5%	419	152	1	572	-1
3.33%	551	184	1	736	1
1.33%	1012	290	1	1303	-1
1%	1122	312	1	1435	-6
0.1%	1757	471	4	2232	0
1% Central Climate Change	1291	371	1	1663	-5
1% Upper Climate Change	1463	410	2	1875	-3

The 6 properties that are removed from flood risk (1% AEP rainfall event) are situated along or near Sassoon Close, as shown in Figure 6-14.

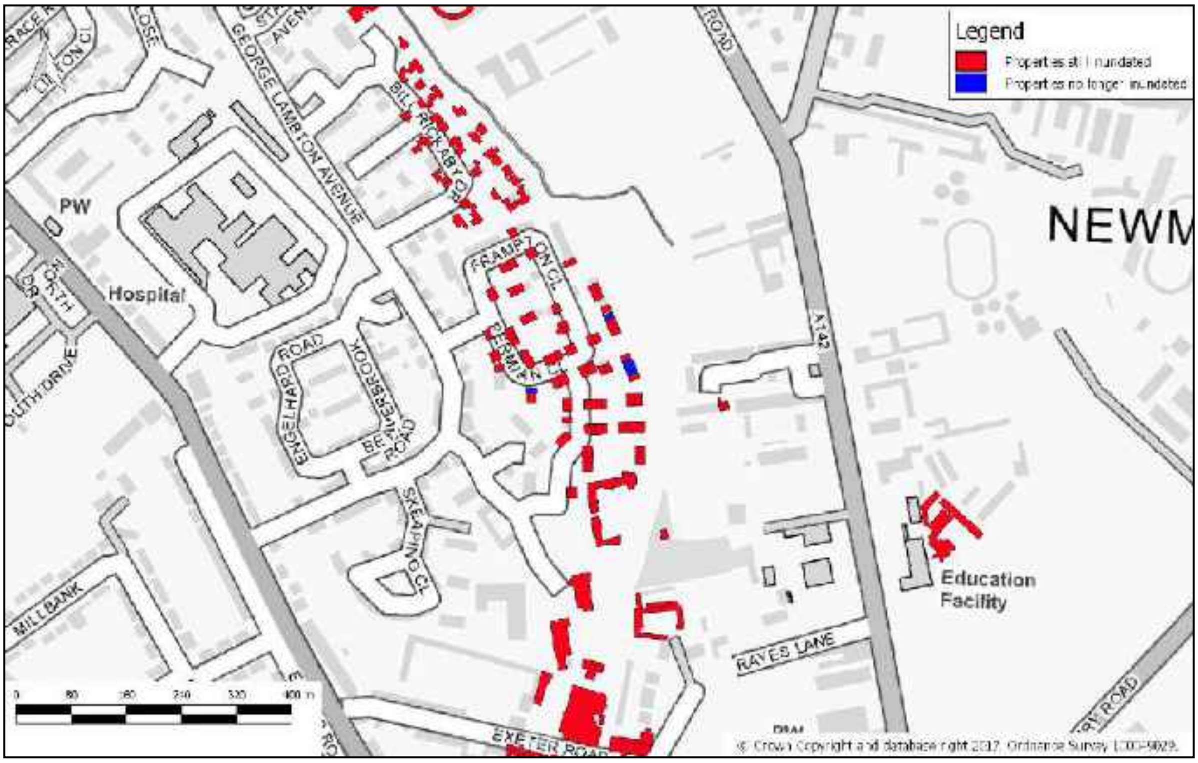
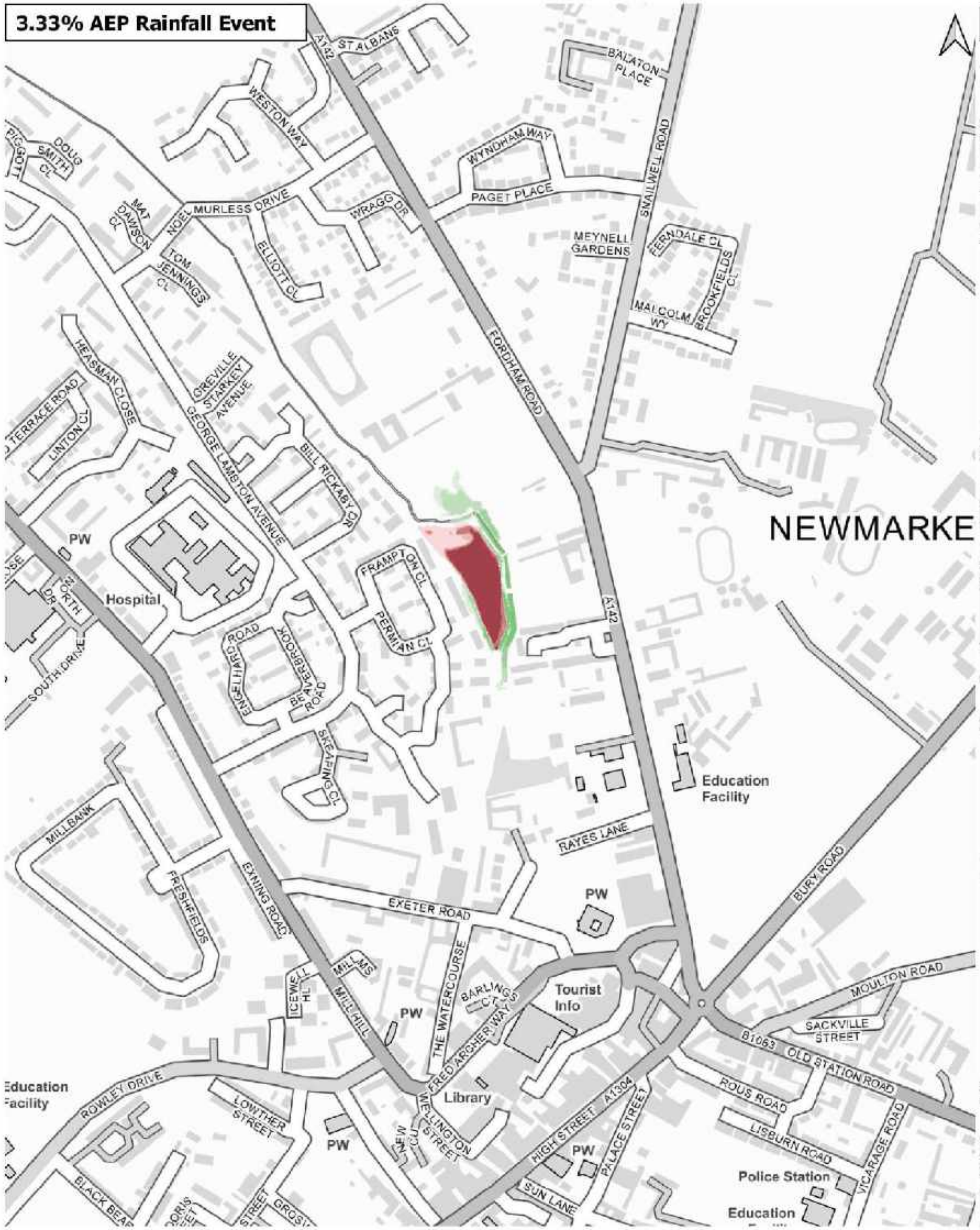
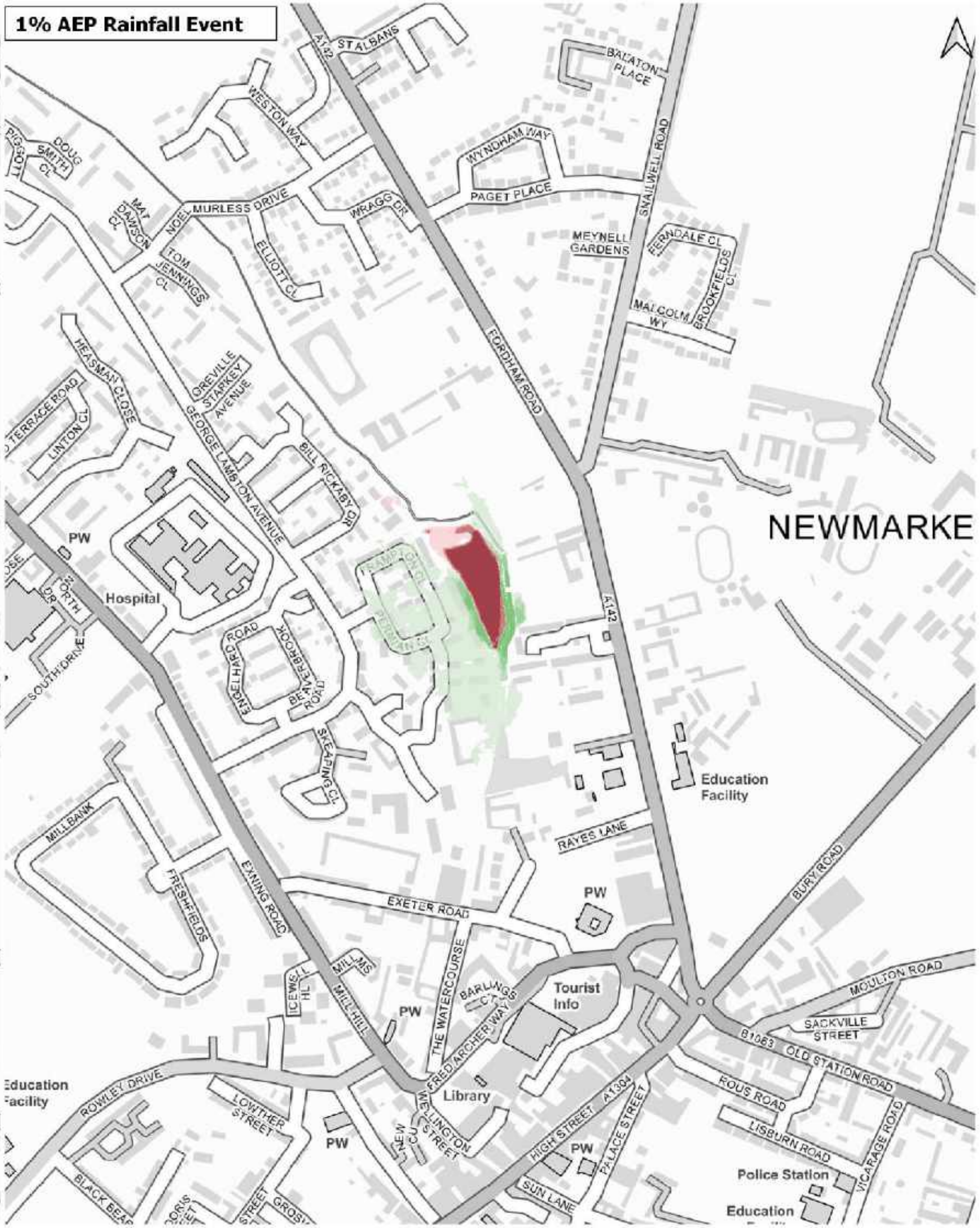


Figure 6-14 Frampton Close Mitigation, 1% AEP, change in property at risk





Model Output Zone

Difference in Peak Depth (m)

<-0.5	0.01 - 0.05
-0.5 to -0.2	0.05 - 0.1
-0.2 to -0.1	0.1 - 0.2
-0.1 to -0.05	0.2 - 0.5
-0.05 to -0.01	>0.5
-0.01 to 0.01	

Title:
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Mitigation Option 3 - Maximum Depth Difference to Baseline Results

Drawing: 6-15
Rev: A

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6.5 Mitigation Option 4 – Combined South West and South East Schemes

6.5.1 Optioneering

Mitigation Option 4 is a combination of mitigation measures outlined in the South East and the South West. Mitigation option 4 was designed to combine the benefits of these two mitigation options in their respective tributaries as well as de-synchronise the peak flow of each watercourse at the confluence in the centre of town (Exeter Road). This attenuation effect should further enhance the flood risk benefits to the properties in town and further downstream.

Figure 6-16 shows that that both the South West and South East mitigation options have an attenuation effect on the flow hydrograph near the centre of town. They provide reductions of 2.8m^3/s and 2.1m^3/s in the peak modelled flow respectively. A combined option (option 4) provides a 5.1m^3/s (9.5%) reduction in modelled peak flow.

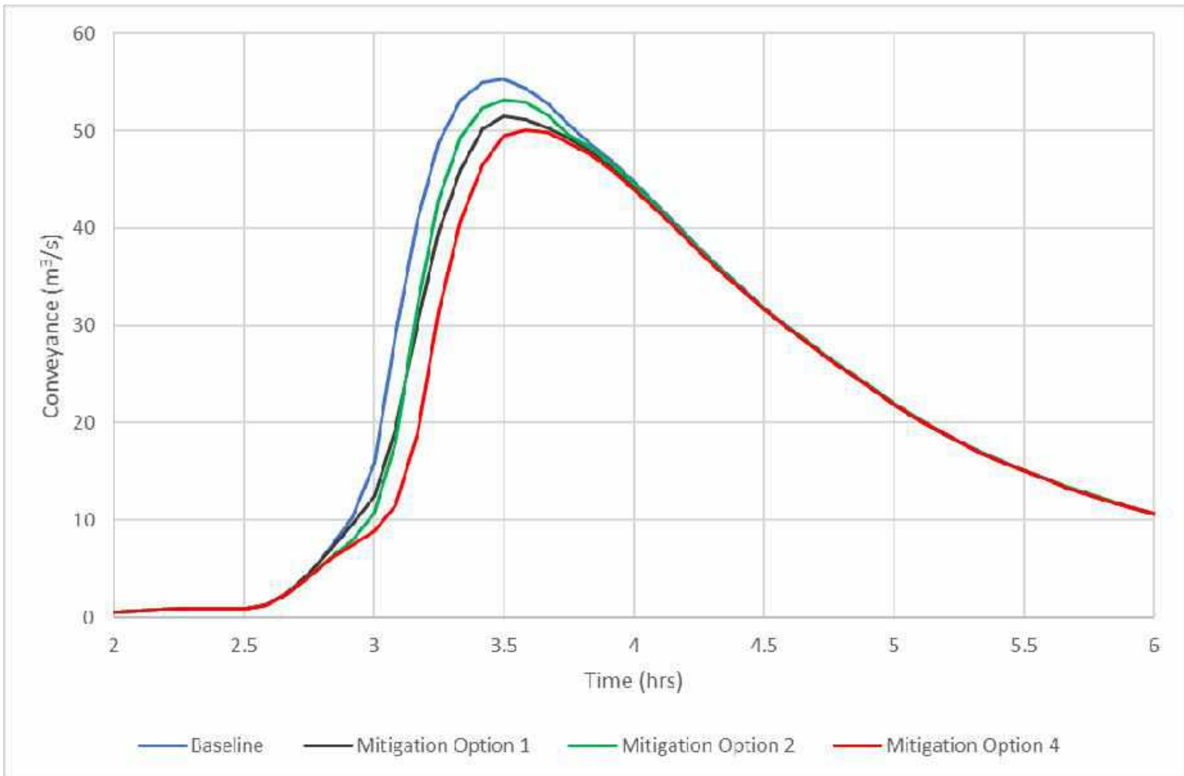


Figure 6-16 Hydrograph 100m downstream of Exeter Road, 1% AEP rainfall event

There are no design changes to the South West and South East options when implemented as part of mitigation option 4. For design details of mitigation option 4, refer to sections 6.1 and 6.2 above.

6.5.2 Mitigation Results

A comparison of the modelled flood depths for the combined mitigation against the baseline results show large reductions in the modelled flood depths across the Newmarket catchment for all modelled rainfall events (5% - 0.1% AEP). Impact mapping for all mitigation measures are shown in Appendix B.

The peak depth differences modelled upstream of the Avenue along the southern flow path and Willow Crescent along the eastern flow path, replicate the results from mitigation options 1 and 2 respectively.

Downstream of Cardigan Street (south western flow path) and Palace Street (south eastern flow path) additional benefits are observed in the 3.33% and 1% AEP rainfall events (Figure 6-18 and Figure 6-19) when compared to the benefits of either the mitigation options alone.

The depth difference results presented in Figure 6-18 and Figure 6-19 indicate that the combined option could provide up to 0.1m and 0.08m reductions in the peak flood levels in the centre of the Newmarket township for the 3.33% and 1% AEP rainfall events respectively. The combined option therefore provides greater benefits than both option 1 and 2 around the centre of town and further downstream to the A14 bypass. Notably, the modelled results indicate that the mitigation option could reduce the peak flood level around Waterloo Close by as much as 0.11m and 0.13m in the 3.33% and 1% AEP rainfall events, respectively. This is a betterment of 0.06m on the modelled flood depth reduction observed in mitigation option 1 for the 1% AEP event.

6.5.2.1 Properties at Risk

Table 6-8 shows the number of properties inundated in the modelled results for the combined mitigation option, for all modelled AEP rainfall events. The combined south west and south east mitigation scheme is expected to remove 124 properties from flooding in the 1.33% AEP rainfall event. This is the greatest number of properties removed from flooding of all mitigation schemes. The scheme also appears very effective across more frequent events such as the 5% and 3.33% AEP rainfall events with 113 and 114 properties removed from modelled flooding.

The total properties impacted for all mitigation options is summarised in Appendix D. The counts presented in Appendix D are aimed at Partnership Funding calculations and are split by areas of deprivation; differences to both the Baseline and 'Do Nothing' are shown.

Table 6-8 Properties at Risk, South Combined Mitigation Scenario

AEP	Residential	Non-Residential	Critical Services	TOTAL	Difference to Baseline
5%	332	127	1	460	-113
3.33%	455	165	1	621	-114
1.33%	909	270	1	1180	-124
1%	1050	297	1	1348	-93
0.1%	1746	469	4	2219	-13
1% Central Climate Change	1268	345	1	1614	-54
1% Upper Climate Change	1443	406	2	1851	-27

Similar to the south west and south east options, modelled results for the combed option suggest that properties along All Saints Drive, Ashley Road, Lowther Street and Bill Rickaby Drive, may be removed from flood risk in the 1.33% AEP rainfall event (Figure 6-17). There are also a number of properties along the bank of the Newmarket Brook to the A14 bypass that could be removed from flood risk.

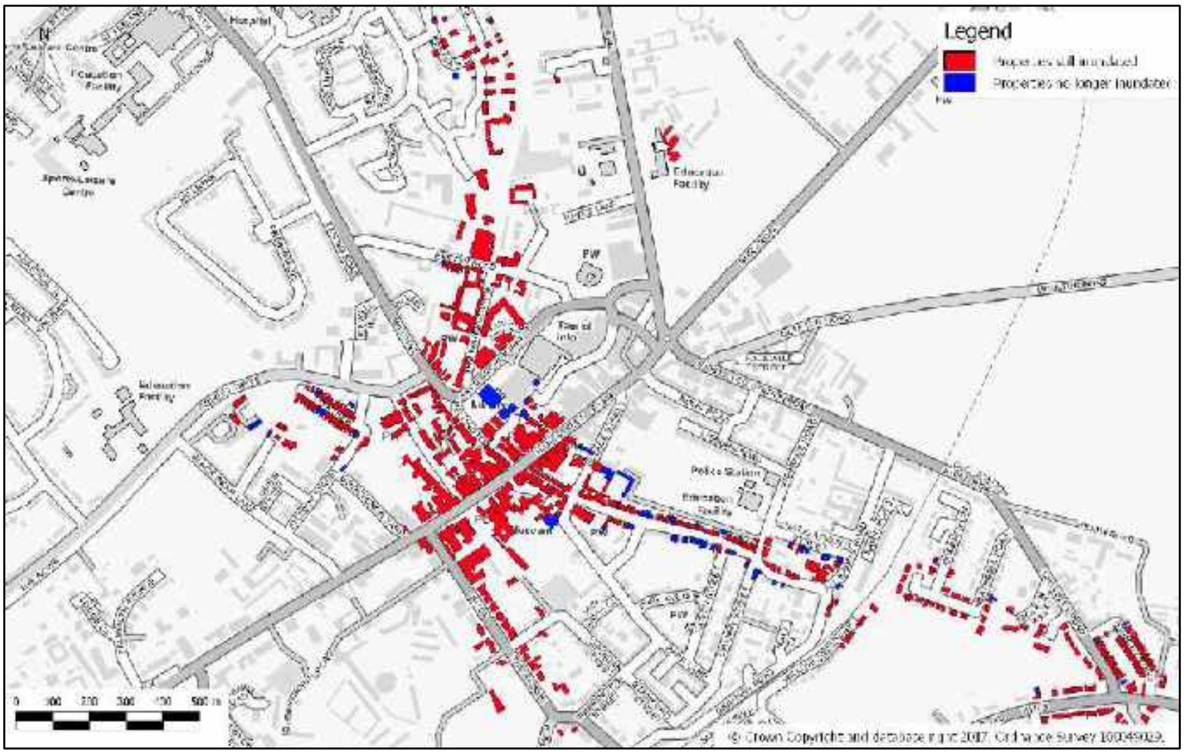
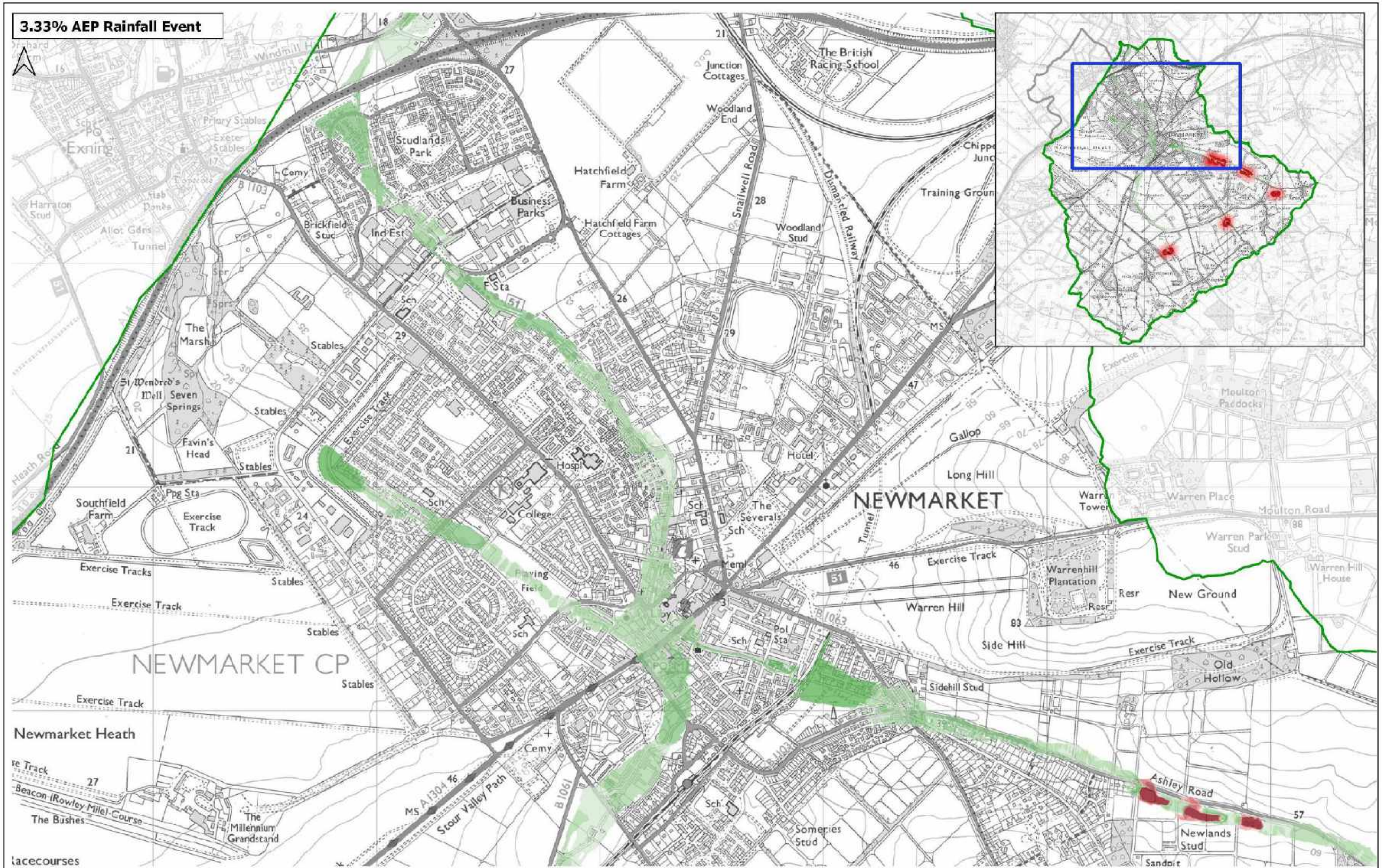


Figure 6-17 South Combined Mitigation, 1.33% AEP, change in property at risk



Model Output Zone

Mitigation Location

Difference in Peak Depth (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title:
Newmarket SWMP Model Update
Mitigation Option 4 - Maximum Depth Difference to Baseline Results

Drawing: **6-18** Rev: **A**

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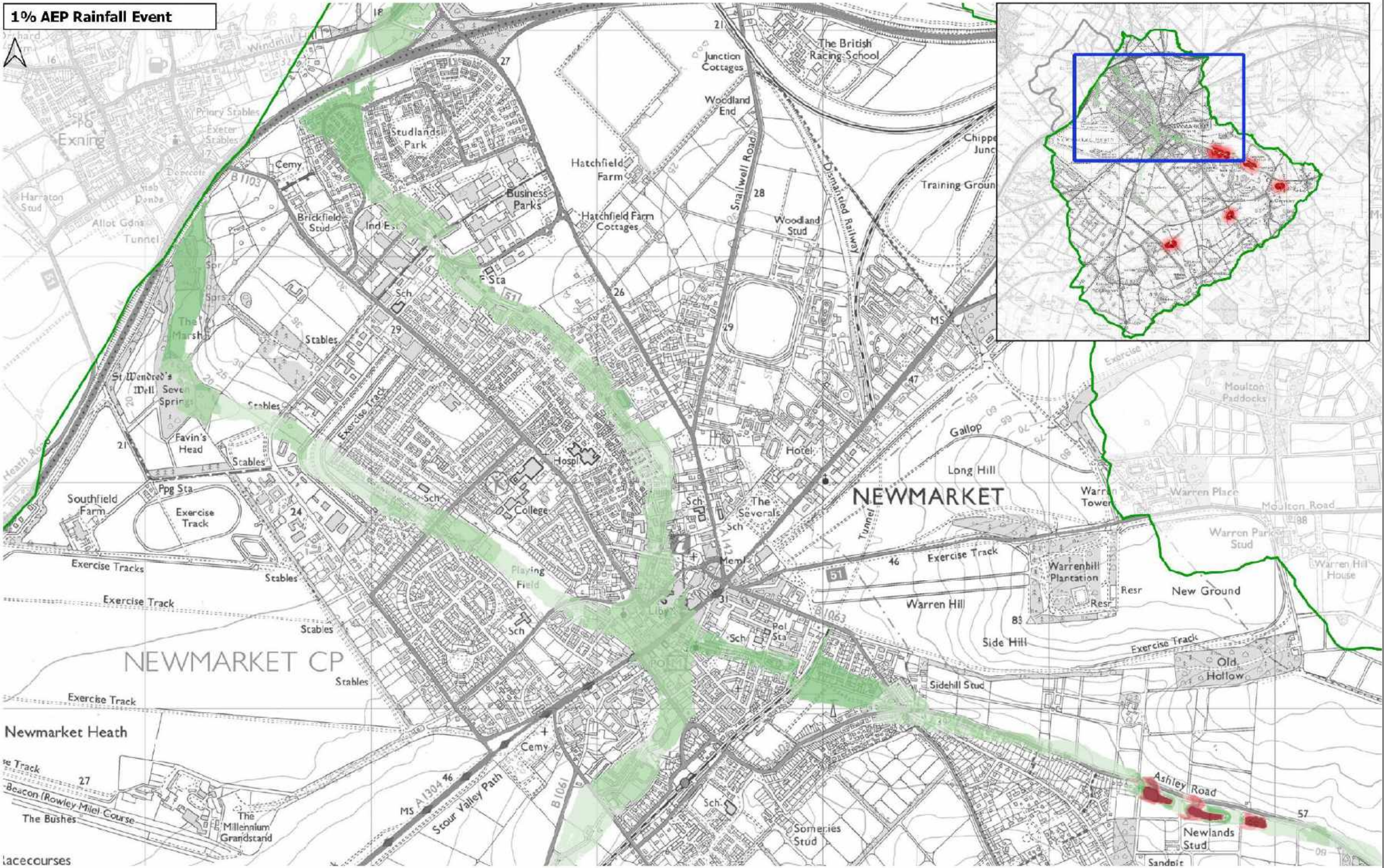

Model Output Zone

Mitigation Location

Difference in Peak Depth (m)

- <-0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- >0.5

Title:

Newmarket SWMP Model Update

Mitigation Option 4 - Maximum Depth Difference to Baseline Results

Drawing: 6-19

Rev: A

Drawn/Check: REJ

Date of issue: 02/04/2018

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6.6 Horse Trail benefit assessment

The horse walk trails throughout Newmarket are considered an important asset to the Newmarket community and Suffolk County Council. As part of the mitigation assessment BMT has considered the potential benefits to the horse trails through the centre of town as a result of the mitigation options modelled. Table 6-9 summarises the peak water level modelled at four key locations along the horse trail, shown in Figure 6-20.

Table 6-9 Modelled flood depth at point location along horse walk trail for the 3.33% AEP rainfall event

	Baseline	Mitigation Option 1	Mitigation Option 2	Mitigation Option 3	Mitigation Option 4
Point 1 – Rowley Drive	0.29	0.25	0.28	0.29	0.25
Point 2 – The Watercourse	1.07	0.99	1.06	1.07	0.98
Point 3 – Macdonald Buchanan House	1.30	1.23	1.29	1.30	1.22
Point 4 – Phantom House Stables	0.45	0.42	0.45	0.32	0.41

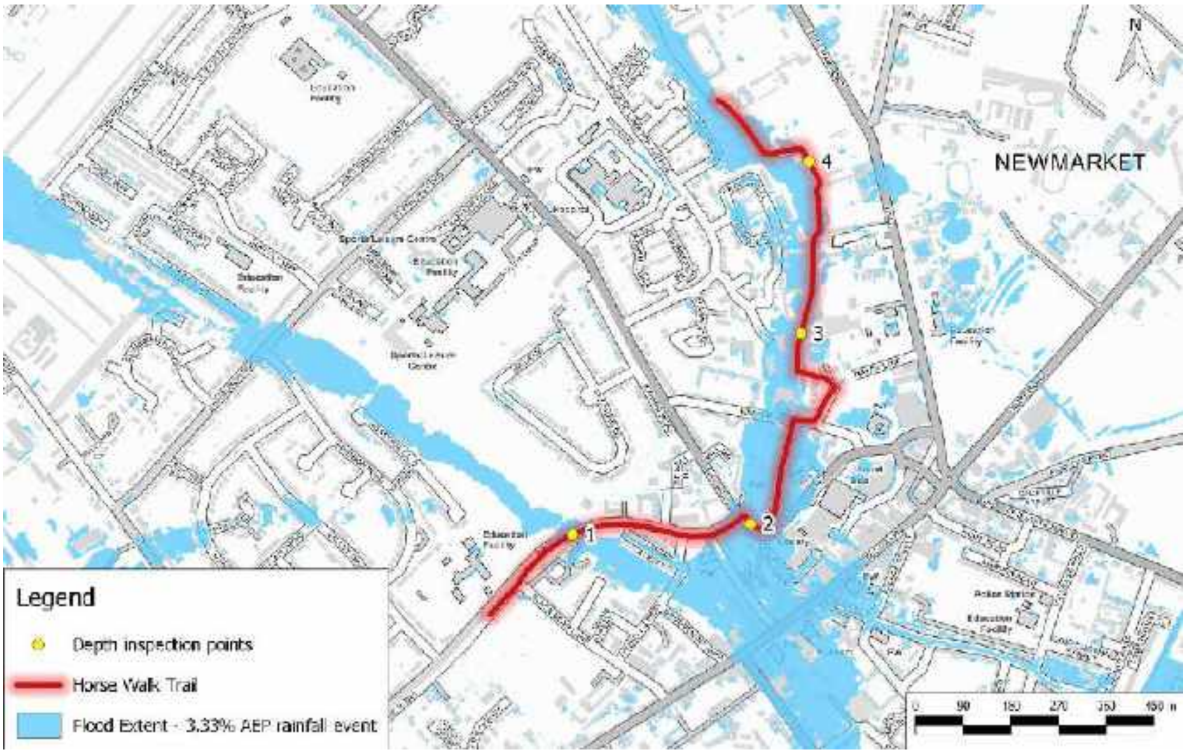


Figure 6-20 Location of horse walk trail and depth point inspection locations

Table 6-9 indicates that mitigation options 1 and 4 are likely to provide the greatest depth reductions to most of the horse walk trail, with >0.05m reductions observed at three of the four inspection points. Mitigation option 3, is expected to reduce the peak flood depth by up to 0.130m at the Phantom House Stables, with little benefit to any other sections of the trail; while option 2 provides very little benefit to much of the horse trail.

The duration for which the horse walk trail is inundated is also important to reduce, doing so means the track is usable sooner and is likely to incur less flood damage. Though the depths of inundation are expected to be reduced through the proposed mitigation options, the duration of time that the horse walk trails are expected to be inundated for is unchanged by any of the mitigation options presented. Therefore, the benefit of these mitigation options will be in reducing the peak flood depth only, which may reduce damage incurred and increase the immunity of the horse walk trails to flooding risk.

Basins in the above mitigation options have, wherever possible, been designed to accommodation the retention of pasture land and fields for horses and other livestock. Batters for basins have been preliminary designed to standards specified in the US Forest Service Equestrian Trail Design Guidebook[11]

[11] United States Department of Agriculture, United States Forest Service, 2007, *Equestrian Design Guidebook for Trails, Trailheads and Campgrounds (0723-2816-MTDC).* https://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232816/index.htm

7 Economic Analysis

This chapter presents the methodology and outcomes of a benefit cost assessment of the damages predicted to accrue over a 100 year appraisal period together with the economic viability of proposed mitigation options.

The methodology used in this appraisal follows the principles of Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG; Environment Agency, 2010), the Multicoloured Manual (MCM; Flood Hazard Research Centre, 2017 including latest 2018 guidance), the Multicoloured Handbook (MCH; Flood Hazard Research Centre, 2016) and the Treasury Green Book (HM Treasury, 2003). A full summary of the methodology used to calculate the damages is provided in Appendix E.

Flood damages from the MCH have been updated to the appraisal base date using Consumer Price Index (CPI) and House Price Index (HPI) factors. An estimation of properties at risk of flooding was completed using property counts estimated using the following datasets:

- The National Receptor Dataset (NRD);
- The Ordnance Survey Master Map (OSMM) building polygons; and
- The predicted flood depth results for the baseline and options scenarios.

7.1 Estimated Flood Damages

Flood damages for the Newmarket catchment have been estimated based on the modelled results across a range of flood events.

The damages are presented as present value damages (PVD) and provide an indication of the annual cost of flooding to a community. It is calculated by determining the damages associated with various design floods multiplied by the likelihood of occurrence across a range of floods. Large events that normally cause substantial damage may not contribute a great deal to the average annual costs due to their low probability. PVD is best understood as the average of flood damages calculated over many years.

The PVD is made up of direct, tangible damages, in this case, the impacts on flooded properties both commercial and residential, as well as indirect or intangible damages such as estimates of evacuation, vehicle damages, emergency services and clean-up costs and road closures, all of which have been included in the calculation of PVD for this appraisal.

7.1.1 Baseline and ‘Do Nothing’ Scenarios

The estimated flood damages for the Newmarket catchment baseline and ‘Do Nothing’ scenarios are presented below in Table 7-1.

Table 7-1 Estimated Present Value Damages, Baseline and 'Do Nothing' Scenario

Present Value Damages	Baseline Scenario	'Do Nothing' Scenario
Direct Damages	£91,698,990	£96,389,500
Indirect Damages (Evacuation, Clean up etc)	£12,847,200	£15,123,400
Other Damages (Road Closure)	£1,525,600	£1,525,600
TOTAL	**£106,071,800**	**£113,038,500**

The direct and tangible PVD is broken down by ward, to give an indication of the spatial distribution of the estimated flood damages.

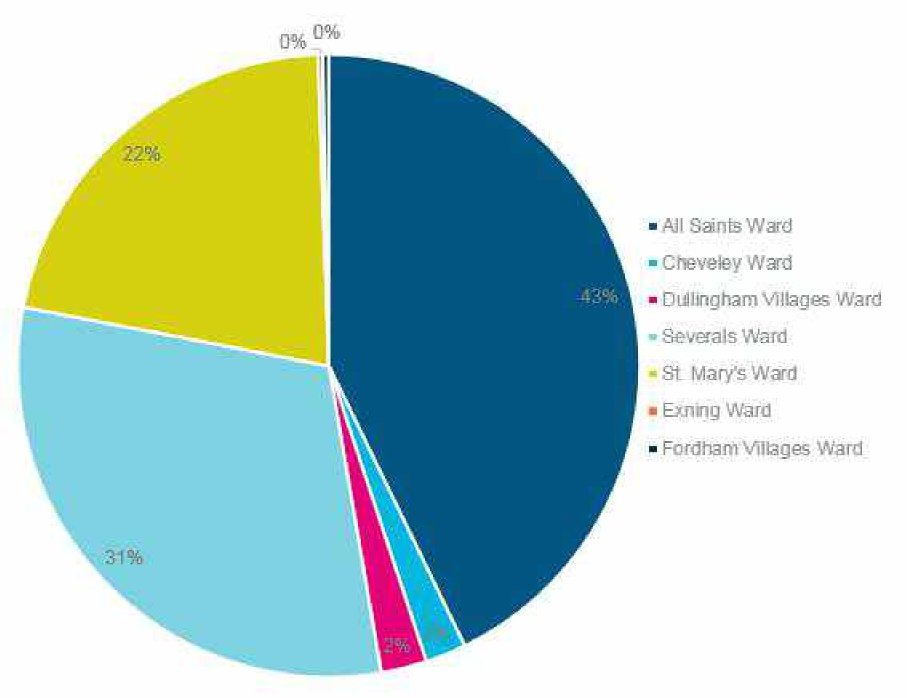


Figure 7-1 Direct PVD by Ward, Baseline Scenario

7.1.2 Mitigation Scenarios

The flood damages for the four mitigation options has been estimated and reported in Table 7-2.

Comparing the mitigation scenario to the baseline scenario (Do Minimum) provides an estimate of the damages averted (Present Value of Benefits – PVB) through implementation of the mitigation measure. The mitigation scenarios have also been compared to the 'Do Nothing' scenario. This difference represents the damages averted by contiuning council's ongoing maintenance, as well as constructing a mitigation option.

Table 7-2 Estimated Present Value Damages, Mitigation Scenarios

Scenario	Present Value Damages	Compared to Baseline		Compared to 'Do Nothing'	
		Present Value Benefits (£)	Change (%)	Present Value Benefits (£)	Change (%)
Do Nothing'	£113,038,500	+£6,966,700	+ 6%	-	-
Baseline	£106,071,800	-	-	-£6,966,700	-6%
Mitigation 1 – South West	£101,248,800	-£4,823,000	-5%	-£11,789,700	-12%
Mitigation 2 – South East	£97,726,700	-£8,345,100	-9%	-£15,311,800	-16%
Mitigation 3 – Frampton Close	£106,040,300	-£31,500	-1%	-£6,998,200	-7%
Mitigation 4 – Combined South	£92,854,500	-£13,217,300	-14%	-£20,184,000	-22%

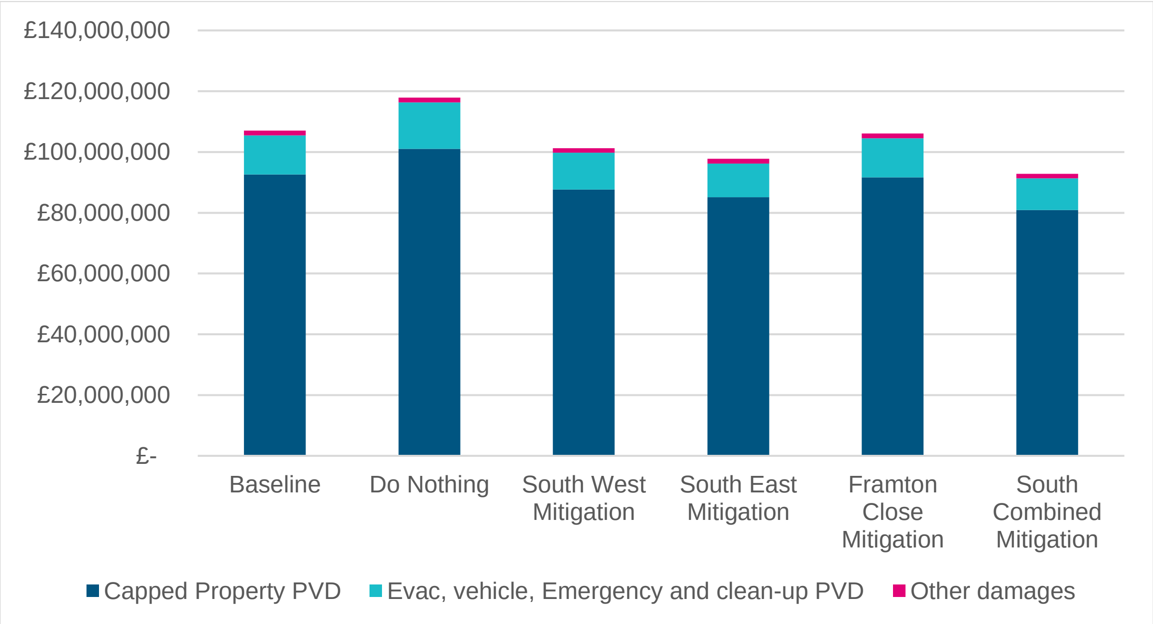


Figure 7-2 Estimated Present Value Damages, Mitigation Scenario, Bar Chart

All modelled mitigation options present a reduction in estimated damages from the baseline case. The mitigation options range from a 1% reduction (Frampton Close Option) to a 15% reduction (Combined South).

7.2 Mitigation Costing

Indicative capital costs for all four mitigation schemes have been calculated based on available costing datasets (SPONS, 2018; EA, 2015). Capital costs are fixed, one-time expenses incurred on the purchase of land, construction material, labour and equipment used in the production of the scheme. In other words, the total cost needed to build the scheme to an operable status. Cost rates for capital works were estimated from Table 1.3 and 1.6 in the '*Cost estimation for flood storage – summary of evidence*' report published by the EA (2015), which are based on a dataset of historical project case studies.

A 60% risk bias was added for all shortlisted options to account for limited knowledge of land purchase prices and unforeseen design considerations. A 60% bias was considered appropriate as options that have been selected are green spaces and the existing land use is not expected to change dramatically. This is expected to reduce the cost of completion for each mitigation option.

Detailed capital costs, including complete operational and decommissioning costs, have not been calculated.

There are significant assumptions in estimating capital costs at feasibility design phase, many of these are outlined below. The cost rates (EA, 2015) take these into account through as an average across numerous case study projects, but this does not allow for exceptional circumstances. As a result, the whole of life costs may be greater than the figures quoted in Table 7-3.

- Cost of land purchase
- Local geology and suitability of excavated material for fill
- Further design and study work
- Buried services
- Site accessibility
- Contract and Project Management
- Scour protection and amenity requirements
- Extreme or ongoing poor weather conditions

An approximate cost for ongoing maintenance throughout the serviceable life of the scheme has been estimated as 1% of the total indicative capital costs, per year. Whole of life costs should be reassessed and expanded upon when more detailed site-specific design work is undertaken.

Table 7-3 Estimated Mitigation Costs

Scenario	Estimated Capital Cost	Operation and Maintenance (per year)	Present Value total cost
Mitigation 1 – South West	£198,000	£1,980	**£255,200**
Mitigation 2 – South East	£1,210,000	£12,100	**£1,559,300**
Mitigation 3 – Frampton Close	£478,000	£4,780	**£616,000**
Mitigation 4 – Combined South	£1,410,000	£14,100	**£1,817,000**

Mitigation option 1 has been costed as the cheapest mitigation option to implement at £255,200 and Mitigation option 4 the most expensive at £1,817,000. As stated previously these costs could vary significantly due to a range of limitations and assumptions the feasibility costing tools and should be considered as a guide to the scale of costs associated with each option.

7.2.1 Baseline (Do Minimum) Cost

Suffolk County Council has provided estimated costs for ongoing maintenance. These costs only include the yearly gully cleansing. The costs do not include watercourse clearance, drainage asset maintenance or erosion control.

The below cost has been based on an estimated cost per gully for cleansing, the total number of gullies in the newmarket catchment and their yearly cleansing frequency.

As per the above mitigation costing, a 60% risk bias has been applied. This risk bias captures the expected addititonal elements in watercourse maintenance not included in the provided cost, a predicted rise in maintenance costs, as well as unforeseen costs.

Scenario	Estimated Yearly Cost	Present Value Total Cost
Baseline (Do Minimum) Costs	£14,808	£706,300

Where mitigation options are compared to the 'Do Nothing' the above Present Value Total Costs have been added.

7.3 Benefit Cost Analysis

A benefit cost ratio (BCR) has been calculated for each of the options. This provides an estimate of the initial feasibility of the project. A ratio of over 1.0 indicates that the benefits of the scheme outweigh the costs and it should be considered for further study or implementation. A ratio of under 1.0 indicates that the costs are higher than the expected benefits.

The benefit cost ratio hase been calculated against both the baseline (Do minimum) and the 'Do Nothing' scenario. These two comparisons have been carried out to facilitate future FDGiA funding applications.

The net present values and benefit cost ratio of each of the options are:

Table 7-4 Benefit Cost Ratio

Scenario	Compared to Baseline			Compared to 'Do Nothing'		
	Present Value total cost	Present Value Total Benefit	Benefit Cost Ratio	Present Value total cost	Present Value Total Benefit	Benefit Cost Ratio
Do Nothing	-	-	**-**	-	-	**-**
Baseline (Do Minimum)	-	-	**-**	£706,000	-£6,966,700	**9.87**
Mitigation 1 – South West	£255,200	-£4,823,000	**18.90**	£961,200	-£11,789,700	**12.27**
Mitigation 2 – South East	£1,559,300	-£8,345,100	**5.35**	£2,265,300	-£15,311,800	**6.76**
Mitigation 3 – Frampton Close	£616,000	-£31,500	**0.05**	£1,322,000	-£6,998,200	**5.29**
Mitigation 4 – Combined South	£1,817,000	-£13,217,300	**7.27**	£2,523,000	-£20,184,000	**8.00**

Table 7-4 shows that mitigation options 1, 2 and 4 presented in this study provide a benefit to cost ratio of greater than 1 compared to the baseline. Mitigation option 1 is expected to provide the greatest whole of life benefit to cost ratio, with a present value benefit 18 times greater than the cost in the baseline scenario. Mitigation option 4 which is a combination of option 1 and 2, provides the next greatest benefit cost ratio at 7.27.

The difference of the baseline scenario compared to the 'Do Nothing' scenario, has a benefit cost ratio of 9.87. This indicates that the activities undertaken by council and the EA to maintain the catchment are hightly cost beneficial. When compared to the 'Do Nothing' instead of the baseline, Mitgation options 1 and 4 are effectively weighted by this 9.87 ratio. Mitigation option 1 decreases to 12.27 and mitigation option 4 increases to 8.00.

The benefit cost ratio indicates the financial benefit per £ spent, and therefore the feasibility of implementing a mitigation option, but does not necessarily define the best option to proceed with. As per section 7-1, mitigation option 4 is likely to provide the greatest PV value to Newmarket and may be considered the preferred mitigation option depending on available investment funding.

8 Conclusions

8.1 Aims and Objectives

The Newmarket SWMP model update study has addressed key limitations in the previous SWMP study, has assessed the catchment wide flood risk including interaction between surface water and sewer flooding, and identified potential options to mitigate the risk of surface water flooding within Newmarket.

An enhanced Integrated Urban Drainage (IUD) model has been developed to calculate and compare the benefits and costs of the flood mitigation measures developed in TUFLOW HPC.

Sensitivity analysis has been carried out to provide a semi-quantitative measure of parameter uncertainty, and qualitative validation undertaken based on anecdotal evidence of flooding. A 'Do Nothing' Scenario has been assessed using DEFRA guidance. This scenario is a requirement for Outline Business Case Assessments and funding grants. A 'Do Minimum' scenario forms the baseline scenario.

8.2 Options Analysis

The list of options proposed in the existing SWMP report were reviewed. A number of these were tested and one was carried forward to mitigation option assessment. An additional three options were tested, outside the list of those proposed in the SWMP.

Three of the options are source control in the upper catchment. The options typically comprise a number of shallow detention basins and earth bunds distributed throughout the catchment draining towards Newmarket.

All four options provide benefit to areas of the Newmarket catchment, with option four, the combined southern flow route option providing flood risk protection to the greatest number of properties. Indicative capital costs to build the preferred scheme to an operable status were calculated, considering the design and planning, land purchase and construction costs. An optimism bias of 60% has been applied to the capital costs to account for unforeseen costs to the scheme.

8.3 Flood Damage Estimation

The flood damages have been estimated for the Do Minimum as well as for four mitigation scenarios using five Annual Exceedance Probability (AEP) rainfall events.

The Present Value flood Damages (PVD) for the Newmarket catchment are provided in Table 8-1. The Present Value of Benefits (PVB) is the difference between the PVD in the Do Minimum (baseline) scenario and mitigated options.

Table 8-1 Present Value Damages; compared to Baseline

Scenario	Present Value Damages	Present Value of Benefits (Change from Baseline) (£)	Change from Baseline (%)
'Do Nothing'	£113,038,500	£6,966,700	+ 6%
Baseline	£106,071,800	-	-
Mitigation 1 – South West	£101,248,800	-£4,823,000	-5%
Mitigation 2 – South East	£97,726,700	-£8,345,100	-9%
Mitigation 3 – Frampton Close	£106,040,300	-£31,500	-1%
Mitigation 4 – Combined South	£92,854,500	-£13,217,300	-14%

Based on the estimated net present value of the costs and benefits over the scheme appraisal period (100 years), the benefit cost ratios for each option have been calculated. A benefit cost ratio of over 1.0 indicates that the scheme is beneficial and should proceed to detailed modelling and costing analysis.

Table 8-2 Mitigation options compared to baseline: Benefit Cost Ratio

Scenario	Present Value total cost	Present Value Total Benefit	Benefit Cost Ratio
Mitigation 1 – South West	£255,200	-£4,823,000	**18.90**
Mitigation 2 – South East	£1,559,300	-£8,345,100	**5.35**
Mitigation 3 – Frampton Close	£616,000	-£31,500	**0.05**
Mitigation 4 – Combined South	£1,817,000	-£13,217,300	**7.27**

Damages and Benefit Cost Ratios have also been compared to the 'Do Nothing' Scenario. These are presented in Table 7-4.

BMT recommends that both mitigation option 1, South West, and mitigation option 4, combined south, are appropriate to proceed to further detailed design or forward to funding calculation. This would further assess the feasibility of the designs and provide more certainty as the options progress to implementation.

9 Limitations and Recommendations

All numerical models are required to make some form of approximation to solve the basic principles of hydraulics, and consequently all have their limitations. These may be related to geometric limitations, numerical simplification, or the use of empirical correlations.

It is important to remember that the hydraulic models in this study have been built to assess flooding from surface water. Flooding from surface water is difficult to predict as rainfall location and volume are difficult to forecast. In addition, local features can greatly affect the chance and severity of flooding. The models may be adapted to model other, or multiple, sources of flooding, but they must be modified accordingly.

The hydraulic model results are suitable for identifying areas susceptible to surface water flooding. Detailed modelling may be required for assessing individual properties at risk and options to mitigate that risk.

9.1 Reducing Model Uncertainty

The level of confidence that may be placed in the results of a hydraulic model are heavily dependent on the data used to inform them. Where gaps have been identified in these datasets, assumptions are needed to provide an appropriate representation of the flooding mechanisms in the study area.

Dataset	Recommendation
Infiltration data	Infiltration rates across the catchment make a very substantial impact to flood risk. Understanding infiltration rates, seasonal changes and soil conditions would improve the overall understanding of flood risk, including property count and damage estimations.
AW drainage network data	A portion of the Newmarket urban area does not have any surface water drainage information. Survey of the additional areas would improve the representation of the urban drainage network and flooding mechanisms
SCC and AW Soakaway details	Large areas of Newmarket are shown as draining to areas marked as soakaways. Understanding the capacity and recharge rates of the soakaways would improve the understanding of urban drainage
Validation and Calibration	The model has been validated to one historic event. The validation data was spatially limited. Historic events of varying size with historic records
Topography	Further details on obstructions, such as fences, walls and bunds could allow further detailed urban flood risk understanding.

Key:
High priority (critical) Moderate priority (beneficial) Low priority (useful)

Resolving the data limitations and gaps above will provide a more accurate understanding of surface water flood risk in Newmarket.

9.2 Improving Flood Damage Estimation

Flood damage estimates are highly sensitive to relatively small changes in the depth of flooding at shallow depths. Therefore, the accuracy of the property threshold level and the predicted depth of flooding is critical in estimating flood damages. Surveyed building threshold levels were not available. Instead threshold levels were estimated by adding a 0.3m threshold height to the average DTM elevation within the building polygon. The threshold height was based on a typical step height of a dwelling entrance in the area, as agreed in consultation with SCC. To improve the accuracy of the damage estimation, building threshold levels should be surveyed and used in the damage calculation process.

Direct/tangible flood damages to residential and commercial property have been calculated. Direct damages result from the physical contact of flood water with property (Brick and Mortar). Vehicle, evacuation, main road closure and emergency services costs have been included as indirect damages. Flooding can have additional indirect, or secondary, impacts on other assets and public utilities (schools, hospitals and wider transport networks), which have not been considered. Furthermore, the intangibles such as health impacts have not been assessed. Although we know that flooding can affect people's health, it is difficult to assign a monetary figure on socio-economic impacts.

9.3 Mitigation Option Development

Broad-scale concept designs have been proposed that are generic in nature and do not include all information that might be required of a final design. Generic detail in the options and other site specific aspects such as the interaction with existing services etc. should be clarified as part of any further detailed design work. Optimisation of the attenuation measures should be undertaken at the detailed design stage to minimise construction costs.

The dimensions of the detention basins and outlet requirements have not been tested to optimise the storage versus drawdown times. This should be considered during detailed design as further flow attenuation and flood mitigation may be realised by throttling the outfall discharge.

Outline costs and benefits have been derived to inform future funding decisions, but further analysis, including the whole life costs is required for completing a Flood Defence Grant in Aid or Local Levy funding application.

Appendix A Maximum Flood Depth and Hazard Maps

Appendix B Mitigation Impact Mapping

Appendix C Structures

Appendix D Estimated Flooded Property Counts

D.1 Property Counts

Property counts were estimated using the following datasets:

- The National Receptor Dataset (NRD);
- The Ordnance Survey Master Map (OSMM) building polygons; and
- The predicted flood depth results for the baseline and options scenarios.

The Environment Agency (EA) methodology uses the NRD property points and building footprints from the OSMM Topographic Area layer. The OSMM and the NRD typically have a degree of mismatch as they are updated at different times (Figure D-1). Where data is lacking, the building classification (residential, non-residential or critical services) has been manually filled. The manual assumption of classification has been based on satellite imagery, mapping and surrounding building class. Where no classification was clear, the building has been assumed to be residential.

Figure D-1 OS MasterMap and NRD

OSMM polygons representing garages and sheds can skew property count and damage estimation results. These have been filtered out using an area threshold of 20m2. A threshold of 20m2 was selected due to the identification of several small residential properties that should be included in the final dataset. Remaining garages and sheds of >20m2 have been manually removed where easily identifiable.

The analysis has been carried out on the 5%, 3.33%, 1.33%, 1%, 0.1% AEP events and 1% AEP with Climate Change allowance; lower bound (20%) and upper bound (40%). The modelled results from the updated SWMP modelling have been used for the baseline flood risk estimation and mitigation option.

D.1.1 Methodology

The latest method developed by the EA for estimating the properties at risk from surface water flooding has been used in this analysis. A summary of the method developed by the EA is provided below. Further details can be found in the report accompanying the uFMfSW Property Points dataset[1].

The building footprints in the OSMM are buffered to reduce the gridded effect of the raised building footprint and flood extent. The recommendation for the buffer size is the modelled grid size, therefore, a 1m buffer has been applied. The analysis is then carried out on the buffered building boundary and is adjusted for internal building perimeters, for example when properties are terraced or semi-detached.

The proportion of the buffered boundary where the depth is greater than a specified threshold is calculated, as shown by the blue line in Figure D-2.

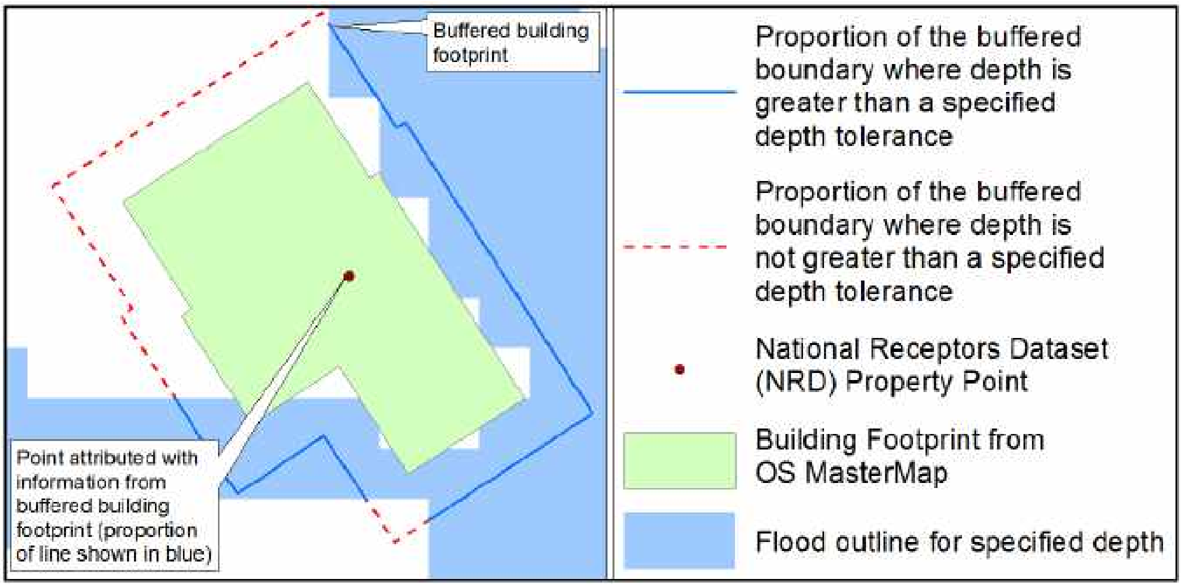


Figure D-2 Property Count Methodology (EA, July 2014)

The final dataset is then filtered according to local judgement on the proportion of the buffered building boundary and depth threshold to produce locally applicable counts of properties that are at risk of surface water flooding.

The properties at risk of surface water flooding within Newmarket have been selected using ≥ 50% wetted perimeter AND ≥ 0.2m depth threshold. The depth threshold corresponds to the average height of building threshold or airbrick allowing floodwater to enter the property. This depth threshold corresponds to the national standard of 0.2m. Surveyed property levels in Sassoon Close have been used to validate this assumption.

Each building polygon that met the criteria is marked as ‘flooded’. For multiple properties within one building (e.g. units within a multi-storey building) only basement and ground floor properties are counted. Property counts have been calculated separately for residential, non-residential and critical infrastructure.

For EA Flood Defence Grant in Aid (FDGiA) funding calculation, flooded properties are typically categorised by ward into deprivation indices for three classifications: 20% most deprived, 20% - 40% most deprived and 60% least deprived.

D.1.2 Summary of Property Counts

The below tables details the estimated flooded property counts for the mitigation options, compared to the 'Do Nothing' and baseline scenarios. These tables split out the counts by property area of deprivation. **Only the residential counts have been included below for the calculation of partnership funding.**

D.1.2.1 Mitigation Option 1: South West

Table D-1 Mitigation Option 1: South West and Baseline Scenario; Estimated Property Counts

AEP	Baseline Scenario				Mitigation Option 1: South West				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	137	283	420	0	105	261	366	-54
3.33%	0	168	382	550	0	154	360	514	-36
1.33%	0	327	686	1013	0	306	676	982	-31
1%	0	360	768	1128	0	347	759	1106	-22
0.10%	0	551	1206	1757	0	549	1205	1754	-3
1% Central Climate Change	0	414	882	1296	0	405	876	1281	-15
1% Upper Climate Change	0	469	997	1466	0	467	992	1459	-7

Table D-2 Mitigation Option 1: South West and 'Do Nothing' Scenario; Estimated Property Counts

AEP	'Do Nothing' Scenario				Mitigation Option 1: South West				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	155	331	486	0	105	261	366	-120
3.33%	0	197	460	657	0	154	360	514	-143
1.33%	0	349	742	1091	0	306	676	982	-109
1%	0	370	810	1180	0	347	759	1106	-74
0.10%	0	547	1246	1793	0	549	1205	1754	-39
1% Central Climate Change	0	416	922	1338	0	405	876	1281	-57
1% Upper Climate Change	0	467	1036	1503	0	467	992	1459	-44

D.1.2.2 Mitigation Option 2: South East

Table D-3 Mitigation Option 2: South East and Baseline Scenario; Estimated Property Counts

AEP	Baseline Scenario				Mitigation Option 2: South East				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	137	283	420	0	137	249	386	-34
3.33%	0	168	382	550	0	168	324	492	-58
1.33%	0	327	686	1013	0	316	620	936	-77
1%	0	360	768	1128	0	358	716	1074	-54
0.10%	0	551	1206	1757	0	550	1204	1754	-3
1% Central Climate Change	0	414	882	1296	0	406	870	1276	-20
1% Upper Climate Change	0	469	997	1466	0	467	986	1453	-13

Table D-4 Mitigation Option 2: South East and 'Do Nothing' Scenario; Estimated Property Counts

AEP	'Do Nothing' Scenario				Mitigation Option 2: South East				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	155	331	486	0	137	249	386	-100
3.33%	0	197	460	657	0	168	324	492	-165
1.33%	0	349	742	1091	0	316	620	936	-155
1%	0	370	810	1180	0	358	716	1074	-106
0.10%	0	547	1246	1793	0	550	1204	1754	-39
1% Central Climate Change	0	416	922	1338	0	406	870	1276	-62
1% Upper Climate Change	0	467	1036	1503	0	467	986	1453	-50

Table D-5 Mitigation Option 3: Frampton Close and Baseline Scenario; Estimated Property Counts

AEP	Baseline Scenario				Mitigation Option 3: Frampton Close				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	137	283	420	0	137	282	419	-1
3.33%	0	168	382	550	0	168	383	551	1
1.33%	0	327	686	1013	0	326	686	1012	-1
1%	0	360	768	1128	0	355	767	1122	-6
0.10%	0	551	1206	1757	0	551	1206	1757	0
1% Central Climate Change	0	414	882	1296	0	410	881	1291	-5
1% Upper Climate Change	0	469	997	1466	0	467	996	1463	-3

Table D-6 Mitigation Option 3: Frampton Close and 'Do Nothing' Scenario; Estimated Property Counts

AEP	'Do Nothing' Scenario				Mitigation Option 3: Frampton Close				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	155	331	486	0	137	282	419	-67
3.33%	0	197	460	657	0	168	383	551	-106
1.33%	0	349	742	1091	0	326	686	1012	-79
1%	0	370	810	1180	0	355	767	1122	-58
0.10%	0	547	1246	1793	0	551	1206	1757	-36
1% Central Climate Change	0	416	922	1338	0	410	881	1291	-47
1% Upper Climate Change	0	467	1036	1503	0	467	996	1463	-40

Table D-7 Mitigation Option 4: Combined South and Baseline Scenario; Estimated Property Counts

AEP	Baseline Scenario				Mitigation Option 4: Combined South				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	137	283	420	0	105	227	332	-88
3.33%	0	168	382	550	0	150	305	455	-95
1.33%	0	327	686	1013	0	300	609	909	-104
1%	0	360	768	1128	0	341	709	1050	-78
0.10%	0	551	1206	1757	0	547	1199	1746	-11
1% Central Climate Change	0	414	882	1296	0	404	864	1268	-28
1% Upper Climate Change	0	469	997	1466	0	461	982	1443	-23

Table D-8 Mitigation Option 4: Combined South and 'Do Nothing' Scenario; Estimated Property Counts

AEP	'Do Nothing' Scenario				Mitigation Option 4: Combined South				Difference
	20% Most Deprived	20%-40% Most Deprived	60% Least Deprived	TOTAL	20% Most Deprived	20 - 40% Most Deprived	60% Least Deprived	TOTAL	
5%	0	155	331	486	0	105	227	332	-154
3.33%	0	197	460	657	0	150	305	455	-202
1.33%	0	349	742	1091	0	300	609	909	-182
1%	0	370	810	1180	0	341	709	1050	-130
0.10%	0	547	1246	1793	0	547	1199	1746	-47
1% Central Climate Change	0	416	922	1338	0	404	864	1268	-70
1% Upper Climate Change	0	467	1036	1503	0	461	982	1443	-60

Appendix E Flood Damage Estimation

Flood damages have been estimated for the baseline, 'do nothing' and three mitigation scenarios. This appendix details the methodology used to estimate the predicted damage in the modelled flood events. This estimation informs assessment of the economic performance of flood alleviation schemes.

The methodology used in this appraisal follows the principles of Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG; Environment Agency, 2010), the Multicoloured Manual (MCM; Flood Hazard Research Centre, 2017 including latest 2018 guidance), the Multicoloured Handbook (MCH; Flood Hazard Research Centre, 2016) and the Treasury Green Book (HM Treasury, 2003).

Flood damages from the MCH have been updated to the appraisal base date using Consumer Price Index (CPI) and House Price Index (HPI) factors. An estimation of properties at risk of flooding was completed using property counts estimated using the following datasets:

- The National Receptor Dataset (NRD);
- The Ordnance Survey Master Map (OSMM) building polygons; and
- The predicted flood depth results for the baseline and options scenarios.

An overview level damage assessment has been carried out. This level of assessment does not consider the property age or social grade of properties.

E.1.1 Residential Property Damages

To calculate the residential losses, the following must be estimated:

- The type of each affected property;
- Property valuation;
- The depth of water in relation to ground floor level; and
- The duration of the flooding.

The property type was taken from the National Receptor Database provided by Suffolk County Council (SCC). Threshold data (finished flood levels) was taken from LiDAR levels in the absence of survey data.

The above data sources are the most reasonable sources of valuation data short of detailed individual property surveys.

Property value - The property value data was obtained from average current values available on property websites. This value was averaged across residential properties in Newmarket.

Depth of water - Flooding has been assessed by comparing predicted flood depths from the hydraulic model to the threshold levels taken from both survey and LiDAR. Damages begin to accrue once depths are within 300mm of a property threshold level, this is to account for below floorboard damage within homes. The damage values are provided by the MCM guidance and accompanying economic damage tables, they are varied depending on the duration of flooding.

Duration of flooding - For Newmarket, the duration of flooding was taken to be less than 8 hours based on the critical duration of flooding being 3 hours

The extent and depth of flooding associated with the modelled return periods was established from hydraulic modelling. All buildings within the study area were assigned a property type (residential or commercial) as well as a unique ID and threshold floor level. To allow an accurate depth / damage relationship (curve) to be derived, water levels were assigned to each property for each return period using the closest water level.

The damages incurred are also dependant on the duration of inundation (i.e. less than 8 hours, longer than 8 hours, or much longer than 8 hours). For this study it was confirmed that all affected properties would be flooded for a total duration of less than 8 hours based on anecdotal evidence from residents and hydraulic modelling.

E.1.2 Non-Residential Property Damages

The MCM provides flood damage data for Non-Residential Properties (NRPs) in terms of floor-plan area of premises inundated, depth and duration of inundation, and type of business. The depth of the flood water was estimated in the same way as for the residential properties (i.e. flood level minus floor level). Property valuations were obtained from business rates data available at www.gov.uk for specific properties. These were uplifted by a factor of 10 as per the MCM guidance

E.1.3 Emergency and Clean-Up Costs

The MCH recommends that emergency costs are calculated as 10.7% of the economic property damage for floods of all annual probabilities; the 10.7% represents the additional damages accrued due to the rural nature of the location. The data sources used by Flood Hazard Research Centre (FHRC) for this estimation included District and County Councils, the fire, police and ambulance services, the military, water authorities and voluntary services.

Clean-up costs are applied to non-residential properties as 3% of total economic damage as defined in the MCH.

E.1.4 Indirect / Intangible Damages

Although there are clear economic benefits to be derived from protecting residential and non-residential properties from flooding, there are other benefits that are more difficult to quantify economically and typically account for a relatively small percentage of the overall losses. Typical indirect and intangible benefits can include benefits associated with the following:

- Vehicle damages
- Utility services
- Road Closures
- Transportation Network - Rail
- Agriculture
- Recreational gains and losses

- Environmental losses
- Evacuation
- Risk to life
- Loss of income
- Indirect damages for schools
- Indirect damages for hospitals
- Intangibles - stress and emotional effects of flooding

The more significant of these aspects have been included in this economic appraisal to derive more accurate damage costs. The following indirect / intangible elements have been assessed and included in the benefits appraisal:

Vehicle Damage

For floods 350mm above ground level, any cars trapped in floodwaters can be taken to be written off. Write off values are based on the average vehicle value in the UK, taken as £3,600 (MCM 2018). When flood levels are greater than 350mm, £3,600 is added to the flooding damage for that property, in that return period, assigning 1 vehicle per property.

Road Closures

Delayed-Hour Method has been used for calculating the damages incurred from closing main ‘A’ roads.

The MCM guidance states that assuming an average speed of 100kph, a single car delay of one hour on a motorway or trunk road will cost the UK economy £12 (MCH). The estimated cost for a single closure has therefore been calculated by multiplying £12 by the vehicle flow per hour and the assumed duration of the road closure (assumed to be 24 hours to reflect the flood impeded time plus additional time required to clean-up, inspect, remove traffic management etc). Daily vehicle flow data was obtained from the Department for Transport AADF (Annual Average Daily Flow) open source data. Damages have been assumed to be incurred when 300mm of flooding occurs causing full road closure.

Evacuation

Evacuation costs have been included based on property type and respective flood depths at each property. The Evacuation ‘Initial - Mid Tier” damages have been taken from the MCM 2018 residential tables. These damages have been included as part of the direct damages calculation and contribute to the PV damages for each property.

E.1.5 Climate Change

As a result of climate change, the initial standard of protection offered by a flood prevention scheme will effectively reduce during its design life. For example, a scheme designed to have a 500 year SOP at year zero, will then have approximately a 120 year SOP at the end of its lifespan (if climate change increases peak flows by 20% over that period).

The Environment Agency (EA) guidance on Flood Risk and Coastal Change provides uplift estimates on peak flows for river basins within England and Wales. The uplift factors relate to the '2020s', '2050s' and '2080s' considering the statistical probability of occurrence Upper end (90th Percentile), Higher Central (70th Percentile) and Central (50th Percentile).

Climate change has been applied to the economic benefit calculations by generating a peak rainfall vs return period logarithmic curve. Then, a 20% peak flow uplift scenario (EA Central Climate Change Horizon has been used as the scheme is outside of Flood Zones 2 and 3) has been applied for climate change with associated peak rainfall vs return period curves. The climate change return periods are converted to their respective probabilities which are used for generating the present value (PV) damages. Each epoch is applied with its relative proportional PV factor and then the damage for all epochs is effectively summed and discounted.

E.1.6 Appraisal Methodology Summary

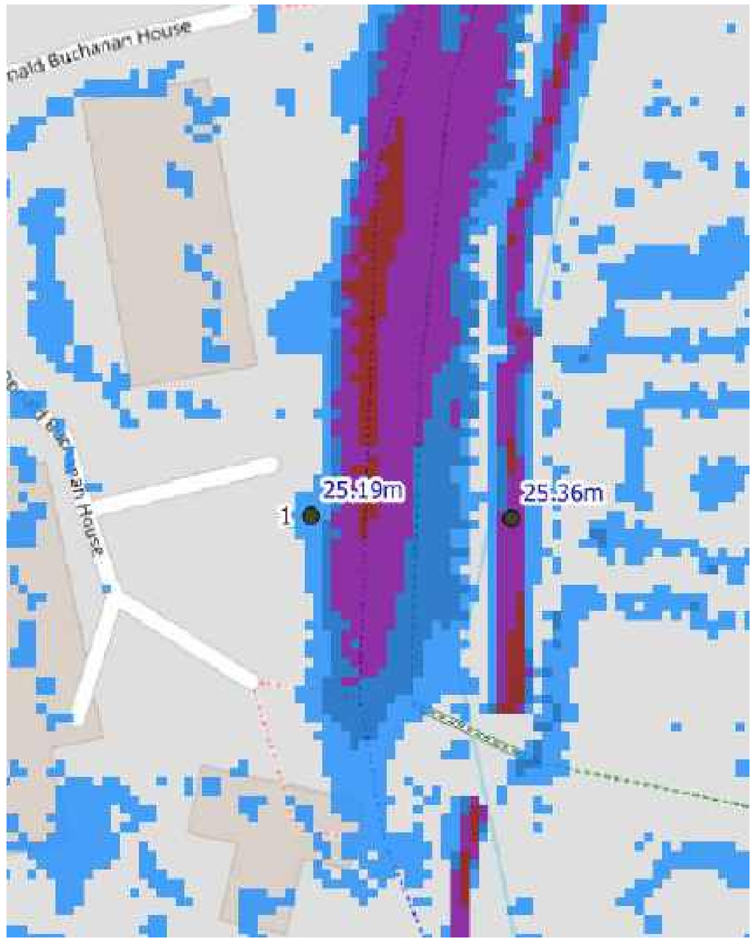
The key appraisal assumptions incorporated into the BCR analysis are summarised below:

- Damages are based on all latest flood mapping and modelling.
- The most recent Consumer Price Index has been applied to the Present Value (PV) damages (April 2019).
- Most recent National Receptor Database used.
- Base year assumed taken as 2020 (i.e. assumed year of construction).
- Climate change allowance included – uplifts (10% at 2020, 15% at 2040 and 25% from 2070 thereafter).
- HM Treasury discount rate 3.5% for years 0-30, 3% for years 31-75, and 2.5% thereafter.
- All economic losses use the latest MCM guidance and tabulated data (2018).
- Flooding losses to land/gardens and agricultural land not included.
- 100 year appraisal period with complete capital replacement of assets at 50 years at discounted rate in accordance with The Green Book, HM Treasury, 2013.
- 10.7% of property damage value added to account for emergency services costs.
- Clean up costs included in depth-damage data from MCM for non-residential property only.
- Damages capped at the estimated 'risk free' property market values (HPI April 2019).
- Emergency and evacuation costs included.
- Indirect losses for vehicle damage and road closures included.
- No direct and indirect damages to schools included.
- Social Intangibles not included.

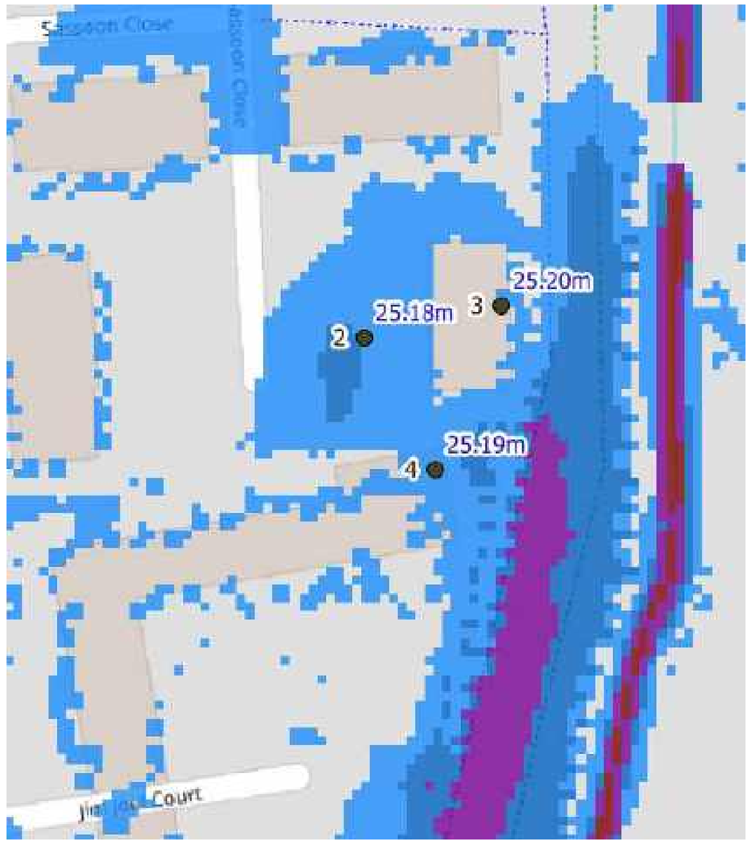
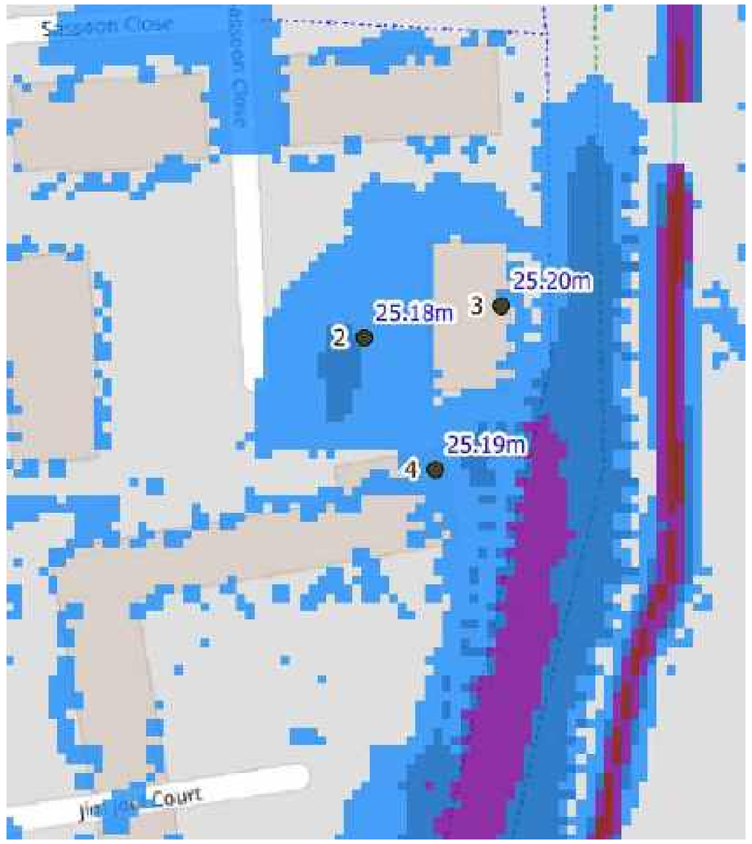
Appendix F May 2012 Model Validation Summary

The validation assessment shows a good correlation between the anecdotal evidence and modelled results for the May 2012 rainfall event. Table 1-9 below discusses the modelled depths and extents and compares these to the photographic evidence provided.

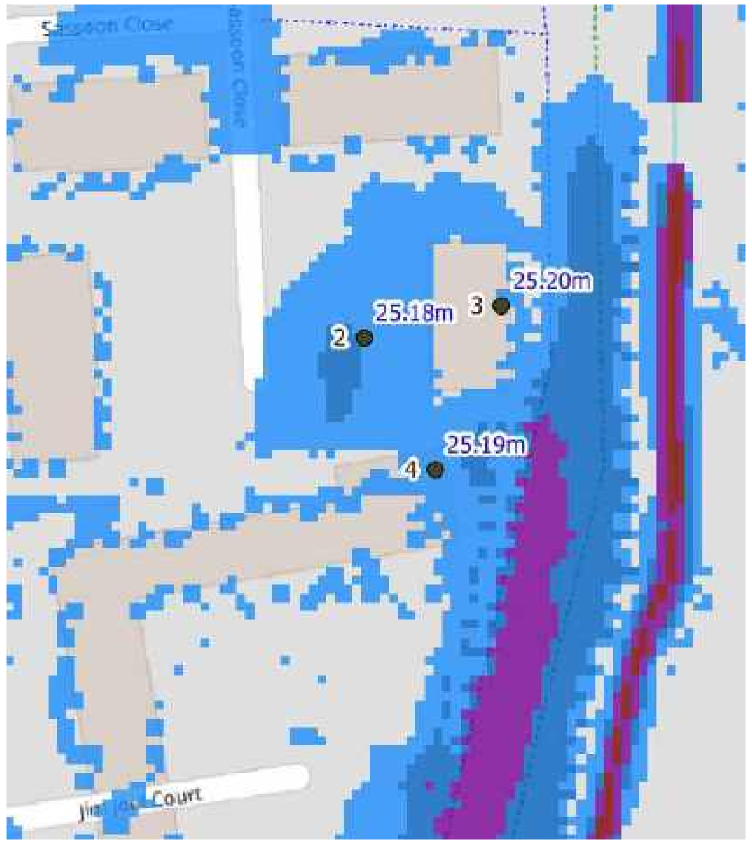
Table 1-9 May 2012 Model Validation Summary

Location	Modelled Flooding at Location	Photograph of Event	Comments
1			The photos left, show flooding of the grassed space and car park adjacent Manny Mercer Court. The modelled flood extent largely replicates this extent of observed flooding. Differences appear to be the result of small (200mm) changes in elevation from the fence line to Manny Mercer Court. In the photos left, the grassed area in the centre of the car park with two trees remains partly dry. Using the elevation of this location, the observed flood level in this area is estimated to be 25.35mAOD during the May 2012 event. The model is producing a good correlation with the observed data with a peak modelled water level of 25.19mAOD in this vicinity, as shown in the image far left. The peak flood level (25.36mAOD) in the Newmarket Brook correlates very well with the observed flood levels in the photos. This suggests that there may be a depression in the left bank in this location at the time of the May 2012 rainfall event, that was not captured in the 2018 survey; allowing water out of the channel sooner. The colour of the water is also an important factor in the provided photos. Brown dirty water is typically indicative of fluvial flooding, meaning the Newmarket Brook banks were most likely overtopped in this vicinity and the cause of this local flooding. The model results shown left, indicate that we are capturing this out of bank flow mechanism.

May 2012 Model Validation Summary

Location	Modelled Flooding at Location	Photograph of Event	Comments
2			The extent of predicted inundation in the model correlates with the photographic evidence provided. The photo indicates flooding of the Sassoon Close car park at a depth of approximately 0.2m to 0.3m. This is estimated from the height of a Nissan Micra tyre (approximately 0.460m) and the submergence of the car tyre in the photo. The model produces similar peak depths of 0.2m - 0.315m across the Sassoon Close car park, as a result of a fluvial flooding mechanism, which is consistent with flooding evident in the photo. The timing of the photo is unknown and may not represent the peak. There is a good match in modelled and observed flood depths in this location.
3		 	The location of this photo was sourced from the photo file data and is estimated to be taken on the Brook side of Sassoon Close. The observed flood depth is approximately 0.2m, just above the persons ankle, pictured left. The BMT model shows ponding around the building footprint of this location but does not simulate the inundation of the properties them self. Given the good correlation at the nearby Sassoon Close car park, this discrepancy in the modelled and observed data is likely the result of assumptions in the building footprints stamped into the uFMfSW DTM datasets (0.5m higher than surroundings) as well as some small differences in the modelled and observed flood levels.

May 2012 Model Validation Summary

Location	Modelled Flooding at Location	Photograph of Event	Comments
4			The location of this photo was sourced from the photo file data and is estimated to be taken at Jim Joel Court. The observed flood depth is approximately 0.2m, just above the persons ankle, pictured left. The BMT model shows partial inundation of the building footprint and ponding around the building at this location. Given the good correlation at the nearby Sassoon Close car park, this discrepancy in the modelled and observed data is likely the result of assumptions in the building footprints stamped into the uFMfSW DTM datasets as well as some small differences in the modelled and observed flood levels.

References

Cowan, W.L., 1956, Estimating hydraulic roughness coefficients: Agricultural Engineering, v. 37, no. 7, p. 473-475.

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