Flood Alleviation Feasibility Study

Little Wymondley

Client:

Hertfordshire County Council

Prepared by:

McCloy Consulting Ltd

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CONTRACT

This report describes work commissioned by Hertfordshire County Council following written instruction. The client's representative for the contract was Sophie Williamson.

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NON-TECHNICAL SUMMARY

This Flood Alleviation Feasibility Study was commissioned by Hertfordshire County Council to investigate the feasibility of options to alleviate an identified flooding problem at Little Wymondley.

Informed by the previous Section 19 Flood Investigation, this assessment has undertaken a flood modelling exercise in order to replicate the flood of 7 February 2014 in order to identify the key factors influencing flooding on that occasion.

The study has determined that the rainfall immediately preceding the flood was approximately equivalent to a 1-in-1 or 1-in-2 rainfall event; however the overriding factor causing flooding has been the saturated catchment upstream caused by longer term preceding rainfall. The high rate of runoff from the saturated catchment in conjunction with the relatively intense rainfall event of 7 February 2014 caused a flood broadly comparable with that of a magnitude of 1-in-30 years, i.e. 3.3 % Annual Equivalent Probability (likelihood of flooding in any given year).

The maximum flood levels and extents were caused by runoff from the Priory Lane catchment, which has a rapid rate of response to rainfall and will cause flooding within an hour of peak rainfall intensity in a storm event of sufficient magnitude to cause flooding. Flooding from the Ash Brook is significantly reduced by culverts at Chantry Lane and the A602 which tend to hold back the flow of water. The flood magnitude overwhelmed the drainage capacity in the village. Factors such as blocked gullies and culverts are likely to have been insignificant in the context of the flood flows passing relative to the inherent deficiency in drainage capacity.

Other flood probabilities have been considered, up to a 1-in-100 rainfall event including an allowance for the effect of climate change on rainfall intensity. Larger events follow similar patterns and areas affected by flooding are broadly similar but flood depths and areal extent are significantly more onerous. The assessment indicates that up to 87 buildings (based on Ordnance Survey Mastermap data) would be affected by the worst-case flood considered, and floodwater would have potential to isolate the village via Stevenage Road east and west for a period of approximately 36 hours for the most onerous storm considered (1 hour 1-in-100 rainfall event (including climate change)).

Options to reduce flooding at the site have been considered. It was determined that no scheme was available that would fully alleviate flooding at the village due to the scale of infrastructure that would be required. An option was modelled comprising attenuating runoff from land adjacent to Priory Lane in conjunction with two critical culvert upgrades. This option was intended to eliminate frequent floods and reduce the severity of low probability flooding for the 1-in-30 year rainfall intensity event and below. The cost in relation to perceived benefit of such a scheme, as well as significant risks to successful delivery causes the proposal to be unfavourable and as such the scheme is not recommended.

Property Level Protection (PLP), comprising flood proofing of individual buildings at risk by measures such as flood doors has been identified as being the measure that is most likely to be effective and cost beneficial. PLP has potential to alleviate internal flooding at the majority of buildings predicted to be affected by flooding, subject to detailed survey and design. Passive measures (i.e. measures that do not need to be erected after a flood warning) would be required due to the flashy nature of flooding at the site and likely ineffectiveness of flood warnings. Little Wymondley is an area within an EA flood alert area, but does not currently lie within an EA flood warning area.

Other management measures have been identified that would tend to reduce the frequency of high probability / small scale nuisance flooding and reduce the severity / duration of flooding during extreme events, by putting in place practical measures to maintain drainage infrastructure (including repairs to structurally damaged culverts); removing road furniture that has potential to exacerbate flooding; upgrading and maintaining key culvert screens; and by managing land use in upstream catchments to reduce potential for flashy runoff toward the village.

The assessment recommends that further work is undertaken to investigate and (if feasible) implement Property Level Protection depending on funding and community uptake. The assessment also recommends a number of flood management options including community led flood management, repair of culverts, and rationalisation of traffic calming measures and culvert screens.

1 INTRODUCTION

1.1 Terms of Reference

This Flood Alleviation Feasibility Study report was commissioned by Hertfordshire County Council (HCC) to investigate the feasibility of options to alleviate an identified flooding problem at Little Wymondley, previously subject to a Flood Investigation under the terms of Section 19 of the Flood & Water Management Act (FWMA) 2010.

1.2 Statement of Authority

This report and assessment has been prepared and reviewed by qualified professional civil engineers in the fields of flood risk, drainage, wastewater, and hydraulic modelling studies. Key staff members involved in this project are as follows:

- Chris Smylie *BSc (Hons) MCIWEM C.WEM* is a Senior Modeller with experience specialising in flood risk modelling and flood risk assessment, sewerage and drainage design and SuDS. Responsible for modelling, hydrological assessments, and reporting.
- Kyle Somerville *BEng (Hons) CEng MIEI* is a Senior Engineer within the company, and is a chartered engineer specialising in engineering hydrology, flood modelling and flood risk investigation and assessment. Responsible for technical review, reporting, and technical project management.
- Anthony McCloy *BEng CEng FIEI* is a Charted Civil Engineer and Director of McCloy Consulting with in excess of 15 years specialising in the water industry, with particular expertise in hydraulic modelling, flood risk assessment, surface water management and sustainable drainage design. Anthony provided technical oversight on the project.

1.3 Background to the Study

A previous Section 19 Flood Investigation (reference ERP-INV-04 Little Wymondley R-04[1]) has been undertaken by Hertfordshire County Council Flood Management Team as Lead Local Flood Authority (LLFA) in response to being made aware of flooding in the village of Little Wymondley on 7 February 2014.

The previous investigation has concluded that the flooding experienced may have been caused or contributed to by extreme rainfall in conjunction with saturated ground conditions; exacerbated by land drainage, culvert condition on Ash Brook and Priory Lane, blockage of culvert trash screens, watercourse condition, the effectiveness or otherwise of highway drainage. The topography of Little Wymondley is significant in that it is a low point within the catchment through which all surface runoff from the catchment must flow.

Among the recommendations of the investigation is that a specialist consultant is appointed to assess the catchment and verify the location and sources of flooding in order to allow development of options for mitigation and flood risk management. Particular emphasis is to be given by this study to assessment of existing trash screens, consideration of the viability of de-culverting parts of watercourses, consideration of the effect of ground levels and kerb heights within roads, and the effect of land management.

1.4 Purpose

The purpose of this study is to satisfy the recommendation stated in the previous Flood Investigation. The study shall primarily comprise a hydraulic assessment of fluvial and surface water flood risk in the Little Wymondley area, the purpose of which is has been defined as follows:

i. Establish and assess the Little Wymondley catchment and confirm the location and extent of all sources of flooding and how they interact using appropriate methodology including establishing depths and flow velocities to determine the level of risk to properties and infrastructure for a range of return periods.

ii. Establish which assets have an effect on flood risk and determine to what extent they have an effect for different return periods including all culverts, trash screens etc. to quantify how much those assets contribute towards flooding in Little Wymondley

iii. Identify options to alleviate, mitigate and/or manage flood risk including feasibility and estimated costs

iv. Validate existing flood risk data, including the EA surface water flood maps and EA Flood Zone maps.

[1] Hertfordshire County Council. (2014). Flood Investigation Report - Little Wymondley , Hertfordshire. Available from: http://www.hertsdirect.org/services/envplan/water/floods/floodrisk/investigations/littlewy/ [Accessed: 9/06/2015].

1.5 Approach

The technical assessment and appraisal shall:

i. Obtain all available information and data relevant to the project collated by HCC for the development of the Section 19 Flood Investigation including the CCTV survey data.

ii. Obtain relevant hydraulic data including surface water flood maps, EA flood data (if available) and local rainfall data.

iii. Identify the hydrological catchment area affecting Little Wymondley, and determine catchment characteristics to determine runoff parameters and losses when subjected to rainfall.

iv. Identify assets/ features that will have an effect on flood risk utilising the CCTV survey data and site observations.

v. Undertake a hydraulic model ascertain the risk from surface water flooding and fluvial (river) flooding.

vi. Model the effect of the identified assets/features to quantify their impact.

vii. Provide flood levels for a range of return periods to inform any flood management/ mitigation measures.

viii. Identify a range of potential options to alleviate flood risk to properties at risk in Little Wymondley.

2 PROJECT SCOPING

2.1 Project Inception & Observations

Following appointment, review of the existing Flood Investigation, and walkover surveys and site inspections on 03 & 04 February 2015, it was initially considered that:

- The flooding incident of 7 February 2014 in the vicinity is likely to be due to a combination of direct surface flooding due to a combination of extreme rainfall and saturated ground conditions, and fluvial flooding caused by exceedance at numerous culverts along the affected watercourse. Flood patterns reported correlate strongly with Environment Agency Surface water flood maps.
- Existing fluvial flows in the ordinary watercourses in the village, and in particular the significant Ash Brook are due to the longer term underlying raised baseflow caused by the significantly wetter than average antecedent weather, are likely to have reduced capacity to accommodate discharge from the highway drainage within the village.
- The extensively culverted nature of the larger ordinary watercourse (Ash Brook) through the village is likely to have caused a significant restriction to peak flows, with flows in excess of culvert capacities caused to flow out of the fluvial and local drainage system overland. Blockage of associated trash screens during flood event may have caused further restrictions.
- Runoff (exacerbated by saturated ground conditions) from fields west of Priory Lane has no means of entering the minor stream as the carriageway would tend to intercept flows before it would otherwise reach the minor stream flowing generally in parallel to it. Additionally, runoff from some lands east of Priory Lane would be unable to enter the stream channel due to the extensively culverted nature of the upper reaches of the minor stream. As a consequence, significant flows would tend to accumulate and flow in Priory Lane toward the village as the preferential drainage route.
- The extensive culverting of the Ash Brook in Stevenage Road reduces effective drainage function to the capacity of the culvert and capacity of the inlets. The effective condition of the culvert is understood to be poor. Overland flooding, caused by any of flooding from the inlet or surcharging from gullies and manhole covers, and direct flooding from runoff that would otherwise drain to the culvert (exacerbated by saturated ground conditions) being unable to enter the culvert, would tend to flow along Stevenage Road into Little Wymondley.

2.2 Agreed Methodology

The agreed scope following project inception and initial appraisal is as follows:

i. Obtain topographic data by means of ground based survey of key watercourse and drainage infrastructure, to be supplemented by EA LiDAR data provided by Hertfordshire County Council. Topographic survey was undertaken over the period 20-23 February 2015.

ii. Establish hydrological catchments and sub catchments draining to Little Wymondley based on an appraisal of a digital terrain model (built from topographic data) and surface water asset records.

iii. Determine catchment wetness based on MORECS data and estimate magnitude (relative probability) of the antecedent rainfall and particular rainfall event that caused or coincided with the surface water flooding.

iv. Build a hydraulic model to replicate the known flood event, verifying using recorded rainfall depths, ground conditions, and using observed depths to validate results. The hydraulic model is to utilise a linked 1-dimensional to 2-dimensional (1D/2D) methodology using the Tuflow software package in order to ascertain the risk from surface water flooding. Fluvial inflows to the 1D model shall in effect be determined by estimating accumulation of direct rainfall runoff into the Ash Brook by a similar macro scale 2D surface water flood model to the wider Ash Brook catchment.

v. Revise the validated model and re-run for a number of agreed "design" flood events (those being flood events for which rainfall data profiles were made available) with a view to establishing the location and extent of sources of flooding, determining and how they interact, and establishing depths and flow velocities in determining the level of risk to properties and infrastructure. The agreed return periods for rainfall depth are:

vi. 30-year rainfall event (0.33% Annual Equivalent Probability (AEP)) – common to sewer performance requirements stated in Sewers for Adoption.

vii. 100-year rainfall event (1% AEP).

viii. 100-year + 20% intensity rainfall event (1%+CC AEP) - common to the flood risk design standard adopted by the National Planning Policy Framework and associated guidance.

ix. The model shall be run for each return period for a number of rainfall durations (i.e. varying intensity) in order to determine the critical duration for each rainfall depth; criticality is determined by the worst-case depth and extent of flooding predicted. Durations considered shall be 1, 3, and 6 hour storms.

x. Seek to establish which drainage assets (i.e. culverts, trash screens etc) have a significant effect on flooding, either by quantitative means (i.e. modelling where feasible) or qualitative means. Quality the contribution of these assets towards flooding in Little Wymondley.

xi. Identify (where feasible) potential measures for flood alleviation or management based on the “design” rainfall event results; and provide an estimate of likely capital costs.

Full details of hydrological analyses and model build parameters and methodology are detailed in Appendix C.

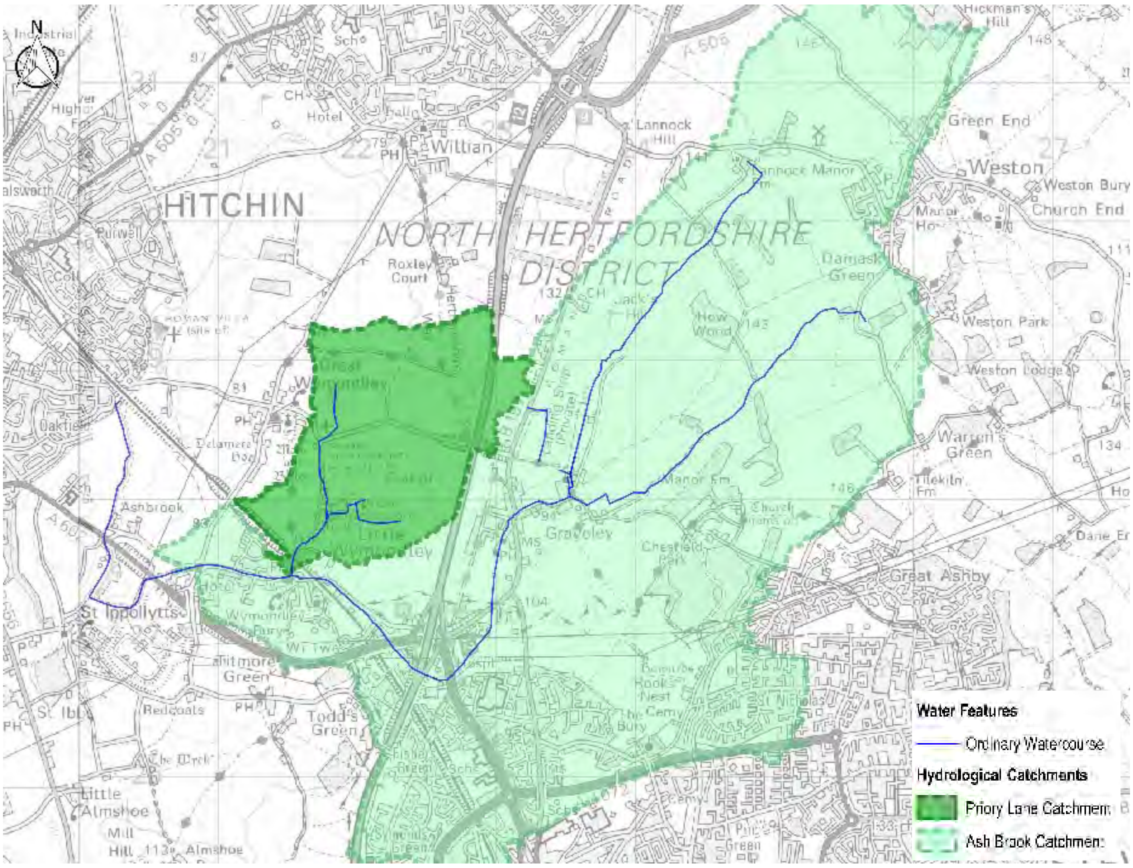
2.3 Areal Extent of Assessment

2.3.1 Contributing Hydrological Catchment

The contributing hydrological catchment has been determined based on a GIS analysis of a LiDAR based terrain model, augmented by artificial factors such as drainage infrastructure. The catchment feeds 2 watercourses affecting the village, hereafter referred to as Ash Brook and Priory Lane Stream.

Catchments are shown on the following figure and in greater detail on Appendix A, figure MCL250-07_FIG_REP 01.

Figure 2-1 Cumulative Hydrological Catchment



The natural contributing catchment is extensively affected by the influence of raised embankments and cuttings associated with trunk routes and railway lines. The catchment has been determined to be larger than that identified in the previous Flood Investigation (FI) (referring to FI Figure 14.1). As such this assessment is more onerous / conservative in that regard.

In relation to major highways, runoff from the A1M and A602 is incorporated within the hydrological catchments. No allowance has been made for any attenuation to highway runoff in the absence of available details, and as such the assessment is conservative in that respect. The area of major highways contributing to the model represents c. 1 % of the total catchment area, and as such is likely to be insignificant in the context of the rainfall events under consideration.

2.3.2 2-Dimensional Surface Model Areas

A macro-scale 2 dimensional model area was built and simulated for the whole Ash Brook catchment area (excluding the Priory Lane stream catchment). The purpose of the macro model was to determine inflow hydrographs into the Ash Brook upstream of the village in the vicinity of Chantry Lane following application of rainfall to the area.

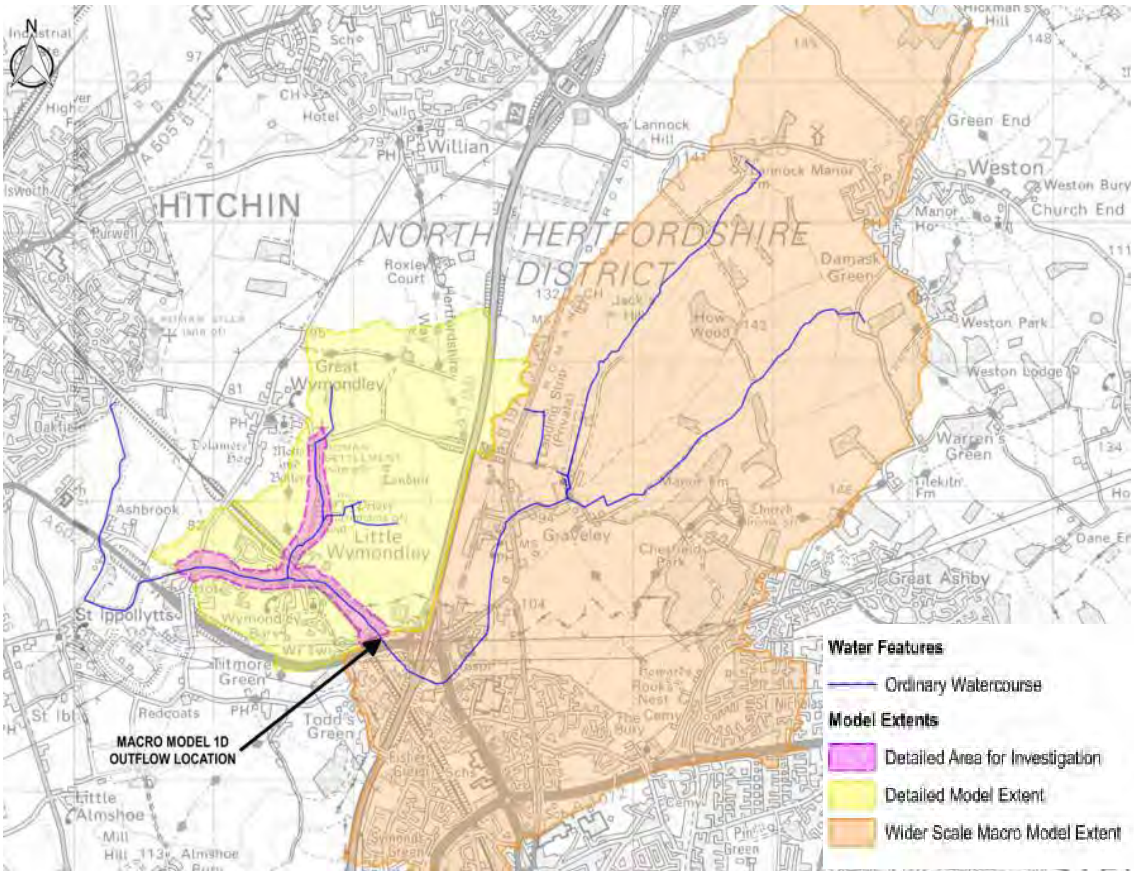
A detailed (3m grid) 2 dimensional model was built for the whole Priory Lane catchment and Little Wymondley village area, extending downstream (west) as far as the Arch Road / Blakemore End Road roundabout. The purpose of the detailed model is to provide property-level accurate estimations of flood depth, extents and velocity in the study area.

The agreed study area of greatest interest (and within which the model outputs are to be validated relative to recorded flood observations) is described as follows:

- Areas coinciding with Stevenage Road from an eastern extent at Chantry Lane to a western extent at Siccut Road.
- Areas coinciding with Priory Lane from a northern extent at Gravely Lane to a southern extent at Stevenage Road.

The detailed 2D model area and Study Area are shown on the following figure and in greater detail on Appendix A, figure MCL250-07_FIG_REP 02.

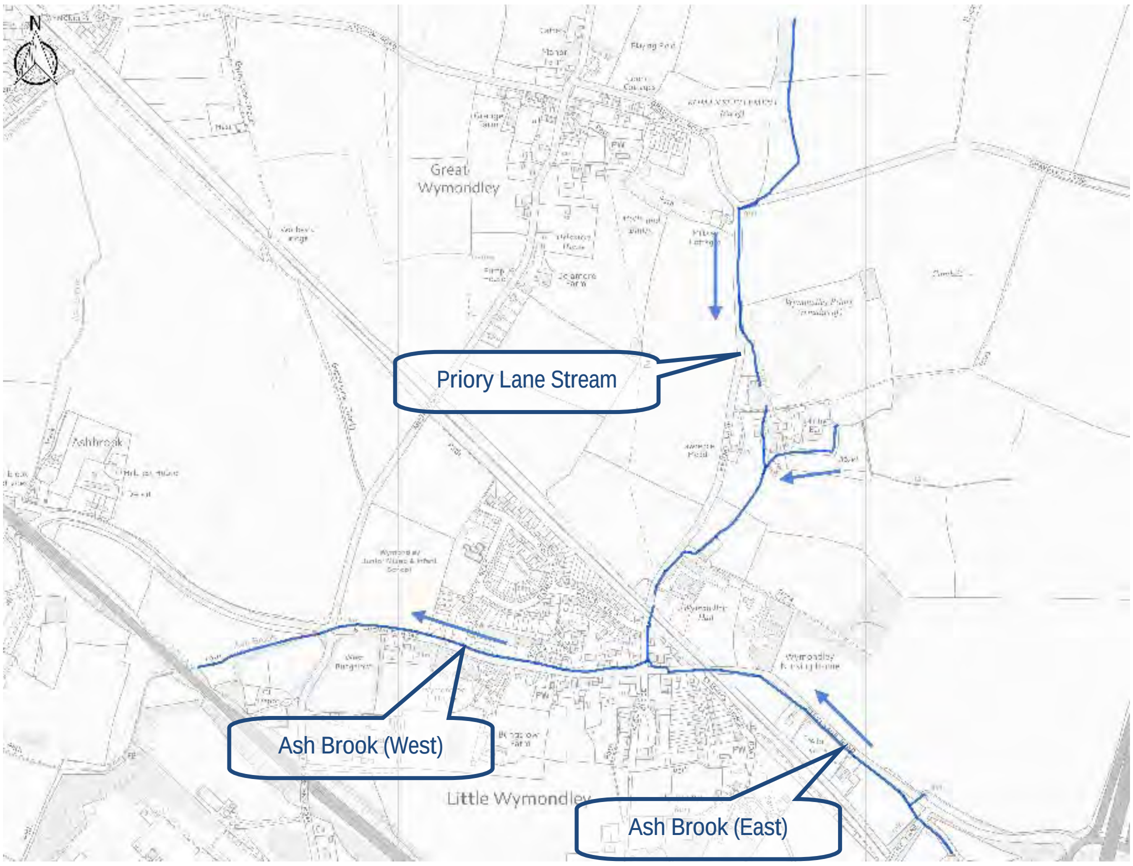
Figure 2-2 Detailed 2D Model Area & Detailed Study Area



2.3.3 1-Dimensional Channel Model Network

Existing watercourse channels, represented as discrete cross sections determined by ground based topographic survey, are included within the area covered by the detailed 2D model area in order to allow interaction of watercourse flows and overland surface flooding. The 1-dimensional network is shown on the following figure and in greater detail on Appendix A, figure MCL250-07_FIG_REP 03.

Figure 2-3 Detailed 1D Model Network

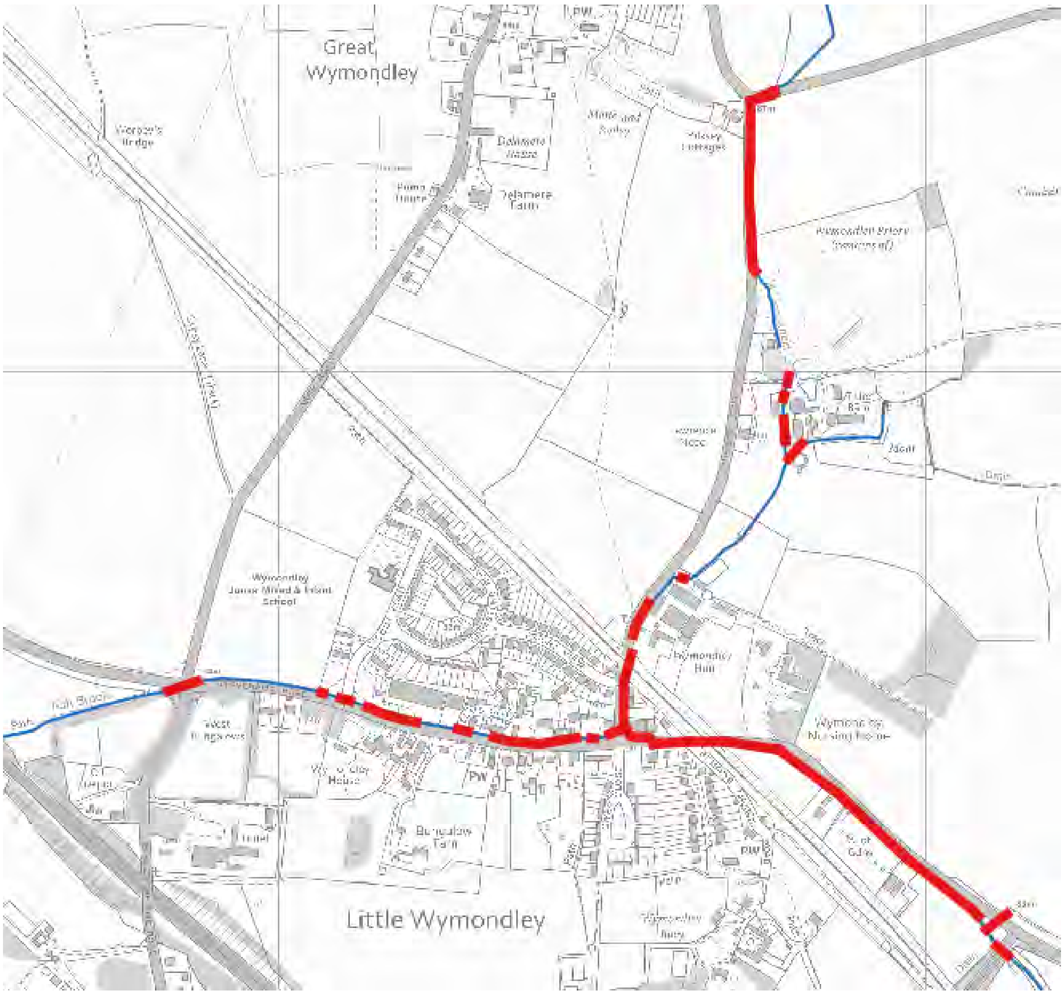


2.3.4 Modelled Culverts

The watercourses affecting the village are extensively culverted, the effect of which is initially anticipated to be significant in relation to flooding in the village. Existing culverts on watercourse channels have been identified based on review of the previous Flood Investigation, verified independently on site and subsequently subject to ground based topographic survey and CCTV condition survey.

The culvert network is included within the 1-dimensional network model and is shown on the following figure (highlighted red) and in greater detail on Appendix A, figures MCL250-07_FIG_REP 04-1 to 04-5 respectively.

Figure 2-4 Detailed 1D Culvert Network



2.4 Limitations of the Assessment

The following limitations apply to the modelling assessment; therefore results should be read accordingly.

- The resolution of the grid size to be applied for 2-D computations (3m) does not permit modelling of the effect of relatively small scale topographic features (e.g. traffic islands, traffic calming etc) as these features are less than the minimum grid square size. The resolution applied is the minimum practicable given the 2D model area to be considered.
- Individual surface drainage features (storm gullies, surface drainage and sewerage networks) are not included within the model. No Anglian Water records are held for either Stevenage Road or Priory Lane which may have further informed the development of the detail model. Incomplete asset information (i.e. no level or size information) was available for surface water infrastructure in Elms Close cul-de-sac; however this could not be included within the model due to those limitations. The performance of these assets would be dependent on water levels in the receiving watercourse. In the instance of the recorded flooding, it is anticipated that all drainage networks and gullies would be surcharged within the detailed study area, and so all runoff would be

retained on the ground surface, therefore the non-inclusion of localised drainage networks is not considered significant.

- Insufficient topographic and drainage information is available to allow detailed assessment of surface water flooding issues remote from the Ash Brook and Priory Lane. The model includes areas a wider catchment than the area of particular interest in order to determine inflows from those areas; however model results are not intended to be accurately representative of flooding in the wider catchment and should be read as such.
- Assessment of buildings affected relies on Ordnance Survey data only and does not include for detailed assessment of building type or use, nor does it include for detailed assessment of floor or threshold levels at properties. Estimates of the number of buildings affected and depth affected should be read in that context, i.e. flood extents shown on mapping provided subsequently **is not suitable** for determining the particular risk of flooding to any given property due to likely variation in building threshold levels.

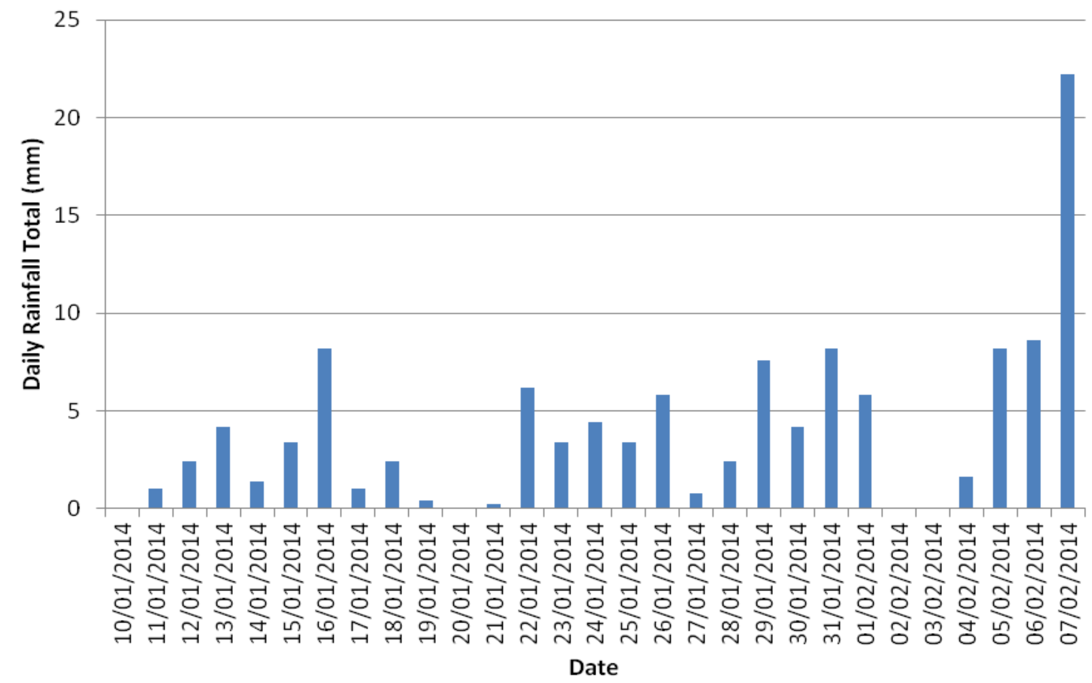
Particular technical limitations of the modelling methodology are discussed further in Appendix C

3 FEBRUARY 2014 FLOOD EVENT

3.1 Rainfall

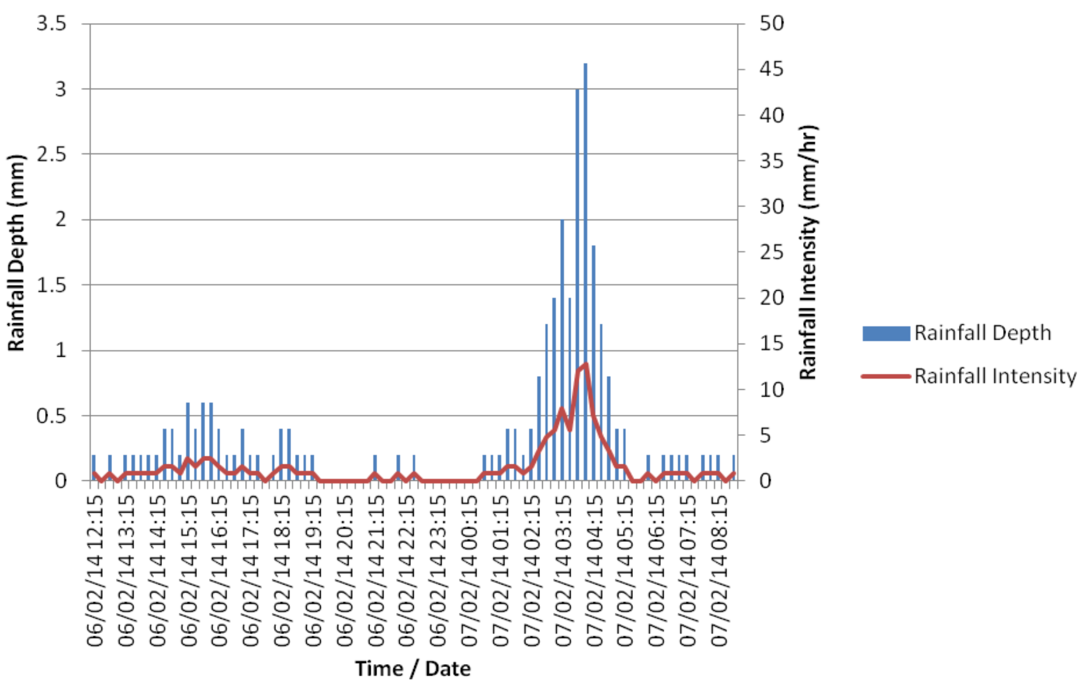
Daily rainfall totals on the period preceding the 7 February 2014 flood as obtained from the Met Office are shown on the following chart.

Figure 3-1 Preceding Rainfall



The discrete rainfall event immediately preceding and coinciding with the 7 February flood is shown on the following chart.

Figure 3-2 Flood Event Rainfall



In order to qualify the relative magnitude of the rainfall event, recorded rainfall has been compared with predicted rainfall at the site with known return periods (probabilities) based on Depth-Duration-Frequency (DDF) models, obtained from the Flood Estimation Handbook (FEH). Rainfall return periods vary by total depth and duration (i.e. intensity), therefore the return period will vary dependant on the period over which the rainfall is considered, as follows:

- The maximum depth of rainfall over a sliding 24 hour period (30mm) equates to a return period of approximately 1-in-1 year.
- The depth of rainfall falling between 1am and 5am (i.e. 19.6mm over 4 hours) equates to a return period of 1-in-2 years.
- The maximum depth of rainfall falling over any 15 minute period (i.e. 3.2mm at 4am, equivalent to 12.8mm/hr) equates to a return period of 1-in-2 years.

It follows that the rainfall depth on and preceding the 7 February 2014 flood was not extreme in its own right, and that the overriding factor causing flooding is more likely to be due to the proportion of that rainfall that acted as surface runoff due to the antecedent wetness of the catchment, caused by a gradual build-up of preceding rainfall over a period of weeks. The New Antecedent Precipitation Index (NAPI) parameter indicates that rainfall beyond one month prior is likely to have had little weighting on the conditions experienced on occasion of the flooding. It is not feasible to quantify the likelihood of occurrence of that preceding rainfall as the DDF models are not intended to model such durations.

3.2 Catchment Wetness

The Met Office Rainfall and Evaporation Calculation System (MORECS) gives real-time assessments of rainfall, evaporation and soil moisture and analysis covers different soil, crops and topography. MORECS data can provide a range of parameters. Of particular interest as part of this investigation is the Soil Moisture Deficit (SMD) and Hydrologically Effective Rainfall (HER).

- SMD is the amount by which the soil moisture content is below the field capacity state. It can also be defined as the amount of water which would have to be added to the soil in order to bring it back to field capacity.
- Water in the soil is held by capillary action against the pull of gravity. The maximum amount of water which can be held in this way is the Field Capacity state of the soil.
- HER is the excess rainfall within a catchment. Any rainfall which is not lost to restore field capacity or via evaporation is a measure of the amount of rainfall that will form surface water runoff.

MORECS data has been obtained for the period from 1 December 2013 up to and including the recorded flood on 7 February 2014, the purpose of which is to allow replication of the effective rainfall (i.e. rainfall that would tend to run off the ground surface rather than infiltrate to groundwater) within the model, and so is an indication of saturation.

Analysis of the data indicates that over the preceding week to the flood event, hydraulically effective rainfall had increased to c. 80% indicating saturation of the ground surface.

Additionally it is widely reported that groundwater levels were high over the winter of 2013/2014 due to high levels of rainfall across the south east of England. An analysis of British Geological Society groundwater levels at Stonor Park[2] (c 15 km north-east) indicates that groundwater levels in 2013 / 2014 represent a 12-year high.

On the basis of the data available it is concluded that the antecedent saturated ground conditions caused by prolonged low intensity rainfall was more significant as a contributing factor to flooding than the extremity of the rainfall immediately preceding the flood.

3.3 Asset Condition

The existing Section 19 Flood Investigation has indicated that residents have reported a number of observations of culverts and inlet screens to have exacerbated flooding due to blockage and/or incapacity. The assessment has sought to replicate the conditions of February 14 as closely as possible through:

- Including factors for blockage due to structural condition (i.e. fractured / collapsed pipes) identified by CCTV condition surveys, and
- Including factors for blockage due to serviceable condition observed and measured during site inspections and topographic survey in February 2015.

Culvert locations are shown in previous Figure 2-4 and on Appendix A, figures MCL250-07_FIG_REP 04-1 to 04-5.

1

[2] British Geological Society. (2014). Groundwater Levels - Stonor Park. Available from: http://www.bgs.ac.uk/research/groundwater/datainfo/levels/sites/StonorPark.html. [Accessed: 14/7/2015]

Table 3-1: February 2014 – Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	%-age Blocked in Feb 14 Model	Structural Assessment (SPG Grade 1-5)	Assessed Blockage Likelihood	Screen present	Comments
1	AshBrk_01	1 No. 0.9m Circular Pipe	30	N/A[3]	High	No	Brick headwall, no wing walls Significant depth of standing water observed in barrel. Vegetation adjacent, evidence of tipping / flood debris.
2	AshBrk_02 – to AshBrk_12	1 No. 0.825 to 0.9m Circular Pipe	Varies 10 - 30%	Varies to 5	High	Yes	Vertical bar screen in poor condition. Sandbag headwall, no wing walls. Moderate / dense brash adjacent and overgrowing. Large items likely to be retailed by upstream AshBrk_01, however smaller litter likely to be retained here. Structurally poor condition. Serviceably poor condition; multiple intrusions and settled deposits.
3	AshBrk_13	1 No. 1.2m Circular Pipe / brick arch culvert	50	5	Low	N/A	No open inlet. Structurally poor condition; fractured brickwork causing deformation.
4	AshBrk_14	1 No. 2.15 x 1.1m Arched Brick Culvert	0	N/A	Moderate	No	Brick headwall, no wing walls. Light / moderate brash adjacent and overgrowing. Access limited. Upstream open channel section is short and fed by closed culverts. Potential for upstream debris being washed to the culvert is limited due to smaller culverts upstream; however the culvert lies at the start of a relatively shallow gradient after relatively steep inflowing catchments and as such is likely to be subject to silt deposition.

1

[3] Indicates no CCTV survey available

Table 3-1: February 2014 – Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	%-age Blocked in Feb 14 Model	Structural Assessment (SPG Grade 1-5)	Assessed Blockage Likelihood	Screen present	Comments
5	AshBrk_15	1 No. 1.05m Circular Pipe	0	N/A	Low	No	Block work headwall, no wing walls. Easily accessed and highly visible. Dense vegetation overgrowing banks upstream. No evidence of fly tipping. Potential for upstream debris being washed to this culvert is limited due to smaller culverts upstream.
6	AshBrk_16	1 No. 1.3m Circular Pipe / Brick Culvert	0	2	Low / Moderate	No	Block work headwall, sandbag lined channel upstream. Utility pipe crosses within culvert barrel. Medium/dense brash overgrowing banks. Potential for upstream debris being washed to this culvert is limited due to smaller culverts upstream. Utility pipes cross the culvert within the barrel.
7	AshBrk_17	1 No. 2.1 x 1.225m Rectangular Box Culvert	50	N/A	Moderate	Yes	Raked vertical bar screen and top bar screen in good condition. Brick headwall and brick / concrete defined channel upstream. Medium/dense brash overgrowing banks. Potential for upstream debris being washed to this culvert is limited due to smaller culverts upstream; however (without maintenance) this culvert would trap all significant leaf litter and trash that would enter the channel over the reach from Priory Lane.

Table 3-1: February 2014 – Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	%-age Blocked in Feb 14 Model	Structural Assessment (SPG Grade 1-5)	Assessed Blockage Likelihood	Screen present	Comments
8	AshBrk_18	1 No. 2.38 x 1.33m Rectangular Box Culvert	0	N/A	Low	Yes	Raked vertical bar screen and top bar screen in good condition. Concrete headwall, overgrown sandbag defined channel upstream. Medium/dense brash overgrowing banks and encroaching channel. Limited reach downstream from previous screen; potential for significant accumulation of litter / trash is limited.
9	AshBrk_19	1 No. 1.05m Circular Pipe	50	1	Moderate / High	No	Concrete headwall, no wing walls. Bank side vegetation recently cleared; potential for significant leaf litter from overhanging trees. Evidence of tipping / flood debris in channel.
10	AshBrk_20	1 No. 1.5m Circular Pipe	0	N/A	Low / Moderate	No	Concrete headwall / face. Shallow cover to deck over culvert soffit. Relatively highly visible to access lane. Trees in channel immediately upstream.
11	AshBrk_21	1 No. 2 x 1.32m Rectangular Box Culvert	0	N/A	Low	No	Concrete headwall, no wing walls. Dense bank side vegetation / leaf litter. Box culvert structure does not pose a significant restriction to flow or any upstream surcharge, no evidence of litter or silt settling.
12	AshBrk_22	1 No. 1.5m Circular Pipe	0	N/A	Low / Moderate	No	Concrete headwall / face. Shallow cover to deck over culvert soffit. Relatively highly visible to access lane. Medium density large trees adjacent. No evidence of litter.
13	AshBrk_23	1 No. 2.62 x 1.4 m Rectangular Box Culvert	0	N/A	Moderate	No	Concrete headwall / face, concrete lined channel / wing wall to one side. Dense vegetation overgrowing banks upstream. No evidence of fly tipping. Potential for upstream debris being washed to this culvert is limited due to smaller culverts upstream.

Table 3-1: February 2014 – Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	%-age Blocked in Feb 14 Model	Structural Assessment (SPG Grade 1-5)	Assessed Blockage Likelihood	Screen present	Comments
15	PryLn_01	1 No. 0.3m Circular Pipe	30	1	Very High	Yes	Informal horizontal bar screen appears to have been deliberately placed shortly upstream of the culvert inlets. Poor access / limited visibility. Dense vegetation / brash overgrowing culvert inlet and channels upstream. CCTV survey indicates poor serviceable condition and extensive siltation.
16	PryLn_01a	1 No. 0.6m Circular Pipe	50	1			
17	PryLn_02 to PryLn 04a	1 No. 0.3m Circular Pipe	Varies 20-40%	Varies – Max 4	N/A	N/A	No open inlet. CCTV survey indicates standing water in pipe indicative of blockages.
18	PryLn_05	1 No. 0.45m Circular Pipe	0	N/A	Low	Yes	Vertical bar screen Easily accessible. Likelihood of blockage limited due to weir upstream, debris would be retained within pond.
19	PryLn_06	1 No. 0.45m Circular Pipe	0	N/A	Low	No	No headwall structure. Easily accessible; vegetation adjacent consists of grass and light brash. Limited potential for tipping other than from riparian landowner (unlikely).
20	PryLn_08	3 No. 0.3m Circular Pipe	0	N/A	Low	No	No headwall structure. Easily accessible; vegetation adjacent consists of grass and light brash. Limited potential for tipping other than from riparian landowner (unlikely).
21	PryLn_09	1 No. 1.2 x 1.06m Rectangular Box Culvert	95	N/A	Moderate	No	No headwall structure. Easily accessible; vegetation adjacent consists of grass and light brash. Evidence of debris / tipping adjacent to channel.

Table 3-1: February 2014 – Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	%-age Blocked in Feb 14 Model	Structural Assessment (SPG Grade 1-5)	Assessed Blockage Likelihood	Screen present	Comments
23	PryLn_11	1 No. 0.575m Circular Pipe	0	N/A	Very High	No	No headwall structure. Poor accessibility. Heavily overgrown / unmaintained channel upstream and adjacent. Debris / brash in channel. Poor condition generally.
24	PryLn_12 to PryLn_13	1 No. 0.6m Circular Pipe	0	5	Very High	No	No headwall structure. Poor accessibility. Heavily overgrown / unmaintained channel upstream and adjacent. Debris / brash in channel. Poor condition generally. Structural intrusions affecting pipe capacity
25	PryLn_14	1 No. 0.6m Circular Pipe	0	N/A	Moderate / High	No	Brick headwall with wing walls, defined inlet Light brash adjacent, channel partially overgrown, evidence of litter / some fly tipping. Culvert likely to be significantly under capacity relative to flows passing.
26	PryLn_15	1 No. 1m Circular Pipe	30	3	Moderate / High	No	Defined headwall, no wing walls. Medium density stands of brash / shrubbery / small trees overgrowing. Culvert likely to be significantly under capacity relative to flows passing. Multiple structural intrusions causing lack of capacity; CCTV survey indicates poor serviceable condition and extensive siltation.

3.4 Model Results & Findings

Flood mapping arising out of the study, showing the maximum flood extent / water depth recorded for the 7 February 2014 event, is shown on Figures FL01 to FL04 included in Appendix B.

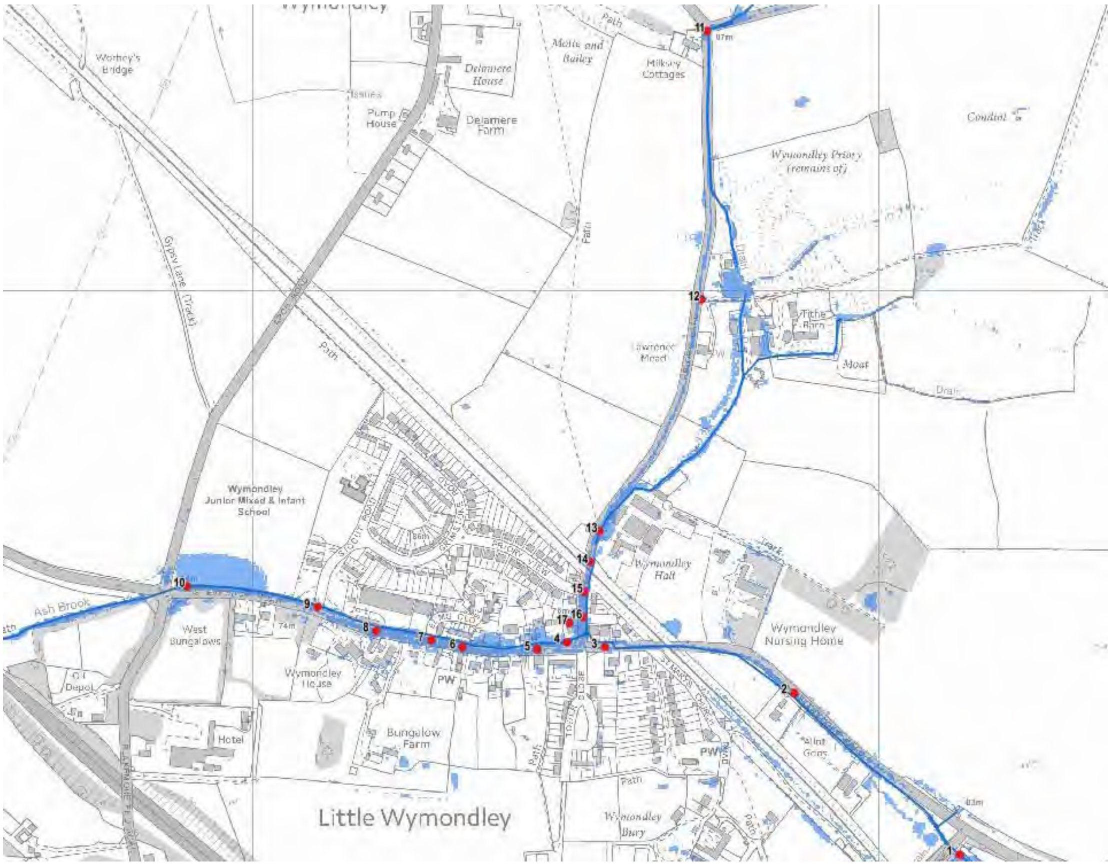
Flood hazard rating (a measure of risk to life derived as a function of flood depth and velocity) has been determined in accordance with the methodology stated in the Supplementary Note clarifying the methodologies outlined in Flood Risks to People Methodology[4] (FD2321/TR1) and 'Framework and Guidance for Assessing and Managing Flood Risk for New Development[5] (FD2320/TR2), and is shown on Figures FL05 to FL08 included in Appendix B.

Details of the model methodology and input parameters are detailed in Appendix C.

3.4.1 Flood Depths & Levels

Modelled water levels / depths at key locations (due to proximity to a main asset / culvert, areas of flooding on the highway, or proximity to a property known to have been affected by flooding) as shown on Figure 3-3 are presented in the following table.

Figure 3-3 Flood Level Report Locations



1

[4] DEFRA and Environment Agency (2006) The Flood Risks to People Methodology, Flood Risks to People Phase 2, FD2321 Technical Report 1, HR Wallingford et al. did the report for DEFRA/EA Flood and Coastal Defence R&D Programme, March 2006.

[5] DEFRA and Environment Agency (2005) Framework and Guidance for Assessing and Managing Flood Risk for New Development, Flood Risk Assessment Guidance for New Development, FD2320 Technical Report 2, HR Wallingford et al. did the report for DEFRA/EA Flood and Coastal Defence R&D Programme, October 2005.

Table 3-2: February 2014 – Estimated Flood Depths & Levels at Key Locations

Ref	Location Description	Channel / Overbank	Coordinate	Max Water Depth - 07/02/2014 (m)	Max Water Level - 07/02/2014 (m OD)
1	Ash Brook upstream of Chantry Lane	Channel	522,129, 227,097	2.36	82.8
2	Stevenage Road at Car Sales Garage	Road	521,865, 227,356	0.23	78.2
3	Stevenage Road 30m East of Priory Lane	Road	521,561, 227,429	0.15	76.5
4	Ash Brook to frontage of Plume of Feathers Pub	Channel	521,502, 227,437	1.60	75.9
5	Stevenage Road to frontage of Bucks Head pub	Road	521,454, 227,425	0.20	75.6
6	Stevenage Road at Wymondley Chapel	Road	521,335, 227,428	0.40	75.2
7	Stevenage Road at Elms Close	Road	521,284, 227,440	0.45	75.2
8	Stevenage Road at Andrew Charles Clockmakers	Road	521,196, 227,455	0.52	75.1
9	Stevenage Road at Siccut Road	Road	521,102, 227,493	0.17	74.5
10	Ash Brook east of Roundabout	Channel	520,893, 227,527	0.89	73.5
11	Priory Lane at Gravely Road	Road	521,726, 228,415	0.42	85.4
12	Priory Lane at The Priory	Road	521,716, 227,985	0.12	82.8
13	Priory Lane at Wymondley Farm	Road	521,552, 227,614	0.39	77.4
14	Priory Lane at Railway Bridge	Road	521,538, 227,564	0.40	76.8
15	Priory Lane at Priory View	Road	521,529, 227,517	0.28	76.2
16	Priory Lane at Bladon Close	Road	521,528, 227,476	0.66	76.2
17	Rear of Plume of Feathers pub	Road	521,505, 227,467	0.20	76.2

3.4.2 Flood Mechanisms

The following table identifies key points of inflow and the effect of drainage infrastructure in the village relative to the estimated magnitude of the flood, in upstream to downstream sequential format from the top of Priory Lane travelling toward the village and from Chantry Lane toward the village and west to Siccut Road. Conditions discussed relate to the assets as-modelled (i.e. including partial blockages where anticipated).

The onset of flooding is observed in the village as follows and detailed further in the following schedule (Table 3-3):

- Watercourse channels approximately bank full with some shallow surface flooding on Stevenage Road at approximately 06 February 2345 hrs.
- Onset of substantial surface flooding of Priory Lane and Stevenage Road at 07 February 0300 hrs.
- Peak of flooding from Priory Lane catchment, causing flooding of Priory Lane and western Ash brook / Stevenage Road at 07 February 0400 hrs. Flooding would tend to recede until 1000hrs after which flood levels would tend to increase as the peak Ash Brook flood passes through the village. Flood extents after this period exclude the effect of emergency pumping etc. (understood to have commenced early/mid morning) and so cannot be accurately replicated within the modelling process.

Table 3-3: February 2014 – Flood Mechanisms

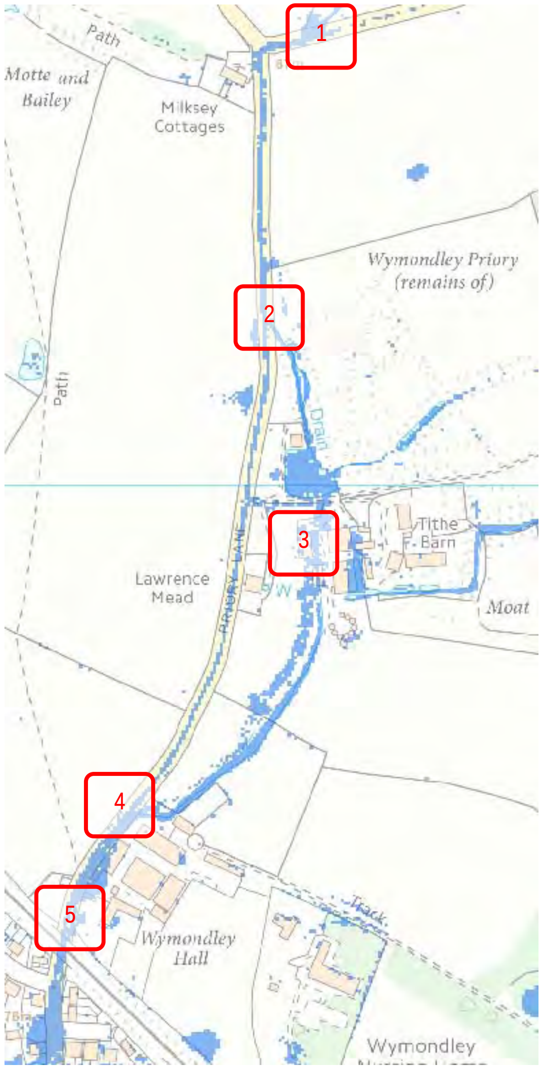
Map (Contains Ordnance Survey data © Crown copyright and database right 2015)	Location / Description	Comments
	Location 1 Gravely Lane	Peak flow passing c. 1.8 m^3/sec. Culvert section from north of Gravely Lane (0.3 m diameter) has a capacity c. 0.08 m^3/sec. i.e. the culvert is c. **95% under capacity** for the peak flow passing. Flows in excess of the culvert inlet capacity flow onto Gravely Lane and south onto Priory Lane.
	Location 2 Priory Lane north of The Priory	Peak flow passing c. 2.2 m^3/sec. Downstream of the culvert c. 0.8 m^3/sec flows in-channel to The Priory; c. 1.4 m^3/sec (i.e. c. 60% of total) remains on Priory Lane.
	Location 3 Vicinity of Priory Farm	Peak flow passing is c. 1.7 m^3/sec (i.e. c. 0.5 m^3/sec flowing parallel on Priory Lane. Various culverts (typically 0.3 m diameter) have a capacity c. 0.03 -0.05 m^3/sec.. i.e. culverts are c. **82% under capacity** for the peak flow passing excluding flows bypassing by flowing on Priory Lane. A number of streams / overland flow paths draining lands east of the Priory drain into Priory Lane pond; the pond appears to have an attenuating (beneficial) effect however these stream contribute a further c. 0.2 m^3/sec to the peak flood.
	Location 4 Vicinity of Wymondley Farm	Peak flow passing is c. 3.6 m^3/sec. Culverts (0.6 m diameter) has a capacity c. 0.55 m^3/sec.. i.e. the culvert is c. **82% under capacity** for the peak flow passing. Flows in excess of the culvert capacity are lost to the adjacent low-lying route in Priory Lane
	Location 5 Upstream of Railway Bridge	Peak flow passing is c. 4.5 m^3/sec. Culverts (0.6 m diameter) has a capacity c. 1.72 m^3/sec. i.e. the culvert is c. **62% under capacity** for the peak flow passing. Flows in excess of the culvert capacity are forced onto Priory Lane and flow south. A significant additional inflow (c. 0.9 m^3/sec) from lands north and west of Priory Lane flows onto the carriageway in this vicinity. A total of c. 2.5 m^3/sec flows onto Priory Lane from agricultural lands adjacent over the road length from Gravely Road.

Table 3-3: February 2014 – Flood Mechanisms

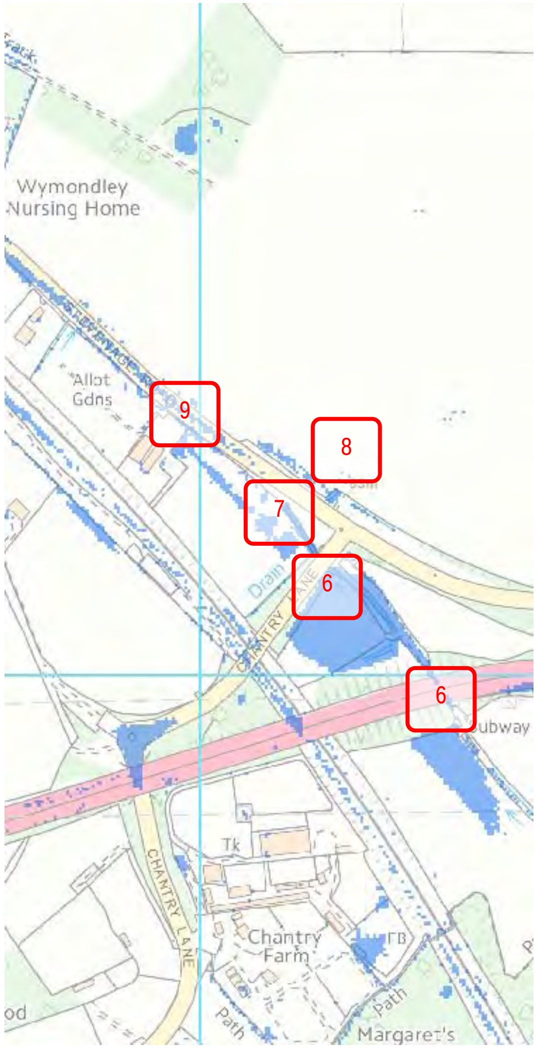
Map (Contains Ordnance Survey data © Crown copyright and database right 2015)	Location / Description	Comments
	Location 6 A602 & Chantry Lane	Peak flow passing in Ash Brook >>10 m³/sec. Two culverts under A602 & Chantry Lane embankments respectively (0.9 m diameter) have a capacity c. 1.8 m³/sec. The culverts provide a **significant beneficial attenuating effect** by reducing peak flows to c. 2.8 m³/sec and subsequently 1.8 m³/sec, with attenuation of volumes in excess of this capacity behind the road embankments.
	Location 7 West of Chantry Lane	Peak flow passing is c. 1.9 m³/sec. Ash Brook culvert section starting in verge / field and continuing in Stevenage Road to Priory Lane (0.9 m diameter) has a capacity c. 0.9 to 1.1 m³/sec. i.e. the culvert is up to c. **52% under capacity** for the peak flow passing. Flows in excess of the culvert inlet capacity tend to flow onto fields south of allotments. Flooding from fields spill onto Stevenage Road at Location [9].
	Location 8 Lands north of Stevenage Road	Peak flow passing is c. 0.72 m³/sec. Overland flooding from agricultural lands tends to flood onto Stevenage Road. Flooding does not increase the peak flood in the Ash Brook due to delay in time to peak vs. the main Ash Brook flood; however the inflow is likely to contribute to the duration of flooding.
	Location 9 170m north-west of Chantry Lane	Peak flow passing is c. 1.9 m³/sec. Culvert is up to c. **52% under capacity** for the peak flow passing. Flood flows from field (flooding from culvert inlet incapacity) flow onto Stevenage Road at this point and continue in the carriageway to the village.

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Table 3-3: February 2014 – Flood Mechanisms

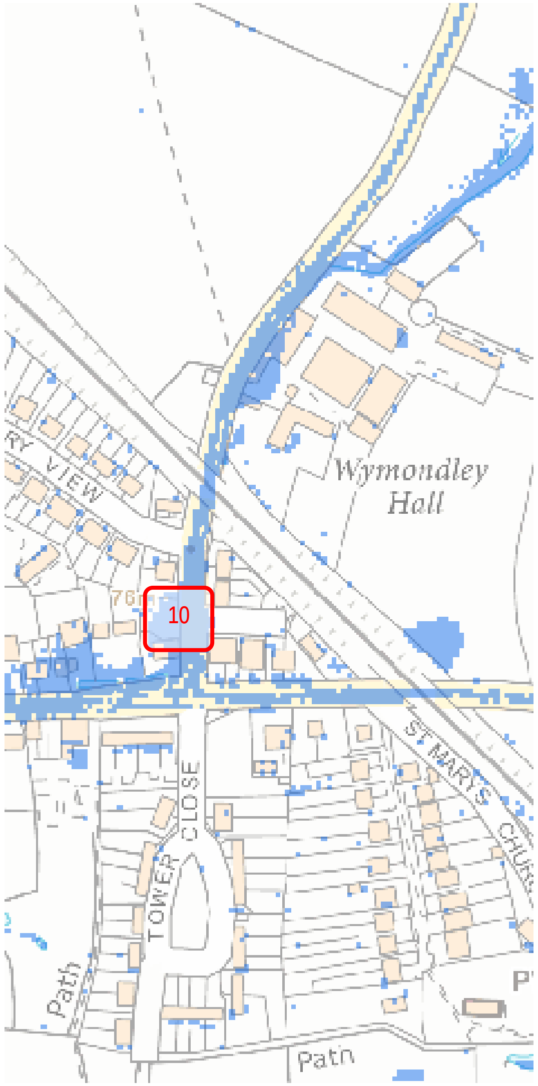
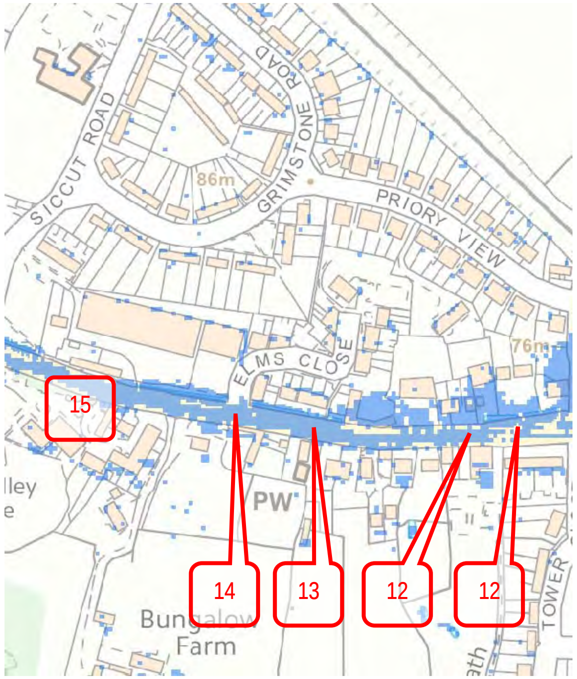
Map (Contains Ordnance Survey data © Crown copyright and database right 2015)	Location / Description	Comments
	Location 10 Priory Lane at Bladon Close and Stevenage Road	Peak flow in from Priory Lane stream c 4.2 m^3/sec. Peak flow in from Ash Brook c 1.8 m^3/sec. All drainage relies on culvert outlet to western Ash Brook under Priory Lane and to frontage of the Plume of Feathers pub (2.15m x 0.6m W x H box culvert) which has a capacity of c. 2.1 m^3/sec. Key outlet culvert is therefore c. **48% under capacity** for the peak flow passing. Other culverts flowing into the outlet culvert from Priory Lane and Stevenage Road / Ash Brook are similarly 65% and 52% under capacity respectively. The outlet culvert will tend to throttle inflows from Ash Brook, the Priory Lane stream, and overland flooding from Stevenage Road and Priory Lane. The critical inflow is overland flooding from Priory Lane. Peak flooding from the Priory Lane catchment occurs c. 10 hrs before peak flow from Ash Brook would be anticipated to arrive at the village centre. Flows in excess of the culvert capacity will tend to store in the low lying area on Priory Lane adjacent to Bladon Close, building up in level until it reaches an overtopping level at which it can spill west overland onto Stevenage Road and adjacent lower lying properties. Patterns indicate that drain down of the storage is restricted by further restrictions downstream (west) in Ash Brook that cause a "backing up" effect.

Table 3-3: February 2014 – Flood Mechanisms

Map (Contains Ordnance Survey data © Crown copyright and database right 2015)	Location / Description	Comments
	Locations 11, 12, 13, 14	Peak flow (coinciding with peak inflow from Priory Lane catchment) is c. 4.5 – 5.1 m^3/sec. Culvert @ Location 11 (1.05m diameter for private access 40 m west of Priory Lane) can convey up to 2.1 m^3/sec and is c. 53% under capacity. Culvert @ Location 12 (1.3m diameter with inlet opposite Bucks Head pub) can convey up to 2.5 m^3/sec and is c. 44% under capacity. Culvert @ Location 13 (2.1 x 1.2m (WxH) box culvert) opposite Wymondley Chapel can convey up to 1.6 m^3/sec and is c. 66% under capacity. Culvert @ Location 14 (2.4 x 1.3m (WxH) box culver) for access to Elms Close can convey up to 3.0 m^3/sec and is c. 41% under capacity. Restrictions in culverts causes a backing-up effect with flows in excess of the culvert and channel capacity forced onto Stevenage Road and/or lands north of the Ash Brook channel.
	Location 15 Culvert in verge to frontage of Andrew Charles clockmakers premises	Peak flow (coinciding with peak inflow from Priory Lane catchment) is c. 5.2 m^3/sec. Culvert section (1.05 m diameter) has a capacity c. 1.4 m^3/sec. i.e. the culvert is c. **73% under capacity** for the peak flow passing. The culvert is the most significant restriction to flows passing through the village centre and causes a noticeable backing up effect extending back through the village. Results indicate that the contribution to peak flows in the Ash Brook from runoff generated within the village itself is likely to be in the order of 0.6 m^3/sec. A further culvert downstream at the Blakemore Road roundabout (2.6x0.76m box culvert) is under capacity; however the restriction causes attenuation onto agricultural ground west of the village and does not significantly affect water levels or drain down times in the village.

3.5 Model Validation

The following schedule details the key observed flooding (photographic records) vs. flood extent and depths predicted by the surface flood model for purposes of determining whether the model is giving results that are representative of the 7th February 2014 flood.

Table 3-4: February 2014 – Observed vs. Predicted Flooding

Ref	Location Description	Observation	Model Result
1	Stevenage Road at industrial units east of allotment gardens (refer photo, Flood Investigation Appendix 3a)	Flooding across entrance flowing onto Stevenage Road	Flood depths between 0.2 – 0.3m flowing in lands parallel to Stevenage Road and flowing onto Stevenage Road at the unit entrance.
2	Stevenage Road at railway bridge / junction of St Marys Church Road.	Flooding of Stevenage Road to a depth of up to approximately kerb / footpath level adjacent to St Marys Church Road.	Flood depths between 0.2 – 0.4m extending over the whole carriageway and over the southern footpath adjacent to St Marys Church Road.
3	Priory Lane opposite Bladon Close	Extensive flooding of Priory Lane opposite Bladon Close at car dealership and rear of Plume of Feathers Pub	Flooding occupying car dealership forecourt and car park to rear of pub. Flood depths up to c. 0.6 m on Priory Lane
4	Stevenage Road at Wymondley Chapel	Flooding of Stevenage Road extending to the edge of the footpath / curtilage of chapel site.	Flooding on Stevenage Road up to c. 0.4m deep; flood extents to curtilage of chapel site.
5	Elms Close, off Stevenage Road	Flood water covered the brick paved car parking area to the front of 35 Elms Close.	Shallow (c 0.1 m) flooding occupying the brick paved parking area.
6	Stevenage Road opposite Elms Close junction	Floodwater overtopping vents built into wall on south of Stevenage Road (surveyed subsequently to be 75.00 m OD)	Flood levels adjacent to vents to c. 75.19 m OD.
7	Stevenage Road adjacent to traffic calming adjacent to Mandavale House	Media reports[6] indicating flood depths of approximately kerb depth (i.e. c. 150 mm).	Flood depths of 150 – 200mm indicated.
8	Millburn Stevenage Road	Flood water was observed entering the property through air bricks at 5.00 AM	Flood depths of 300 - 350mm indicated around the property.
9	35 Elms Close	Resident reported rack levels close to property threshold, indicated water levels had began to recede by 7.00 am when observations were made .	Peak flood levels within the model occur prior to the observation and have begun to recede by this timestep, with flood outline matching reported levels.
10	Stevenage Road opposite May Cottage	Internal flooding reported within the property which is constructed over culvert AshBrk_16	Flood depths of 170 - 200mm indicated around the property.

1

[6] The Comet. (2014). GALLERY: Houses and roads affected by widespread flooding across Hertfordshire. Available from: http://www.thecomet.net/news/gallery_houses_and_roads_affected_by_widespread_flooding_across_hertfordshire_1_3289230. [Accessed: 27/7/2015].

In addition to particular observations of flood depths and extents, the extents, patterns, and directions of flow generally correlate with the flood described by the previous HCC Flood Investigation; results correlate with patterns anticipated by Environment Agency surface water flood maps.

The high degree of correlation between predicted and observed flood extents, depths, and times of onset of flooding indicate that the model results can be relied upon as representative of the flood event and is suitable for use in testing over design flood return periods and/or mitigation proposals (whilst accepting model limitations outlined previously).

Further validation of the model relative to design flood return period models is discussed subsequently in Section 4.2.2.3.

3.6 Appraisal of effect of Culvert Condition

The model replicating the 7 February 2014 flood event has included blockages due to the structural and serviceable condition of the modelled culverts as detailed previously in Section 3.3. In order to determine the significance of those blockages, a variation of the model has been run with all blockages cleared, i.e. representing the most favourable feasible scenario if all structures and assets were performing optimally.

The effect on flood depths (compared to the baseline model) at the locations shown on previous Figure 3-3 is presented on the following table. Associated flood extent mapping is shown on Figures FL09 to FL12 included in Appendix B.

Table 3-5: February 2014 – Effect of Blockages

Ref	Location Description	Channel / Overbank	Max Water Depth (with Blockages) - 07/02/2014 (m)	Max Water Depth (Blockages Removed) - 07/02/2014 (m)	Effect of Removal on Water Depths (m)
1	Ash Brook upstream of Chantry Lane	Channel	2.36	1.47	-0.89
2	Stevenage Road at Car Sales Garage	Road	0.23	0.24	0.01
3	Stevenage Road 30m East of Priory Lane	Road	0.15	0.15	0
4	Ash Brook to frontage of Plume of Feathers Pub	Channel	1.6	1.6	0
5	Stevenage Road to frontage of Bucks Head pub	Road	0.2	0.2	0
6	Stevenage Road at Wymondley Chapel	Road	0.4	0.36	-0.04
7	Stevenage Road at Elms Close	Road	0.45	0.42	-0.03
8	Stevenage Road at Andrew Charles Clockmakers	Road	0.52	0.46	-0.06
9	Stevenage Road at Siccut Road	Road	0.17	0.17	0
10	Ash Brook east of Roundabout	Channel	0.89	0.87	-0.02
11	Priory Lane at Gravely Road	Road	0.42	0.42	0
12	Priory Lane at The Priory	Road	0.12	0.13	0.01
13	Priory Lane at Wymondley Farm	Road	0.39	0.39	0
14	Priory Lane at Railway Bridge	Road	0.4	0.39	-0.01
15	Priory Lane at Priory View	Road	0.28	0.28	0
16	Priory Lane at Bladon Close	Road	0.66	0.66	0
17	Rear of Plume of Feathers pub	Road	0.2	0.19	-0.01

Analysis of the dataset indicates the following:

- The average effect across the detailed model reach areal extents (referring to Figures FL09 to FL12 included in Appendix B) would be to increase water levels by 0.035m (i.e. 35mm, c. 1.3").
- Removal of the throttle and attenuation caused by the significant blockage of the culvert under Chantry Lane would serve to increase flows toward the culvert in Stevenage Road which would not have capacity to convey the larger flow, causing marginally increased depth of flooding on Stevenage Road over a greater duration. The Chantry Lane culvert blockage is likely to have been of greater beneficial effect than the adverse effect of the screen blockage to the culvert approximately 50 m downstream reported by residents.
- Removal of blockages on Ash Brook in the village centre west of Priory Lane would serve in general to decrease flood levels by up to 0.06m (i.e. 60mm, c. 2.4") along Stevenage Road.
- Flood levels on Priory Lane south of the railway bridge are largely unaffected.
- Removal of blockages on culverts on Priory Lane north of the railway bridge would remove throttles and attenuation and would serve to increase flows on Priory Lane, increasing flood depths on the carriageway by c. 0.005m (5mm, 0.2") north of Wymondley Farm.
- The anticipated change in areal extent of flooding associated with the relatively insignificant variations in water level between the blockage vs. non blockage scenarios is negligible.

In summary, the serviceable and structural condition of the culverts and screens is unlikely to have been a significant contributing factor to the flooding experienced; the fundamental lack of capacity within the drainage network by orders of magnitude relative to inflows to the village meant that the infrastructure was overwhelmed irrespective of the comparatively minor effects of blockages. Where a reduction in flood level is observed locally, the effect would not have been anticipated to be sufficient to have caused any significant decrease in the flood risk to buildings.

In particular, the effect of blockage of the culvert at Chantry Lane is likely in this instance to have proven to be beneficial in providing a throttle in an area where water could be temporarily attenuated.

3.7 Appraisal of effect of road furniture & traffic calming

The existing Flood Investigation has indicated that residents have reported that traffic calming measures may have caused or exacerbated flooding on Stevenage Road. Traffic calming measures are identified at the following locations:

Figure 3-4 Traffic Calming & Street Furniture

While the model methodology and grid size would not permit detailed analysis of the effect of the structures, observed flood patterns are detailed as follows (description numbering referring to numbered locations in Figure 3-4:

1. **Single-file narrow lane** – modelling indicates that the narrowing causes a restriction to floodwater flowing from east to west in Stevenage Road. The narrowing causes a build-up in flood level upstream (east) of the calming measure of c. 0.15m and may cause or exacerbate floodwater to enter the property to the north.
2. **Median island –** modelling indicates that this feature has no effect on flood depths; flood levels in this area are dictated by the build-up of floodwater in the low lying area on Priory Lane. The floodplain at this location is effectively static storage.
3. **Single-file narrow lane and shallow ramp** – floodwater on Stevenage Road at this location is caused by out of bank flows from the adjacent open Ash Brook and/or backing up through road gullies that discharge directly to the watercourse in areas where the carriageway is lower lying than the adjacent river bank. There is no indication that the narrowing causes any increase in flood depth; estimated velocities and direction of flow indicate the floodplain is effectively storage. The road east of the narrow lane is slightly depressed by c. 0.16 m relative to adjacent road levels. Floodwater in this depression would be reliant on road gullies to allow drain down of water on the road back to the Ash Brook channel after flood levels in the watercourse had receded; lack of or failure of gullies at this low point is more likely to have contributed to the extended flooding observed at this location.
4. **Single-file narrow lane** – floodwater on Stevenage Road at this location is caused by conveyance overland of floodwater in excess of the capacity of the adjacent culvert (*AshBrk_19*). Modelling indicates that the narrowing may cause an increase of c. 0.15m upstream (east) due to it causing a restriction in conveyance capacity. The narrowing does not cause flooding but may exacerbate the depth and duration of flooding.
5. **Single-file narrow lane –** no significant flooding on Stevenage Road is predicted at this location.

3.8 Summary of Findings

The **key findings** of the replication of the 7 February 2015 flood event are as follows:

i. The peak flood in the village is likely to have been caused by inflows from the Priory Lane catchment. A combination of lack of capacity in the stream draining the catchment in conjunction with significant areas draining directly onto Priory Lane results in the majority of flooding being carried within the carriageway and accumulating at the low point adjacent to Bladon Close.

ii. The effect of restricted culverts on the Ash Brook at Chantry Lane and upstream provides a **significant attenuating effect** that was critical in preventing a much greater magnitude flood in the village. The effect of screen blockages on culverts in this vicinity is likely to have increased the attenuating effect to the benefit of the village. Subsequent blockages would however have increased the nuisance effect by reducing capacity in the Stevenage Road culvert and causing increased overland flooding on and adjacent to Stevenage Road.

iii. The magnitude of the flood flow overwhelmed the drainage capacity through the village in terms of channel and particularly culvert capacities. The effect of reduced culvert capacity due to screen blockages is likely to have been insignificant relative to the much greater effect of the restrictions posed by the culvert dimensions relative to the flood flow passing. Cleared culverts would not have prevented flooding.

iv. Traffic calming measures have been identified at two locations (Figure 3-4 – locations 1 & 4) that would tend to exacerbate the depth of flooding by causing a restriction to flow at road surface.

v. Floodwater on Stevenage Road is reliant on road gullies to allow drain down of water back to the river channel. Blockage of gullies would tend to exacerbate the duration of flooding on the road after water levels in the watercourse channel have receded.

4 DESIGN FLOODS

4.1 Preamble

Design flood events have been agreed for investigation in relation to predicted flood extents and depths, and in order to investigate potential flood alleviation options to satisfy typical flood protection standards. Agreed return periods for rainfall depth events for purposes of this assessment are:

- 30-year rainfall event (0.33% Annual Equivalent Probability (AEP))
- 100-year rainfall event (1% AEP)
- 100-year + 20% intensity rainfall event (1%+CC AEP) - common to the flood risk design standard adopted by the National Planning Policy Framework and associated guidance.

In each case, modelling has determined that the critical duration (in terms of observed areal flood extent and water depth) is the 1-hour storm. All subsequent discussion relates the critical duration only.

Modelling of design floods assumes a preceding dry catchment and has been replicated by adopting effective rainfall values used to derive surface water flood mapping, which allows for typical initial and continuous losses arising out of the normal dry soil moisture conditions.

4.2 Model Results

Flood mapping showing the maximum flood extent / water depth predicted for each respective flood probability is shown on Figures FL30-1 to FL30-4, FL100-1 to FL100-4, and FL100CC-1 to FL100CC-4 respectively included in Appendix B. Similarly, flood hazard rating for each scenario is shown on Figures FL30-5 to FL30-8, FL100-5 to FL100-8, and FL100CC-5 to FL100CC-8 respectively included in Appendix B

Details of the model methodology and input parameters are detailed in Appendix C.

4.2.1 Flood Depths & Levels

Modelled water levels / depths at key locations (common to those presented for the 7 February 2014 model as shown on Figure 3-3) are presented in the following table.

Table 4-1: Design Floods – Estimated Flood Depths & Levels at Key Locations

Ref	Location Description	Coordinate	Channel / Overbank	30-Year / 3.3 % AEP		100-Year / 1 % AEP		100-Year / 1 % AEP + Climate Change	
				Max Water Depth (m)	Max Water Level (m OD)	Max Water Depth (m)	Max Water Level (m OD)	Max Water Depth (m)	Max Water Level (m OD)
1	Ash Brook upstream of Chantry Lane	522,129, 227,097	Channel	1.72	82.1	2.35	82.7	3.75	84.1
2	Stevenage Road at Car Sales Garage	521,865, 227,356	Road	0.28	78.2	0.38	78.3	0.51	78.4
3	Stevenage Road 30m East of Priory Lane	521,561, 227,429	Road	0.16	76.5	0.25	76.6	0.35	76.7
4	Ash Brook to frontage of Plume of Feathers Pub	521,502, 227,437	Channel	1.58	75.9	1.75	76.1	1.84	76.2
5	Stevenage Road to frontage of Bucks Head pub	521,454, 227,425	Road	0.15	75.6	0.41	75.8	0.53	76
6	Stevenage Road at Wymondley Chapel	521,335, 227,428	Road	0.31	75.1	0.58	75.4	0.71	75.5
7	Stevenage Road at Elms Close	521,284, 227,440	Road	0.36	75.1	0.65	75.4	0.78	75.5
8	Stevenage Road at Andrew Charles Clockmakers	521,196, 227,455	Road	0.36	75	0.71	75.3	0.87	75.5
9	Stevenage Road at Siccut Road	521,102, 227,493	Road	0.17	74.5	0.4	74.8	0.44	74.8
10	Ash Brook east of Roundabout	520,893, 227,527	Channel	0.53	73.1	1.23	73.8	1.71	74.3
11	Priory Lane at Gravely Road	521,726, 228,415	Road	0.32	85.2	0.64	85.6	0.71	85.6
12	Priory Lane at The Priory	521,716, 227,985	Road	0.12	82.8	0.13	82.9	0.14	82.9
13	Priory Lane at Wymondley Farm	521,552, 227,614	Road	0.36	77.3	0.58	77.6	0.76	77.7
14	Priory Lane at Railway Bridge	521,538, 227,564	Road	0.64	76.9	1.02	77.3	1.24	77.5
15	Priory Lane at Priory View	521,529, 227,517	Road	0.37	76.2	0.55	76.3	0.63	76.4
16	Priory Lane at Bladon Close	521,528, 227,476	Road	0.65	76.1	0.85	76.4	0.96	76.5
17	Rear of Plume of Feathers pub	521,505, 227,467	Road	0.18	76.1	0.38	76.4	0.49	76.5

4.2.2 Discussion

4.2.2.1 Flood Magnitudes

In all instances, sources of flooding and patterns are as per those identified for the 7 February 2014 event (refer to Section 3.4).

Analysis of flood extents, depths, and flows passing indicates that the 30-year rainfall event causes a flood broadly comparable to the combined effect of 1-in-2 year rainfall on a saturated catchment event of 7 February 2014.

Extreme (100-year + Climate Change) rainfall events follow similar patterns and areas affected by flooding are broadly similar but flood depths and areal extent are significantly more onerous. Flood magnitudes within the Priory Lane catchment are greater than the February 2014 by a factor of c. 2.5. Peak flood flows at the southern (downstream) end of Priory Lane from the Priory Lane catchment would be anticipated to c. 10.5 m^3/sec.

In the case of Ash Brook, of significance is that for the 100-year + Climate Change rainfallevent, the attenuating effect offered by culverts at Chantry Lane and the A602 would be reduced as the storage available would completely fill causing overtopping of the respective embankments and flooding into the village. Peak flooding in the Ash Brook into the village (east of the junction with Priory Lane) would be anticipated to c. 6.7 m^3/sec.

For the 100-year + Climate Change rainfall event, the Priory Lane catchment would be anticipated to cause a flashy response, with an initial peak flood 1.25 hours after commencement of the storm (1 hour storm duration analysed). Floodwater would then recede before building to a further peak approximately 9 hours after commencement of the storm, caused by inflows from Ash Brook. The attenuating effect on the Ash Brook releasing a relatively stable rate of water into the catchment would be anticipated to recede from areas affecting buildings after a period of approximately 30 hours; however flooding would be anticipated to continue in on Stevenage Road east of the village for up to 40 hours.

4.2.2.2 Flood Impact

The number of buildings affected predicted to be affected by flooding from Ash Brook / Priory Lane stream systems for the 30-year, 100-year, and 100-year + Climate Change floods respectively (*based on buildings as defined by Ordnance Survey Mastermap data*) is *32, 68*, and *85* respectively. This finding is presented as indicative based on available data and should be subject to confirmation by detailed building survey.

It is noted that while the 30-year event appears to be comparable to the February 2014 flood, a discrepancy exists between the number of buildings predicted to be affected vs the number of reported instances of internal flooding in February 2014; this is likely to be due to the limitations of the topographic data used to determine building outlines and locations, and the lack of topographic survey to confirm building threshold levels dictating individual property flood risk.

In the case of the 100-year + 20% intensity rainfall event (1%+CC AEP, the village would be impassable by emergency vehicles (assuming a typical maximum depth of floodwater normally passable of 0.3m) via Stevenage Road from the east after c. 1 hour and from the west after 1:40 hours. The village between Siccut Road and Chantry Lane would feasibly remain substantially impassable for a period of 36 hours.

4.2.2.3 Model Output Validation

Flood extents have been compared with Environment Agency flood map data in order to obtain validation that the results obtained are realistic and reliable. Model output shows a high degree of correlation of results (flood extents) when compared with like for like predicted events.

4.2.2.4 Asset Performance

The following details the expected performance of key culverts in and around the village relative to floods passing, as well as indicating an indicative required culvert size[7] that would be required at that location to contain the flood flow without causing build-up of water levels.

1

[7] Equivalent culvert capacities stated are based on a coarse appraisal of typical inlet capacity by means of the method recommended by the Technical Note - *Calculating Discharge from Culverts under Inlet Control Using Stage at the Inlet, Elizabeth M. Toman1; Arne E. Skaugset III; and Amy N. Simmons (2014)* and excludes effect of surcharge and other hydraulic losses and are presented for informative purposes only.

Table 4-2: 1% (Climate Change) Design Flood – Culvert Performance

Model Ref	Size / Description	Total Flow Passing m^3/sec.	Flow In Culvert m^3/sec.	%-Under-capacity	*Equivalent Culvert Diameter Required (m)*
AshBrk_01	1 No. 0.9m Circular Pipe	7.7	2.8	64%	*2.4*
AshBrk_02 -_12	1 No. 0.825 to 0.9m Circular Pipe	6.7	1.0	85%	*2.4*
AshBrk_13	1 No. 1.2m Circular Pipe	6.2	1.0	84%	*2.4*
AshBrk_14	1 No. 2.15 x 0.61m Rectangular Box Culvert	12.6	2.1	83%	*2.7*
AshBrk_15	1 No. 1.05m Circular Pipe	13.1	2.2	83%	*2.7*
AshBrk_16	1 No. 1.3m Circular Pipe	13.1	2.4	82%	*2.7*
AshBrk_17	1 No. 2.1 x 1.225m Rectangular Box Culvert	13.1	3.2	76%	*2.7*
AshBrk_18	1 No. 2.38 x 1.33m Rectangular Box Culvert	15.4	5.1	67%	*2.7*
AshBrk_19	1 No. 1.05m Circular Pipe	13.4	1.9	86%	*2.7*
AshBrk_21	1 No. 2 x 1.32m Rectangular Box Culvert	13.1	4.8	63%	*2.7*
PryLn_01	1 No. 0.3m Circular Pipe & 1 No. 0.6m Circular Pipe	5.3	0.15	97%	*1.8*
PryLn_02 - 04a	1 No. 0.3m Circular Pipe	5.4	0.07	99%	*1.8*
PryLn_05 - 09	Various small dia. pipes	6.0	0.6	90%	*2.1*
PryLn_12	1 No. 0.6m Circular Pipe	10.3	0.5	95%	*2.4*
PryLn_13	1 No. 0.6m Circular Pipe	10.3	0.5	95%	*2.4*
PryLn_14	1 No. 0.6m Circular Pipe	10.1	0.9	91%	*2.4*
PryLn_15	1 No. 1m Circular Pipe	10.5	1.4	87%	*2.4*

4.3 Summary of Findings

The key findings of the design flood event models are as follows:

vi. The 7 February 2014 flood event is broadly comparable in terms of flood depth and extent to the equivalent flood caused by a 30-year (33% AEP) rainfall event;. Limitations in relation to the assessment of the number of buildings affected relative to the number of instances of internal flooding reported are acknowledged.

vii. All floods considered flood by the same mechanism but with magnitude (flood depth / areal extent) increasing significantly for the 100-year (1% AEP) rainfall event. Up to 85 buildings would be anticipated to be affected for the largest flood considered.

viii. The critical flood mechanism for the village in all instances is that from runoff to watercourses from the Priory Lane catchment. A combination of lack of capacity in the stream draining the catchment in conjunction with significant areas draining directly onto Priory Lane results in the majority of flooding being carried within the carriageway and accumulating at the low point adjacent to Bladon Close.

ix. The effect of restricted culverts on the Ash Brook at Chantry Lane and upstream would continue to provide a significant attenuating effect up to the 100-year (1% AEP) event, after which the impounding embankments are shown to overtop and flow overland toward the village causing a greater extent of flooding on Stevenage Road east of the village centre

x. The magnitude of flood flow passing for all “design” rainfall events is significantly greater than the maximum existing capacity of culverts and drainage channels within the village. The flood in is typically approximately 10 times the capacity of the Priory Lane drainage network.

5 FLOOD ALLEVIATION & MANAGEMENT

5.1 Scoping

As established in the analysis of the 7 February 2015 flood (approximately equivalent in flood magnitude to a 30-year rainfall event) and higher magnitude floods applicable to flood protection standards, the infrastructure in the village is substantially deficient in terms of conveyance capacity for the flood flows that would be anticipated to flow through the village. The village lies in a natural depression floodplain in which water will inevitably tend to accumulate.

Any flood alleviation scheme would be required to **either** increase the conveyance capacity for water reaching the village in order that the water could be safely pass through the built area; **or** would be required to limit the rate of flood flows reaching the village in order to relieve pressure on drainage infrastructure in the village.

Scoping of alleviation and flood management options based on results and initial calculations outlining the capacity required of any significant drainage scheme was undertaken in conjunction with Hertfordshire County Council Flood Management Team. It was determined that:

- an arterial drainage / flood defence scheme to improve conveyance through the village of the scale and nature that would be required to substantially alleviate flooding in the Little Wymondley area <u>was not considered feasible</u> based on the indicative culvert sizes that would be required (presented in previous Table 4-1) and should not be considered further by this assessment.
- the assessment should focus on identifying and discussing broad measures that may feasibly reduce flood flows into the village and removal of particular pinch points; and
- the assessment should discuss management of subsequent residual risk and measures that may reduce the impact of high probability "nuisance" flooding and may reduce the impact of extreme floods.

5.2 Potential Flood Alleviation / Property Protection Measures

5.2.1 <u>Catchment Attenuation / Detention</u>

5.2.1.1 <u>Priory Lane Catchment</u>

It has been determined that the limiting in-channel capacity of the Ash Brook downstream of Priory Lane is approximately 1.4 m^3/sec. Peak floods from the Ash Brook catchment are sufficiently delayed relative to the flood from the Priory Lane catchment such that the majority of that capacity would be available to convey flooding from Priory Lane.

For the design (1%+Climate Change) scenario, the peak contribution to flooding from the Priory Lane catchment is approximately 10 m^3/sec. An assessment of the required volume of attenuation / detention on lands within the Priory Lane catchment, such that the flow out of the catchment would not exceed the Ash Brook capacity (1.4 m^3/sec) results in a volume to be detained of c. 28,200 m^3.

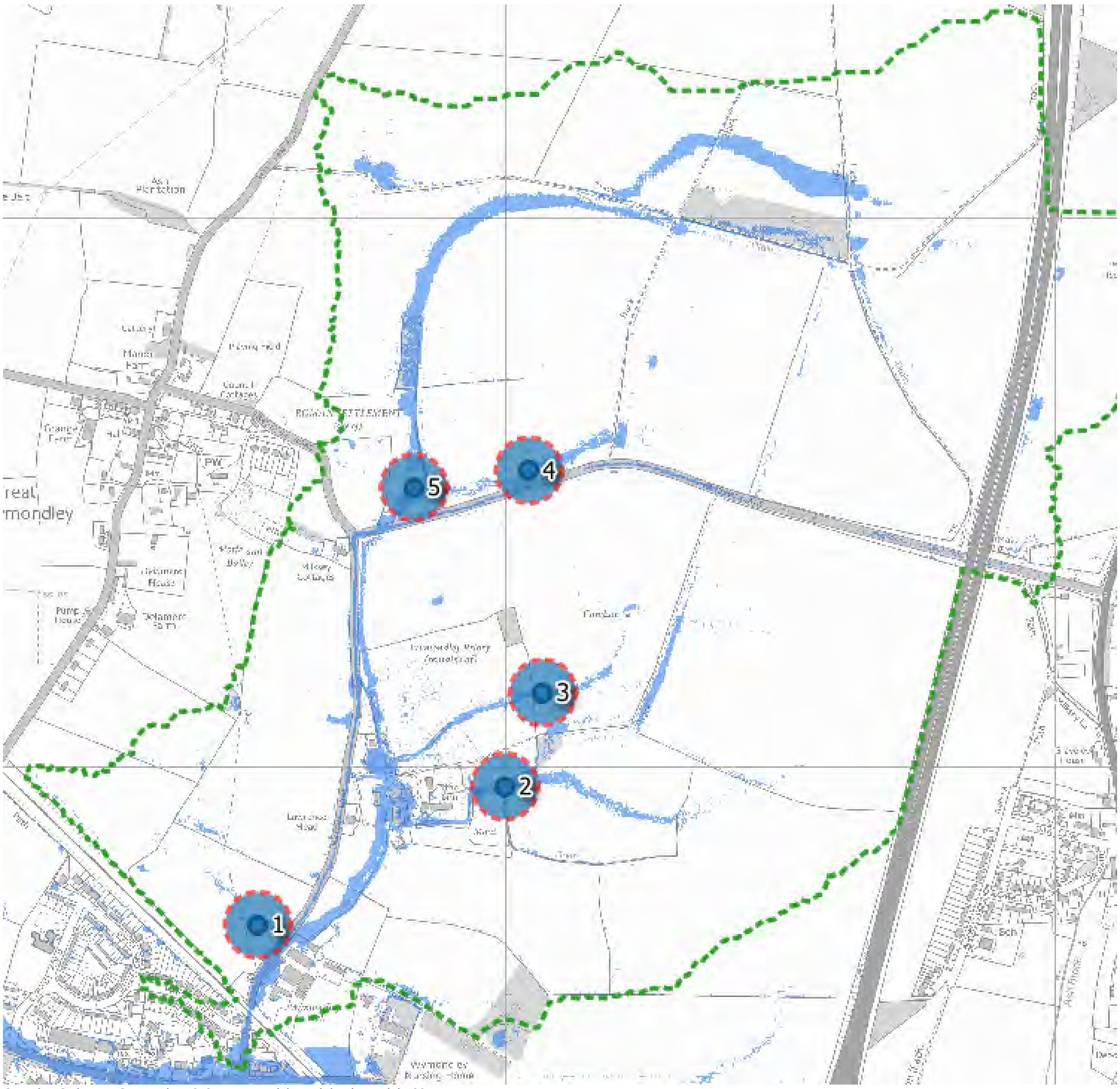
Assuming a typical maximum depth of stored water of 0.5 m in order to minimise requirement for significant impounding structures, the required land-take area to provide the attenuation is approximately 5.6 Ha. Detention locations would be required to be located in areas where surface runoff is concentrated and before the water had entered Priory Lane carriageway; as such the number of areas where detention would be feasible is finite. Indicative locations have been identified at the main points of concentrated overland flow as shown on the following figure. All locations are on private / 3rd party lands.

Works to construct detention would entail placement of clay core berms or similar to detain floodwater in conjunction with a throttling culvert at each location. Such impounding structures would have an inherent need for maintenance; dependant on their size, they may fall within the thresholds (10,000 m^3) requiring compliance with the Reservoirs Act as proposed to be amended by the Flood and Water Management Act 2010. Ownership and maintenance would therefore be a significant undertaking and would not be the responsibility of the Lead Local Flood Authority.

A model variation including a schematised effect of such a scheme (in conjunction with other measures) has been undertaken, the effect of which is considered in Section 5.3.

The measure would not be anticipated to entirely prevent flooding of Priory Lane given the nature of direct overland discharges and field drainage discharging directly onto the road, some of which it would not be feasible to intercept into an detention system; however the scheme if feasible would significantly reduce the peak flood (flow rate) from the catchment.

Figure 5-1 Priory Lane Catchment Attenuation



5.2.1.2 Ash Brook Catchment

Significant attenuation exists within the Ash Brook catchment caused by culverts and associated detention and impoundment behind road embankments at Chantry Lane, the A602, and the A1(M).

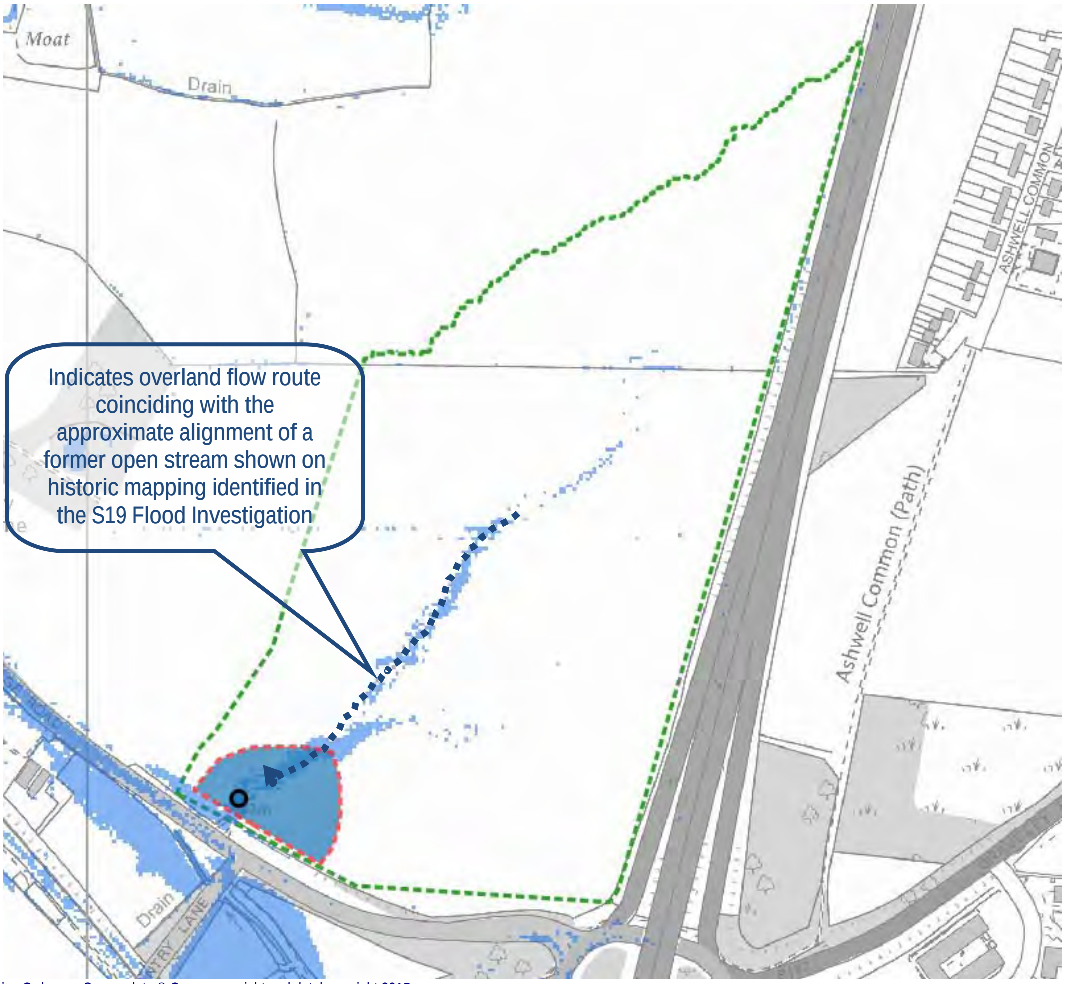
A further sub-catchment and flow path has been identified on agricultural lands north of Stevenage Road / west of A1(M) as shown on the following figure at which attenuation or detention may be feasible.

Where all flows were detained for the design (1%+Climate Change) scenario (i.e. best case / most effective scenario), the required volume to be detained would be c. 5250 m^3. Assuming a typical maximum depth of stored water of 0.5 m in order to minimise requirement for significant impounding structures, the required land-take area to provide the attenuation is approximately 1 Ha. Similarly to Priory Lane catchment, ownership and maintenance of such structures would be a significant undertaking and would not be the responsibility of the Lead Local Flood Authority.

A model variation including a schematised effect of such a scheme (in conjunction with other measures) has been undertaken, the effect of which is considered in Section 5.3.

The measure would not prevent flooding of Stevenage Road, but would potentially reduce pressure on the Ash Brook culvert infrastructure by reducing inflows, and may reduce nuisance flooding caused by direct runoff from this catchment across Stevenage Road.

Figure 5-2 Ash Brook Catchment Detention



5.2.2 Key Culvert Upgrades

In scoping of alleviation options, potential for increasing all culverts in the village to sizes to convey the design floods has been discounted as infeasible.

Culverts acting as particular throttles that potentially exacerbate flooding have been identified as follows:

- AshBrk_02 -_12 (0.825 to 0.9m Circular Pipe) in Stevenage Road from approximately 50m downstream of Chantry Lane to the railway bridge / junction with Priory Lane – is identified as causing overland flooding of Stevenage Road east of the railway bridge, due to overland flooding from the culvert inlet. Consideration has been given to increasing the culvert dimension of 1.35m dia., that being a capacity equivalent to the typical downstream capacity (on the basis that any larger increase would be ineffective).
- AshBrk_19 (1.05m Circular Pipe) adjacent to Stevenage Road to the frontage of Andrew Charles clockmakers, identified as causing a significant restriction and backing up effect relative to adjacent upstream culverts. Consideration has been given to increasing the culvert dimension of 1.5m dia., that being a capacity equivalent to the typical capacity elsewhere on the watercourse reach (on the basis that any larger increase would likely be ineffective given similar restrictions upstream).

A model variation including a schematised effect of such a scheme has been undertaken, the effect of which is considered in Section 5.3. No consideration has been given to the detailed technical feasibility of such a scheme or issues surrounding ownership maintenance of sections of the culvert by multiple parties for purposes of this appraisal.

The measure is intended to relieve "pinch points" in the Ash Brook culvert infrastructure in order to potentially allow conveyance of floods with similar magnitude to that of February 2014 to pass through the village without causing significant flooding (excluding the effect of flooding from Priory Lane). Flooding would still be anticipated for rainfall events with magnitude greater than 1-in-30 year.

5.2.3 Property Level Protection

Due to the localised and complex nature of flooding anticipated, it is infeasible to implement large-scale flood defences; as such increasing resilience at building-scale is an important aspect of the broader flood risk management system.

Property-level Flood Resilience (FRe) measures are appropriate where flood duration is short, water speed is slow, and where generally depth of water is no greater than 600mm above the property threshold. At depths greater than this other measures should be implemented or flood waters should be allowed into the property, due to the risk of structural damage from build-up of hydrostatic pressure to the external walls and doors of the building. Alternatively other FRe systems (such as building skirt systems) may be appropriate to provide flood resistance up to depths of c. 900mm.

A review of buildings anticipated to be affected for the present scenario (based on Ordnance Survey data) by flooding from the Ash Brook / Priory Lane flood mechanism indicates the following:

Table 5-1: Property Level Protection Applicability

Design Rainfall Event	33%-AEP	1%-AEP	1% + Clim. Change
Number of Affected Properties	32	68	87
Of which flood depth of up to 0.6 m	31	65	85
Of which flood depth 0.6 - 0.9 m	-	*1*	*10*
Of which flood depth greater than 0.9m[8]	1	2	2

Onus would be placed on the building occupants to take action to protect properties from flood damage by ensuring that the PLP measures are mounted/fixed place in the event of a flood warning or prior to / during extreme wet weather. Passive measures, including flood doors, are considered more suitable than manual measures which require mounting and de-mounting in the instance of Little Wymondley, due to the nature of flash flooding experienced.

Reference is made to the ‘Homeowners Guide to Flood Resilience’, which illustrate the variety of ways in which a home can be protected through the fitting of various products and installations. The document can be downloaded at;

http://www.knowyourfloodrisk.co.uk/pdf/protection-guide.pdf

Not all methods are suitable for all buildings or all types of flood risk, so careful consideration of appropriate measures is required prior to undertaking any works. FRe and Property Level Protection measures should be planned, designed, implemented and maintained generally as per the guidance stated in ‘Six Steps to Property Level Flood Resilience – Guidance for Property Owners’[9] and ‘Six Steps to Property Level Flood Resilience – Guidance for Local Authorities and Professionals’[10]

Examples of property level protection measures are given in the following table.

Table 5-2: Flood Resistance and Resilience Measures

Permanent Measures		Details of measures
Flood Resistance Measures	Measures to prevent water entering doors/windows	Raised threshold Automatic/self-closing barriers Water-resisting doors/windows Sealant around doors/windows

1

[8] Note that initial review indicates the buildings affected by floodwater to a depth greater than 0.9m are agricultural / garages.

[9] I. White, P. O’Hare, N. Lawson, S. Garvin and A. Connelly: Six Steps to Property Level Flood Resilience – Guidance for Property Owners. SMARTeST. Manchester, 2013. www.smartfloodprotection.com

[10] I. White, P. O’Hare, N. Lawson, S. Garvin and A. Connelly: Six Steps to Property Level Flood Resilience – Guidance for Local Authorities and Professionals. SMARTeST. Manchester, 2013. www.smartfloodprotection.com

Table 5-2: Flood Resistance and Resilience Measures

Permanent Measures		Details of measures
	Measures to prevent water penetrating walls	Re-pointing and repairing cracks, Sealing service outlets Covering weep-holes, Facing bricks Rendering, Wall sealant, Permanent wall barrier, Tanking, Water-resisting air bricks
	Measures to prevent water entering service pipes	Non-return valves on waste pipes
	Measures to prevent water penetrating floors	Reinforced floor with continuous damp-proof membrane Suspended floor Raised floor levels Tanking or sealing of concrete floors Tanking of basements
	Measures to prevent water entering doors/windows	Removable barriers to doors and windows Sandbags/adsorbent bags Demountable barriers Free-standing barriers Perimeter wall with flood gates
	Measures to prevent water penetrating walls	Air-brick covers
	Measures to prevent water entering service pipes	Toilet plugs Bolt-down manhole covers Vent covers Pipe bungs
Flood Resilience Measures	Measures to limit water damage	Water compatible internal walls using waterproof paints and plasters Water compatible floors such as tiling rather than carpets or floorboards Water compatible appliances and fixtures
	Remove vulnerable items from flood risk	Raised utilities and appliances Removable fixtures and fittings Relocate valuables
	Measures to expel water	Sump and pump

5.3 Option Appraisal

The following schedule identifies initial capital costs, benefits and limitations of the flood alleviation options proposed and considers the effect of implementing schemes with varying design horizons. Two combined options are considered, i.e.

Option 1 – Catchment Detention in conjunction with Key Culvert Upgrades and Property Level Protection

Option 2 - Property Level Protection only.

"Do Nothing" costs for each design scenario are presented for comparison based on a typical insurable loss per affected building. Cost breakdowns are included in Appendix D

Flood mapping for Option 1 (for each return period) are included on figures MCL250-07_FIG_FL_OP1_1 to OP1_4, refer to Appendix B.

Table 5-3: Flood Alleviation Option Appraisal

Option	Option 1 Catchment Detention in conjunction with Key Culvert Upgrades and Property Level Protection	Option 2 Property Level Protection only
Description	• Attenuate Priory Lane flows to a rate that village drainage infrastructure can convey. • Detain an area of catchment to reduce Ash Brook peak flows. • Remove culvert pinch points in order to provide benefits up to 1-in-30 yr flood. • Provide Property Level Protection to buildings not removed from floodplains affected up to 1-in-100 yr + Climate Change flood.	• Provide Property Level Protection to buildings affected up to 1-in-100 yr + Climate Change flood.
Effect of Scheme[11]	The scheme would • be anticipated to cause a significant reduction in high probability nuisance flooding on Stevenage Road. • Significantly reduce flood extents and depths for floods up to c. 33%-AEP. Flooding would not exceed 0.3m on Stevenage Road at any location, i.e. the road would remain passable to emergency services and the majority of traffic. Flood depths exceeding 0.3m would remain on Priory Lane at Bladon Close. The scheme would remove 20 buildings from the floodplain. • Significantly reduce (but not remove) the extent and depth of flooding up to c. 1%-AEP. Flooding would not exceed 0.3m on Stevenage Road west of Priory Lane; some flooding exceeding 0.3m would remain east of Priory Lane. The scheme would remove 54 buildings from the floodplain. • Reduce the extent and depth of flooding up to c. 1%+Climate Change-AEP and would remove 46 buildings from the floodplain. Scheme excludes those buildings with an estimated depth of floodwater greater than 0.9m.	The scheme would have no effect on flood extent, depth, or the nature of flooding. The scheme would seek to alleviate flooding at the point of need. Scheme excludes those properties with an estimated depth of floodwater greater than 0.9m.
Summary of Initial Capital Costs	AshBrk_02 -_12 Culvert Upgrade – c. £1.5m AshBrk_19 Culvert Upgrade – c.£190k Catchment detention – c. £550k (of which £300k land acquisition) Property Level Protection @ c. £7.5k / property including contingencies	Property Level Protection @ c. £7.5k / property including contingencies

1

[11] Effect of scheme in terms of buildings removed from floodplain is subject to confirmation of property threshold levels relative to adjacent flood levels and is limited by the degree of accuracy of the map data used.

Table 5-3: Flood Alleviation Option Appraisal

Option	Option 1 Catchment Detention in conjunction with Key Culvert Upgrades and Property Level Protection			Option 2 Property Level Protection only		
Design Rainfall Event	33%-AEP	1%-AEP	1% + Clim. Change	33%-AEP	1%-AEP	1% + Clim. Change
Residual Damage Value[12]	-	-	£30k	£30k	£60k	£60k
Option Cost	£2,374k	£2,381k	£2,566k	£250k	£510k	£650k
"Do Nothing" Damage Value[13]	*£960k*	*£2,040k*	*£2,610k*	*£960k*	*£2,040k*	*£2,610k*
Environmental Considerations	A Water Framework Directive (WFD) assessment shall be necessary for the project. The project will directly affect receiving watercourses. The introduction of detention / wetland features are anticipated to have a beneficial environmental impact.			N/A		
Delivery Risks	Feasibility of catchment detention is entirely dependent on availability of 3rd party land at a finite number of suitable locations. Catchment detention would have significant implications in terms of ownership and maintenance of attenuating structures and would not be the responsibility of the LLFA. Effectiveness of upgraded culverts would be dependent on suitable ongoing maintenance arrangements. Upgrading key culverts without upstream catchment detention would not be anticipated to have any significant beneficial effect due to the critical flood coming from Priory Lane catchment, i.e. feasibility of catchment detention is of greater significance. Costs estimates stated are made in the absence of any preliminary design / outline design and include contingencies and allowances for Optimism Bias; costs should be read as such.			Passive property level protection preferred due to the short (c. 1 Hr) time to peak flooding in the Priory Lane catchment. **Manual measures are likely to be ineffective in the absence of a suitable flood warning system.** Costs estimates stated are made in the absence of any preliminary design / outline design and include contingencies and allowances for Optimism Bias; costs should be read as such.		

1

[12] Determined based on a typical average claim of £30k per property to represent damage due to internal flooding applied to properties to which PLP is not suitable (i.e. depth greater than 0.9m).
[13] Determined based on a typical average claim of £30k per property affected to represent damage due to internal flooding.

5.4 Flood Management Options

The following measures are intended for consideration and implementation irrespective of the feasibility or implementation of flood alleviation measures.

The measures are intended to reduce the impact of flooding when it occurs, either by reducing the duration of flooding or managing the consequence of flooding. The measures may reduce the frequency of high probability nuisance flooding but should not be interpreted as having any effect in terms of preventing extreme flooding.

5.4.1 Rationalisation of Traffic Management

Referring to the findings of previous Section 3.7, the following is recommended for consideration:

- Remove traffic calming lane at location #1 (referring to Figure 3-4) in order to relieve potentially increased flood risk to the adjacent dwelling to the north.
- Remove traffic calming lane at location #4 (referring to Figure 3-4) in order to reduce flood depths on Stevenage Road cause by the restriction in conveyance capacity on the road to floodwater.

Elsewhere, the residual effect of prolonged flooding should be managed by ensuring frequent maintenance of road gullies in order to ensure that the carriageway is able to drain down in areas where floodwater accumulates.

These measures should be read in the context that they may reduce the peak flood depth and duration of flooding for high probability flooding, but such measures would not be anticipated to prevent flooding.

5.4.2 Culvert Maintenance

CCTV survey (where available or feasible) has indicated that in a number of instances culverts are in poor structural condition.

While increasing drainage capacity to prevent flooding is considered infeasible, consideration should be given to repairing or replacing culverts identified as being in poor condition (SPG3 or above, refer to Table 3-1) in order to maximise existing drainage capacity in the system. Responsibility for replacement or repairs is the riparian landowner where the structure is not adopted by HCC Highways or Network Rail.

Replacement or repair of culverts may reduce the peak flood depth and duration of flooding for high probability flooding, but such measures would not be anticipated to prevent flooding.

5.4.3 Rationalisation of Culvert Screens

Culvert screens are present at 5 culverts within the modelled watercourses. The purpose of screens should be to prevent access to culverts and prevent entry of large debris that could cause a significant reduction of the culvert opening capacity.

However, failure to maintain screens, and in particular to clear the ongoing build-up of small debris (leaf litter / vegetative brash etc.) will cause a blockage risk in itself, typically by causing an accumulation and weir effect that would tend to raise water levels before they access the culvert. Risk of screen blockage can be reduced by ensuring that vertical bars are raked at an angle, with a top bar screen such that if the whole vertical bar is blocked floodwater can overtop the blockage and flow through the horizontal top screen into the culvert.

The following table appraises the culverts present makes recommendations for their future use. Responsibility for future maintenance requirements as structures on ordinary watercourses (i.e. the responsibility of riparian landowners unless adopted by adopted by HCC Highways or Network Rail or determined otherwise) should be determined by the local authority and/or managed as part of a Community Flood Management Strategy (refer to following Section 5.3.3).

Where new screens are proposed they should be in compliance with the requirements of the Trash and Security Screen Guide (Environment Agency 2009) and the Culvert Design & Operation Guide (CIRIA 2010). Consent for any new or replacement screen would be required from the Lead Local Flood Authority under Section 23 of the Land Drainage Act.

Table 5-4: Culvert Screen Rationalisation

Model Ref	Size / Description		Assessed Blockage Likelihood	Appraisal	Recommendation
AshBrk_02 – to AshBrk_12		1 No. 0.825 to 0.9m Circular Pipe	High	Vertical bar screen in poor condition. Effect of blockage would be significant, preventing any inflow to the culvert; as a consequence all floodwater would back up and eventually flow overland and onto Stevenage Road.	• Replace with raked bar screen and top bar screen. • Improve / formalise access for maintenance. • Formalise **frequent** maintenance arrangements ensuring that debris removed is not deposited in an area likely to fall back into the channel.
AshBrk_17		1 No. 2.1 x 1.225m Rectangular Box Culvert	Moderate	Raked vertical bar screen and top bar screen in good condition. Effect of blockage is reduced by top bar screen. In event of blockage of raked and top bars, floodwater would be forced onto Stevenage Road.	• Retain screen • Improve / formalise access for maintenance. • Formalise maintenance arrangements ensuring that debris removed is not deposited in an area likely to fall back into the channel.
AshBrk_18		1 No. 2.38 x 1.33m Rectangular Box Culvert	Low	Raked vertical bar screen and top bar screen in good condition. Effect of blockage is reduced by top bar screen. In event of blockage of raked and top bars, floodwater would be forced onto Stevenage Road.	• Retain screen • Improve / formalise access for maintenance. • Formalise maintenance arrangements ensuring that debris removed is not deposited in an area likely to fall back into the channel.

Table 5-4: Culvert Screen Rationalisation

Model Ref	Size / Description		Assessed Blockage Likelihood	Appraisal	Recommendation
PryLn_01		1 No. 0.3m Circular Pipe	Very High	Informal horizontal bar screen appears to have been deliberately placed shortly upstream of the culvert inlets. Effect of blockage would be significant, preventing any inflow to the culvert; as a consequence all floodwater would back up and eventually flow overland and onto Priory Lane	• Replace with raked bar screen and top bar screen in conjunction with localised culvert improvements. • Improve / formalise access for maintenance. • Formalise **frequent** maintenance arrangements ensuring that debris removed is not deposited in an area likely to fall back into the channel.
PryLn_05		1 No. 0.45m Circular Pipe	Low	Vertical bar screen Screen is visible and accessible. Consequences of blockage are not significant to lands other than those under control of the riparian landowner.	• No action required.

5.4.4 Community-Led Flood Management

Watercourses affecting the village are "ordinary[14]" and as such it is understood that they are ordinarily subject to maintenance by riparian landowners only, unless otherwise agreed. Community-led flood resilience supported by local authorities may be considered in order to:

- Identify the main flood issues affecting residents in conjunction with local councillors, community groups, the lead local flood authority, and emergency services to a grid coordinate accuracy (informed by this assessment) – to include identification of vulnerable groups, flooding "hotspots", areas where traffic management is to be prioritised (in order to prevent bow wave effects) and areas / individuals to be prioritised for care or evacuation in the event of flooding.
- Increase community awareness of roles and responsibilities (e.g. highlight the potential effect of fly tipping of garden waste into watercourses), and coordinate riparian maintenance of watercourses, culverts, grille screens, key gullies etc by the community where that maintenance is not the responsibility of a statutory agency.
- Increase community awareness of available resources, e.g. Met Office flood warnings, Environment Agency Flood Warnings Direct subscriptions.
- Increase community awareness of the flood hazard generally.
- Coordinate community emergency responses to include awareness of ongoing flood alerts / warnings, preparedness (erection of demountable property-level protection as may be appropriate), distribution of sandbags (if likely to be effective or similar / preferred measures). Consider implementation of an early warning system to monitor water levels in Priory Lane stream (by telemetry linked ultrasonic system or similar) that would be monitored and maintained by the community unless otherwise agreed.

Community-led measures are likely to reduce the severity and frequency of "nuisance" flood events and reduce the impact of severe floods; however such measures would not be anticipated to prevent flooding.

5.4.5 Catchment Land Management

The catchment draining to Priory Lane is essentially rural, comprising agricultural arable / tillage land use, and as such land management may feasibly have a significant effect particularly catchment response to high probability rainfall. It is acknowledged that there is substantial evidence that local flooding can be affected by changes in (rural) land management and management practices[15]. Evidence[16] published suggests that variability in proportionate runoff from grass fields can vary by up to c. 60% when comparing grass fields underlain by good soil structure versus poor (compacted) soil structure.

Land management measures influencing rate of runoff that are likely to be feasible include:

- Ploughed furrows that run parallel to contours would tend to retain water whereas furrows running downslope would tend to allow water to rapidly flow toward watercourses.
- Installation of a field boundary drain, in particular to lands west of Priory Lane, would allow interception of runoff and field drainage that would otherwise drain directly onto Priory Lane.
- Development of a land management framework that would encourage improvement of soil structures (therefore improving infiltration and reducing runoff reaction to rainfall events) and/or encourage vegetation types that may encourage evapo-transpiration.

Any such works would be subject to landowner agreement. Land management measures should be read in the context that they are likely to mitigate high probability "nuisance" flooding and may reduce the peak flood and duration of flooding for extreme flooding, but such measures would not be anticipated to prevent flooding.

1

[14] Main rivers are defined by DEFRA in England and are usually larger streams and rivers, but also include some smaller watercourses. A main river is defined as a watercourse marked as such on a main river map, and can include any structure or appliance for controlling or regulating the flow of water in, into or out of a main river. The Environment Agency's powers to carry out flood defence works apply to main rivers only. An "ordinary" watercourse that is one not part of a main river and includes rivers, streams, ditches, drains, cuts, culverts, dikes, sluices, sewers (other than public sewers within the meaning of the Water Industry Act 1991) and passages, through which water flows. The Lead Local Flood Authority has responsibility for approving works that affect the flow of an ordinary watercourse under the terms of the Land Drainage Act 1991.

[15] DEFRA/EA R&D project FD2114 Review of impact of rural land use & management on flood generation

[16] NSRI (Cranfield) Deeks LK, Clarke MA, Holman IP, Howden NJK, Jones RJA, Thompson TRE & Truckell IG (2008) What effect does soil compaction in grassland landscapes have on rainfall infiltration and runoff?

6 SUMMARY & CONCLUSIONS

6.1 Summary of Findings

The primary reason for flooding on 7 February 2014 has been determined to be exceptionally high rates of runoff from intense rainfall of low return period (1-in-1 / 1-in-2 years) caused by saturated ground conditions within the catchment due to an extended preceding period of wet weather conditions over the preceding period. The flood that resulted is approximately equivalent to a flood caused by rainfall with a return period of 1-in-30 years.

The peak flood through the village is anticipated to have been caused by runoff from the Priory Lane catchment. The potential impact of flooding from the Ash Brook is significantly reduced by culverts at Chantry Lane and the A602 which have an attenuating effect, which have been determined as being of significant benefit to the village.

The flood magnitude overwhelmed the drainage capacity in the village. Factors such as blocked gullies and culverts are likely to have been insignificant in the context of the flood flows passing relative to the inherent deficiency in drainage capacity.

The flood is likely to have been exacerbated by the lack of drainage infrastructure on Priory Lane, which would have routed significant rates and volumes of runoff on Priory Lane itself. The presence of traffic calming structures may have locally increased flood levels by causing a restriction to flows, but would not have caused flooding. Blockages in culverts (in combination) have been determined as likely having had a beneficial effect by causing an increased attenuating effect upstream, particularly at Stevenage Road east of the village.

The flood extent and hazard of floods caused by design rainfall events with 1-in-30, 1-in-100, and 1-in-100 + Climate Change return periods has been determined. Analysis of flood extents, depths, and flows passing indicates that the 30-year event is broadly comparable to the event of 7 February 2014. Larger events follow similar patterns and areas affected by flooding are broadly similar but flood depths and areal extent are significantly more onerous. In all instances the Priory Lane catchment would be anticipated to cause a flashy response, while flooding from Ash Brook is significantly attenuated upstream causing a longer duration flood that has potential to cut the village off for an extended period (c. 36 hours). Asset (culvert) performance is in all instances significantly under-capacity relative to floods passing for the larger flood events.

Potential options for flood alleviation have been discussed; no single measure is available that would be feasible and fully alleviate flooding at the site. The effectiveness of a number of measures has been quantitatively assessed in combination, with the aim of reducing the severity of flooding. By providing catchment attenuation / detention in conjunction with key culvert upgrades, significant betterment would be anticipated in terms of the number of properties affected by flooding would be anticipated; however the scheme would not prevent flooding of Priory Lane or Stevenage Road. Anticipated cost versus benefit for such a scheme has been estimated to be unfavourable. Delivery risks associated with the scheme are significant; the project would be dependent on availability of suitable 3rd party land at a finite number of locations. In the absence of catchment detention, culvert upgrades alone would not be anticipated to have any significant beneficial effect.

Alternatively, implementation of Property Level Protection is feasible and is favourable in terms of cost benefit and feasibility of delivery, while accepting that future flooding of the village is likely.

A number of measures to manage the impact of flooding, and measures to manage drainage infrastructure such that the duration of flood events is minimised, have been identified.

6.2 Conclusions

The assessment has determined that it is infeasible to provide a flood alleviation / arterial drainage type scheme that would prevent flooding of the village up to the typical design (1-in-100 + Climate Change return period) rainfall event.

The preferred option arising from this assessment based on likely costs and feasibility of delivery is property level protection in conjunction with measures to manage flooding.

Property level protection may feasibly offer alleviation at a local scale to the majority of properties affected, up the maximum design standard, The short duration, flashy nature of flooding in conjunction with typical flood depths anticipated in the village in the majority of flood events considered means that the site lends itself to passive property level protection.

Active (i.e. manually demountable) measures are unlikely to be effective due to there being insufficient warning time to activate those measures in advance of a flood, unless a catchment specific active flood warning system was implemented. Feasibility of such measures has not been considered further by this study.

Flood management measures are available to better manage residual risk of flooding through community involvement, better coordination and management / maintenance of drainage infrastructure, and minor works to improve local pinch points caused by screens and traffic calming measures.

6.3 Recommendations

This assessment recommends the following for action and/or further investigation:

i. Further investigate in detail the implementation of Property Level Protection dependant on funding and/or community uptake. All PLP should be subject to detailed site inspection, survey, assessment of eligibility and/or need (depending on building use) and PLP design. Wherever practicable and feasible, PLP measures should be self activating and not require human intervention to fit, mount or activate measures in the event of a flood warning. Manually activated measures should be considered only in conjunction with a local flood warning system.

ii. Implement the recommended Flood Management options, i.e.

iii. Rationalise (remove) the identified problem traffic calming features;

iv. Implement recommendations at culvert screens;

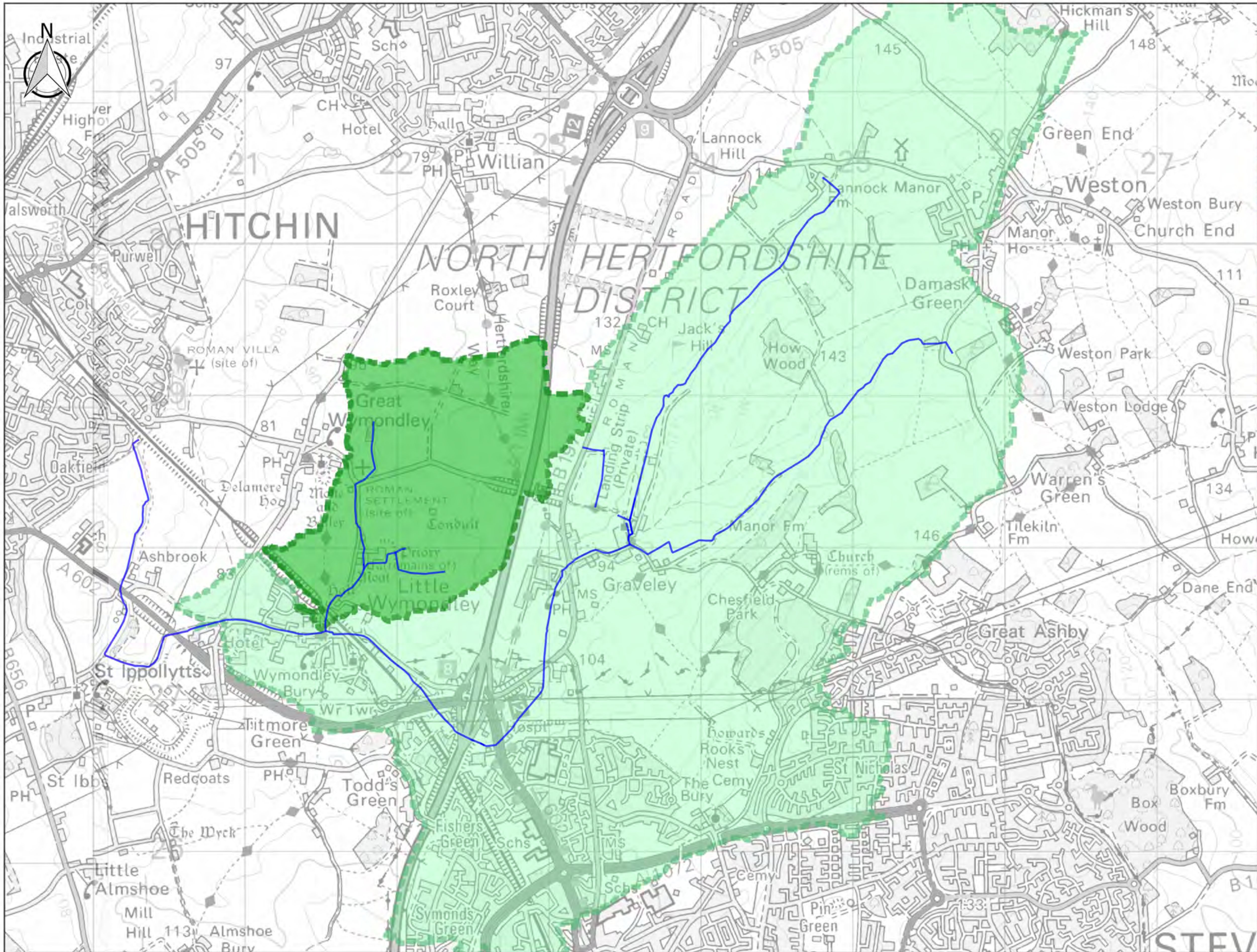
v. Implement a community led flood management scheme;

vi. Implement culvert maintenance (repair / replacement) at those structures identified as being in poor structural condition.

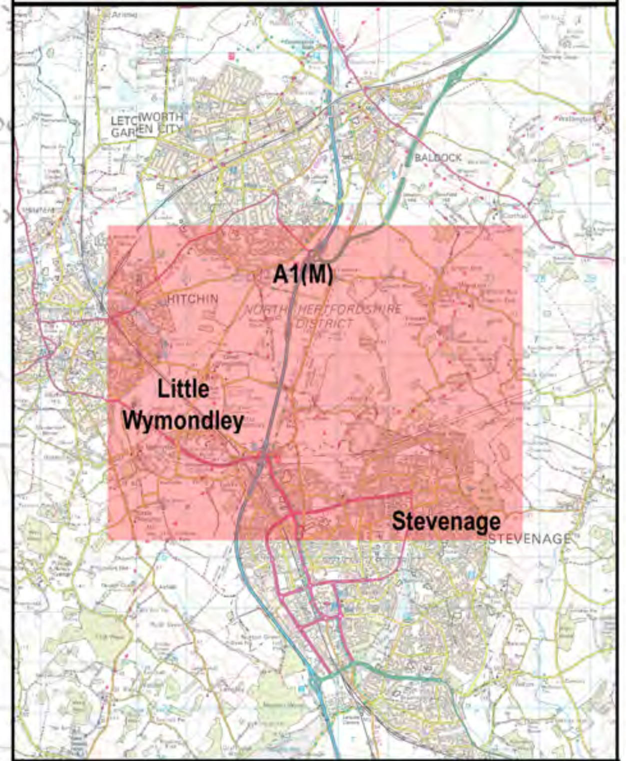
vii. Investigate potential for land management measures with local landowners / occupiers particularly within the Priory Lane catchment, with the intention of implementing measures that would reduce runoff into the catchment.

Appendix A

Figures & Maps



AREA OVERVIEW



LEGEND

Water Features

- Ordinary Watercourse

Hydrological Catchments

- Priory Lane Catchment
- Ash Brook Catchment

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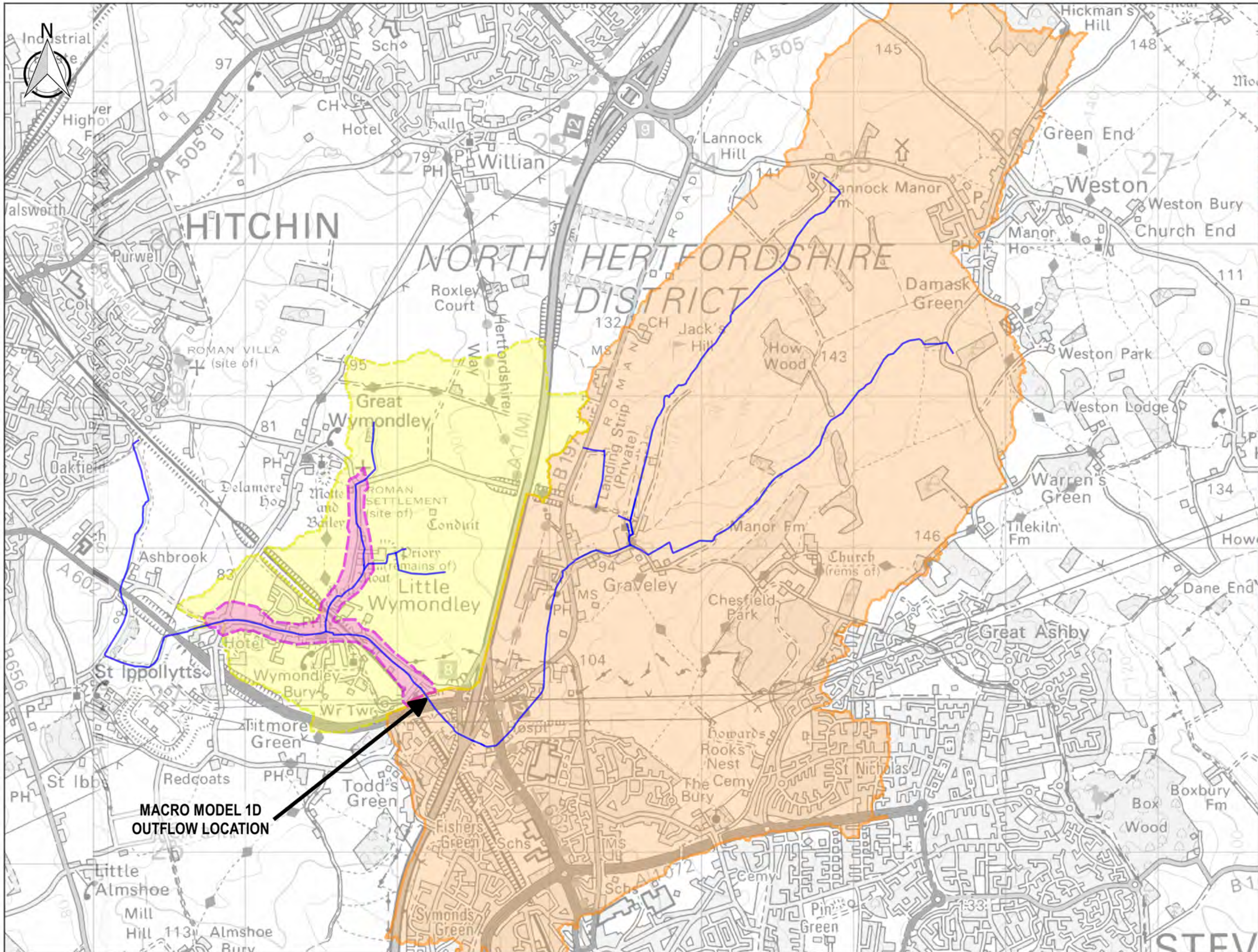
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_REP 01			
FIGURE DESCRIPTION			
CUMULATIVE HYDROLOGICAL CATCHMENT			
DRAWN BY	SCALE	REVISION	DATE
NB	1 : 25,000 @ A3	1	22/07/2015

Hertfordshire



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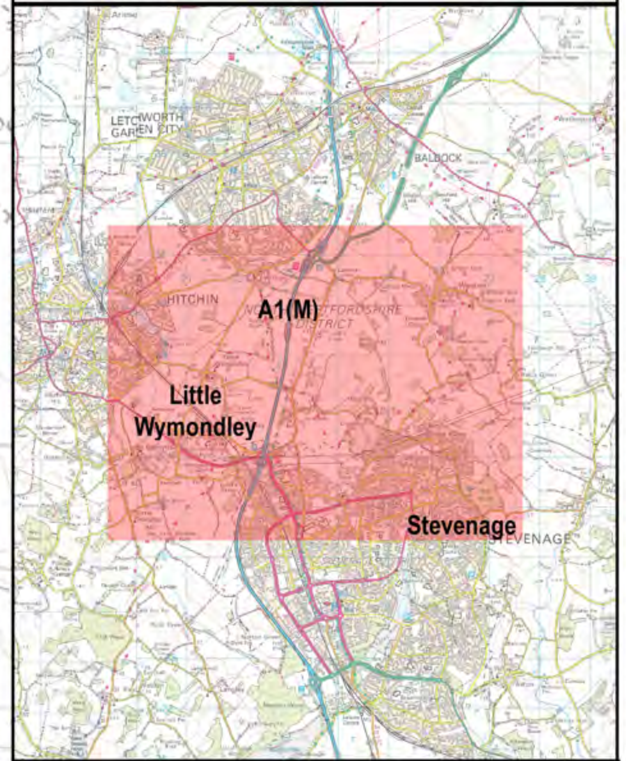

LEGEND

Water Features

- Ordinary Watercourse

Model Extents

- Detailed Area for Investigation
- Detailed Model Extent
- Wider Scale Macro Model Extent

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PROJECT TITLE
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY

FIGURE NUMBER
MCL250-07_FIG_REP 02

FIGURE DESCRIPTION
2D MODEL EXTENTS & DETAILED STUDY AREA

DRAWN BY	SCALE	REVISION	DATE
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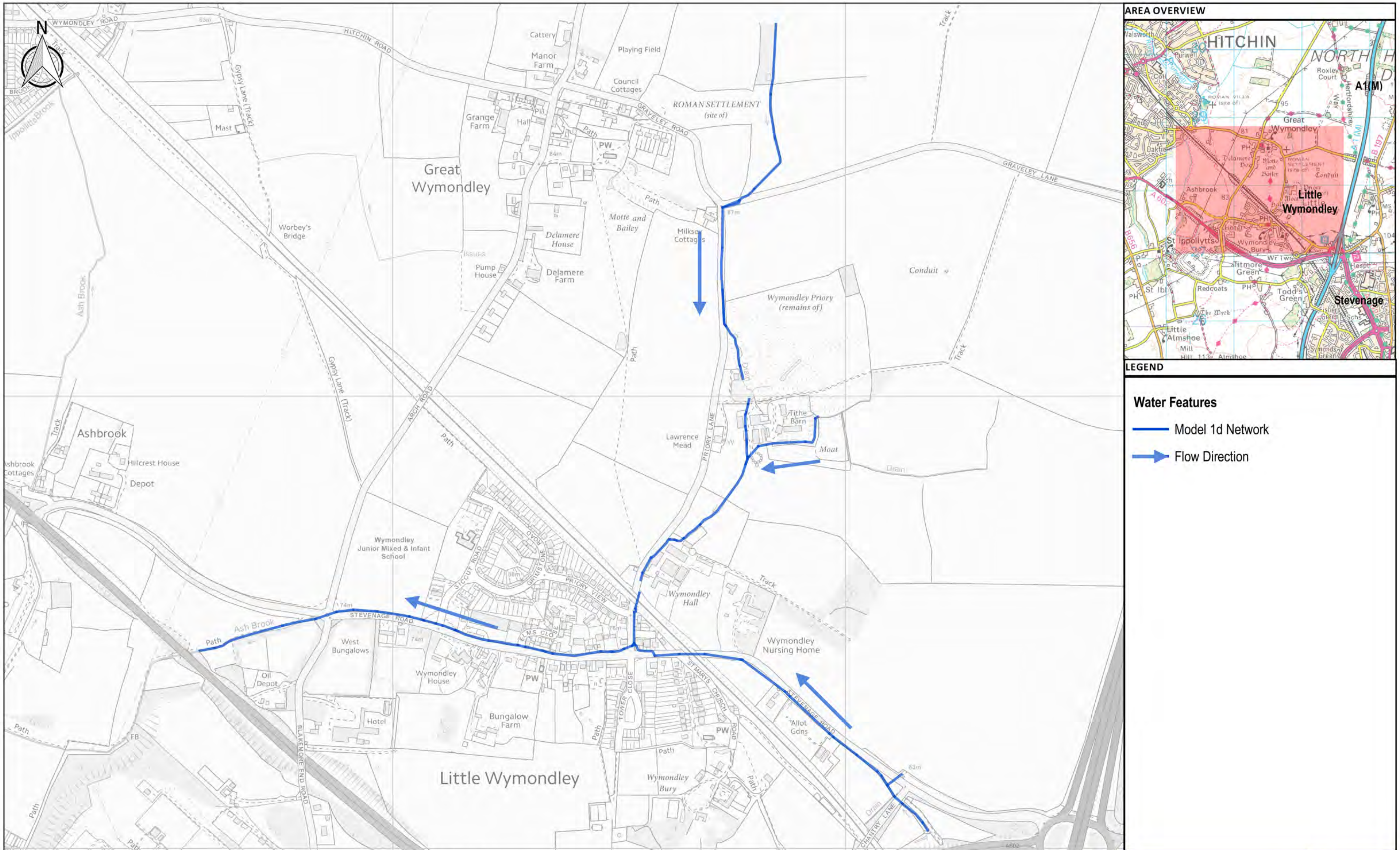
Hertfordshire



PROJECT TITLE
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY

FIGURE NUMBER
MCL250-07_FIG_REP 03

FIGURE DESCRIPTION
1D MODEL NETWORK

DRAWN BY	SCALE	REVISION	DATE
NB	1 : 7500 @ A3	1	22/07/2015

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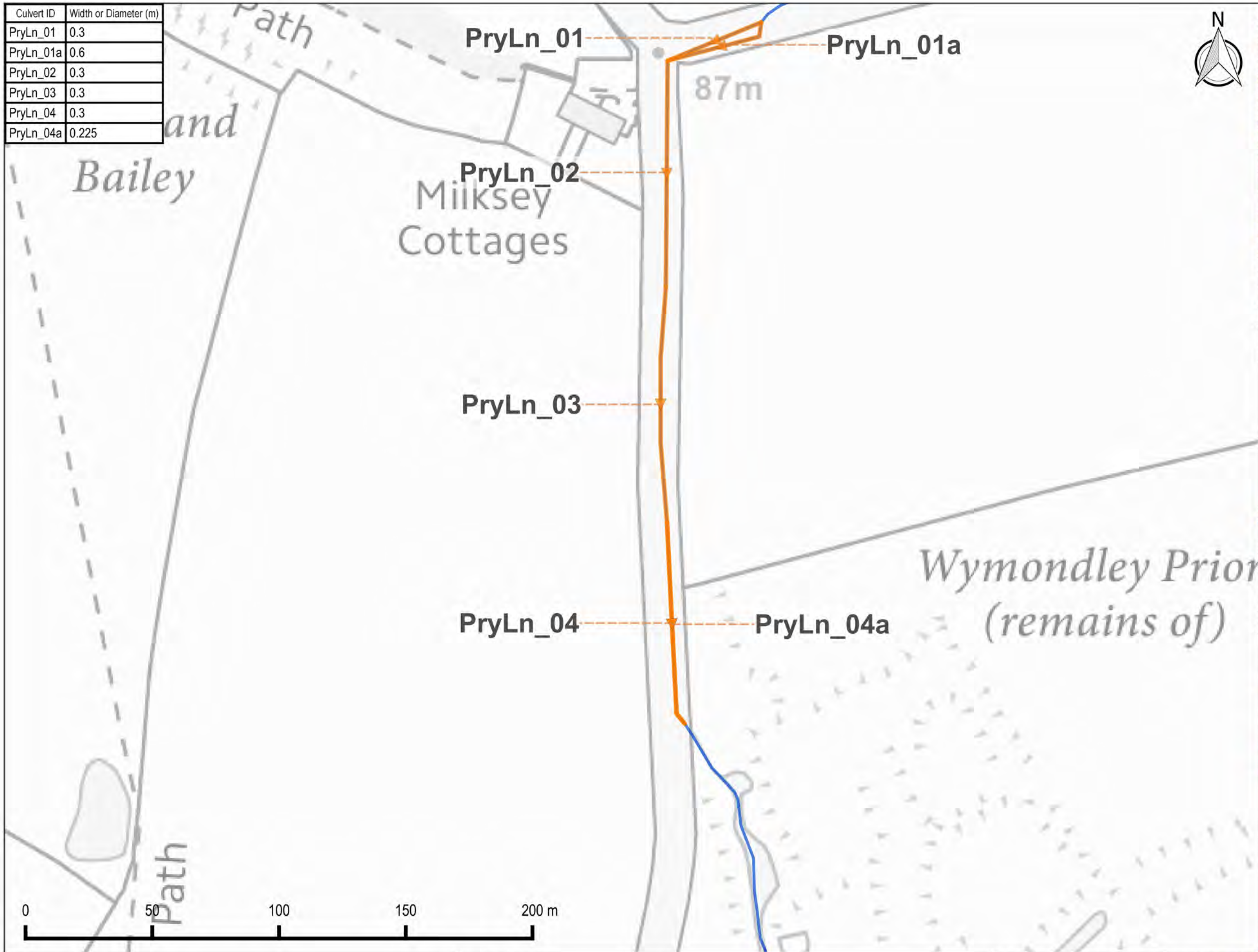
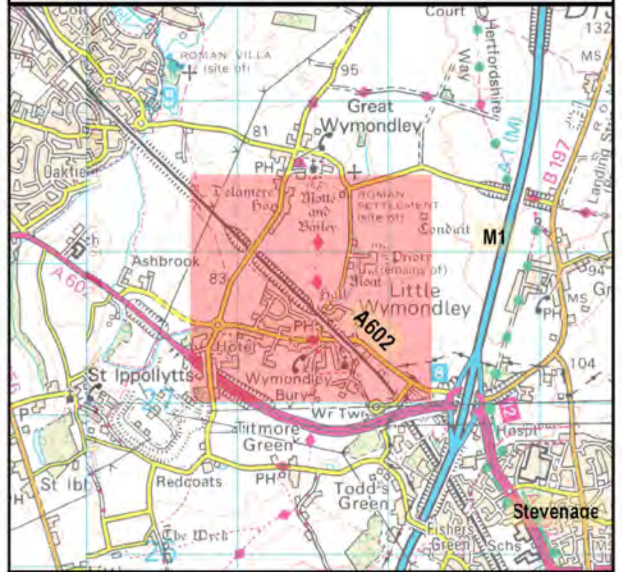
Hertfordshire

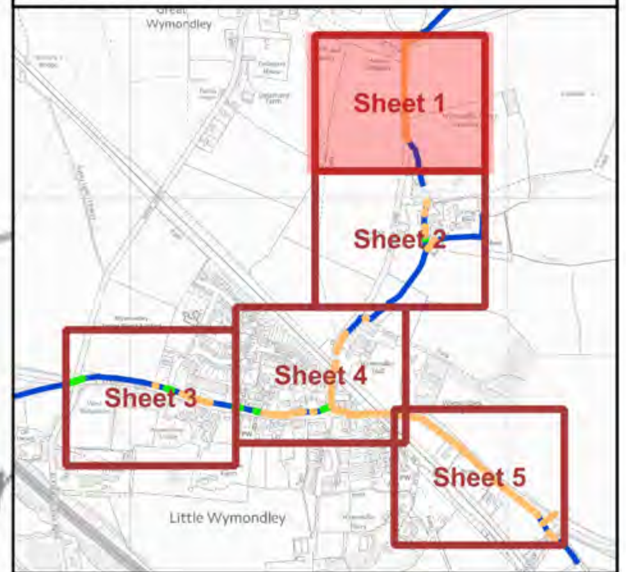
Culvert ID	Width or Diameter (m)
PryLn_01	0.3
PryLn_01a	0.6
PryLn_02	0.3
PryLn_03	0.3
PryLn_04	0.3
PryLn_04a	0.225



AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Water Features

Modelled Watercourse (1D Network)

Culverts

Circular Culvert

Rectangular Culvert

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_REP 04MCL250-07_FIG_REP 04 Sheet 1			
FIGURE DESCRIPTION			
Detailed 1D Culvert Network - Sheet 1			
DRAWN BY	SCALE	REVISION	DATE
CS	NTS	1	04/06/2015

Hertfordshire

Culvert ID	Width or Diameter (m)
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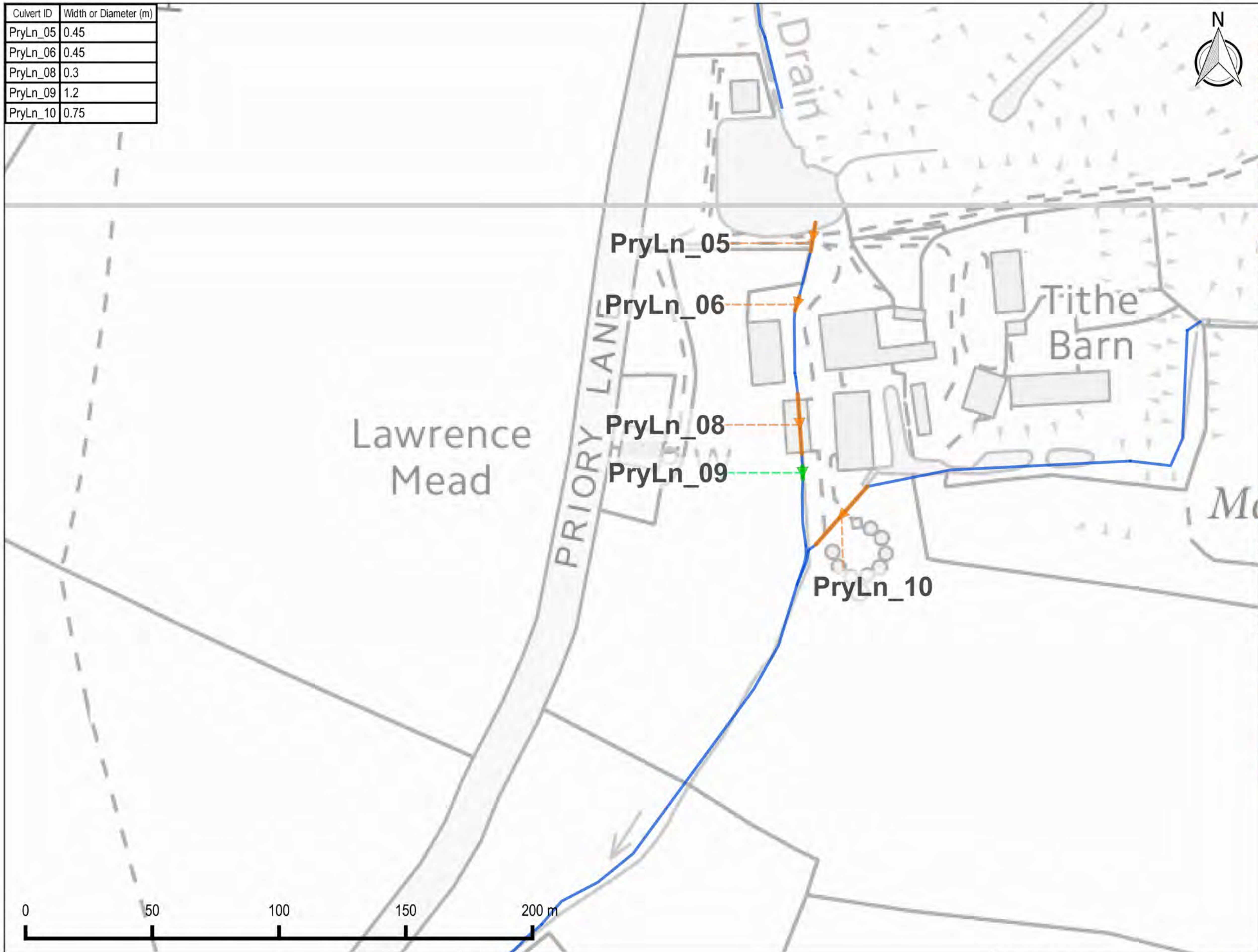
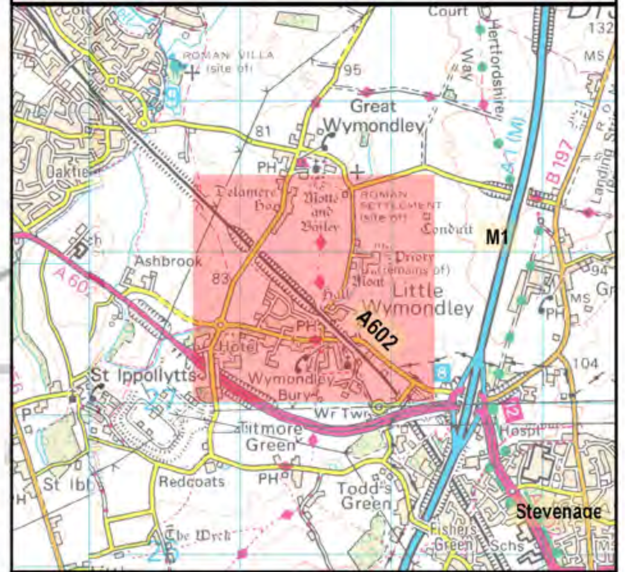
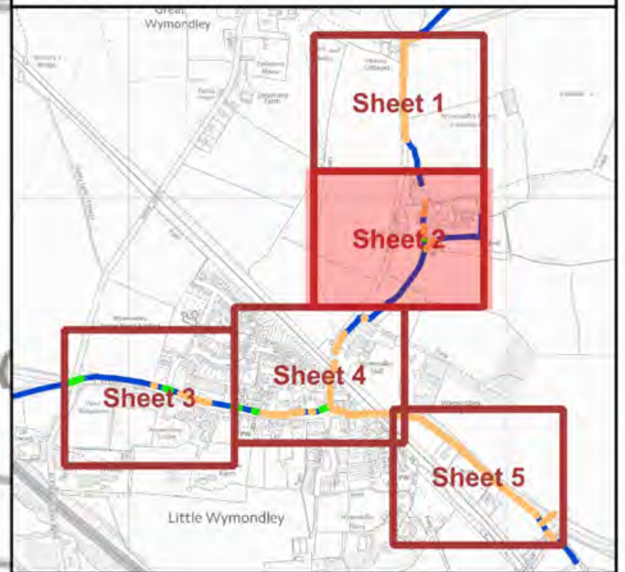
PryLn_06	0.45
PryLn_08	0.3
PryLn_09	1.2
PryLn_10	0.75



AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Water Features

Modelled Watercourse (1D Network)

Culverts

Circular Culvert

Rectangular Culvert

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_REP 04MCL250-07_FIG_REP 04 Sheet 2			
FIGURE DESCRIPTION			
Detailed 1D Culvert Network - Sheet 2			
DRAWN BY	SCALE	REVISION	DATE
CS	NTS	1	04/06/2015

Hertfordshire

Culvert ID	Width or Diameter (m)
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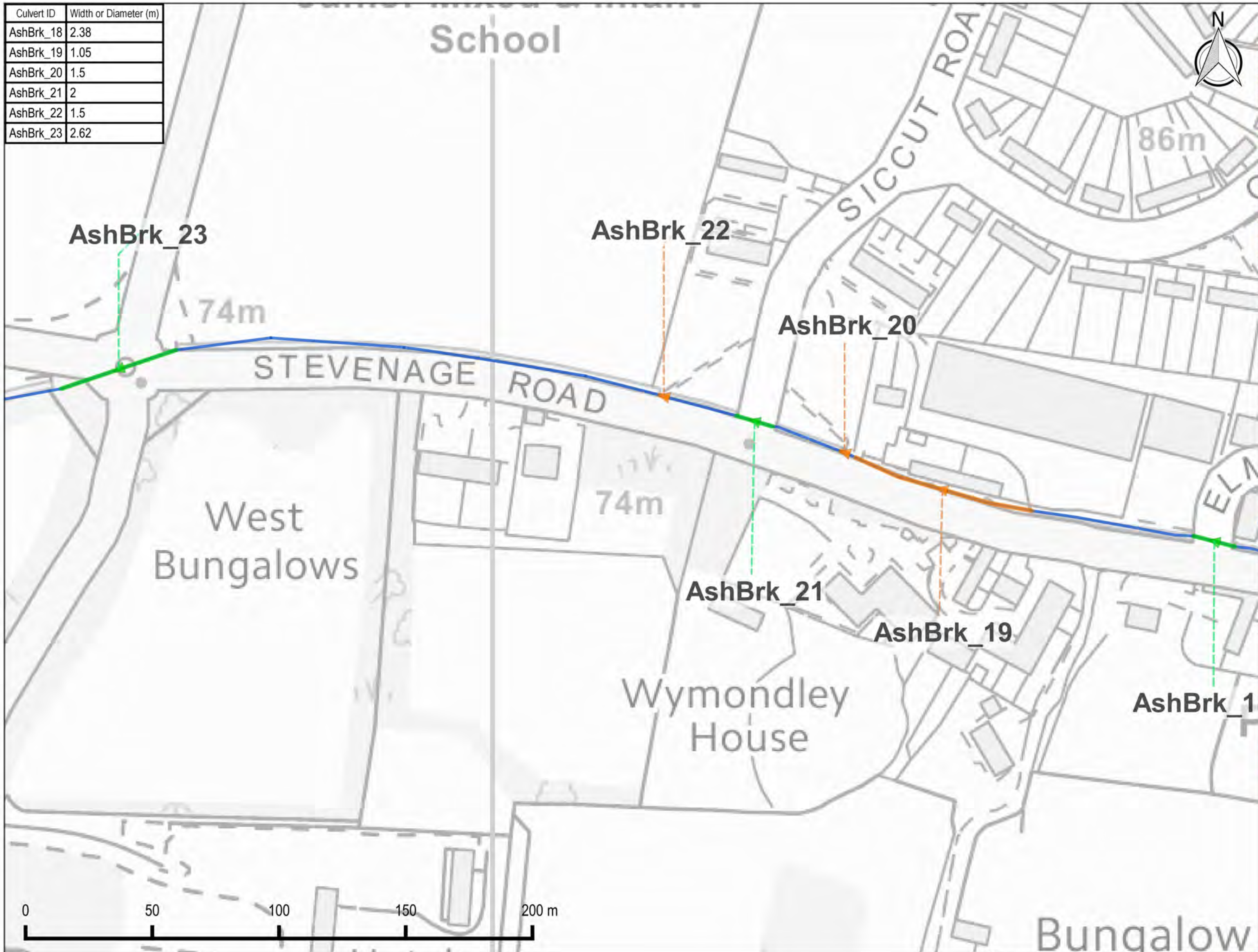
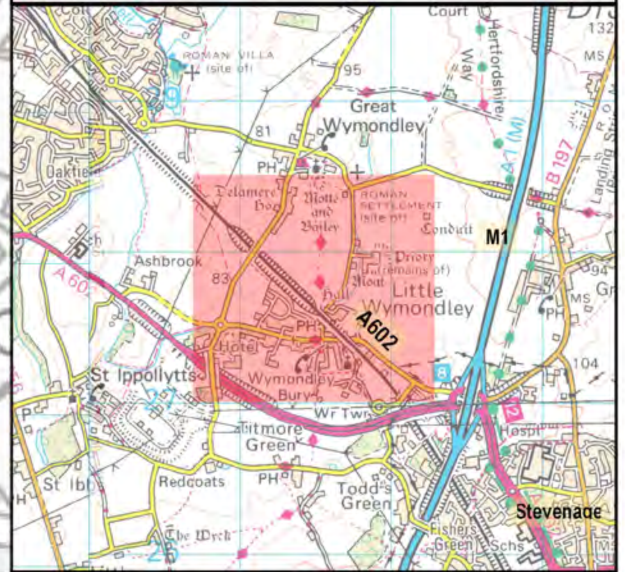
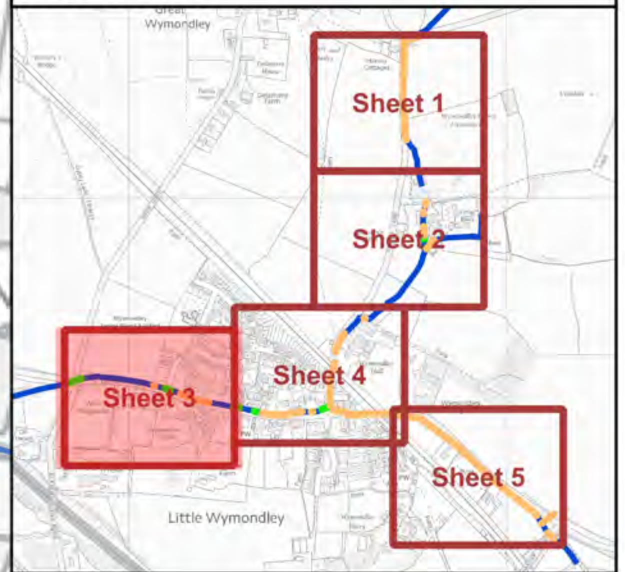
AshBrk_20	1.5
AshBrk_21	2
AshBrk_22	1.5
AshBrk_23	2.62



AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Water Features

- Modelled Watercourse (1D Network)

Culverts

- Circular Culvert
- Rectangular Culvert

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PROJECT TITLE
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY

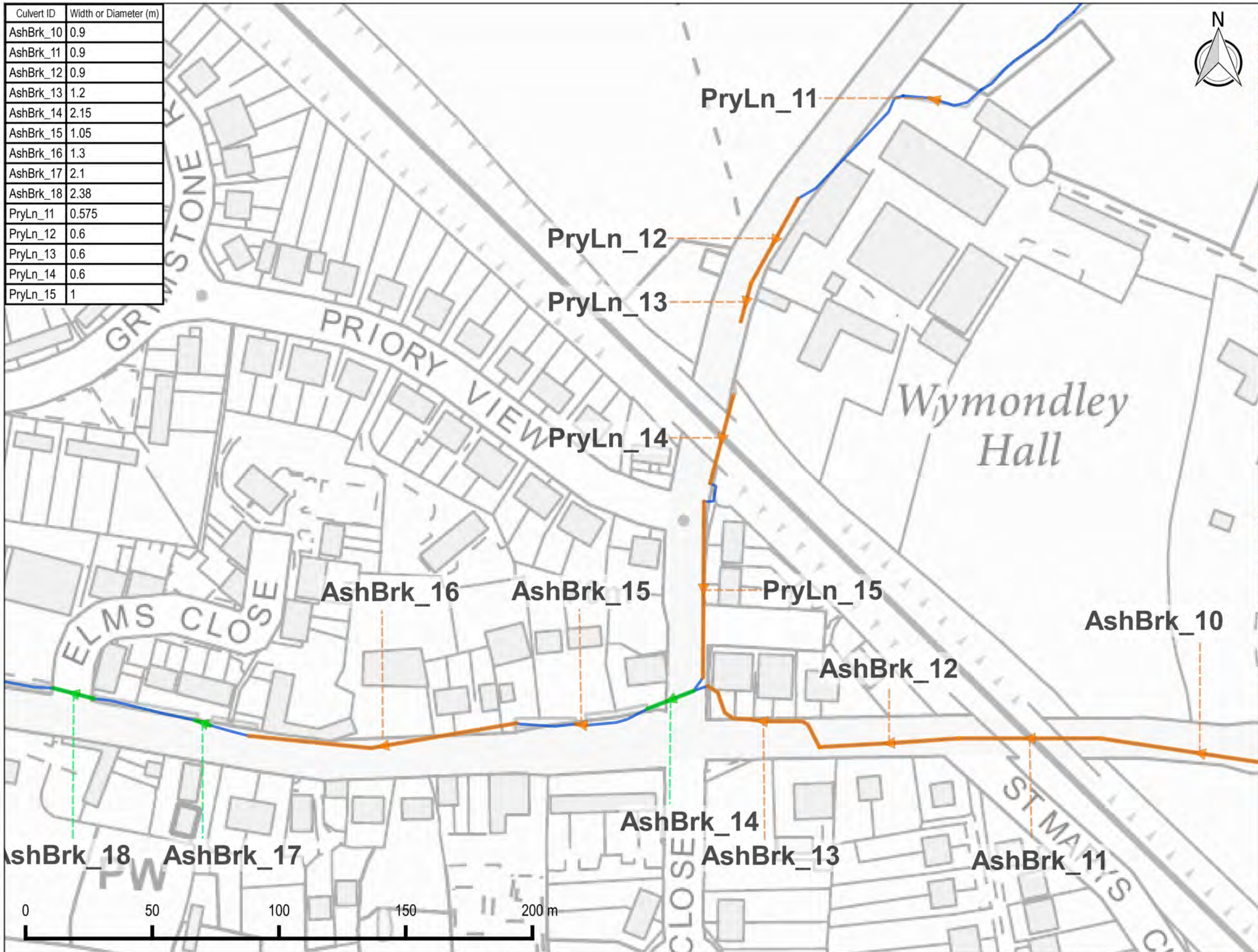
FIGURE NUMBER
MCL250-07_FIG_REP 04MCL250-07_FIG_REP 04 Sheet 3

FIGURE DESCRIPTION
Detailed 1D Culvert Network - Sheet 3

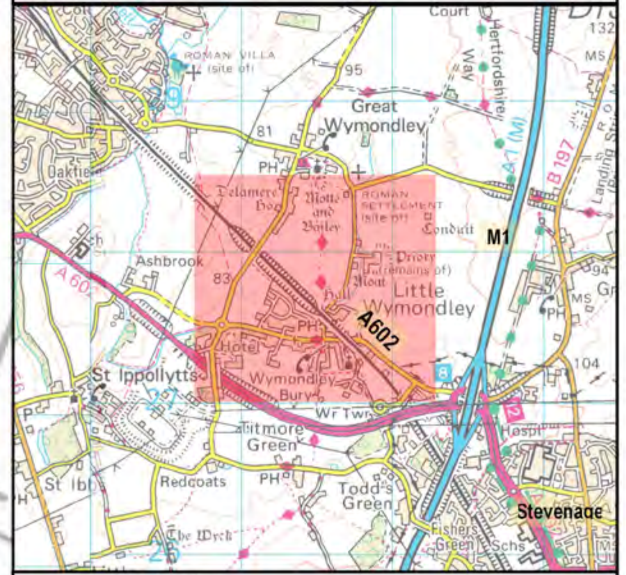
DRAWN BY	SCALE	REVISION	DATE
CS	NTS	1	04/06/2015

Hertfordshire

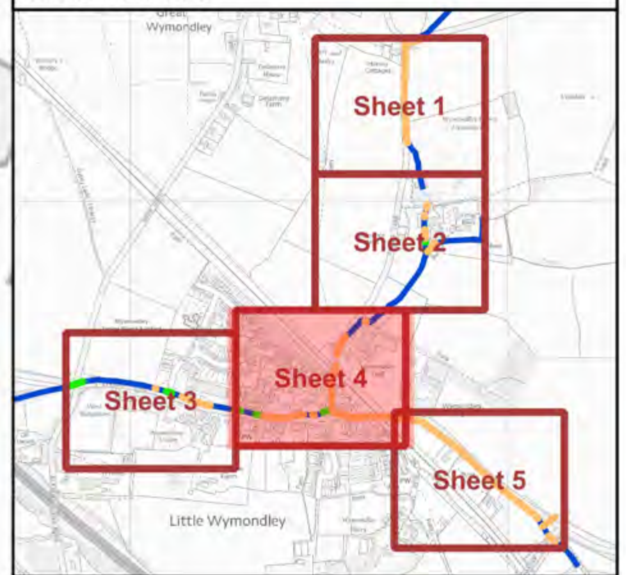
Culvert ID	Width or Diameter (m)
AshBrk_10	0.9
AshBrk_11	0.9
AshBrk_12	0.9
AshBrk_13	1.2
AshBrk_14	2.15
AshBrk_15	1.05
AshBrk_16	1.3
AshBrk_17	2.1
AshBrk_18	2.38
PryLn_11	0.575
PryLn_12	0.6
PryLn_13	0.6
PryLn_14	0.6
PryLn_15	1



AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Water Features

Modelled Watercourse (1D Network)

Culverts

Circular Culvert

Rectangular Culvert

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_REP 04MCL250-07_FIG_REP 04 Sheet 4			
FIGURE DESCRIPTION			
Detailed 1D Culvert Network - Sheet 4			
DRAWN BY	SCALE	REVISION	DATE
CS	NTS	1	04/06/2015

Hertfordshire

Culvert ID	Width or Diameter (m)
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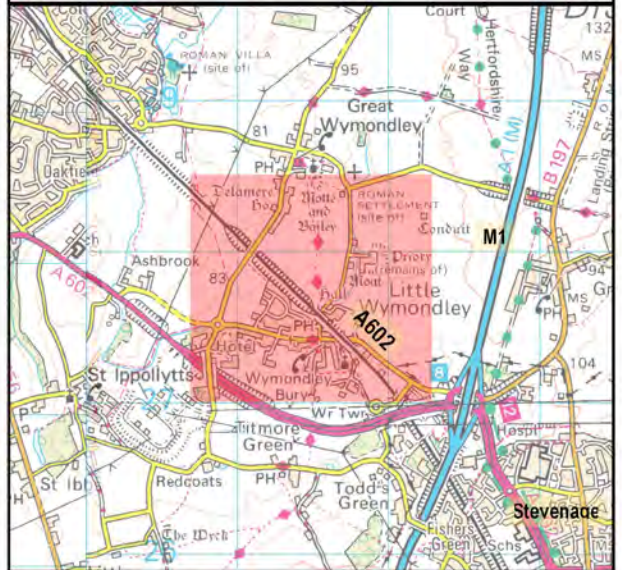
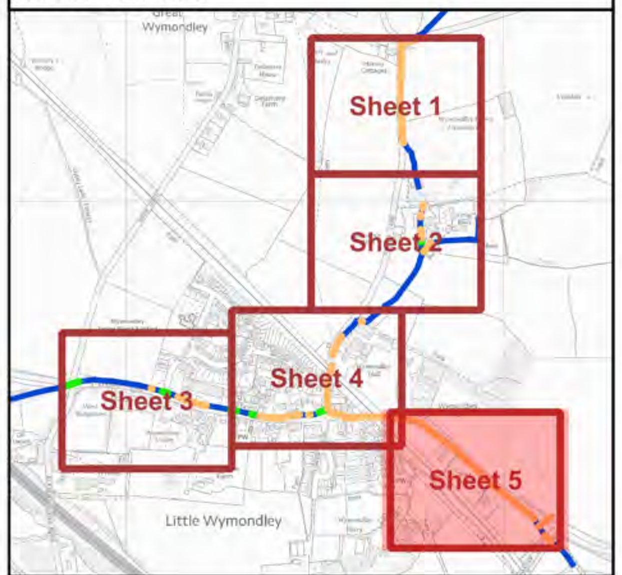
AshBrk_02	0.825
AshBrk_03	0.825
AshBrk_04	0.825
AshBrk_05	0.825
AshBrk_06	0.825
AshBrk_07	0.825
AshBrk_08	0.825
AshBrk_09	0.825
AshBrk_10	0.9
AshBrk_24	0.6

AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Water Features

- Modelled Watercourse (1D Network)

Culverts

- Circular Culvert
- Rectangular Culvert

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PROJECT TITLE
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY

FIGURE NUMBER
MCL250-07_FIG_REP 04MCL250-07_FIG_REP 04 Sheet 5

FIGURE DESCRIPTION
Detailed 1D Culvert Network - Sheet 5

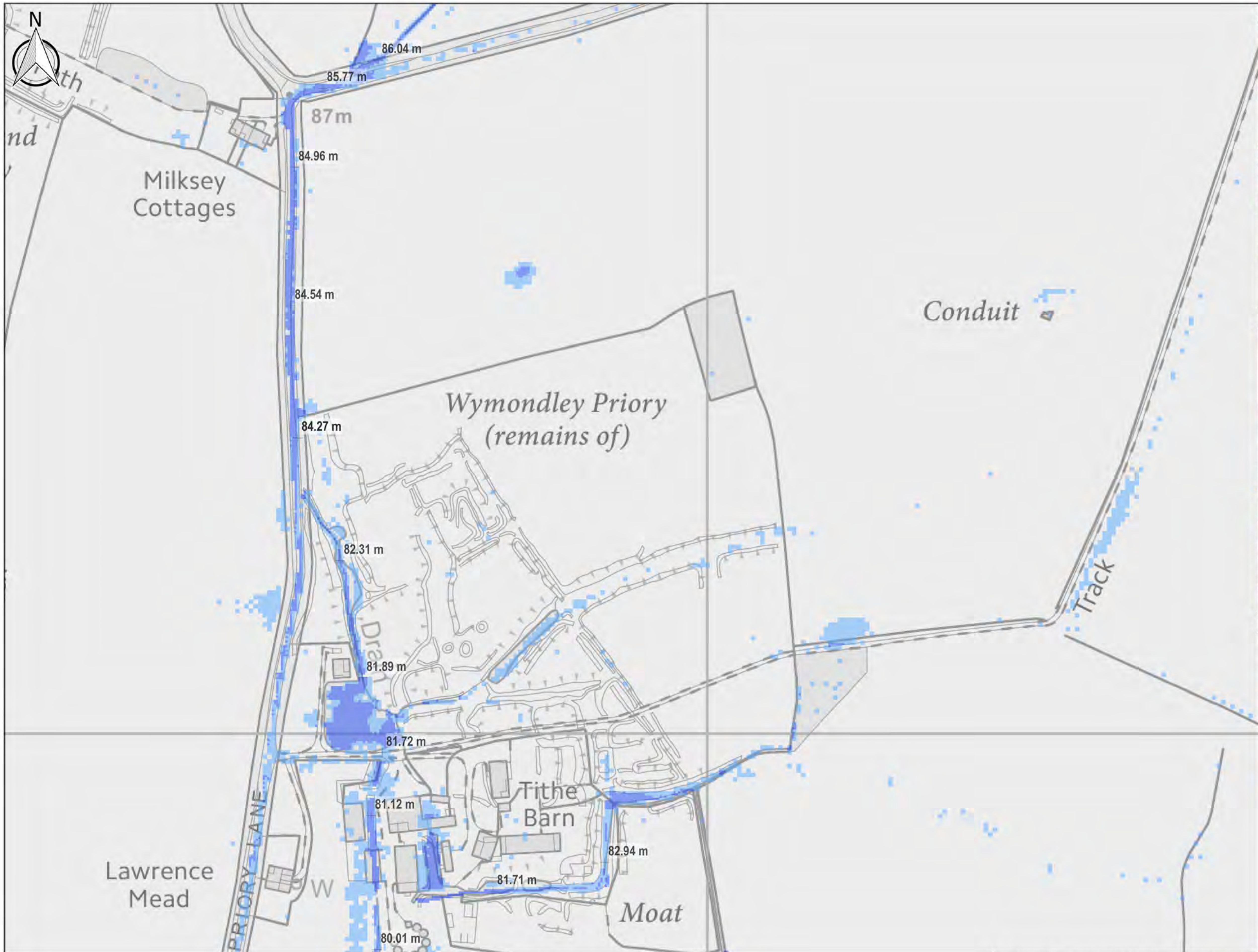
DRAWN BY	SCALE	REVISION	DATE
CS	NTS	1	04/06/2015

Hertfordshire

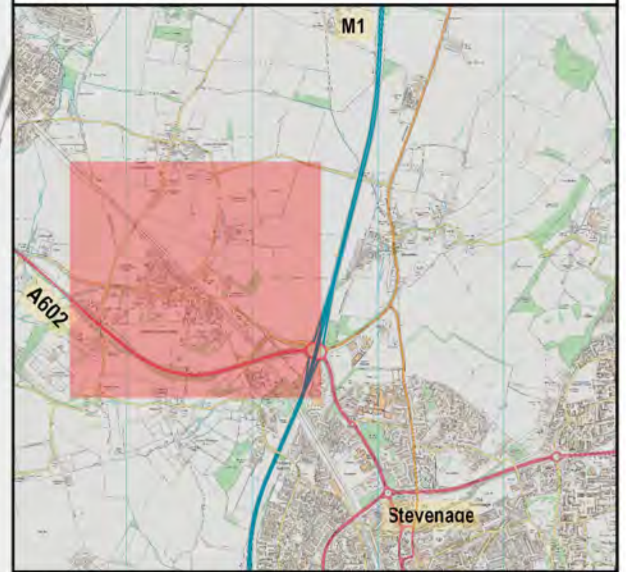
Appendix B

Flood Extents Mapping

1) February 2014 Replication



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents February 2014 Replication (Max Water Level)

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL01			
FIGURE DESCRIPTION			
February 2014 Replication (Max Water Level) - Sheet 1			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	3	30/07/2015

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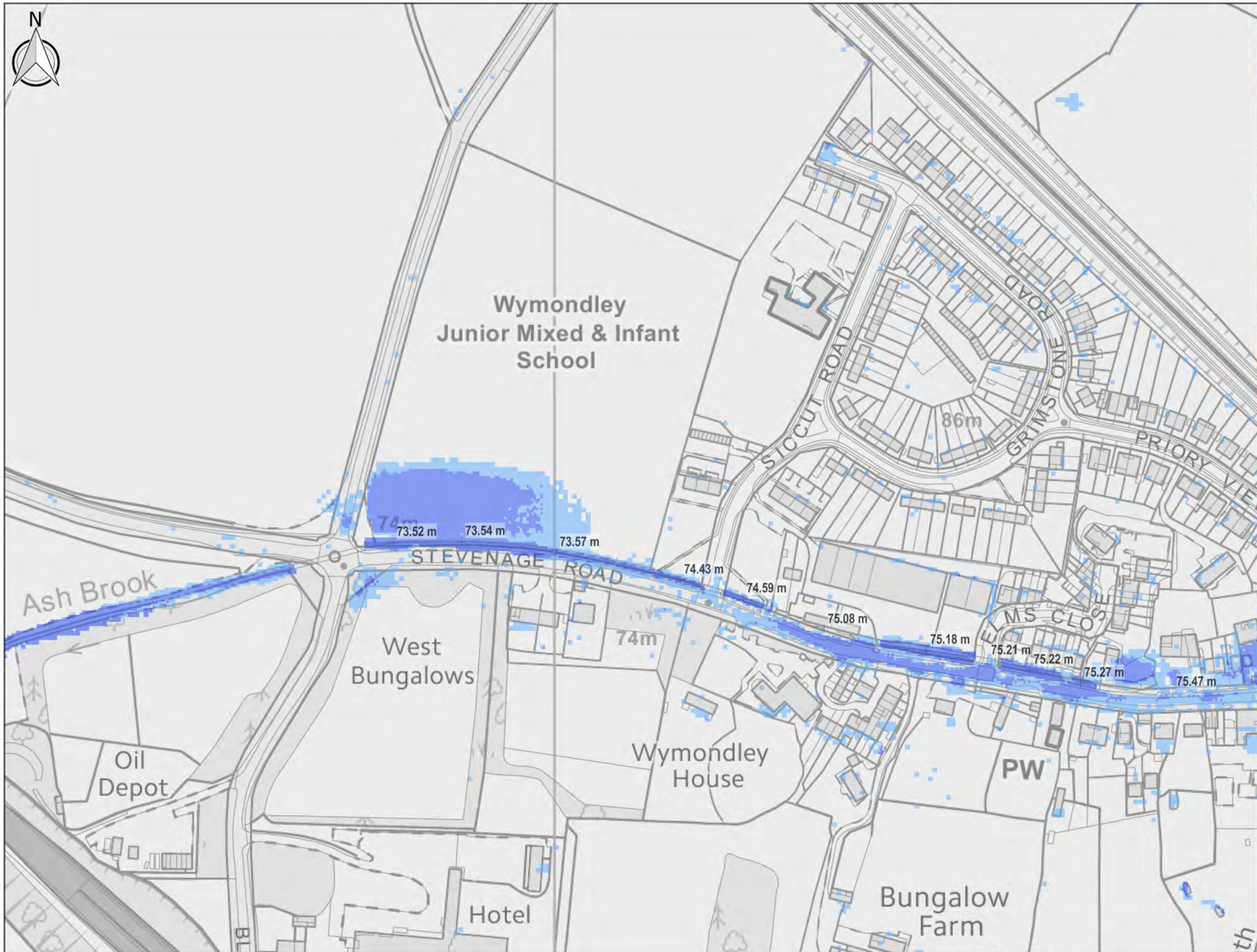
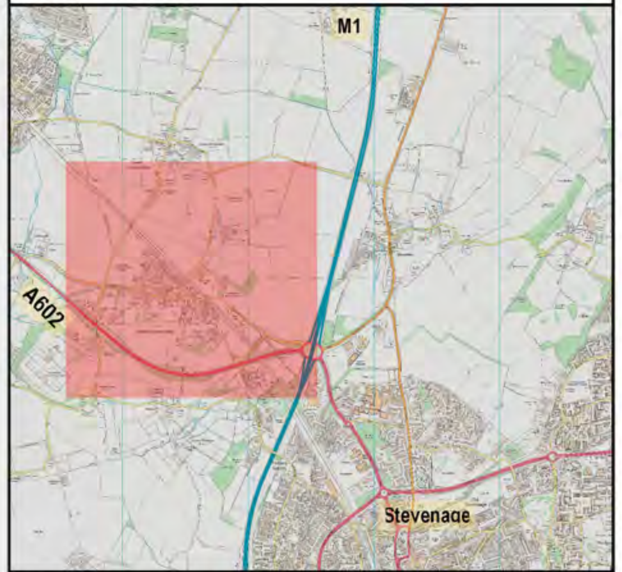
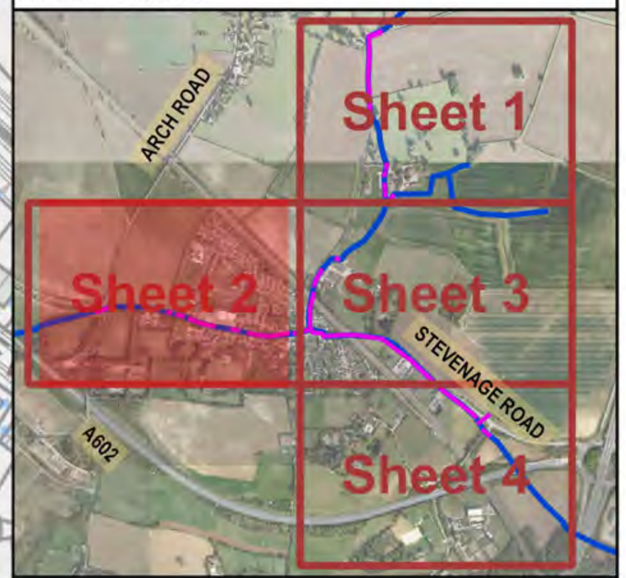


AREA OVERVIEW



MODEL OVERVIEW



LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents February 2014 Replication (Max Water Level)

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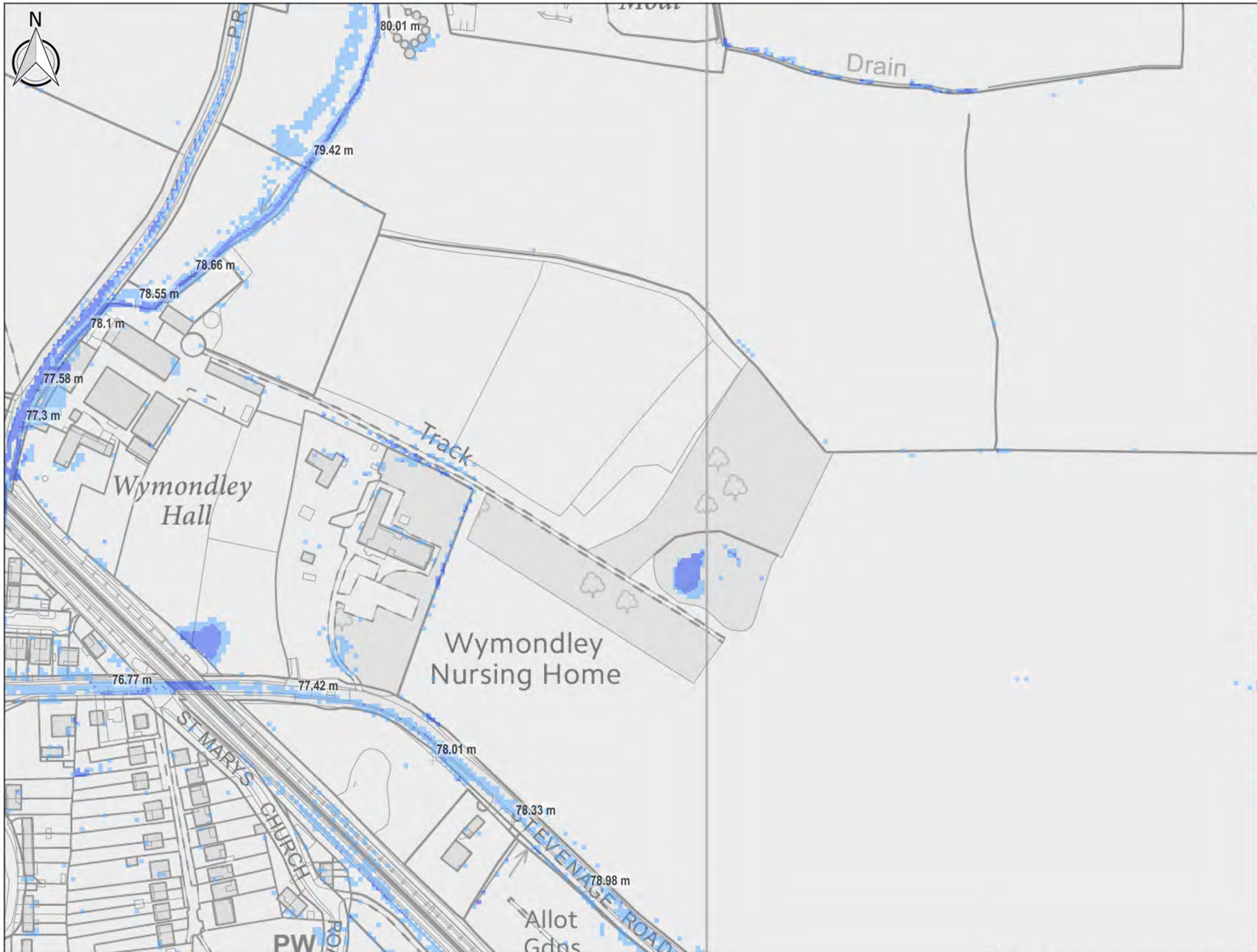
PROJECT TITLE
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY

FIGURE NUMBER
MCL250-07_FIG_FL02

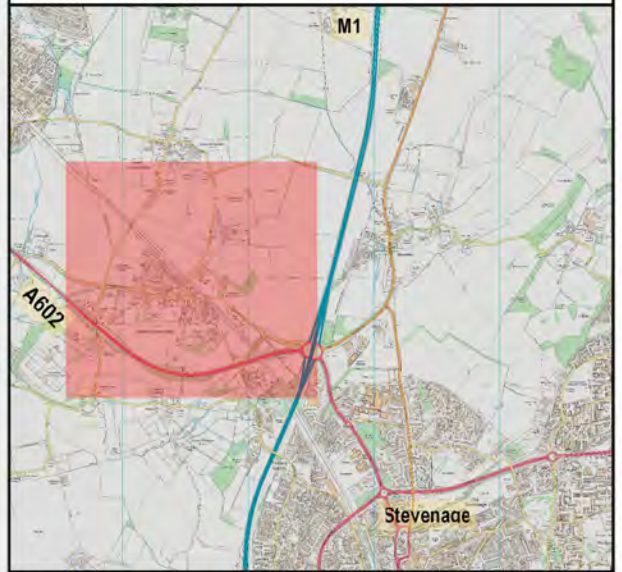
FIGURE DESCRIPTION
February 2014 Replication (Max Water Level) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	3	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents February 2014 Replication (Max Water Level)

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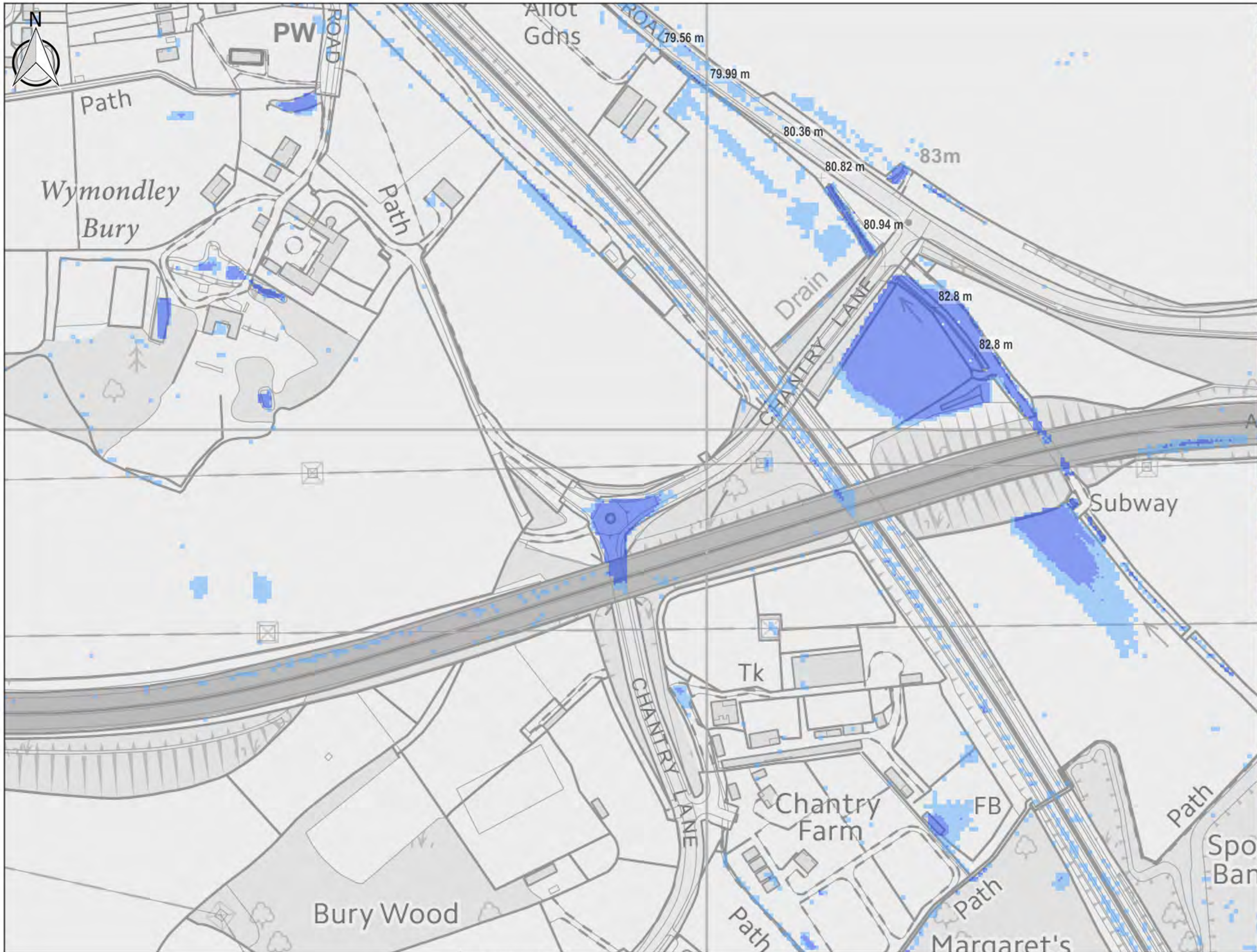
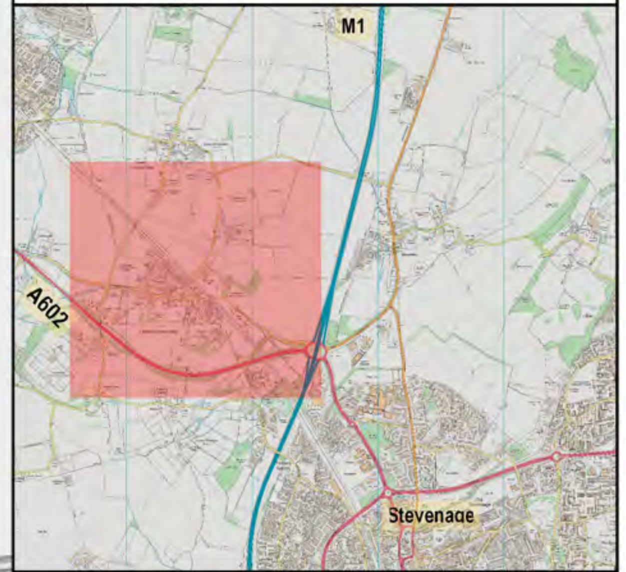
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL03			
FIGURE DESCRIPTION			
February 2014 Replication (Max Water Level) - Sheet 3			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	3	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents February 2014 Replication (Max Water Level)

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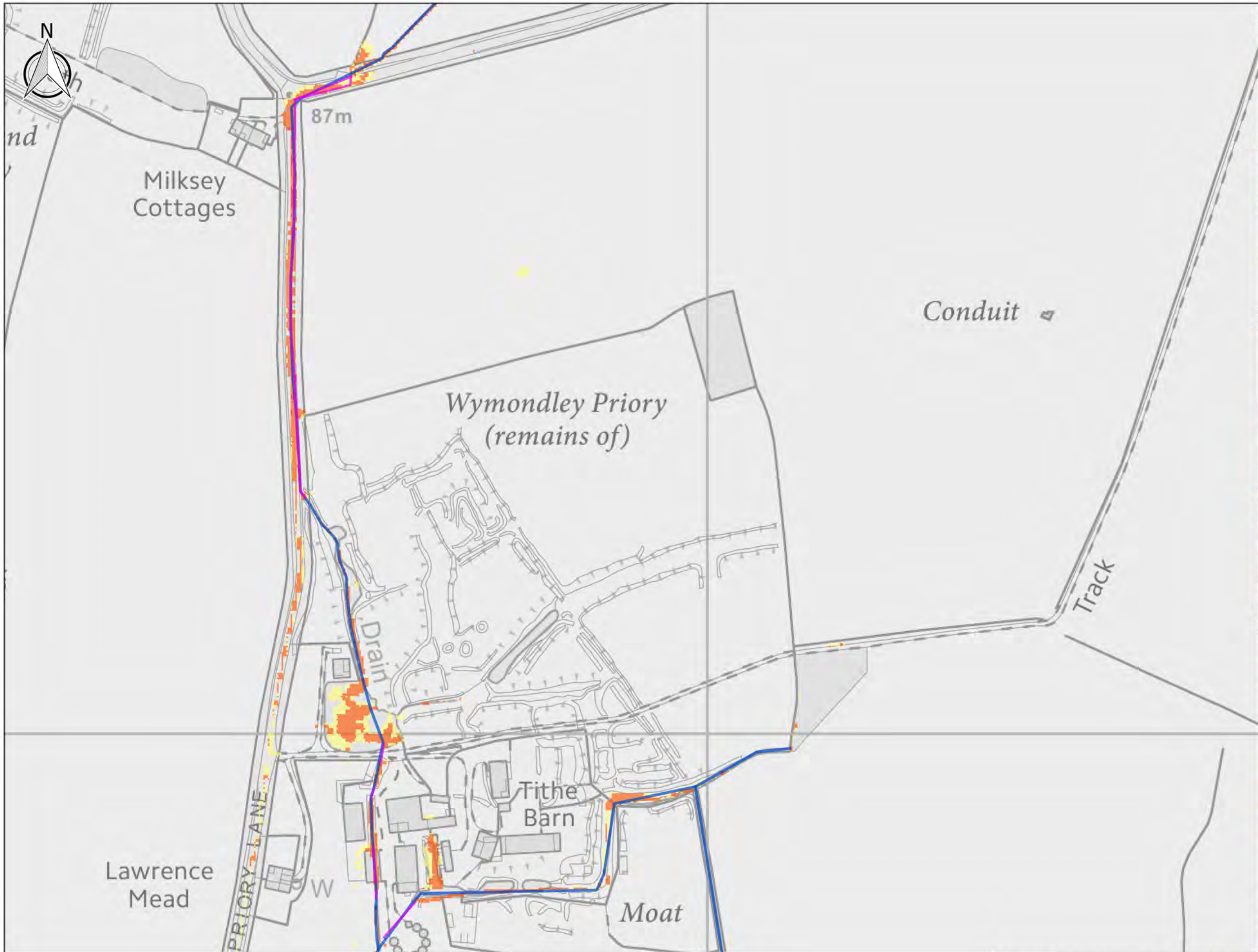
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL04
FIGURE DESCRIPTION	February 2014 Replication (Max Water Level) - Sheet 4

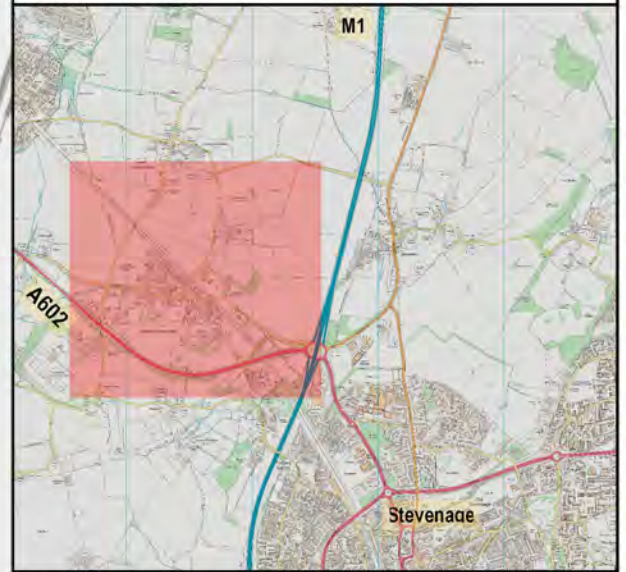
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	3	30/07/2015

Hertfordshire

2) February 2014 Replication (Flood Hazard Rating)



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

February 2014 - Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL05
FIGURE DESCRIPTION	February 2014 Replication (Flood Hazard Rating) - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	2	30/07/2015

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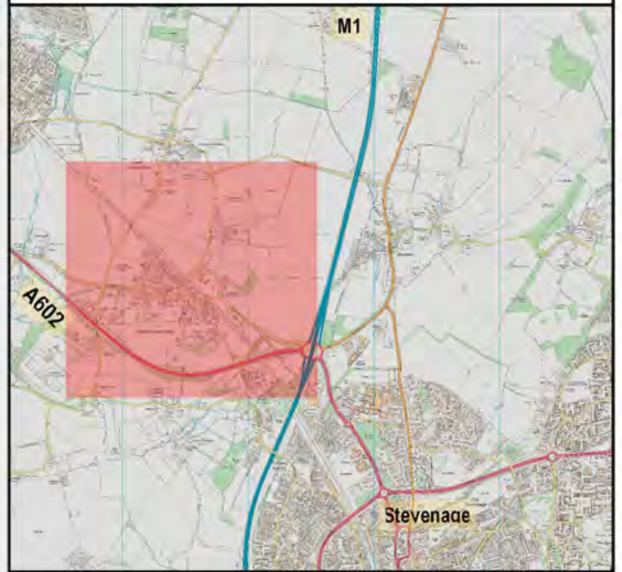
AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

February 2014 - Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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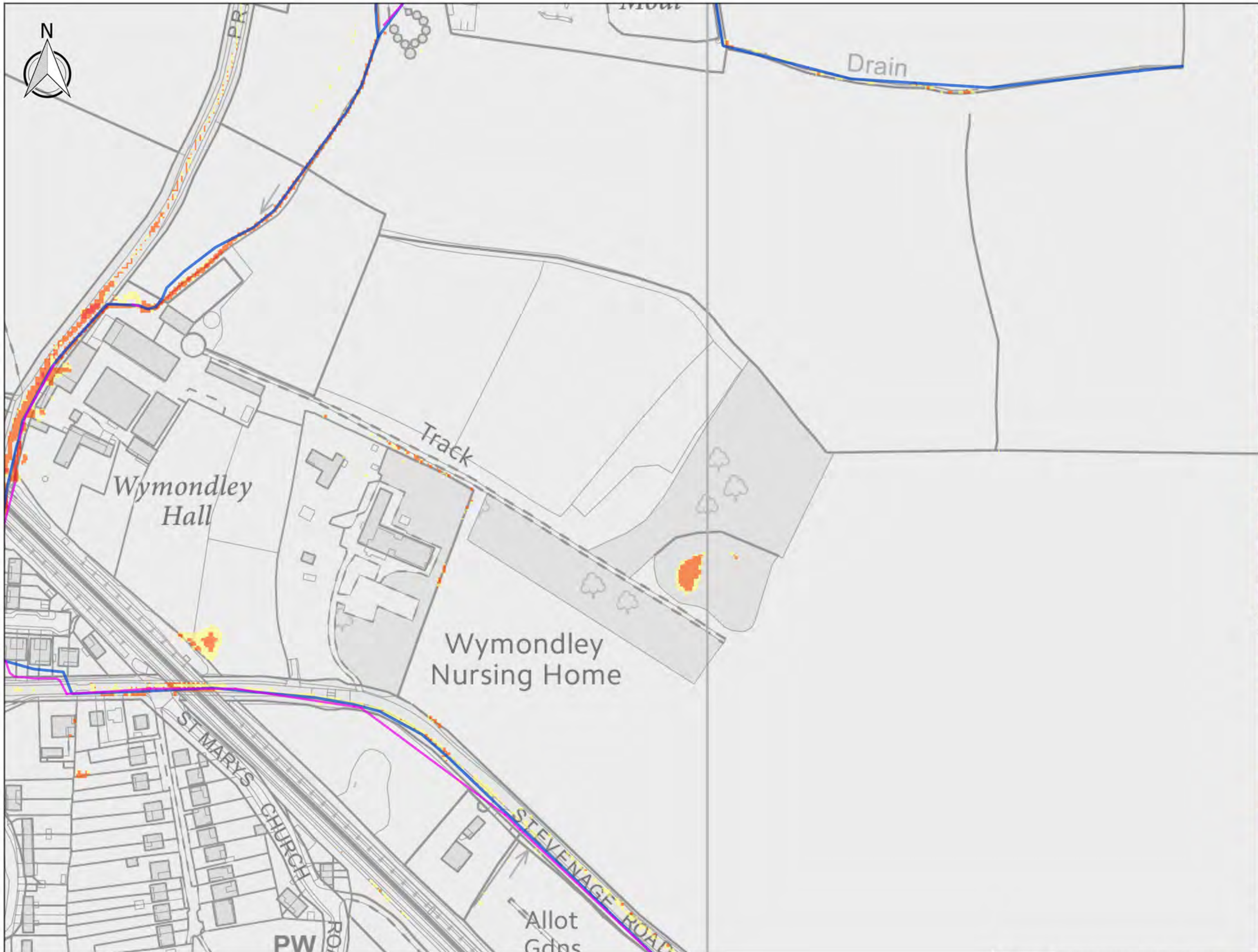
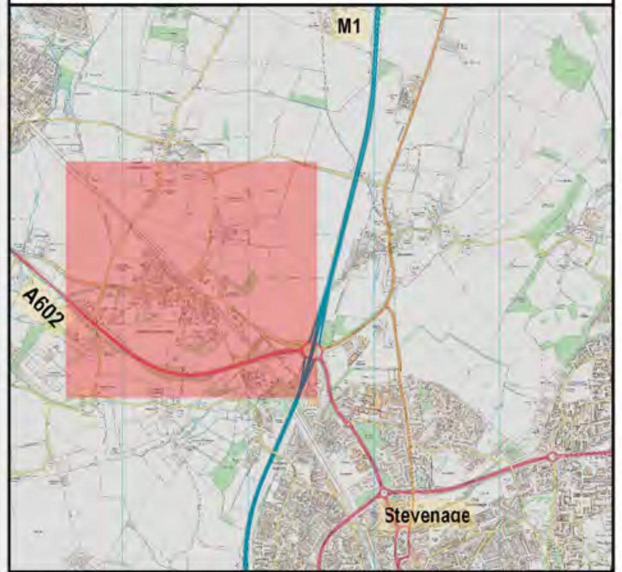
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL06			
FIGURE DESCRIPTION			
February 2014 Replication (Flood Hazard Rating) - Sheet 2			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	2	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

February 2014 - Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL07
FIGURE DESCRIPTION	February 2014 Replication (Flood Hazard Rating) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	2	30/07/2015

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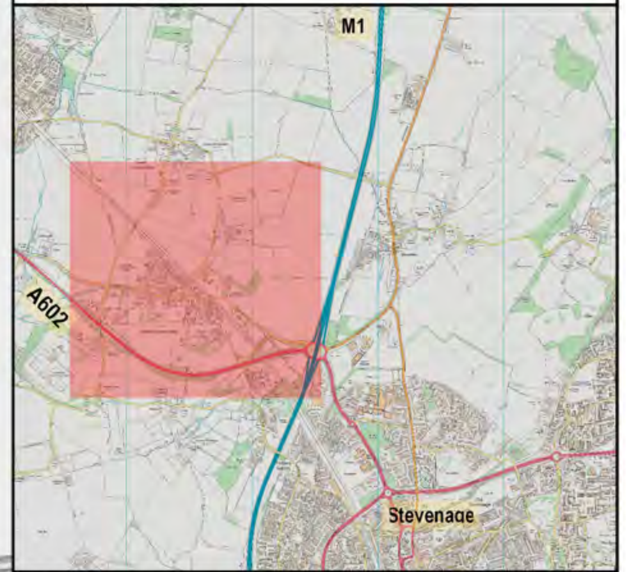
AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

February 2014 - Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL08
FIGURE DESCRIPTION	February 2014 Replication (Flood Hazard Rating) - Sheet 4

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	2	30/07/2015

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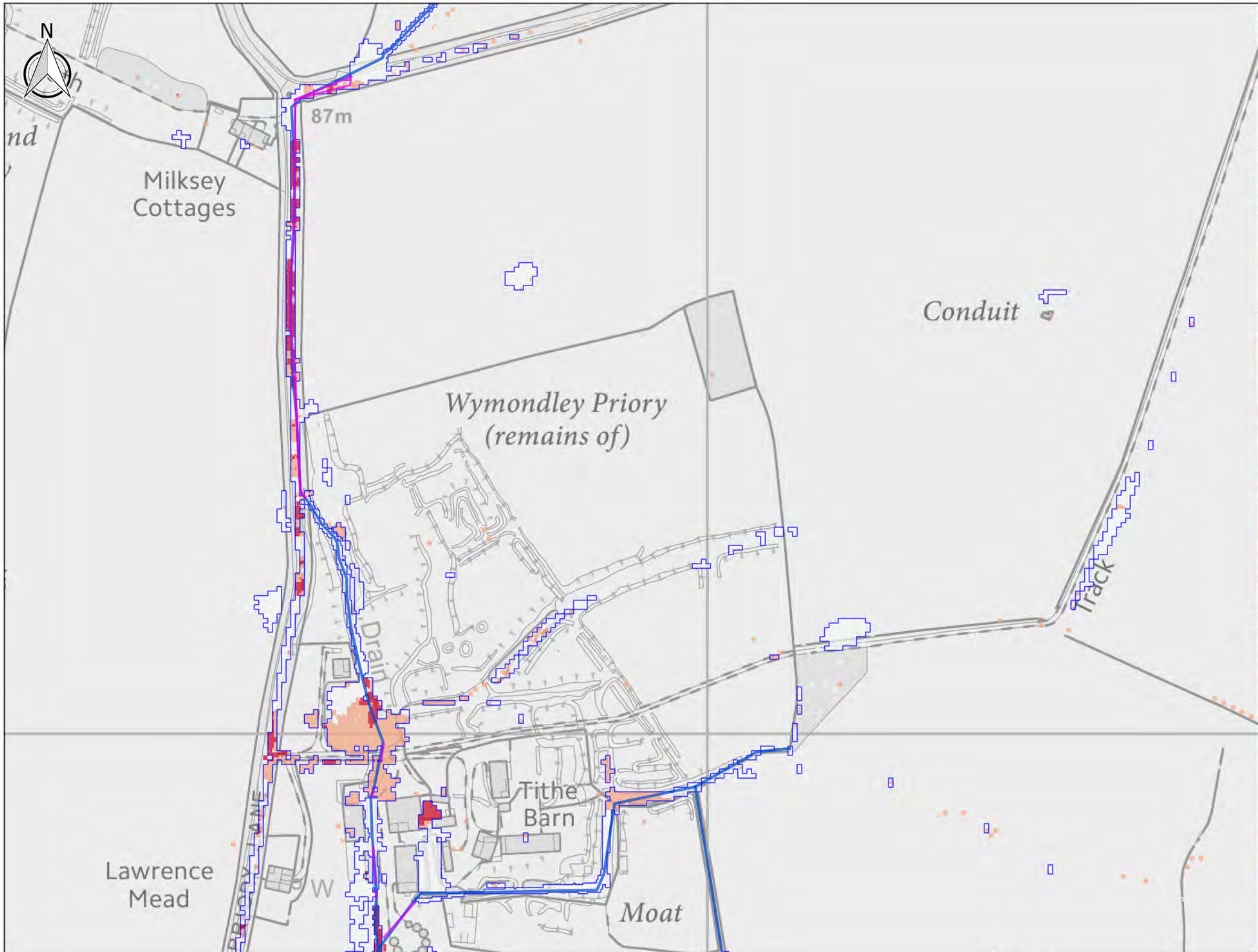
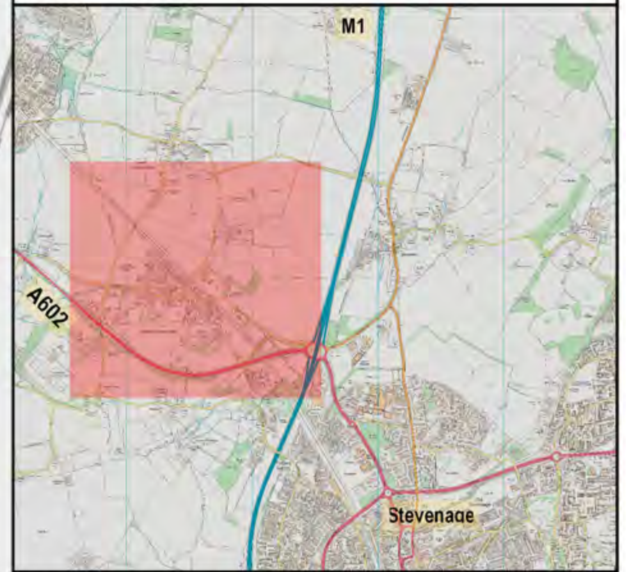
3) February 2014 Replication (Predicted Effects of Blockage)



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Effect of Removing Blockages (m)

- -1
- -0.1
- 0
- 0.001
- 0.1
- Outline

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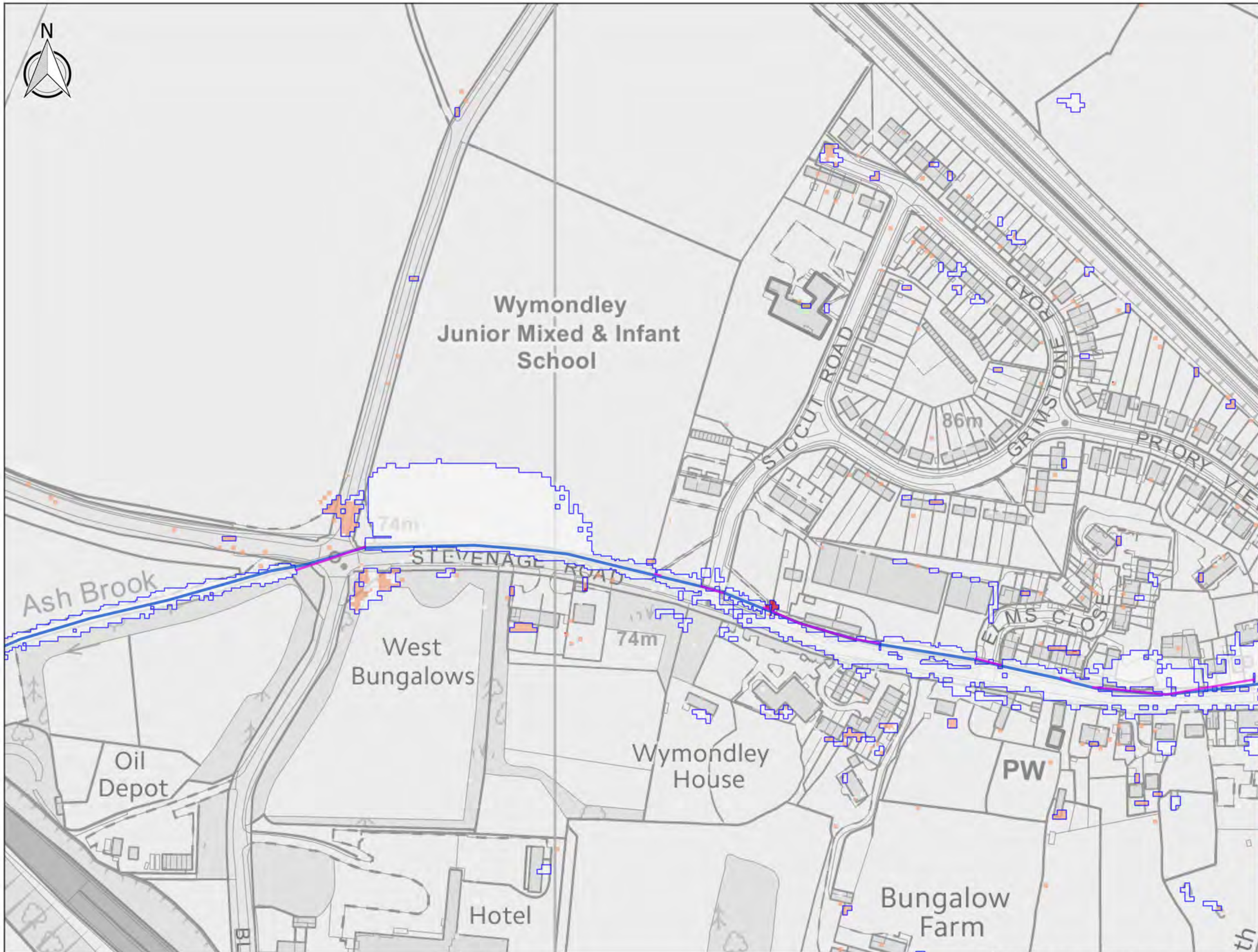
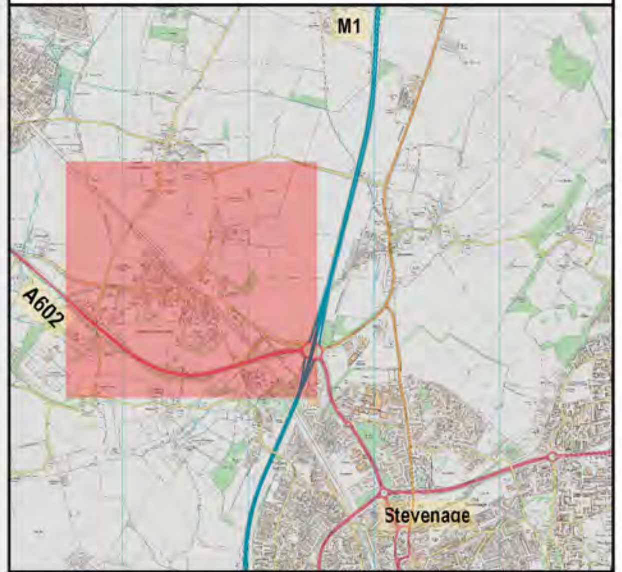
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL09
FIGURE DESCRIPTION	February 2014 Replication (Predicted Effects of Blockage on Flood Extent) - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Effect of Removing Blockages (m)

- -1
- -0.1
- 0
- 0.001
- 0.1
- Outline

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL10
FIGURE DESCRIPTION	February 2014 Replication (Predicted Effects of Blockage on Flood Extent) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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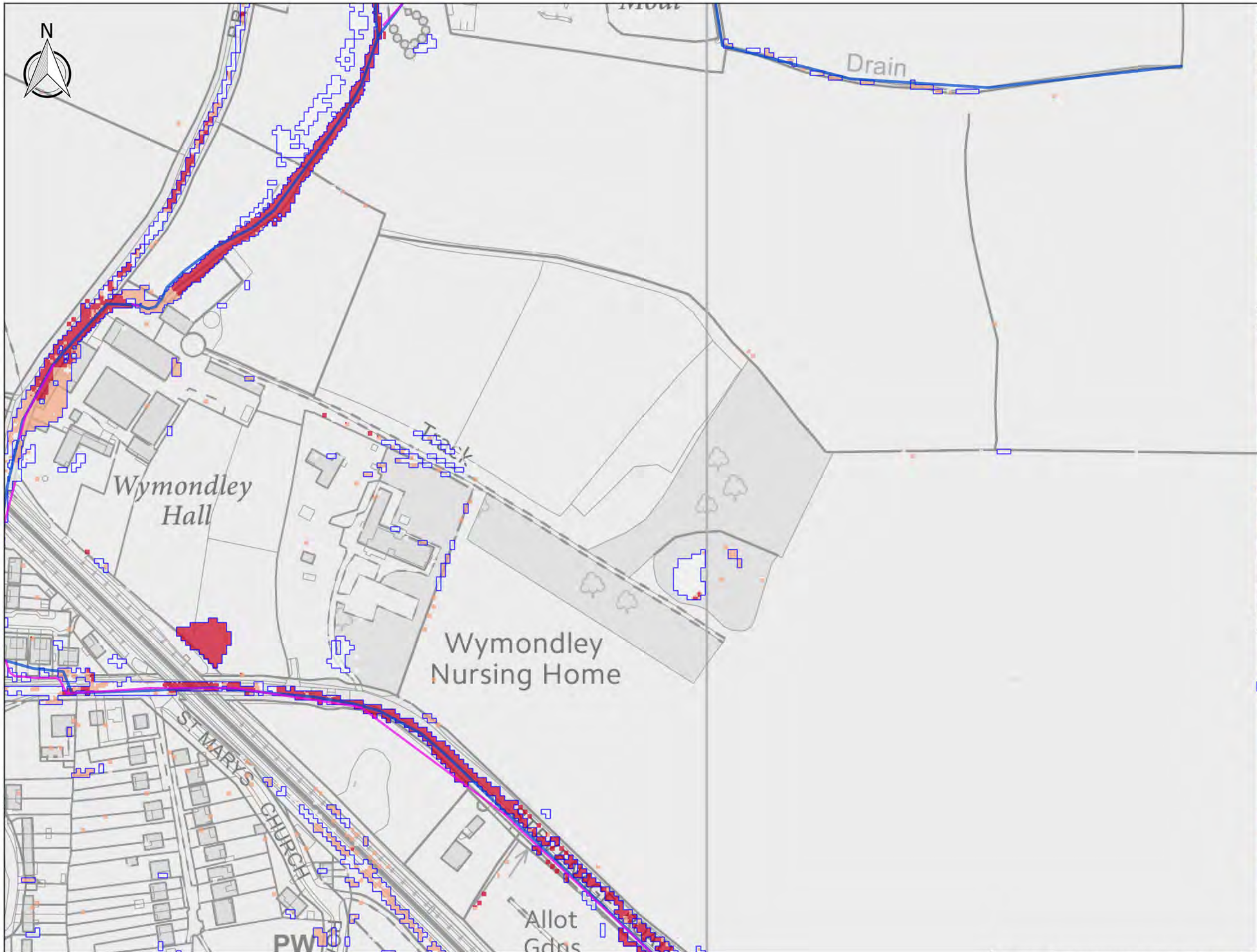
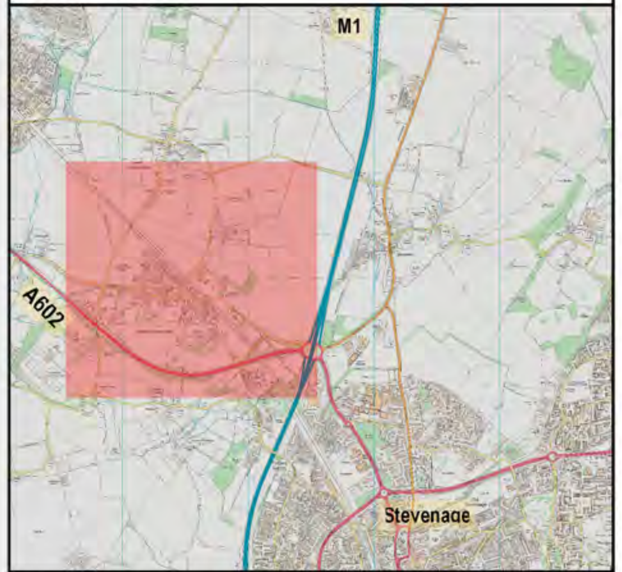


AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Effect of Removing Blockages (m)

- -1
- -0.1
- 0
- 0.001
- 0.1
- Outline

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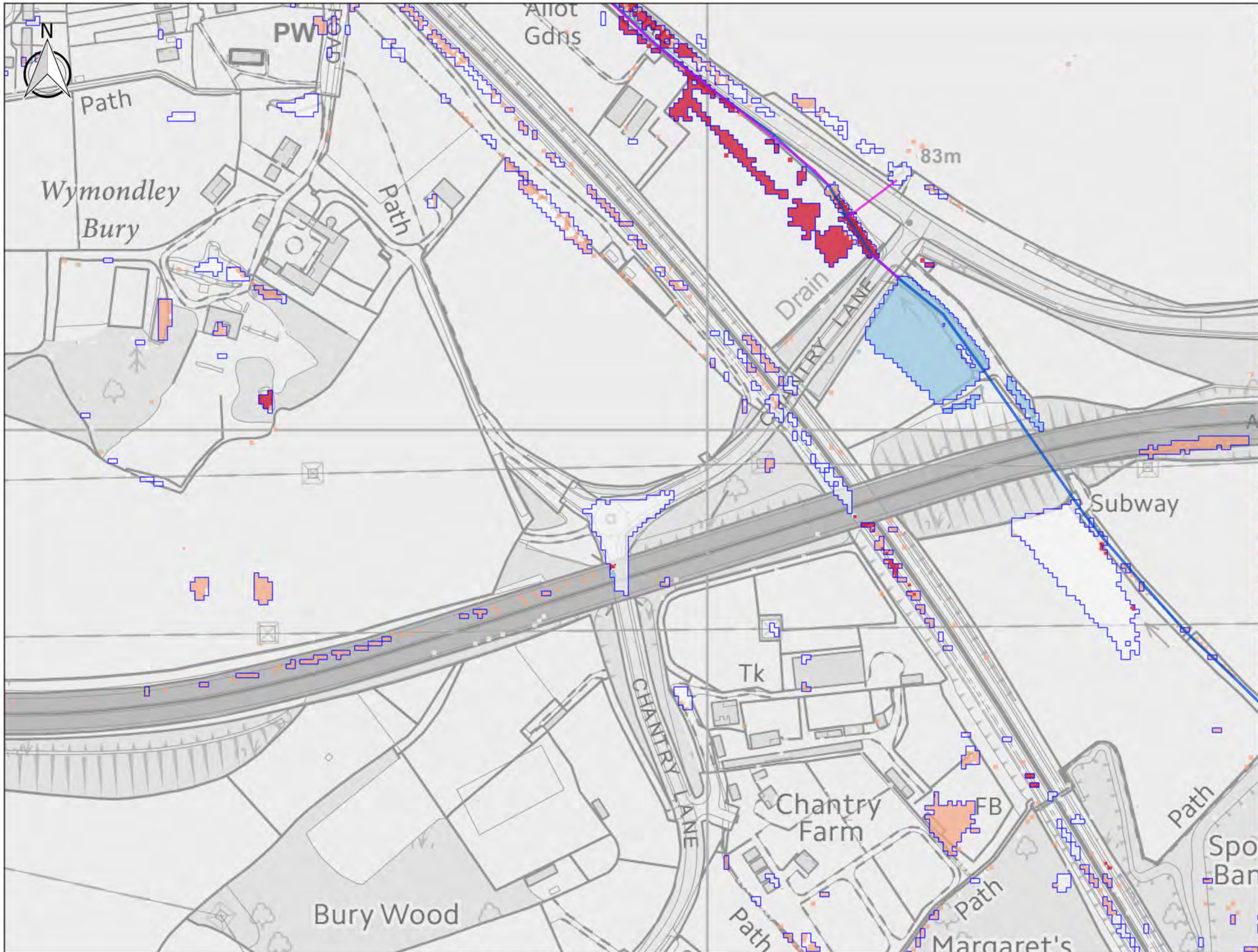
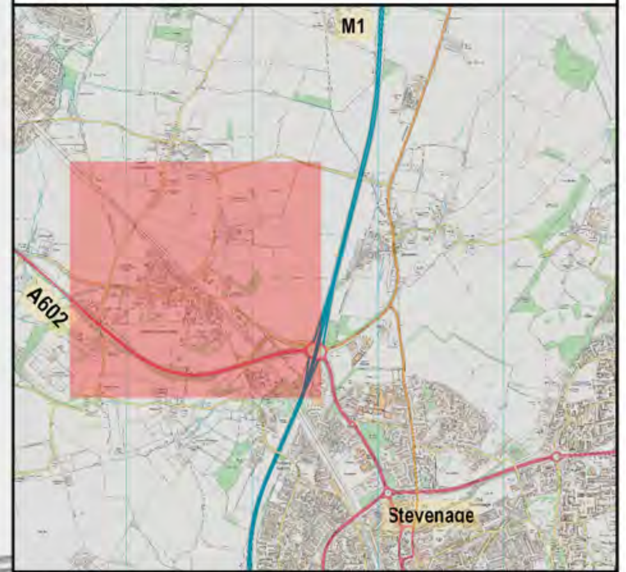
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER	MCL250-07_FIG_FL11		
FIGURE DESCRIPTION	February 2014 Replication (Predicted Effects of Blockage on Flood Extent) - Sheet 3		
DRAWN BY CS	SCALE 1:2500 @ A3	REVISION 1	DATE 30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Effect of Removing Blockages (m)

- -1
- -0.1
- 0
- 0.001
- 0.1
- Outline

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL12			
FIGURE DESCRIPTION	February 2014 Replication (Predicted Effects of Blockage on Flood Extent) - Sheet 4		
DRAWN BY CS	SCALE 1:2500 @ A3	REVISION 1	DATE 30/07/2015

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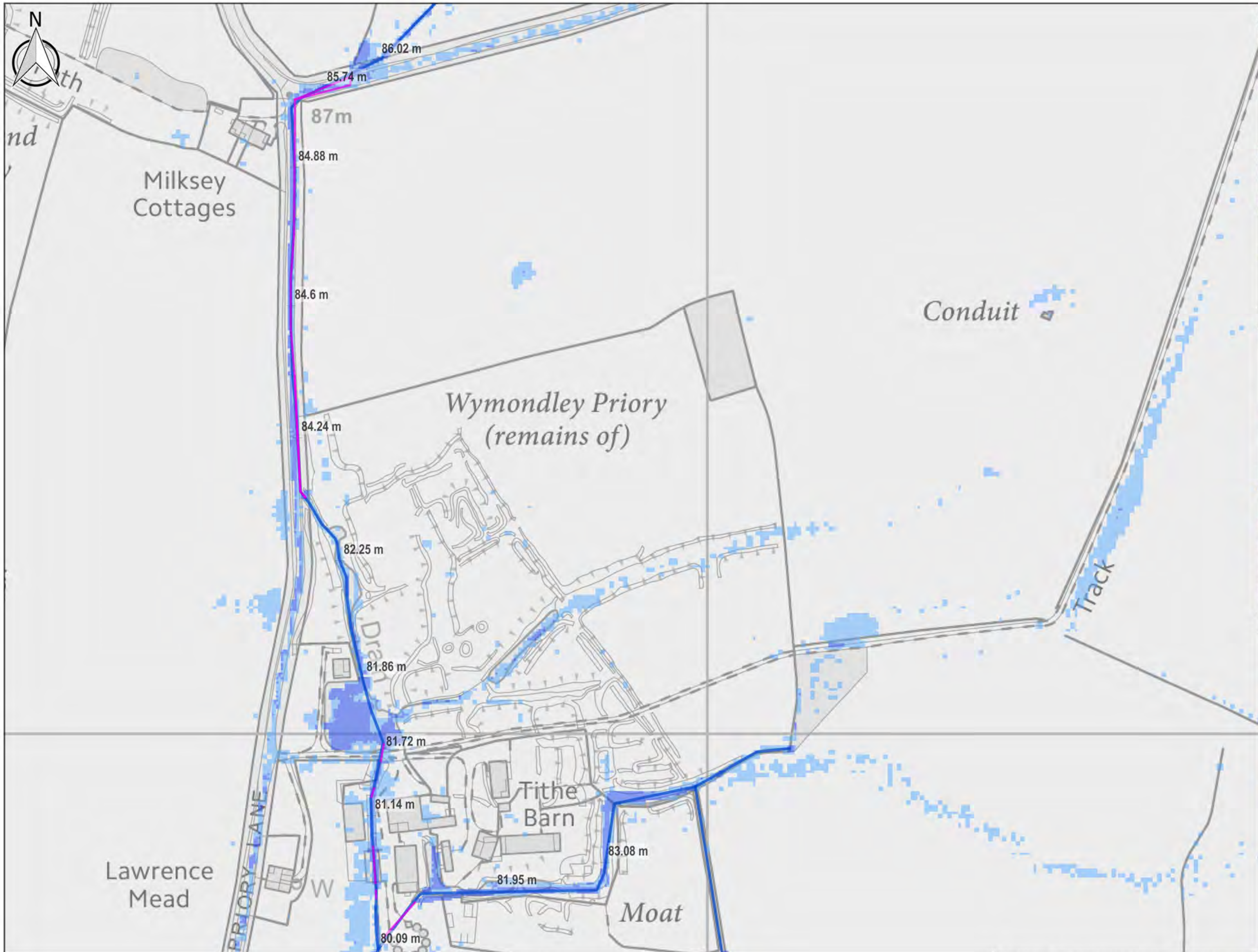
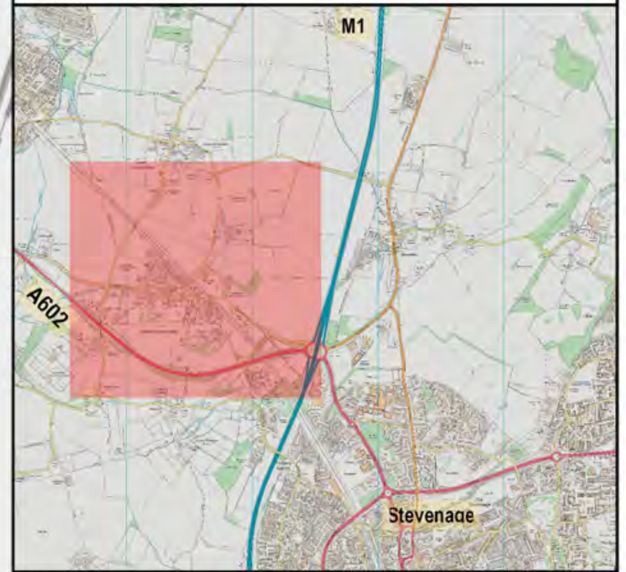
4) 30-yr Rainfall - 1 Hour Event



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 30-yr Rainfall - 1 Hour Event (Max. Water Level)

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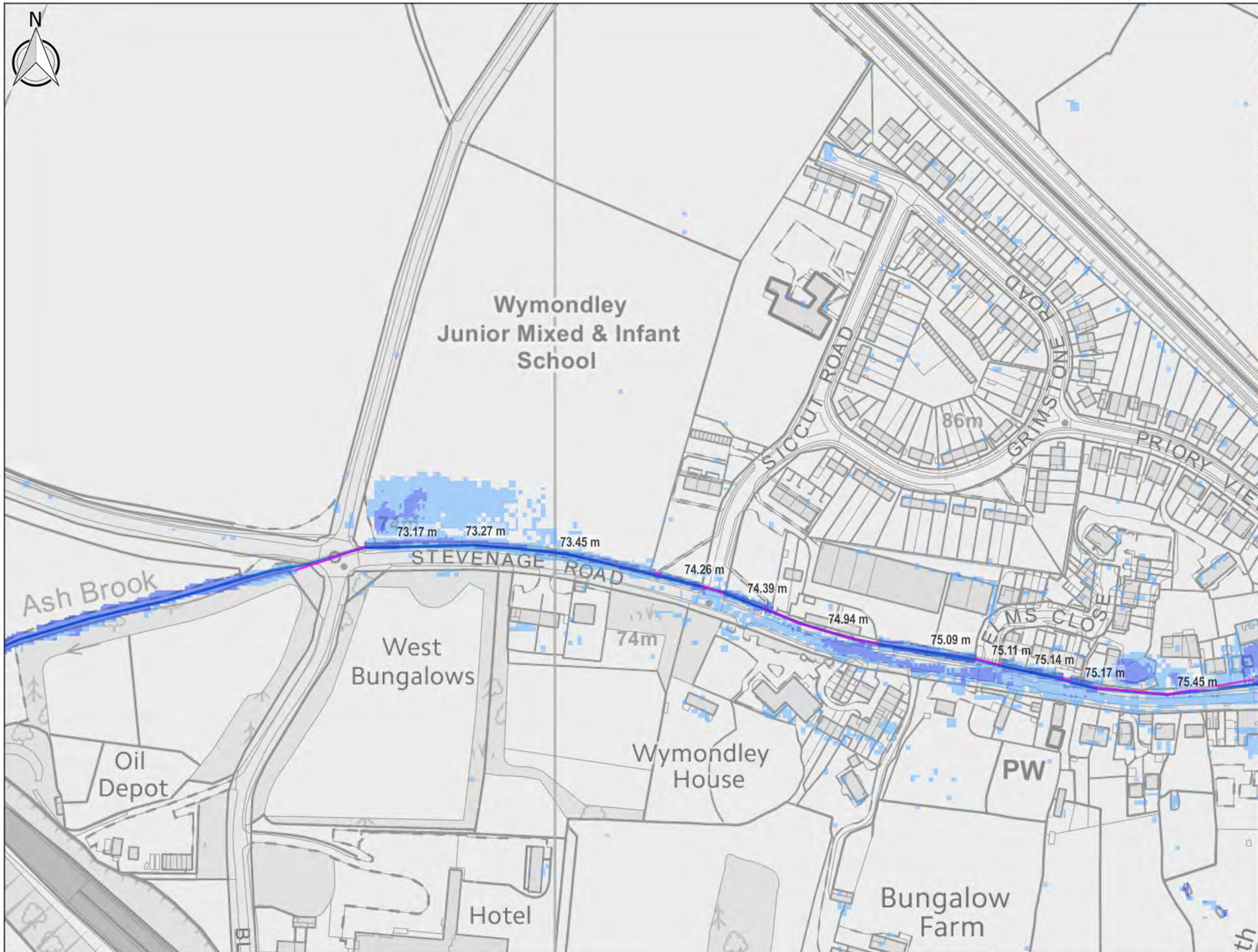
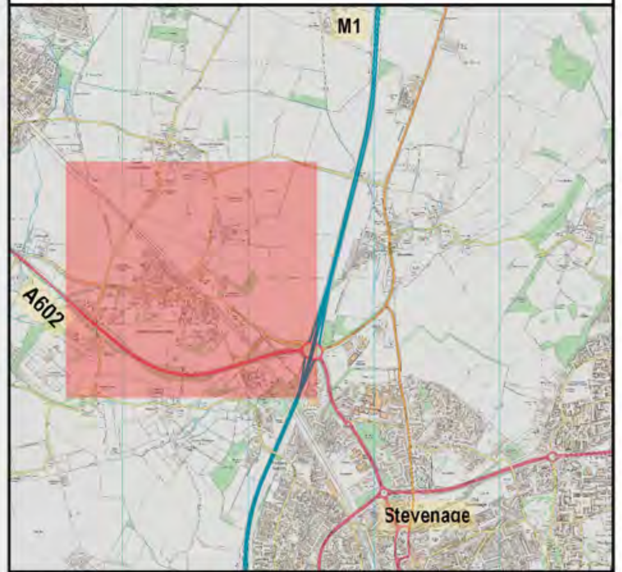
PROJECT TITLE LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER MCL250-07_FIG_FL30_1			
FIGURE DESCRIPTION 30-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 1			
DRAWN BY CS	SCALE 1:2500 @ A3	REVISION 1	DATE 30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 30-yr Rainfall - 1 Hour Event (Max. Water Level)

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL30_2			
FIGURE DESCRIPTION			
30-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 2			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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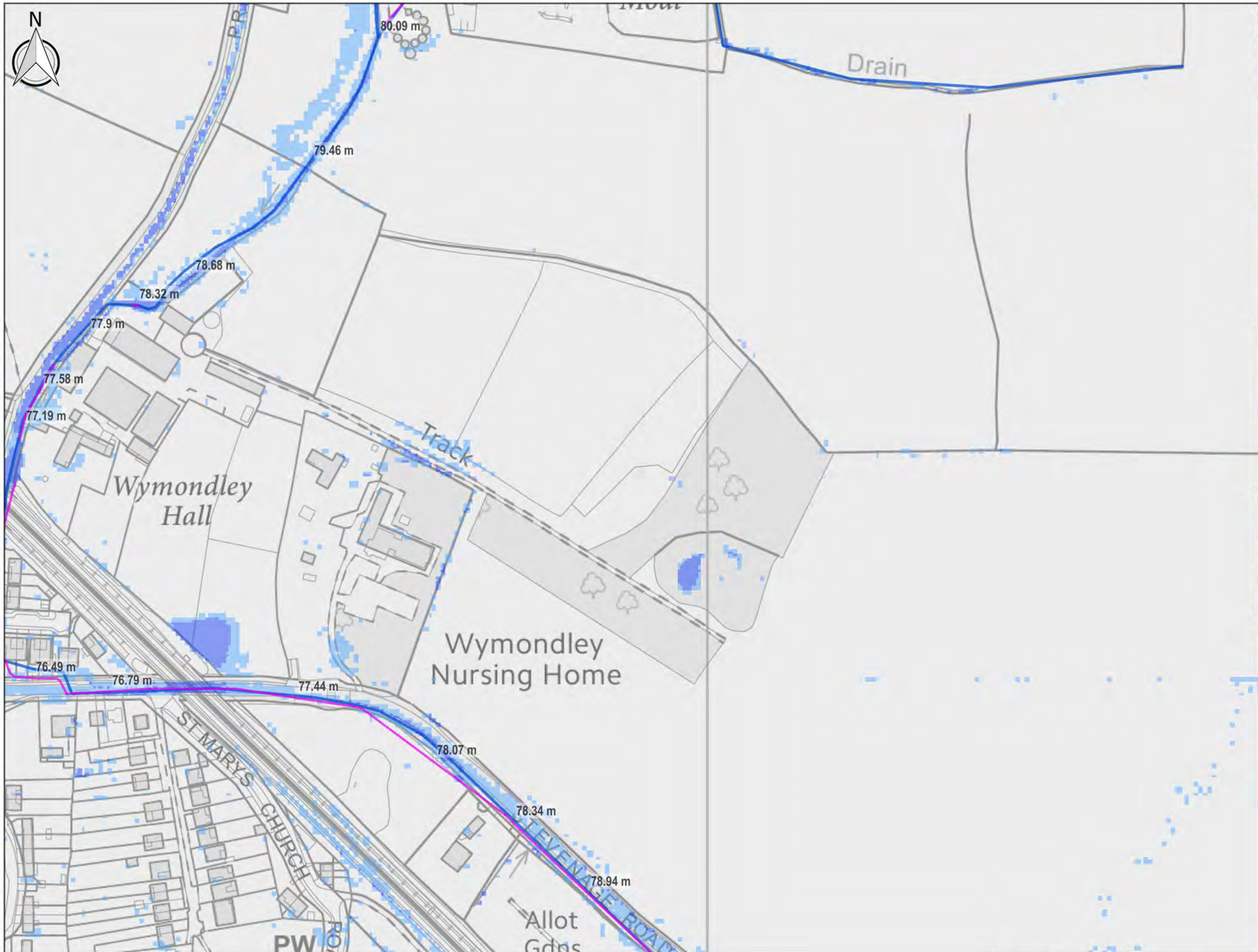
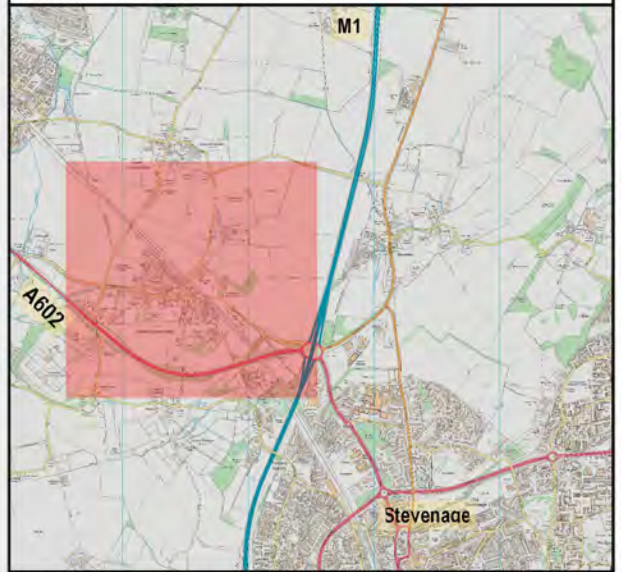


AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 30-yr Rainfall - 1 Hour Event (Max. Water Level)

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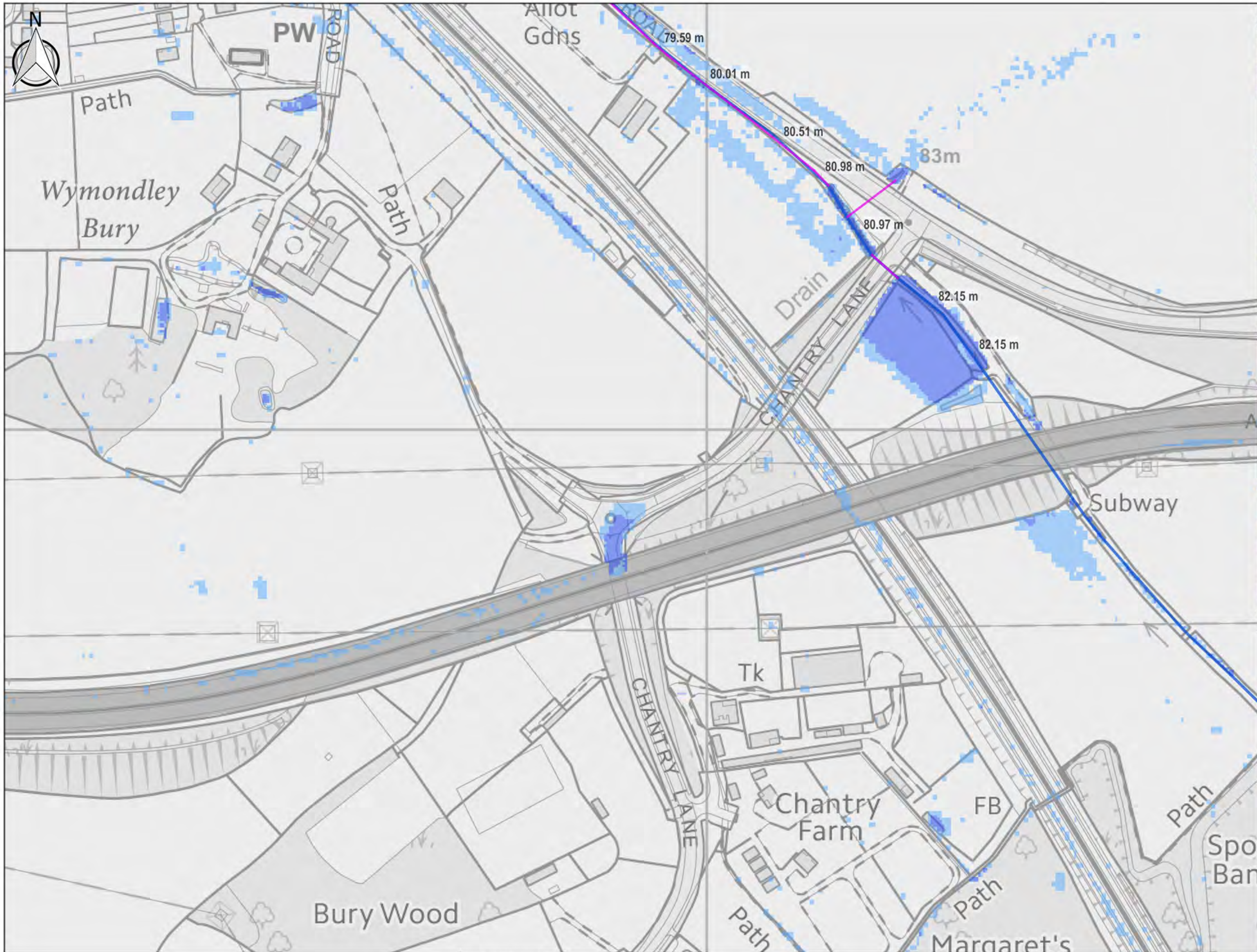
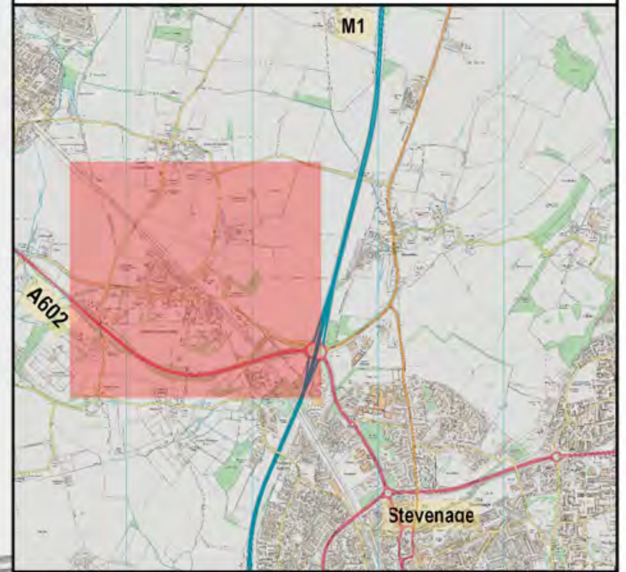
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL30_3
FIGURE DESCRIPTION	30-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 30-yr Rainfall - 1 Hour Event (Max. Water Level)

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELEY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL30_4			
FIGURE DESCRIPTION			
30-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 4			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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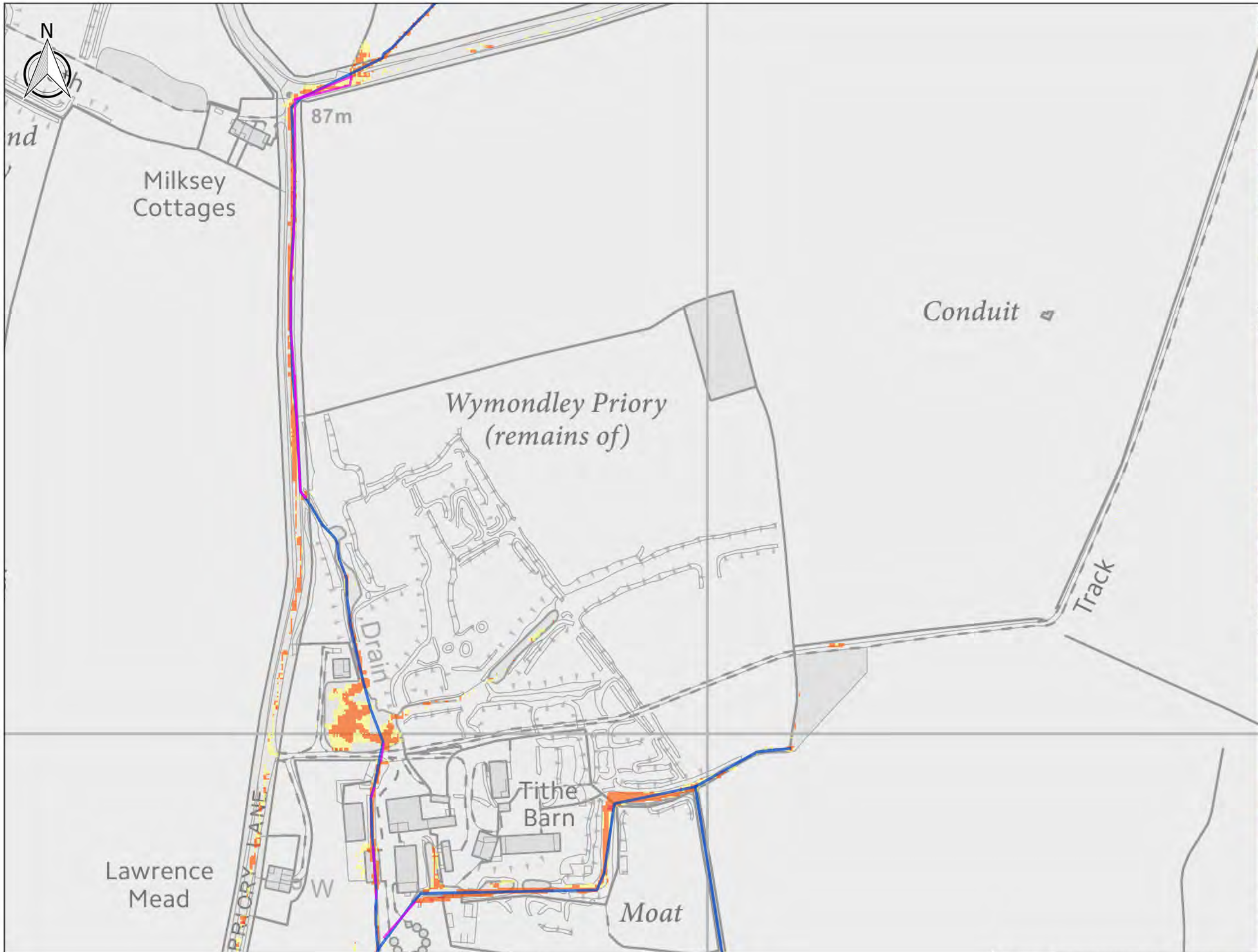
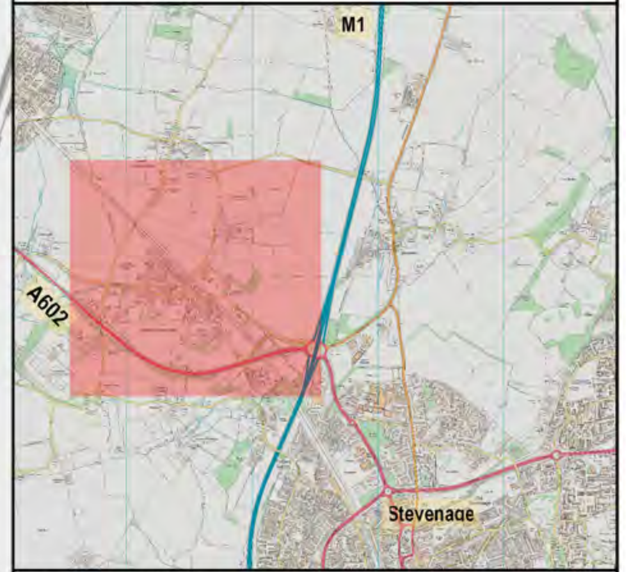
5) 30-yr Rainfall - 1 Hour Event (Flood Hazard Rating)



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

30-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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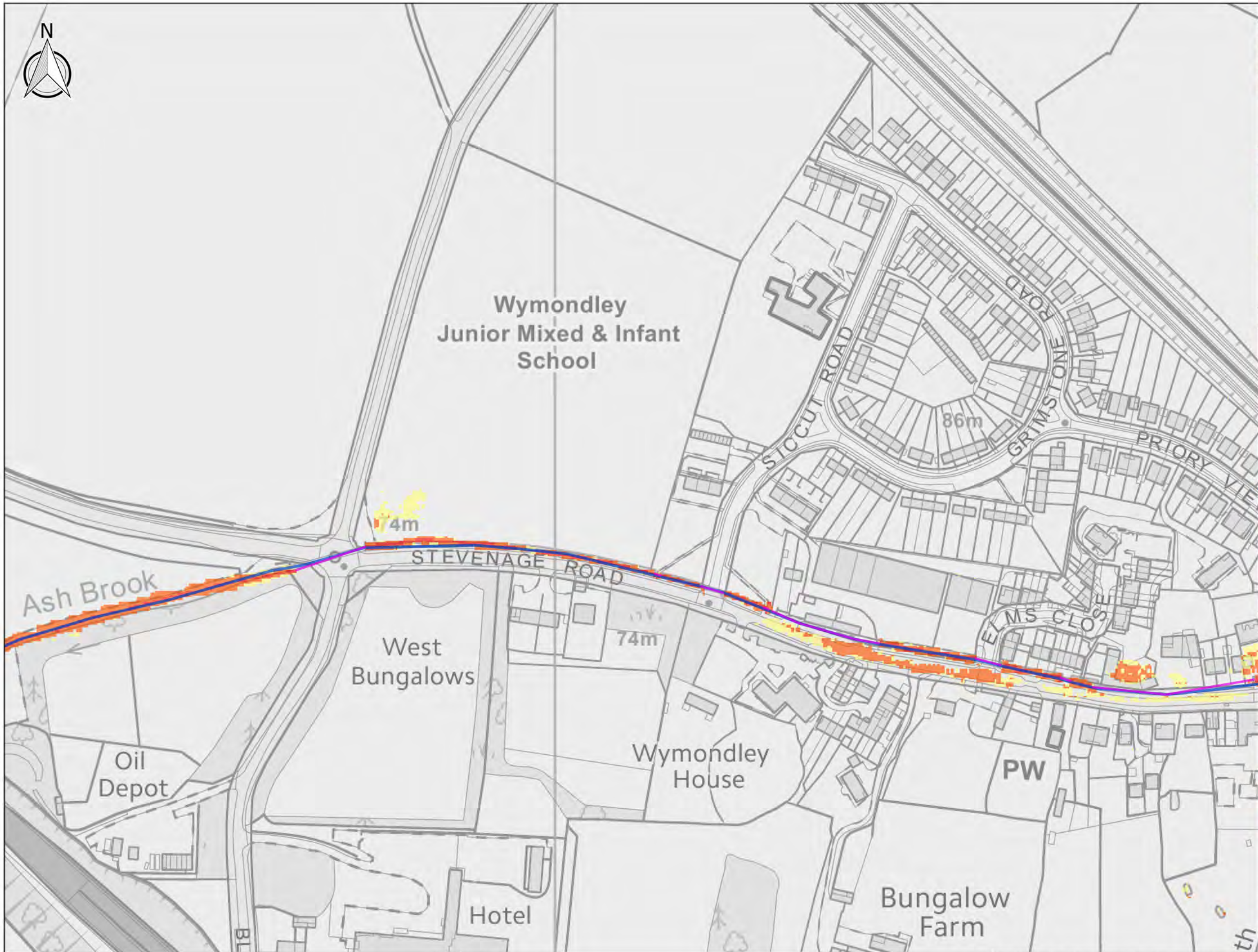
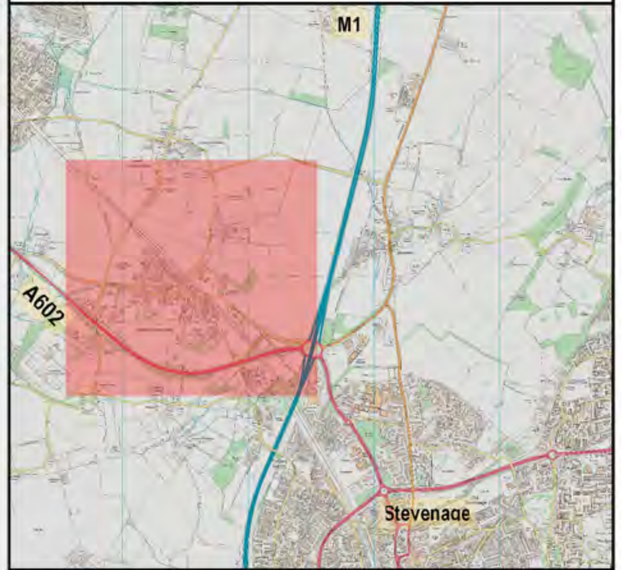
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL30_5
FIGURE DESCRIPTION	30-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

30-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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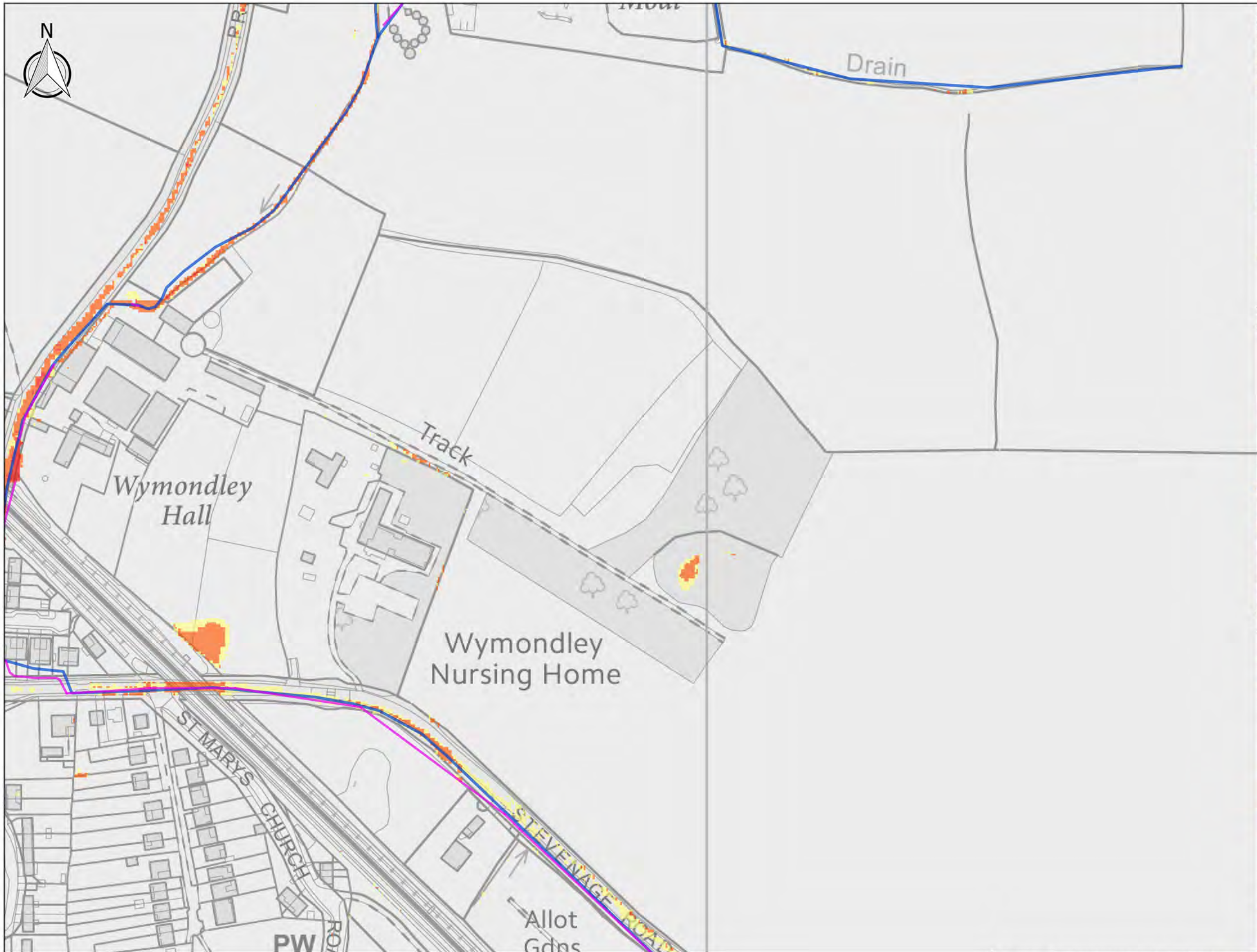
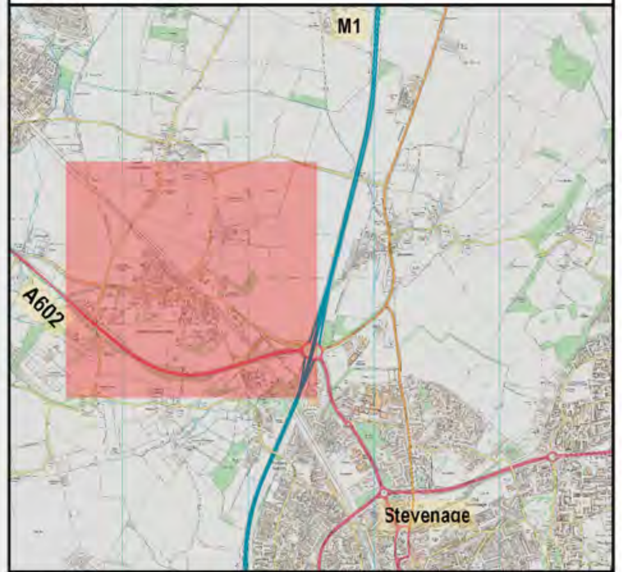
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL30_6
FIGURE DESCRIPTION	30-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

30-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL30_7
FIGURE DESCRIPTION	30-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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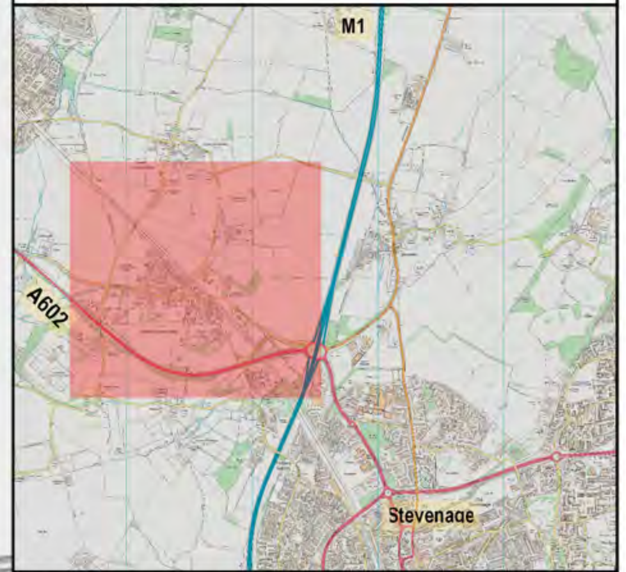
AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

30-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL30_8			
FIGURE DESCRIPTION			
30-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 4			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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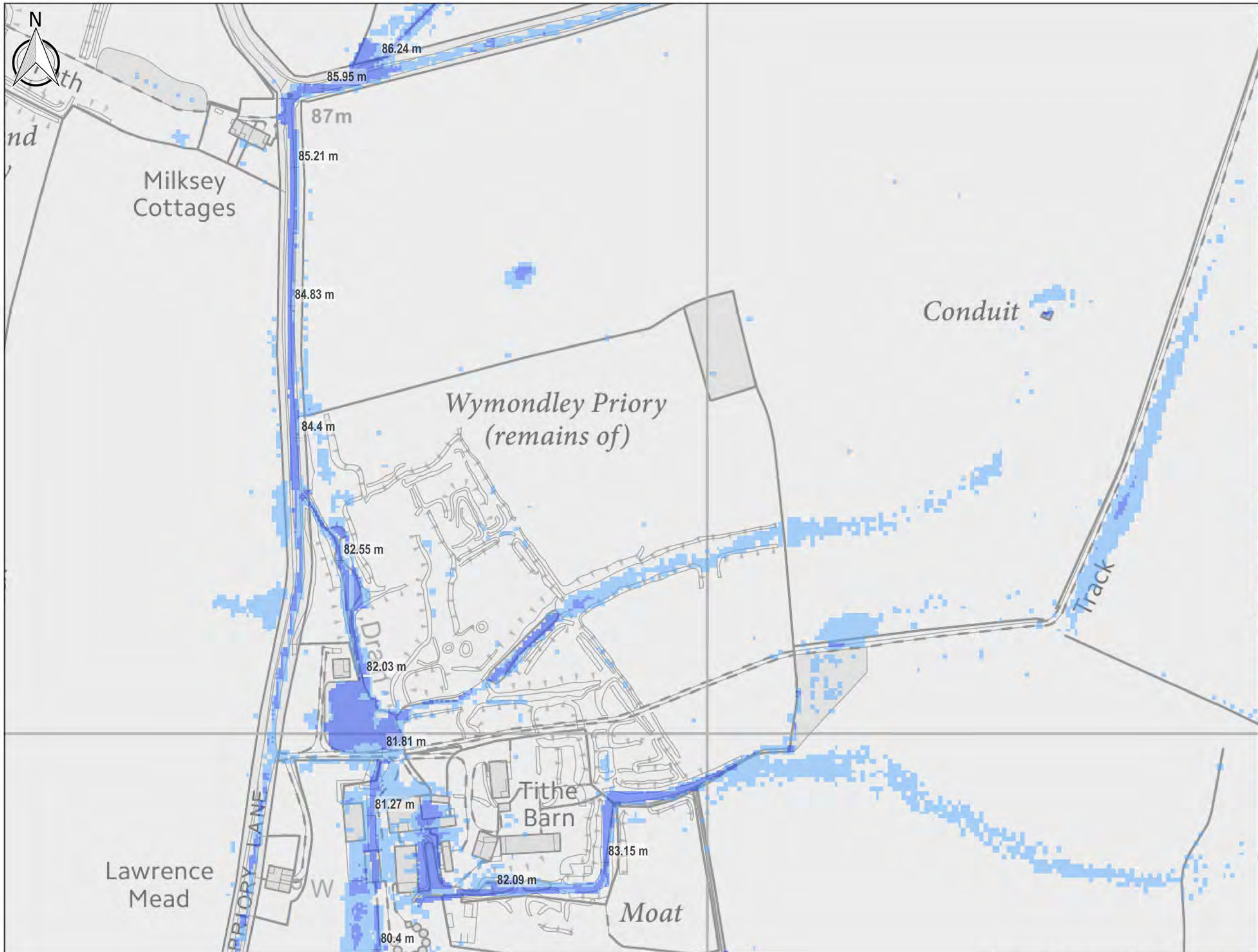
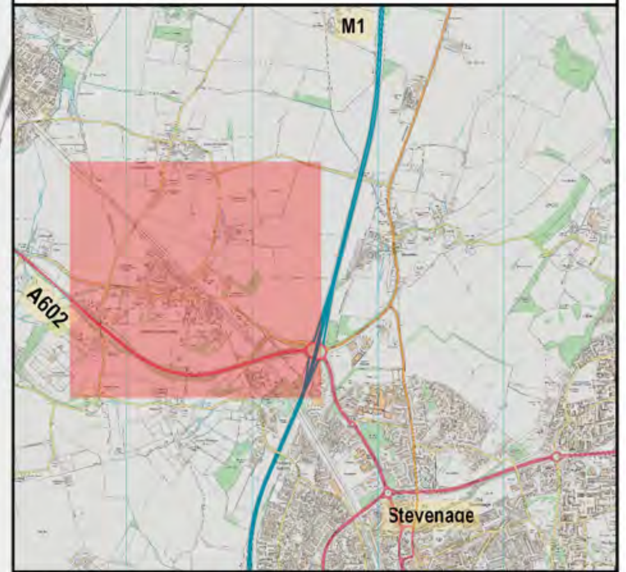
6) 100-yr Rainfall - 1 Hour Event



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr Rainfall - 1 Hour Event (Max. Water Level)

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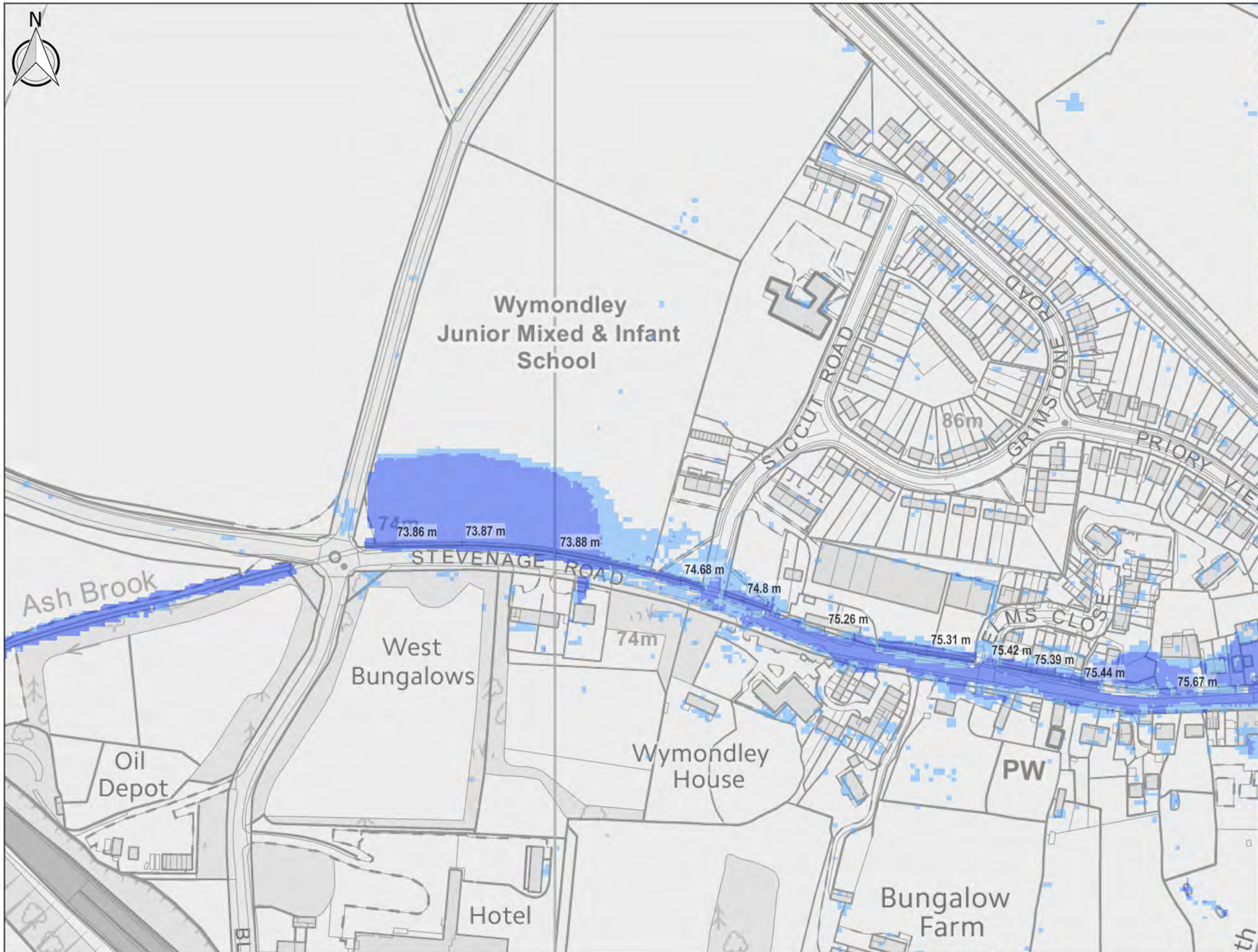
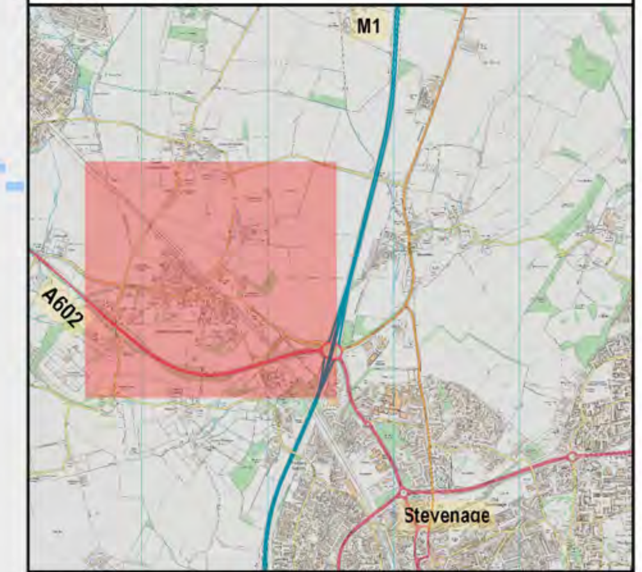
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100_1
FIGURE DESCRIPTION	100-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr Rainfall - 1 Hour Event (Max. Water Level)

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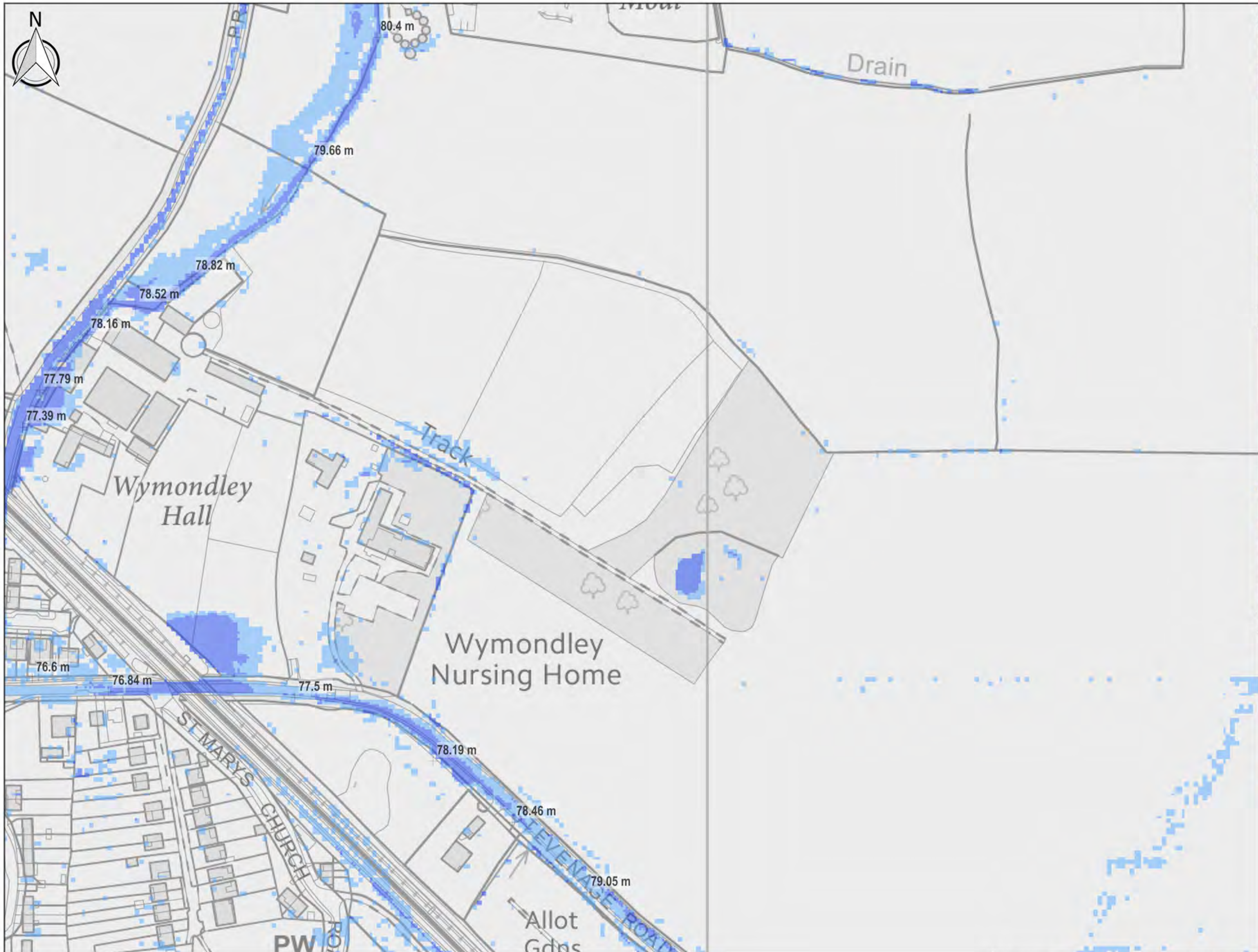
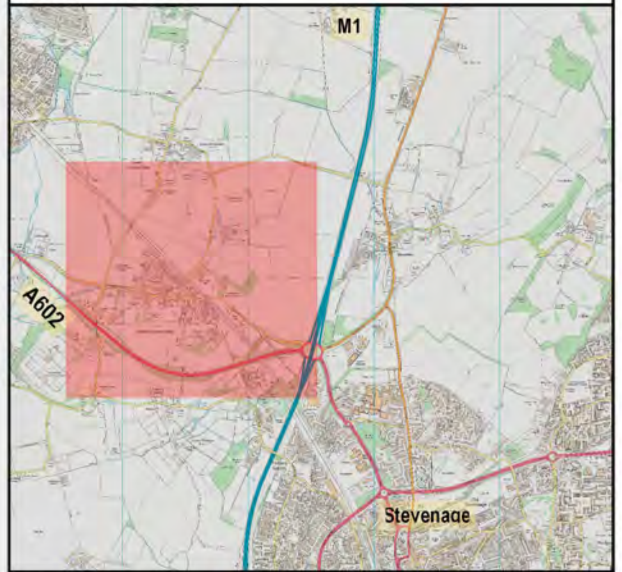
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100_2
FIGURE DESCRIPTION	100-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr Rainfall - 1 Hour Event (Max. Water Level)

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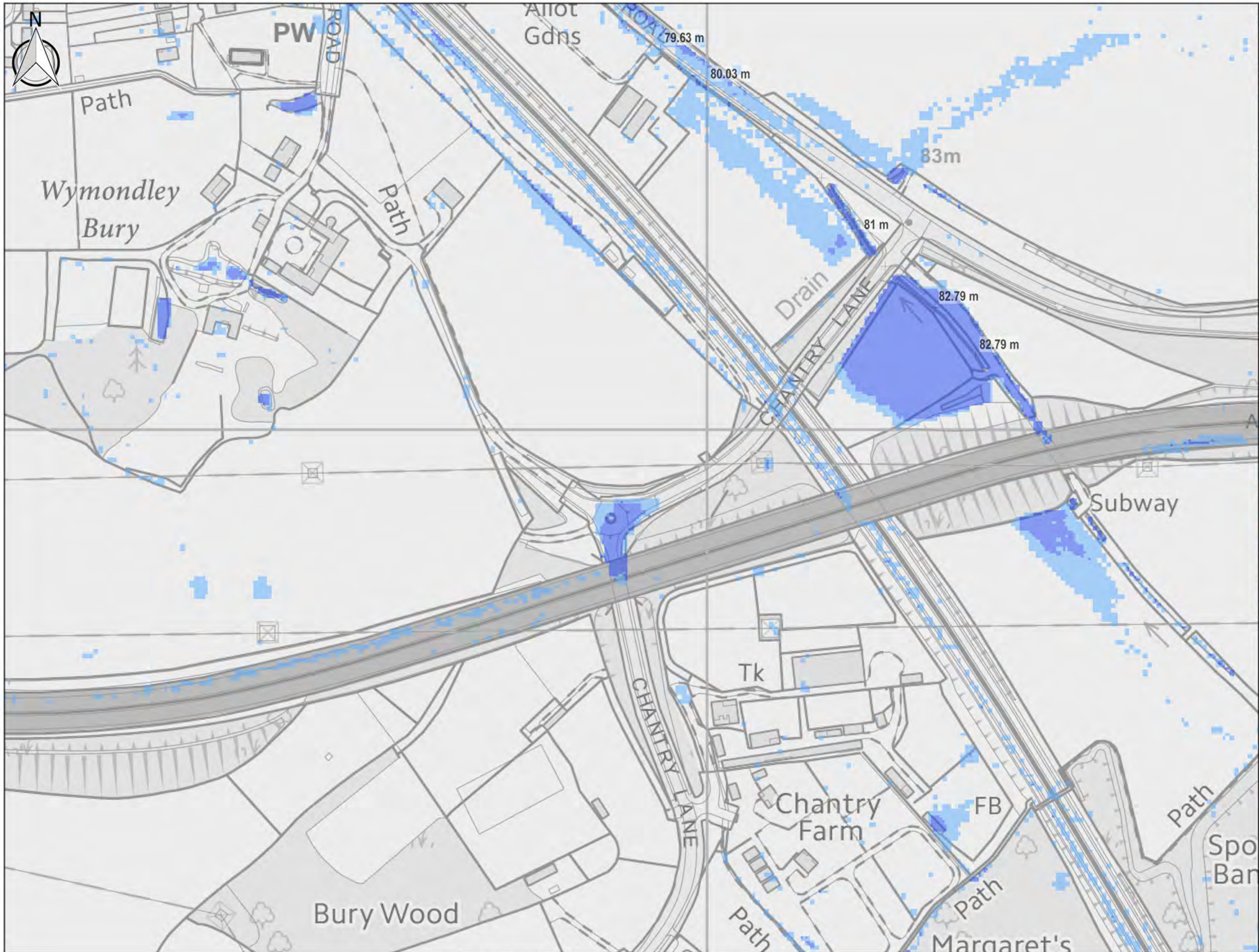
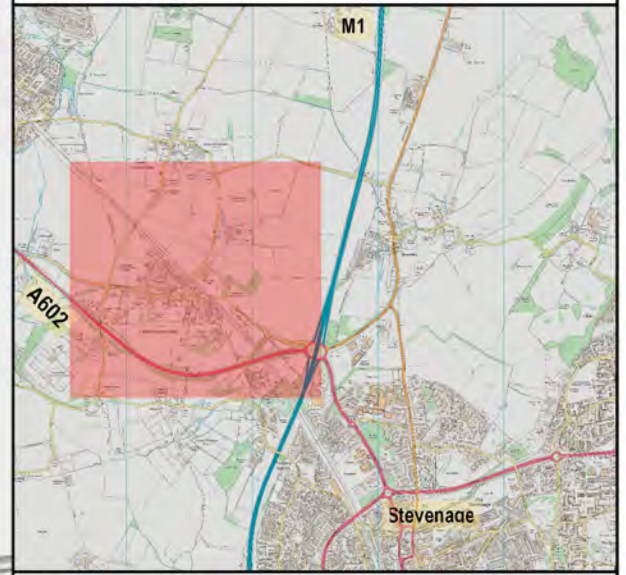
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100_3
FIGURE DESCRIPTION	100-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr Rainfall - 1 Hour Event (Max. Water Level)

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100_4
FIGURE DESCRIPTION	100-yr Rainfall - 1 Hour Event (Max. Water Level) - Sheet 4

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

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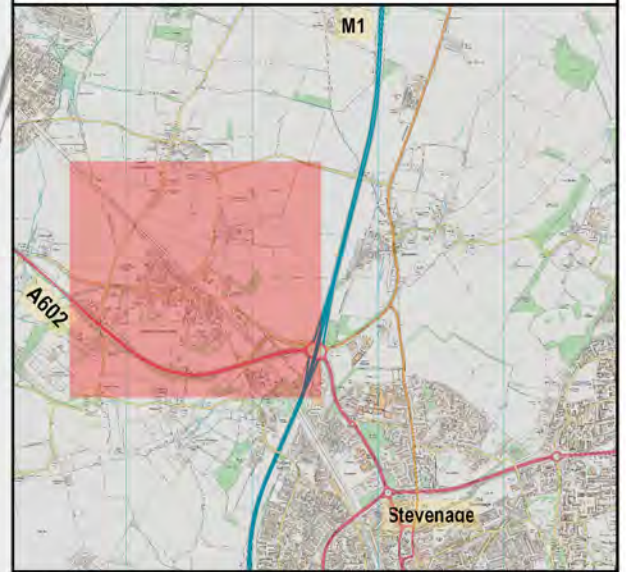
7) 100-yr Rainfall - 1 Hour Event (Flood Hazard Rating)

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Q100-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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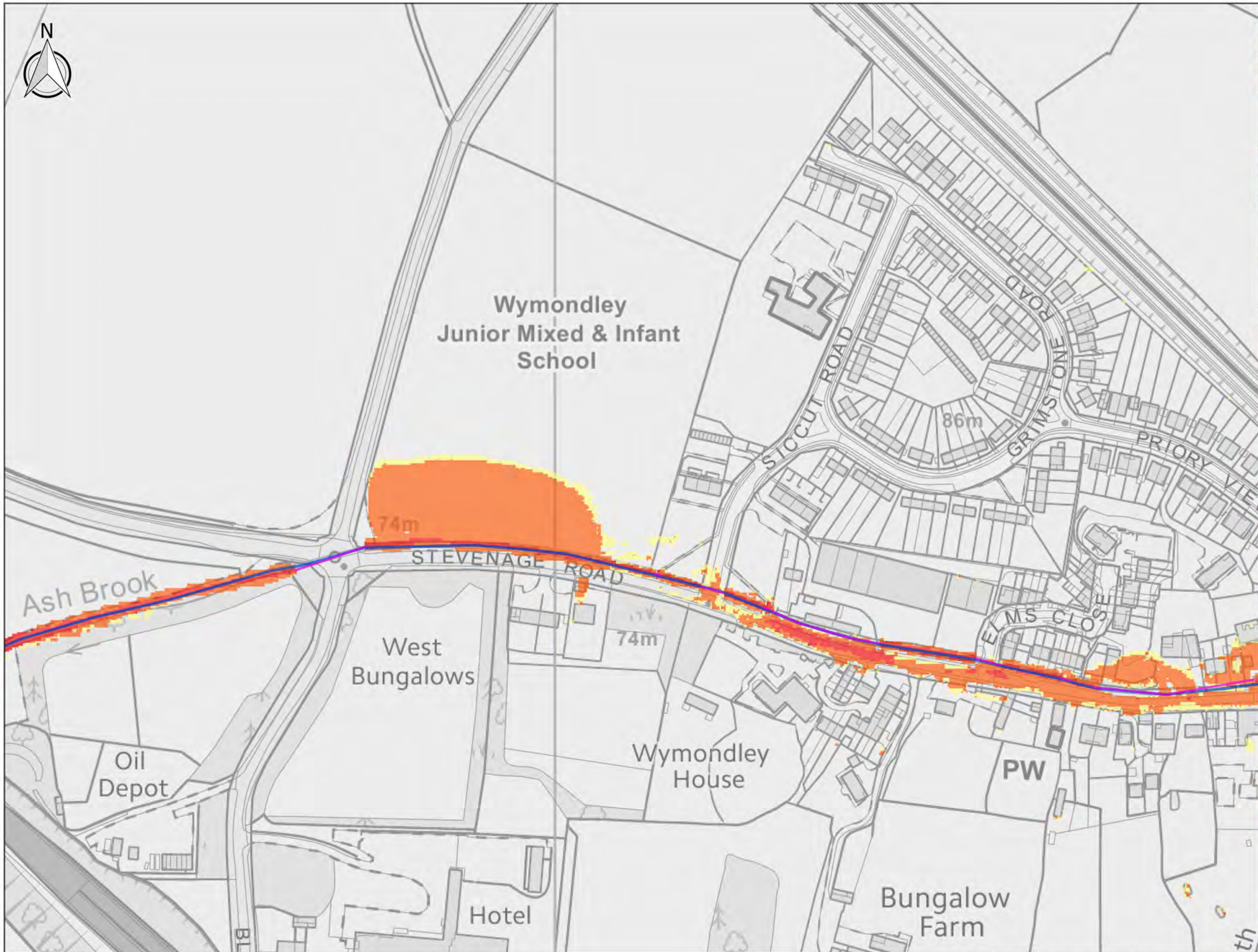
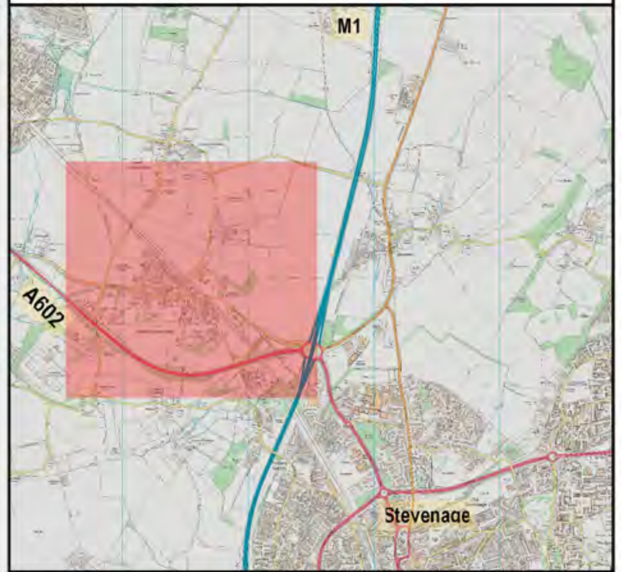
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL100_5			
FIGURE DESCRIPTION			
100-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 1			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Q100-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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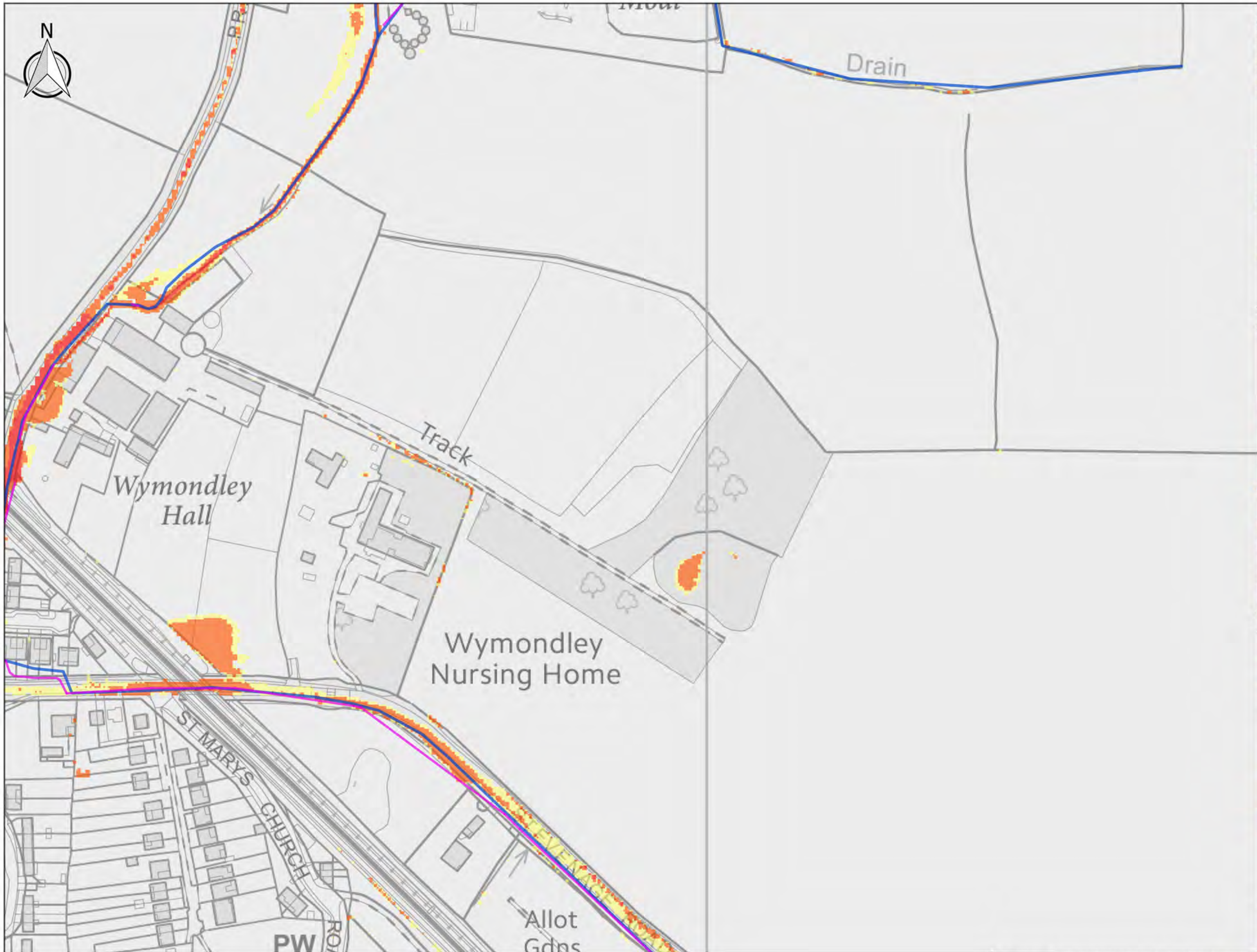
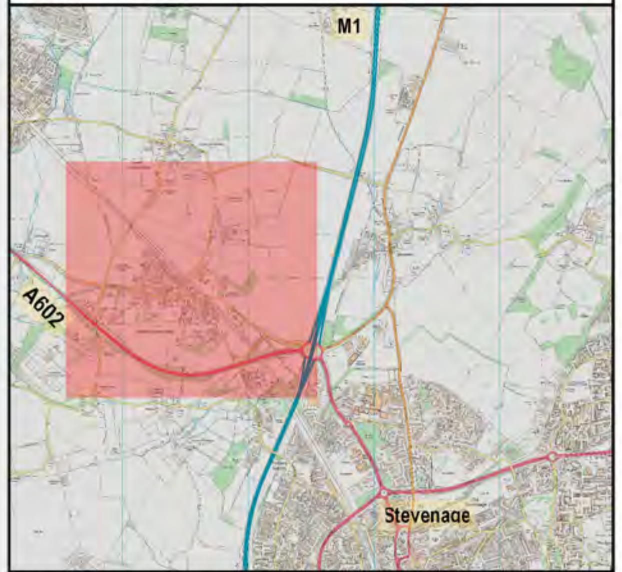
PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER			
MCL250-07_FIG_FL100_6			
FIGURE DESCRIPTION			
100-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 2			
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Q100-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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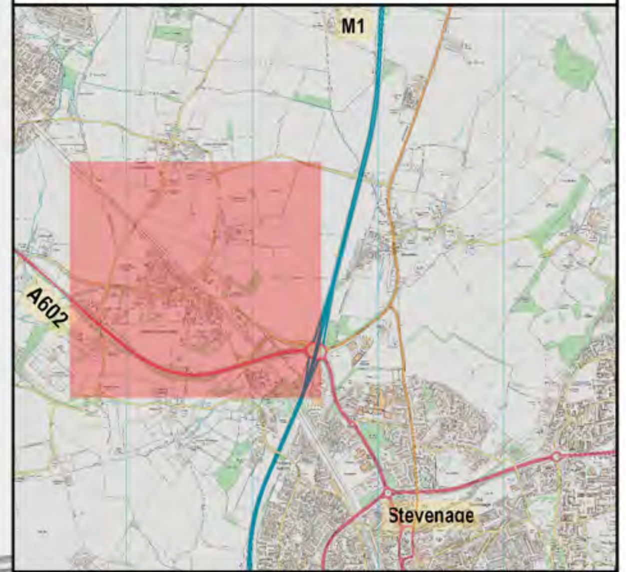
PROJECT TITLE LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER MCL250-07_FIG_FL100_7			
FIGURE DESCRIPTION 100-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 3			
DRAWN BY CS	SCALE 1:2500 @ A3	REVISION 1	DATE 30/07/2015

Hertfordshire

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

Q100-yr 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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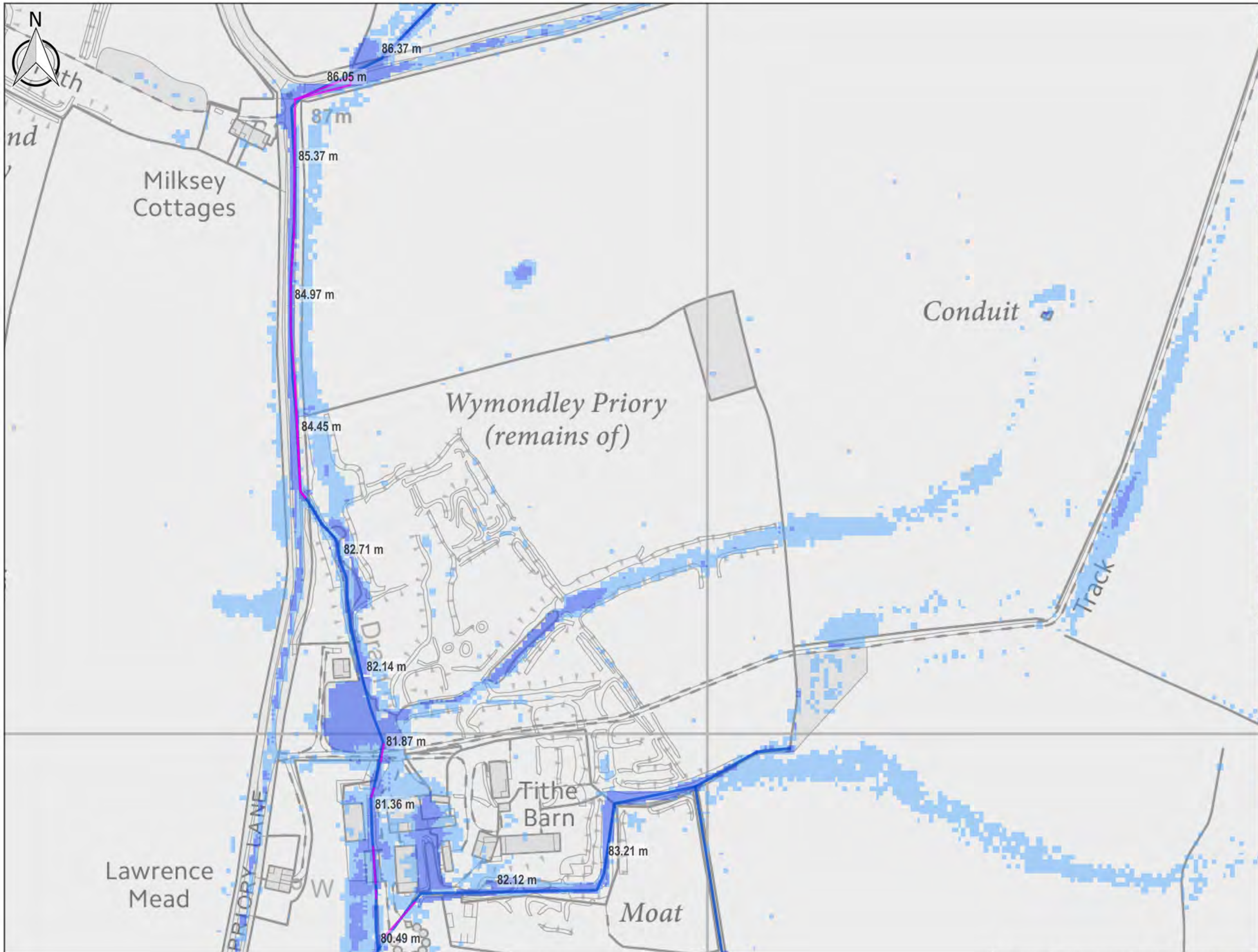
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100_8
FIGURE DESCRIPTION	100-yr Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 4

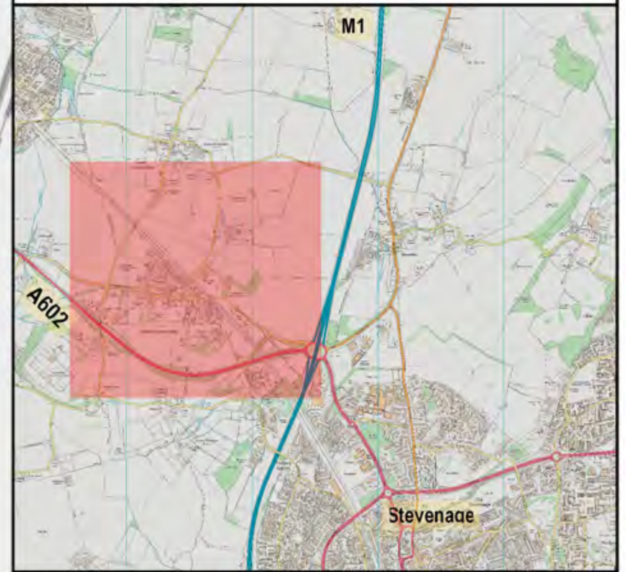
DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire

8) 100-yr + Climate Change Rainfall - 1 Hour Event



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level)

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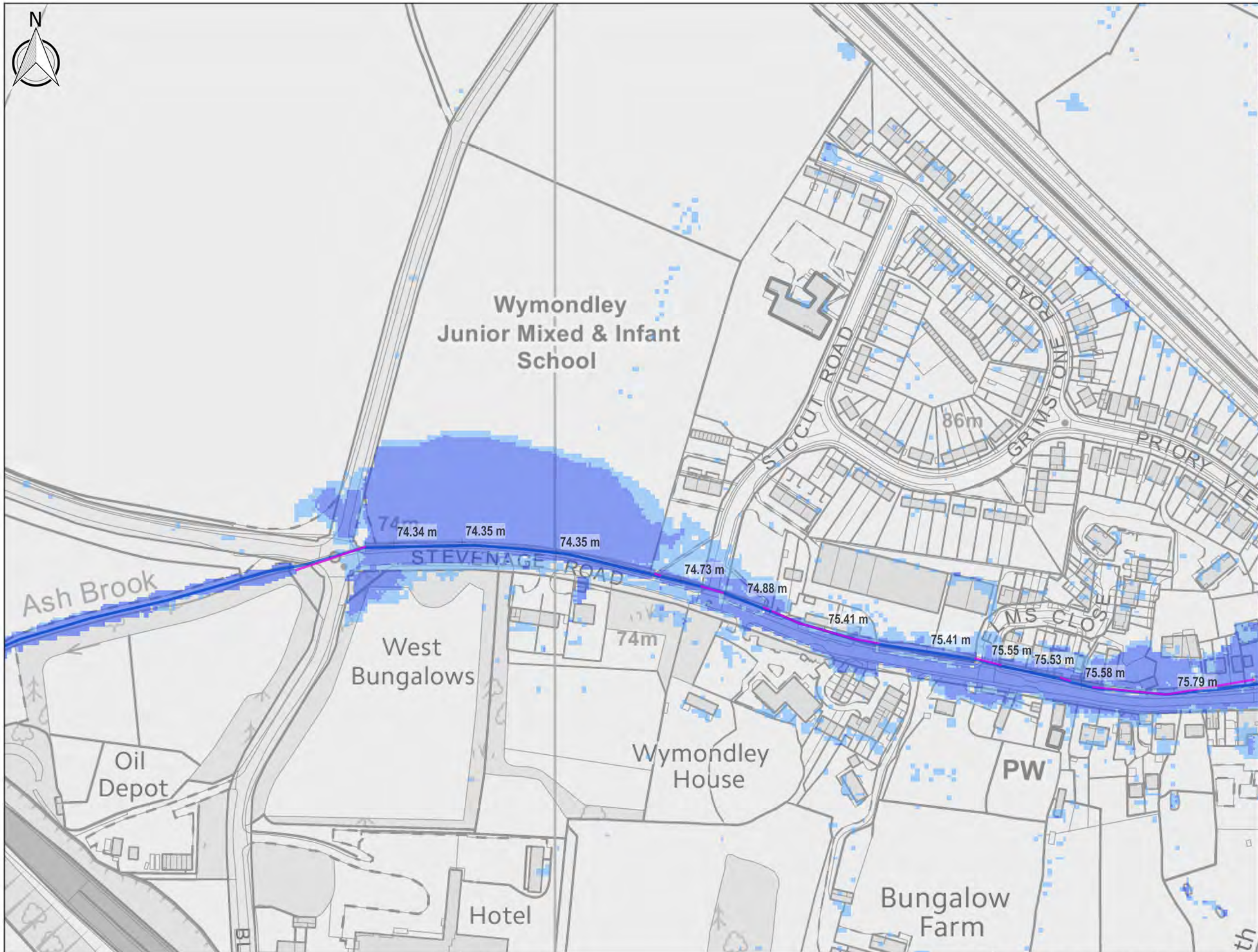
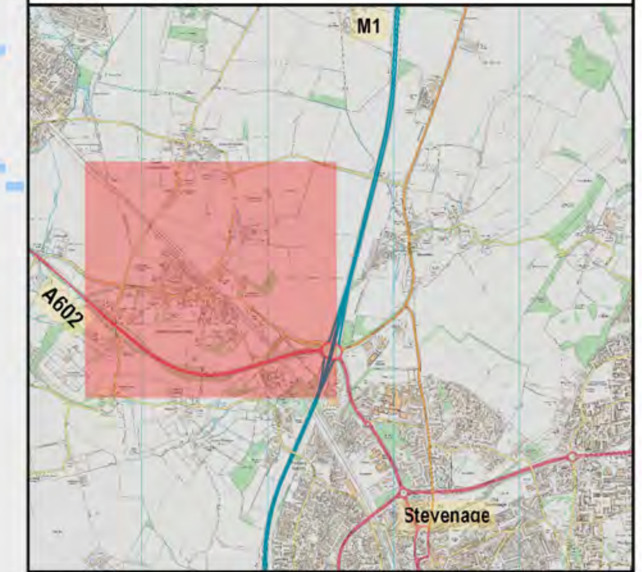
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100CC_1
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level) - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level)

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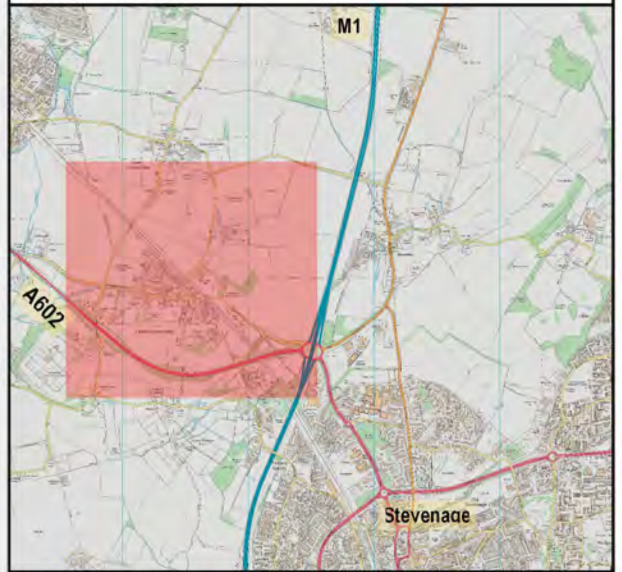
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100CC_2
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level)

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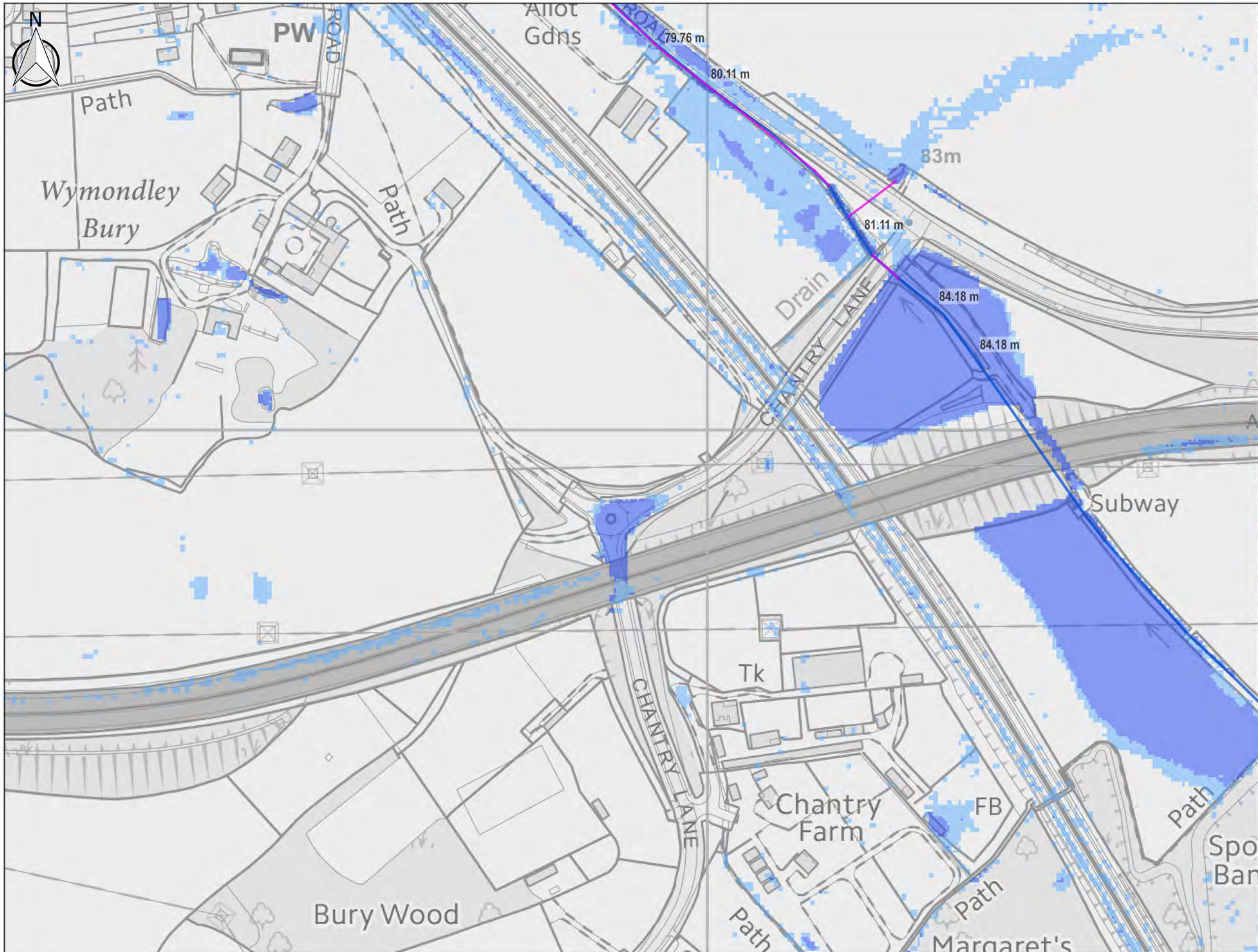
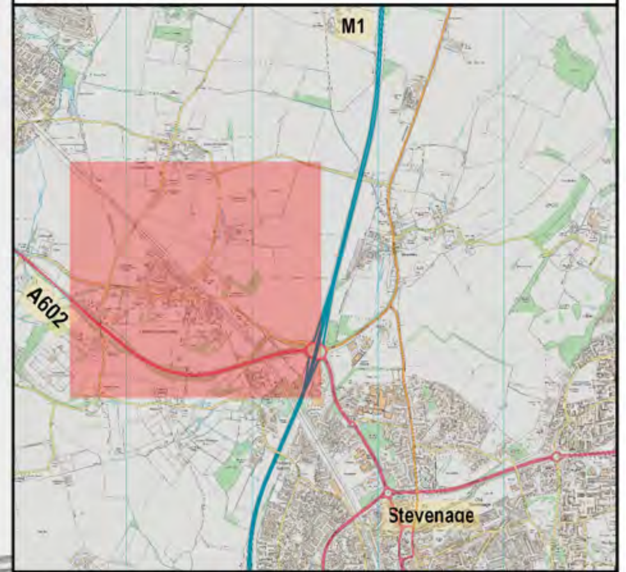
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100CC_3
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent Depth

- < 0.3m
- >= 0.3m

Flood Extents 100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level)

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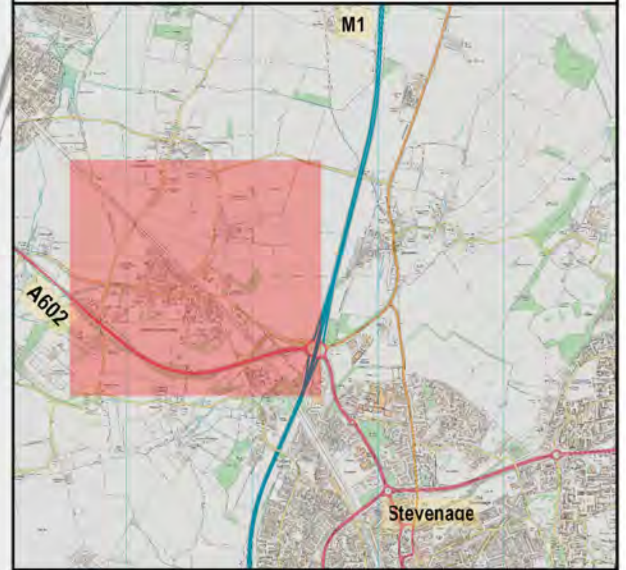
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY		
FIGURE NUMBER	MCL250-07_FIG_FL100CC_4		
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Max. Water Level) - Sheet 4		
DRAWN BY CS	SCALE 1:2500 @ A3	REVISION 1	DATE 30/07/2015

Hertfordshire

9) 100-yr + Climate Change Rainfall - 1 Hour Event

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

100-yr + Climate Change 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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PROJECT TITLE			
LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY			
FIGURE NUMBER	MCL250-07_FIG_FL100CC_5		
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 1		
DRAWN BY: CS	SCALE: 1:2500 @ A3	REVISION: 1	DATE: 30/07/2015

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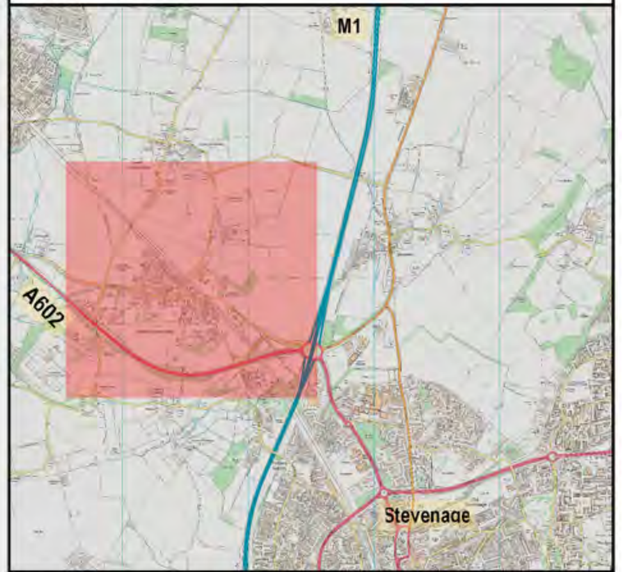
AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

100-yr + Climate Change 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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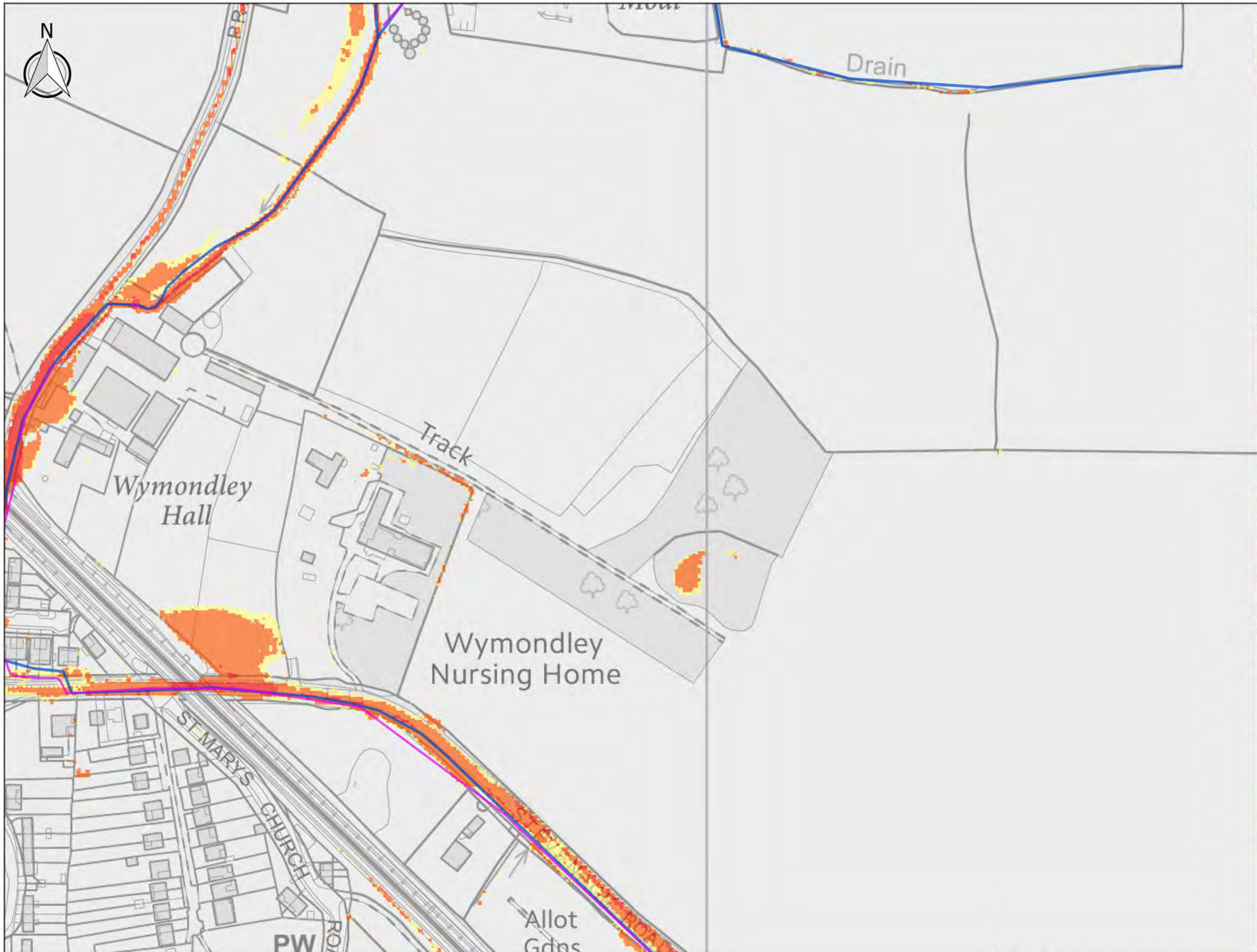
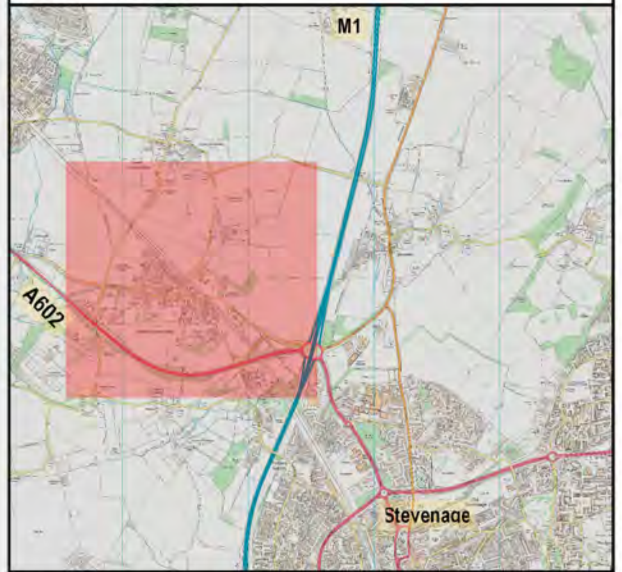
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100CC_6
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

100-yr + Climate Change 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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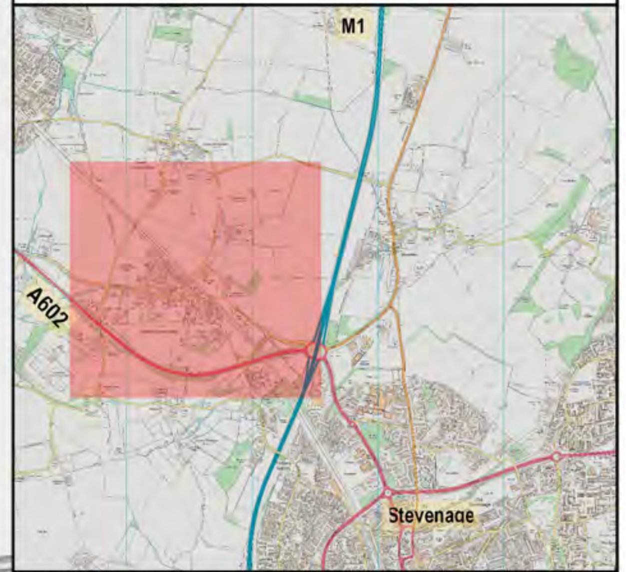
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL100CC_7
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	30/07/2015

Hertfordshire

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

- Modelled Culverts
- Ordinary Watercourse

100-yr + Climate Change 1 Hour Event: Flood Hazard to People

- Very Low Hazard - Caution
- Danger for Some
- Danger for Most
- Danger for All - Inc. Emergency Services

Flood Hazard to People Classification presented in accordance with the methodology stated in Table 13.1 of FD2320/TR2

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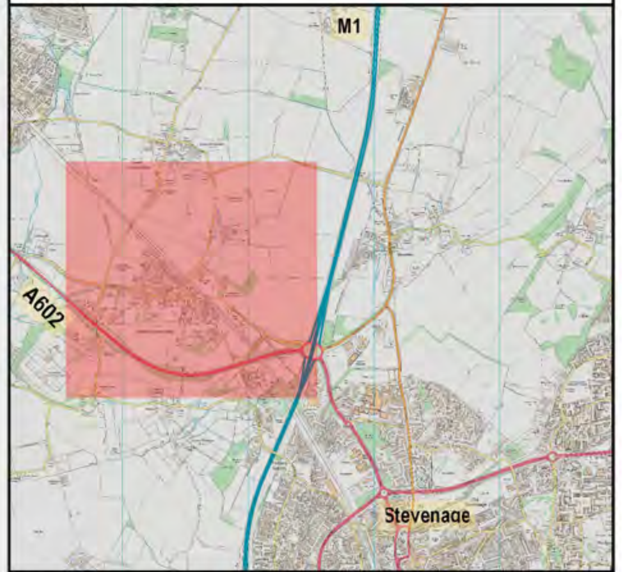
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELEY - FLOOD STUDY		
FIGURE NUMBER	MCL250-07_FIG_FL100CC_8		
FIGURE DESCRIPTION	100-yr + Climate Change Rainfall - 1 Hour Event (Flood Hazard Rating) - Sheet 4		
DRAWN BY: CS	SCALE: 1:2500 @ A3	REVISION: 1	DATE: 30/07/2015

Hertfordshire

10) Alleviation Option 1

AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent for Alleviation Option 1

- 30 year Rainfall
- 100 year Rainfall
- 100 year + CC Rainfall

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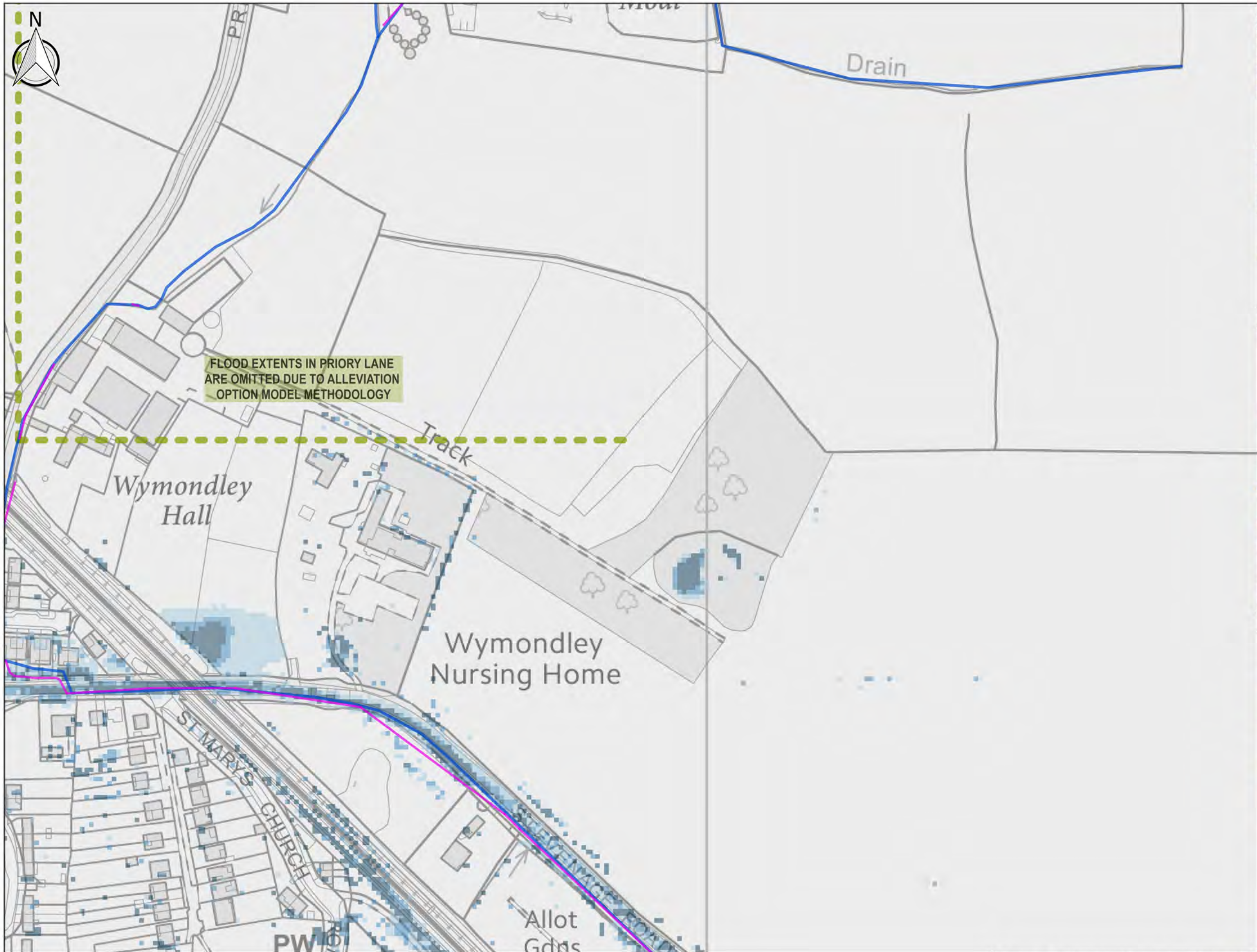
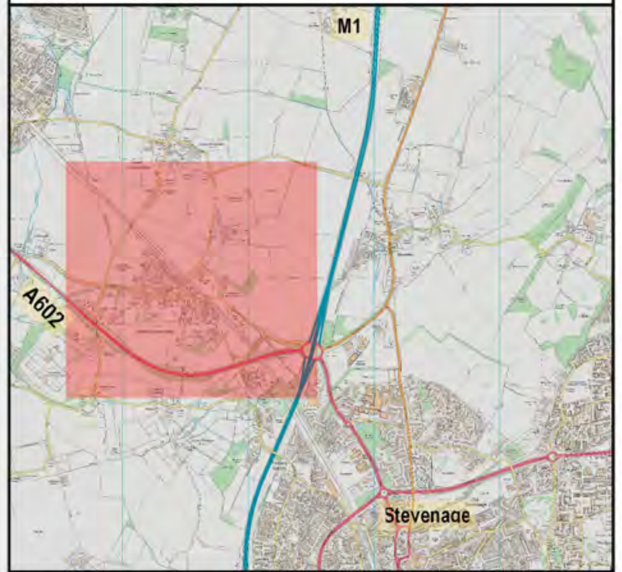
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL_OP1_1
FIGURE DESCRIPTION	Alleviation Option 1 - 30-yr / 100-yr / 100+CC-yr Flood Extents - Sheet 1

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	31/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent for Alleviation Option 1

- 30 year Rainfall
- 100 year Rainfall
- 100 year + CC Rainfall

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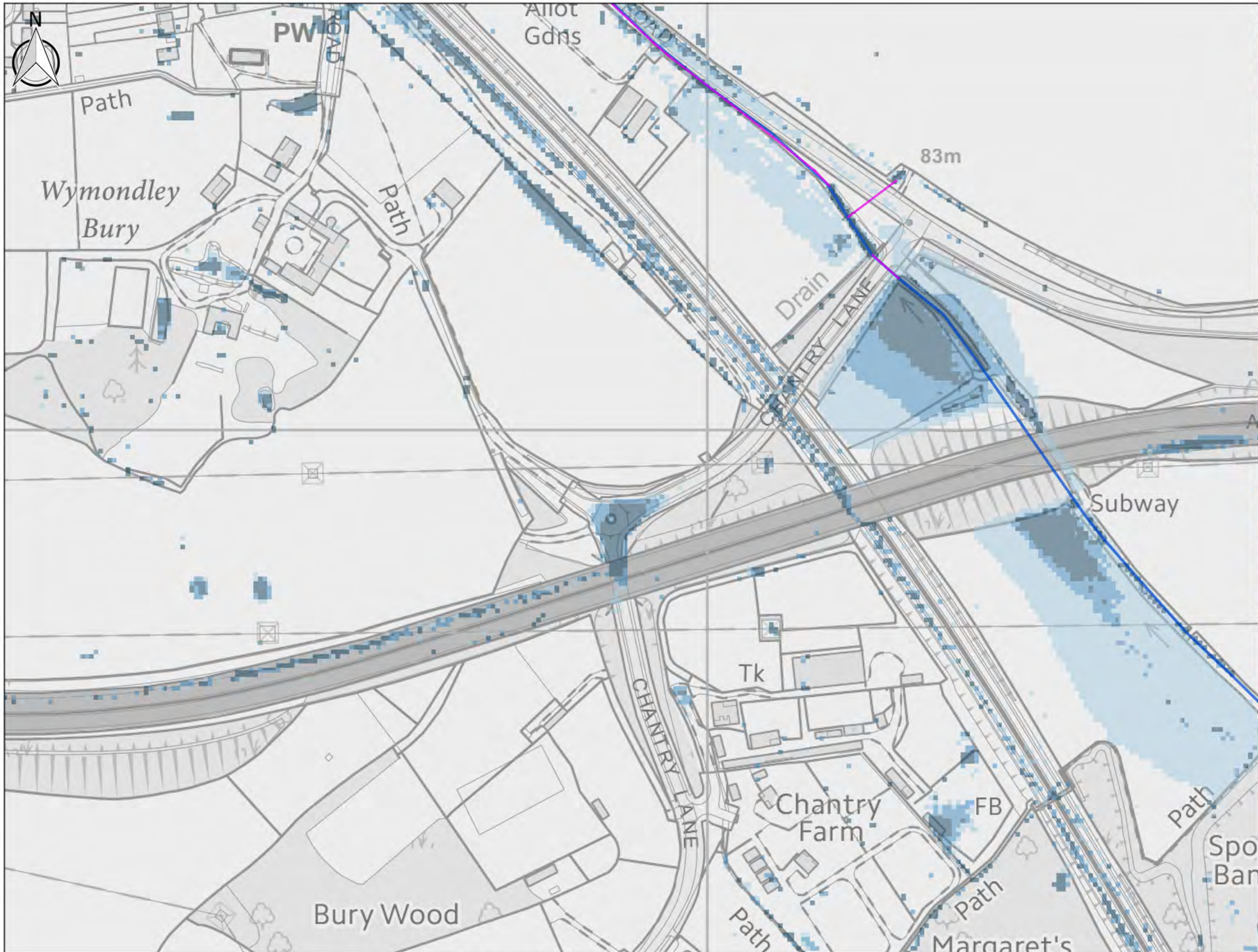
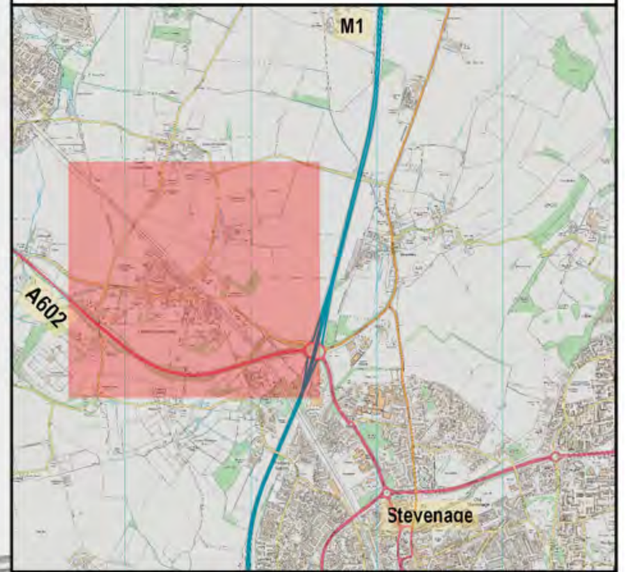
PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL_OP1_2
FIGURE DESCRIPTION	Alleviation Option 1 - 30-yr / 100-yr / 100+CC-yr Flood Extents - Sheet 2

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	31/07/2015

Hertfordshire



AREA OVERVIEW



MODEL OVERVIEW

LEGEND

Modelled Features

- Ordinary Watercourse
- Modelled Culverts

Flood Extent for Alleviation Option 1

- 30 year Rainfall
- 100 year Rainfall
- 100 year + CC Rainfall

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PROJECT TITLE	LITTLE WYMONDLEY & GRAVELY - FLOOD STUDY
FIGURE NUMBER	MCL250-07_FIG_FL_OP1_3
FIGURE DESCRIPTION	Alleviation Option 1 - 30-yr / 100-yr / 100+CC-yr Flood Extents - Sheet 3

DRAWN BY	SCALE	REVISION	DATE
CS	1:2500 @ A3	1	31/07/2015

Hertfordshire

Appendix C

Hydraulic Model Parameters

MODEL PARAMETERS

Introduction

The purpose of this model is to assess options mitigating the impact of pluvial and fluvial flooding on the village of Little Wymondley, Hertfordshire. An overland flow model of the contributing catchment was developed using the latest version of TUFLOW software at present, TUFLOW build 2013-12-AD-iDP-w64. The 64bit version facilitates faster run times, while the double precision model increases the accuracy of the software for direct rainfall models.

TUFLOW was chosen as it solves full two-dimensional depth averaged shallow water equations to produce a virtual representation of flow paths, velocities, volumes and depths associated with rainfall runoff. The river channel and culvert system have been represented in 1D, while the floodplain / flow path has been represented in 2D.

Rainfall events have been applied directly to a terrain surface (detailed subsequently) to determine an estimation of surface water flow velocities, volumes and depths.

The model has the intended purpose of:

- Replicating a recorded flood event on 7 February 2014
- Determining flood extents, depths, water levels and velocities for a range of “design” rainfall events namely 30yr, 100yr & 100yr + Climate Change return periods
- Determining the effects of schematised flood alleviation measures.

Model Extents

The primary points of interest for flood risk are the localised low point on Stevenage Road outside Elms Close at 521333 227429, and at the Plume of Feathers Public House located at the junction of Priory Lane and Stevenage Road at 521516 227457.

The extent of the modelled area is dictated by the hydrological catchment upstream of the downstream model extent located at grid reference 520573 227437.

The catchment area contributing has been delimited using an automated process utilising terrain model data. These model extents were further verified onsite by visual inspection. The entire catchment contributing from the downstream extent of the model is approximately 17.69 km^2. This catchment has been split into smaller catchments using the same process to determine individual catchments for the three inflow points outlined above.

Model Coverage

The area of assessment for the model has been determined using Graphical Information Systems (GIS) analysis of a LiDAR based terrain model, utilising the software to determine flow direction and accumulation for each cell to delineate the natural catchment. This assessment has also considered other factors such as drainage infrastructure where details are available. The Ash Brook catchment has been delineated for the agreed downstream extent of the model, with this catchment further split to facilitate detailed modelling of the watercourse. Environments Agency's surface water flood maps were also utilised in order to help define the surface water catchments.

Effectively, two models have been built for the purpose of this assessment, i.e.

- A detailed model (“Model 1” in detail the effects of flooding within Little Wymondley, with an agreed extent to provide comprehensive analysis of the flooding issue in Little Wymondley, with a downstream boundary at the extent outlined above, and an upstream extent at a point on the Ash Brook upstream of Chantry Lane. Runoff from the A1(M) has also been included within this model.
- A secondary model (“Model 2”) to determine point inflows to the upstream point of the detailed model. The upstream model was used to apply rainfall over the upstream catchment determining the inflows to the detailed model, accounting for the attenuating effects of the A1(M) upstream of the inflow point. This model has included runoff from the southern area of the A1(M) which drains to the catchment under investigation.

Model Grid Size

The detailed model (Model 1) grid size has been determined to facilitate a balance of maintaining a practicable model simulation time whilst maintaining sufficient accuracy for the study; in this case a grid size of 3m has been utilised. This was to facilitate the use of a rainfall event simulated over a number of days from recorded data to replicate a recorded flooding event. Given the detailed model area and duration of rainfall events to be modelled, the grid size was inherently limited by processing times; trial-and-error testing indicated that any further increased cell resolution would have resulted in a significant increase in processing times to days rather than hours.

For analysis using design rainfall events of 30yr, 100yr & 100yr + Climate Change (CC) return periods, the cell size remained at 3m for Model 1. The storm durations were shorter than the verification event, although the attenuation of flows upstream of the study area meant that the model had to be run for longer time periods in order to include the flows from the upstream catchment over their full duration.

Model 2 used a larger cell size to account for the fact that Model 2 has a much larger catchment and the same level of detail was not required in this area. The grid size for Model 2 was set to 10m, allowing the same rainfall event from February to be assessed, providing inflows for the detailed model whilst keeping run times to a manageable timeframe for the much larger catchment. This cell size was also retained for the design rainfall events outlined above, maintaining consistency in the approach to Model 2 for all model runs.

In both cases the model represented an appropriate degree of accuracy whilst maintaining reasonable run times for the project.

Model Topography

A terrain model was generated to represent the topography of the area, primarily defined using LiDAR data as provided by Hertfordshire County Council for use in the project. The LiDAR data in grid format was utilised as the surface used for the base conditions of the model. This data was originally obtained from Environment Agency and was previously utilised in a national surface water flood mapping study.

This LiDAR data terrain was altered using TUFLOW to include on-site topographic survey to improve terrain definition particularly around watercourse channels, including top of bank levels, kerb levels and road embankments. This was carried out by utilising the software to alter the underlying DTM, reinforcing heights using shapefiles to specify locations and alter the values as required.

The process was also used in Model 1 to smooth out steep changes in topography and remove any significant mass errors in locations where steep slopes relating to road and railway embankments led to mass balance errors and artificially high flood depths.

In Model 1, an online pond located at The Priory has been artificially introduced to the terrain. The outlet to the pond is controlled by a weir which spills to a culvert conveying flows across the lane for Priory Farm. Based upon the antecedent weather conditions the pond has been modelled as full at the time of the storm event, with water levels set to the surveyed weir levels. These levels were also retained for the design event runs to negate the storage effect of the pond to ensure a worst case scenario has been assessed..

Building footprints for the detailed model have been represented using building polygons from OS Mastermap data and applying a standard figure to raise elevations by 150mm in line with the methodology preferred by TUFLOW. This allows a preferential flow path to be created around the building threshold without causing steep changes in topography which would lead to model instabilities. To account for water levels breaching the building thresholds the roughness values for building footprints have been varied with height, this has been explained further below.

In Model 2, there was a need to input culverts at road embankments in order facilitate known flows through embankments within the 2D area, including the crossings at the A1(M) and the A602. As the level of detail required was less than that of Model 1, building footprints were not included within the topography of Model 2.

Figure C1: Model 1 Conditions

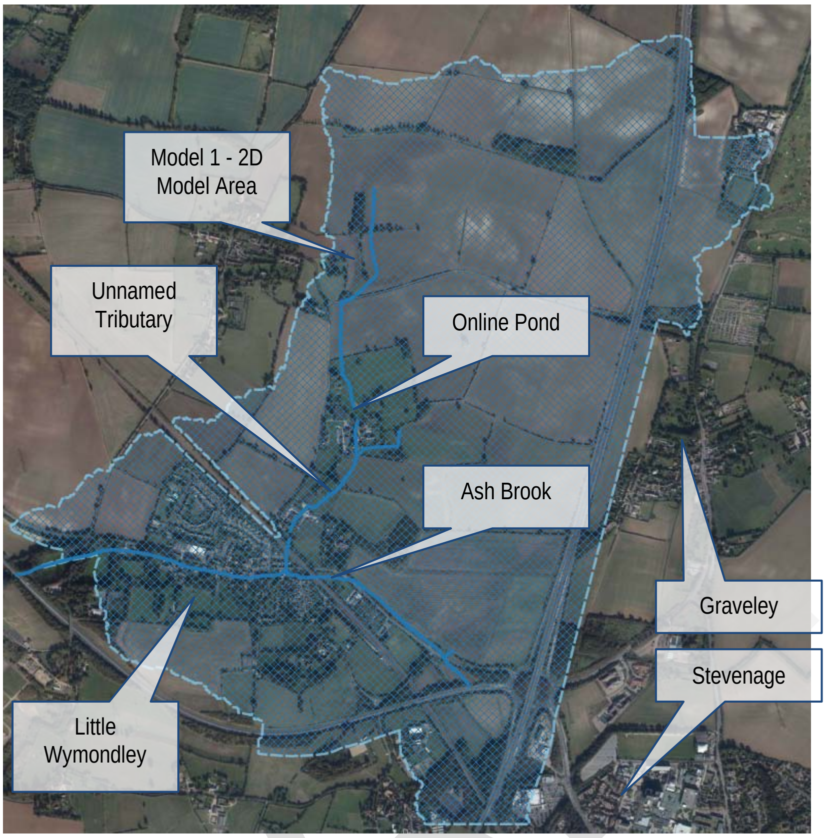
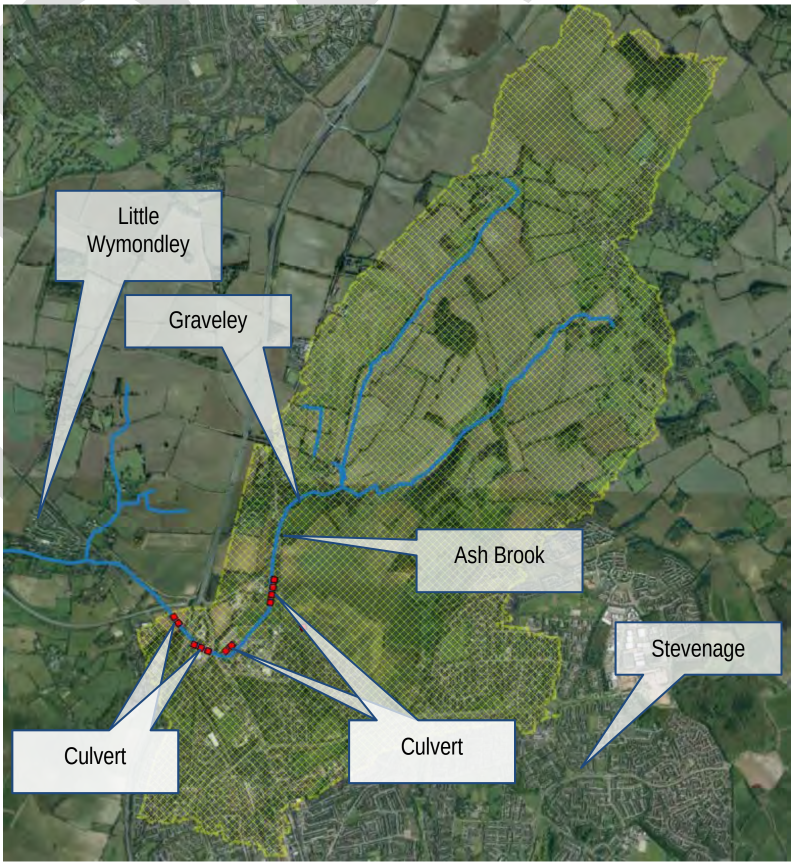


Figure C2: Model 2 Conditions



Watercourses

Two watercourses affect the study area, as follows.

- Ash Brook flows from east to west along Stevenage Road. The catchment for the upstream inflows to this watercourse is 14.1km^2, which includes the settlement of Gravely and drains an area of north Stevenage. The watercourse is extensively culverted over its reach as detailed subsequently.
- A secondary unnamed watercourse runs from north to south along Priory Lane (hereafter Priory Lane Stream), discharging to the Ash Brook at the junction of Priory Lane and Stevenage Road. The watercourse with catchment 2.29km^2 is similarly extensively culverted, with numerous culverts and field crossings along Priory Lane. The watercourse drains to and from a pond within The Priory itself which acts as an attenuation feature.

Watercourses in this model have been modelled as 1D, using the ESTRY component of TUFLOW Software. Representation of channel geometry used discrete cross sections taken transversely at key locations along the watercourse. These cross sections were taken by an approved surveyor to a specification prepared by McCloy Consulting Ltd., tied to Ordnance Datum. The positions of the cross sections were based primarily on the location of structures and significant changes in channel and structure geometry. Other factors influencing the final cross-section locations were conditions on site (visibility, access and obstructions).

Structures

Structures within the Model 1 area have also been assessed as 1D components with the ESTRY module. Structures were identified during the initial site walkover and details have been taken from a combination of sources, including the topographic survey, existing CCTV survey data and additional CCTV survey carried out during the course of this investigation.

Structures identified and the nature of their representation within the model are scheduled as follows:

Table C1: Culverts & Assets As Modelled

Ref	Model Ref	Size / Description	Notes
1	AshBrk_01	1 No. 0.9m Circular Pipe	Modelled as surveyed
2	AshBrk_02 – to AshBrk_12	1 No. 0.825 to 0.9m Circular Pipe	Pipe sizes vary along this stretch, dimensions based upon existing cctv, on site survey and commissioned cctv
3	AshBrk_13	1 No. 1.2m Circular Pipe / brick arch culvert	CCTV indicates both circular pipe and brick arch culvert with varying dimensions, 1.2m diameter circular pipe used as conservative representation
4	AshBrk_14	1 No. 2.15 x 1.1m Arched Brick Culvert	Modelled as box culvert to keep within the culvert system, TUFLOW bridge arch not applicable in this case
5	AshBrk_15	1 No. 1.05m Circular Pipe	Modelled as surveyed
6	AshBrk_16	1 No. 1.3m Circular Pipe / Brick Culvert	Modelled as surveyed
7	AshBrk_17	1 No. 2.1 x 1.225m Rectangular Box Culvert	Modelled as surveyed
8	AshBrk_18	1 No. 2.38 x 1.33m Rectangular Box Culvert	Modelled as surveyed
9	AshBrk_19	1 No. 1.05m Circular Pipe	Modelled as surveyed

Table C1: Culverts & Assets As Modelled			
Ref	Model Ref	Size / Description	Notes
10	AshBrk_20	1 No. 1.5m Circular Pipe	Modelled as surveyed
11	AshBrk_21	1 No. 2 x 1.32m Rectangular Box Culvert	Modelled as surveyed
12	AshBrk_22	1 No. 1.5m Circular Pipe	Modelled as surveyed
13	AshBrk_23	1 No. 2.62 x 1.4 m Rectangular Box Culvert	Modelled as surveyed
15	PryLn_01	1 No. 0.3m Circular Pipe	Based upon combination of existing CCTV and survey
16	PryLn_01a	1 No. 0.6m Circular Pipe	Based upon combination of existing CCTV and survey
17	PryLn_02 to PryLn 04a	1 No. 0.3m Circular Pipe	Based upon combination of existing CCTV and survey
18	PryLn_05	1 No. 0.45m Circular Pipe	Pipe acting as outlet from pond structure, upstream invert level set to level of weir to replicate that only flows above this level reach culvert - approach used to increase model stability
19	PryLn_06	1 No. 0.45m Circular Pipe	Modelled as surveyed
20	PryLn_08	3 No. 0.3m Circular Pipe	Modelled as surveyed
21	PryLn_09	1 No. 1.2 x 1.06m Rectangular Box Culvert	Modelled as surveyed
23	PryLn_11	1 No. 0.575m Circular Pipe	Modelled as surveyed
24	PryLn_12 to PryLn_13	1 No. 0.6m Circular Pipe	Modelled as surveyed
25	PryLn_14	1 No. 0.6m Circular Pipe	Modelled as surveyed
26	PryLn_15	1 No. 1m Circular Pipe	Based upon existing CCTV

Model 2 also includes a number of structures which have also been modelled as 1D components, these structures are located at embankments which act as restrictions to flow across the 2D surface. In contrast to Model 1, these structures are connected directly to the 2D surface, with a point inflow at the culvert entrance and a discharge point downstream of the culvert to the 2D surface.

In the case of the 7 February 2014 replication, blockages of culverts has been replicated by using the TUFLOW input parameter by defining the %-age availability of the cross section area available for flow conveyance particular to each culvert structure.

Boundary Conditions

At the downstream extent of the model a boundary condition was applied to allow the flows to leave the 2D boundary, preventing "glass walling" at the downstream boundary. This was represented as a HQ boundary, which represents a water level (H) versus Flow (Q) boundary condition, with a water surface slope value specified at 0.01, which is in meters per meter and corresponds to a 1% water surface slope.

A simplified model was created to develop a stage-discharge flow curve for this location in Model 1, based upon the underlying topography, roughness and specified water surface slope based upon TUFLOW recommended approach. This boundary has been sited sufficiently downstream of the study area to prevent the possibility of levels being artificially influenced by any restrictions.

Boundary conditions were also applied along the 1D network to replicate the interaction of the river channel with the 2D surface - the height of this boundary was set using the levels recorded in the topographic survey to record river cross sections.

Roughness Values

Mannings Roughness values have been applied according to the type of surface, with the surface type having been delineated as determined previously. This data has been digitised at a scale between 1:1,250 and 1:10,000 and as such accuracy is deemed suffice for use in the model build process. These roughness values are applied within the TUFLOW boundary condition database file, with values described in the following table.

Feature Code	Descriptive Group	Comment	Manning's' Roughness
10021	Buildings	Roughness changes according to depth, <300mm & >300mm	0.015 & 0.5
10056	General Surface	Pasture	0.05
10089	Water	Inland	0.04
10167	Rail	Railway	0.12
10172	Roads Tracks and Paths	Tarmac	0.02
10056	Hardstanding	Hardstanding	0.03

Due to the nature of the 2D area, buildings have been modelled as raised footprints, to allow a flow path around buildings to be assessed while retaining the stability of the model by not including steep changes in topography. A lower roughness value has been applied to depths below 300mm to allow runoff from the building to flow across the surface, while above this threshold the resistance was increased to represent the obstruction to flow paths presented by buildings.

Assumptions and Limitations of Modelling

The representation of any complex system by a model requires a number of assumptions to be made. In the case of the two dimensional hydraulic model of the surface water system developed for the purposes of the study it is assumed that:

- The terrain model (based on LiDAR supplemented by ground-based topographic and bathymetric survey) accurately represents the surface topography and associated flow paths.
- The design flows are an accurate representation of flows of a given return period. Design flows are reliant on rainfall records (in the case of the 7 February 2014 Replication model.
- Roughness does not vary with time.

The primary limitations of the study are noted as follows

- Sewerage and culverted surface water drainage have not been modelled;.
- The model does not represent any topographic features smaller than the minimum grid size (3m) in the case of Model 1;
- Model 2 does not fully represent the Ash Brook watercourse, it is in the main a 2D model with 1D culvert elements included to facilitate flows through embankments within the surface;
- Insufficient topographic and drainage information is available to allow detailed assessment of surface water flooding issues remote from the Ash Brook and Priory Lane within Model 1. The model includes areas a wider catchment than the area of particular interest in order to determine inflows from those areas; however model results are not intended to be accurately representative of flooding in the wider catchment and should be read as such.
- Insufficient topographic information is available to allow detailed modelling of building thresholds or floor levels.

MODEL HYDROLOGY & FLOW ESTIMATION

Model Inflows (Rainfall Data)

7 February 2014 Replication

Environment Agency has provided recorded rainfall data from the weather station at Whitewell STW (NGR TL1919720812) which was used to determine a rainfall hyetograph, the values from which were used in applying direct rainfall within the model.

Met Office Rainfall and Evaporation Calculation System (MORECS) data was obtained from the Met Office to verify the rainfall data used for model verification, the data for which was recorded at the weather station at Ashbrook Sewerage Works (NGR 5201E 2275N).

Design Events (including Flood Alleviation)

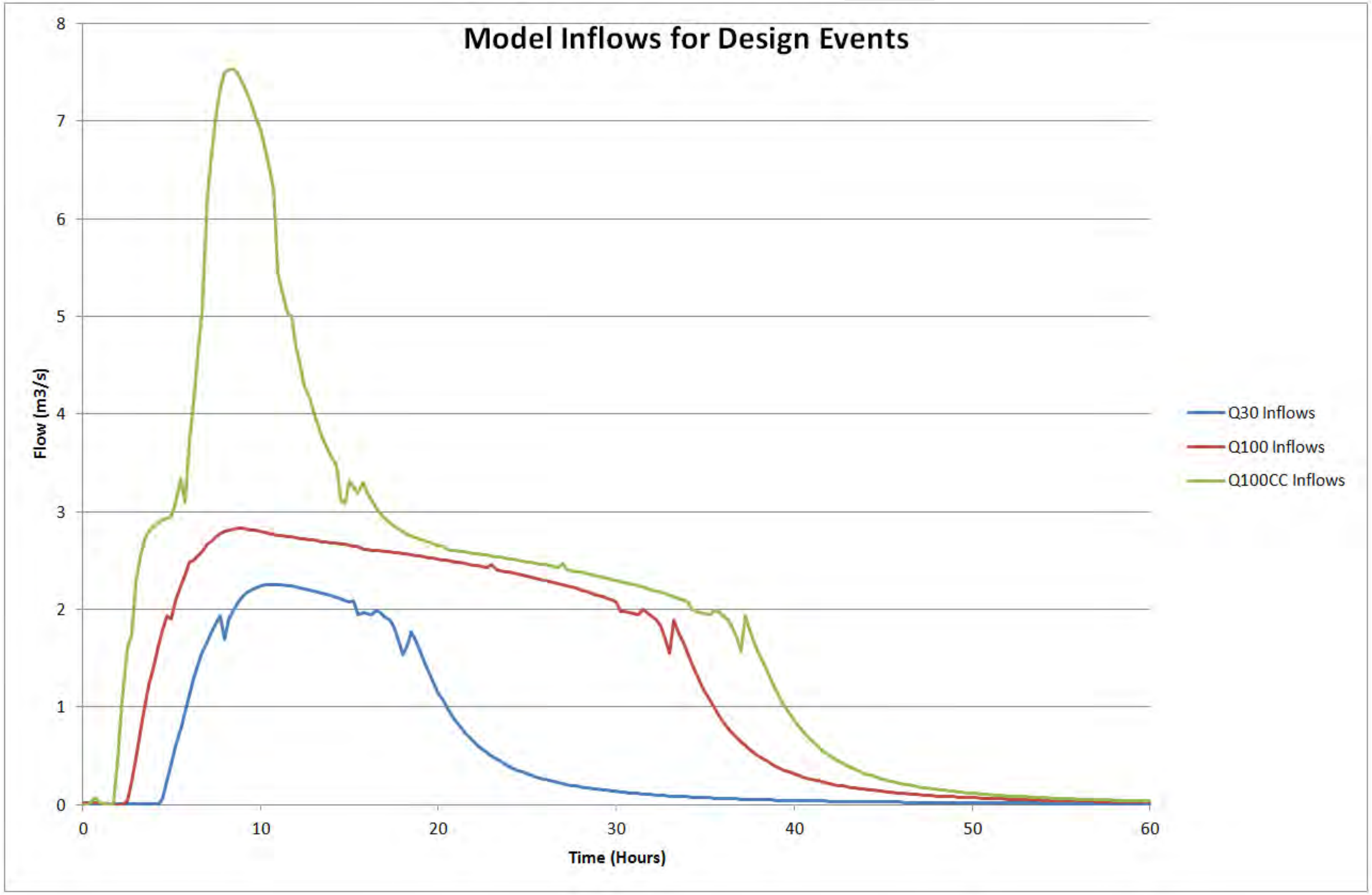
Environment Agency has provided total rainfall data and effective rainfall data including rainfall hyetograph profiles for return periods of 30, 100, and 1000 year and 1, 3, and 6 hour durations. Effective rainfall profiles (common to EA surface water flood mapping) provide coverage to the whole (Model 1 + Model 2) area and have been used in all instances.

For climate change modelling the 100 year profile was used and a 30% increase applied to the rainfall hyetograph in order to replicate the predicted effects of climate change on the design scenario.

Model Outflows

As indicated Model 2 has been used to determine point inflows to the Model 1 1D network. Model outflows at the outlet have been determined by the Tuflow Plot Output (PO) system which has determined flow passing a cross section (representing the full width of flow at that location) at each model timestep. That data has been collated and formed into a hydrograph for each rainfall scenario for input into Model 1. Resulting hydrographs are indicated graphically on the following figure.

Figure C3 Model 2 Outflow / Model 1 1D Inflow Hydrographs



Drainage Network & Ground Condition Representation

Catchment Surface Delineation

Catchment surfaces have been wherever feasible determined based on Ordnance Survey Mastermap polygonised classification data provided by Hertfordshire County Council for purposes of the assessment.

Residual areas of Model 2, for which Mastermap data is unavailable, have been determined using Open Street Map data which was deemed suitable given the level of detail within Model 2. For these areas the building polygons were used along with the road and railway lines which were buffered to create polygons which represented the areas covered by these surfaces.

Roads & Hard standing Areas

Direct rainfall models usually include an allowance for surface drainage networks and surface water losses associated with this. The investigation has identified that surface water runoff from roads within the model area drains via gullies along the road generally discharging directly to the adjacent respective watercourse.

Insufficient information has been made available by the local water or highway authority to allow surface drainage systems to be incorporated within the model. The consequences of this limitation are not considered significant; the assessment of flood mechanisms has determined that the gullies are unlikely to be fully functional during some or all instances of flooding, as water levels within the Ash Brook prevent discharge to the watercourse and/or would surcharge gullies.

In the absence of a surface drainage network within the model, losses associated have been rationalised as follows (varying dependant on the nature of the modelled event)

- 7 February 2014 Replication - model has assumed that there is an initial loss of 5mm rainfall, with no continuing losses due to likelihood of surcharge / gully incapacity.
- Design Events (including Flood Alleviation) – model permits no losses due to the nature of the effective rainfall profile (incorporating losses) used.

Undeveloped Surfaces

For purposes of 7 February 2014 Replication, the analysis of MORECS data indicated that the weather prior to the flood event had led to c. 80% saturation of the ground surface. An initial loss of 5mm was applied across the remaining catchment, in line with industry standards which generally accept that grassed areas will intercept the first 4-5mm of rainfall.

TUFLOW has a built in infiltration feature which can model soil losses via three options, namely, Initial Loss / Continuing Loss, Green-Ampt method and Horton Approach. For the purposes of model verification the Green - Ampt method has been used, which applies infiltration losses to permeable surfaces based upon underlying soil type, identified through assessment of boreholes in the vicinity. TUFLOW uses the hydraulic properties associated with a textural class to vary infiltration over the model time period. Different approaches have been used for the verification event and the design events.

An initial moisture content of 60% was used for the verification model, to allow for the rainfall included within the modelled time series, which preceded the flood event by 3 days.

The rate of infiltration is monitored throughout the simulation and once soil is saturated no further infiltration occurs. Using the information from the borehole results a soil layer was created across the 2D area, representing a sandy clay. The values contained within the TUFLOW software are presented in the table below, it should however be noted that these values are not based upon UK soils and TUFLOW represents these as simplified hydraulic properties.

USDR Soil Type	Suction (mm)	Hydraulic Conductivity (mm/h)	Porosity (fraction)
SANDY CLAY	239.0	0.6	0.321

For Design Events, models permit no losses due to the nature of the effective rainfall profile (incorporating losses) used and effectively uses 100% runoff in these scenarios.

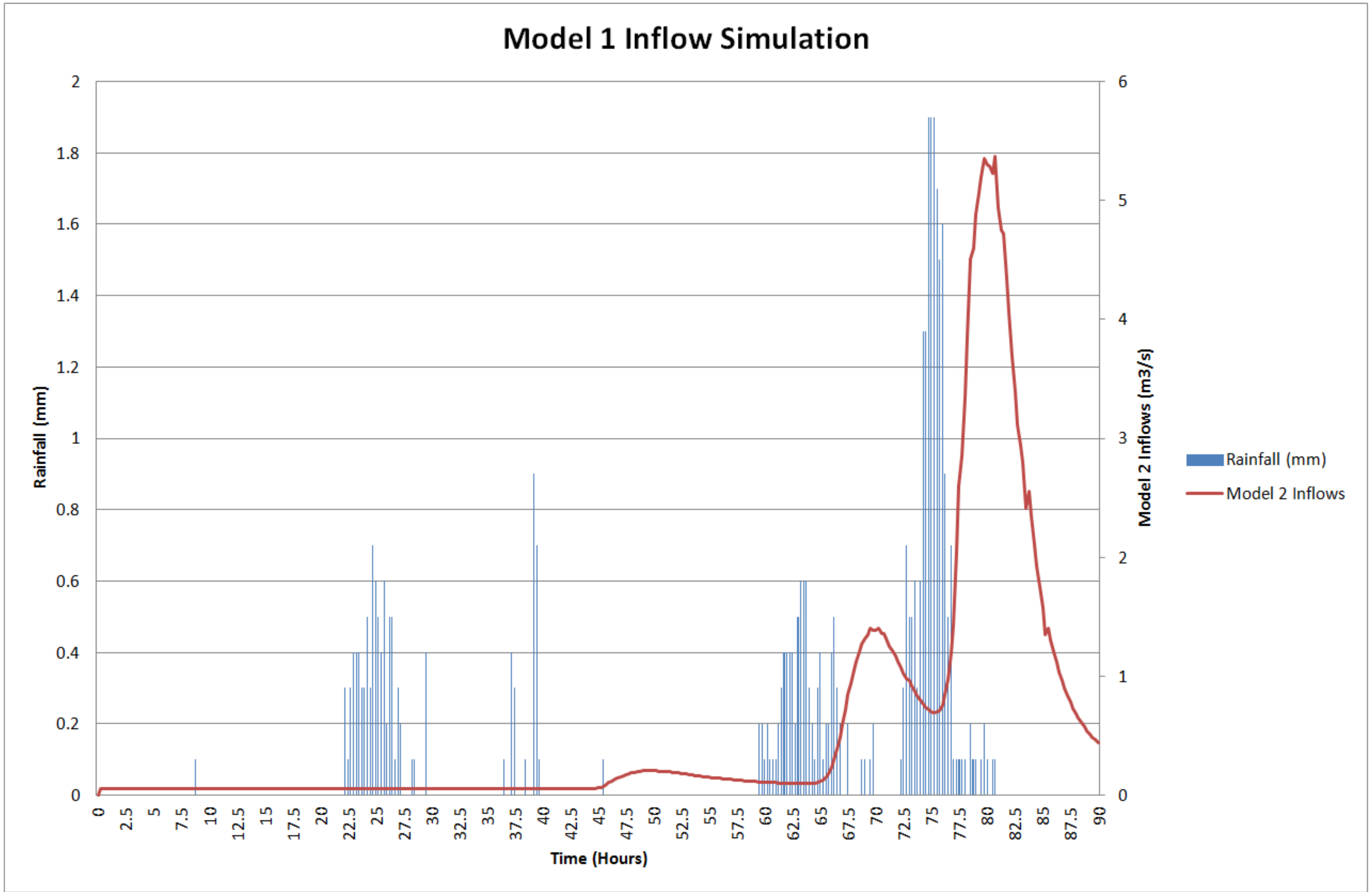
Simulation Times

7 February 2014 Replication

The replication event extends from 0000hrs, 04 February 14 to 1800hrs, 07 February 14 (i.e. a period of 90 hours / 3.75 days). The model duration is intended to replicate the increasing wetting of the catchment and gradual accumulation of flows in watercourses prior to the high intensity rainfall on 6/7 February that was understood to have triggered the flood event.

The model duration includes a period of 12 hours after the end of the rainfall event to allow for drain down of the flood and lag time caused by the Ash Brook (Model 2) hydrograph response.

Figure C4 Model 4 Inflow Chart



Design Events (including Flood Alleviation)

Initial model runs were undertaken to determine the critical duration rainfall event (influenced by how a catchment responds to rainfall caused by characteristics of topography, land use, size of the upstream catchment and nature of drainage systems). Rainfall durations considered and associated model simulation times are as follows:

- 1 hour rainfall – 40 hour simulation,
- 3 hour rainfall – 40 hour simulation
- 6 hour rainfall – 40 hour simulation

In all instances the 1-hour rainfall event has been determined to be critical, with criticality determined as causing the most onerous flood (in terms of flood extent / depth) in the vicinity of the pub in Little Wymondley, Stevenage Road and the area around Elms Close. The depths associated with these locations can be seen in the following table.

Table C2: Critical Duration Analysis

Return Period	Location Description	1HR Event Water Depth (m)	3HR Event Water Depth (m)	6HR Event Water Depth (m)
Q30	Stevenage Road East of Priory Lane	0.21	0.21	0.19
Q30	Priory Lane at Bladon Close	0.68	0.67	0.63
Q30	Stevenage Road at Wymondley Chapel	0.41	0.41	0.37
Q100	Stevenage Road East of Priory Lane	0.31	0.27	0.24
Q100	Priory Lane at Bladon Close	0.88	0.83	0.75
Q100	Stevenage Road at Wymondley Chapel	0.64	0.58	0.48

There were some further refinements to the design model once the critical duration had been identified, including the removal of some blockages, hence these figures will differ slightly from those presented in the main body of the report.

All subsequent model runs including testing of alleviation options adopted a 1-hour rainfall profile and 40 hour simulation time, with that run time determined by trial and error as the time taken for inflows from Model 2 to peak and substantially recede.

Figure C5 Q30 Inflow Chart

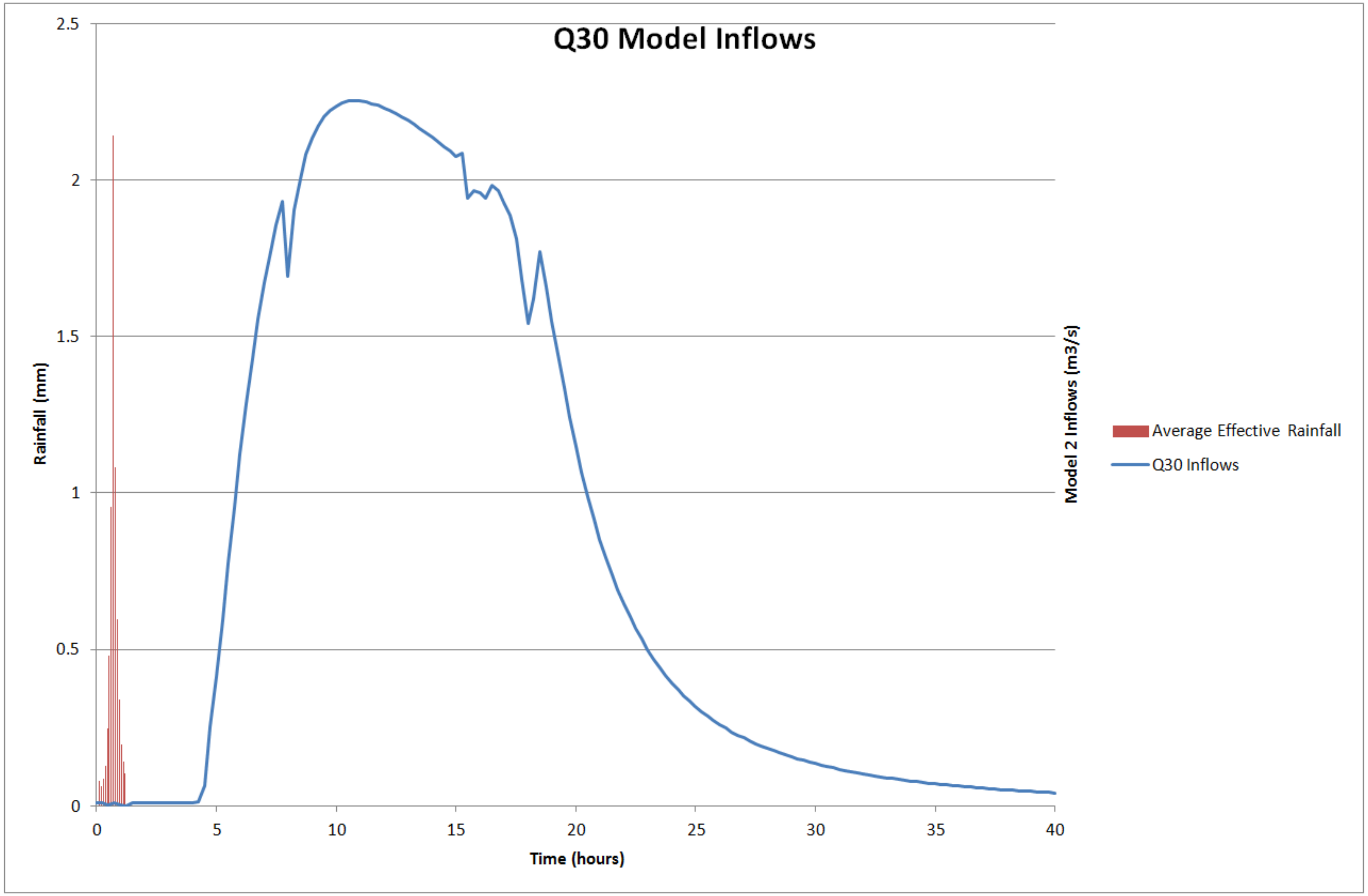


Figure C6 Q100 Inflow Chart

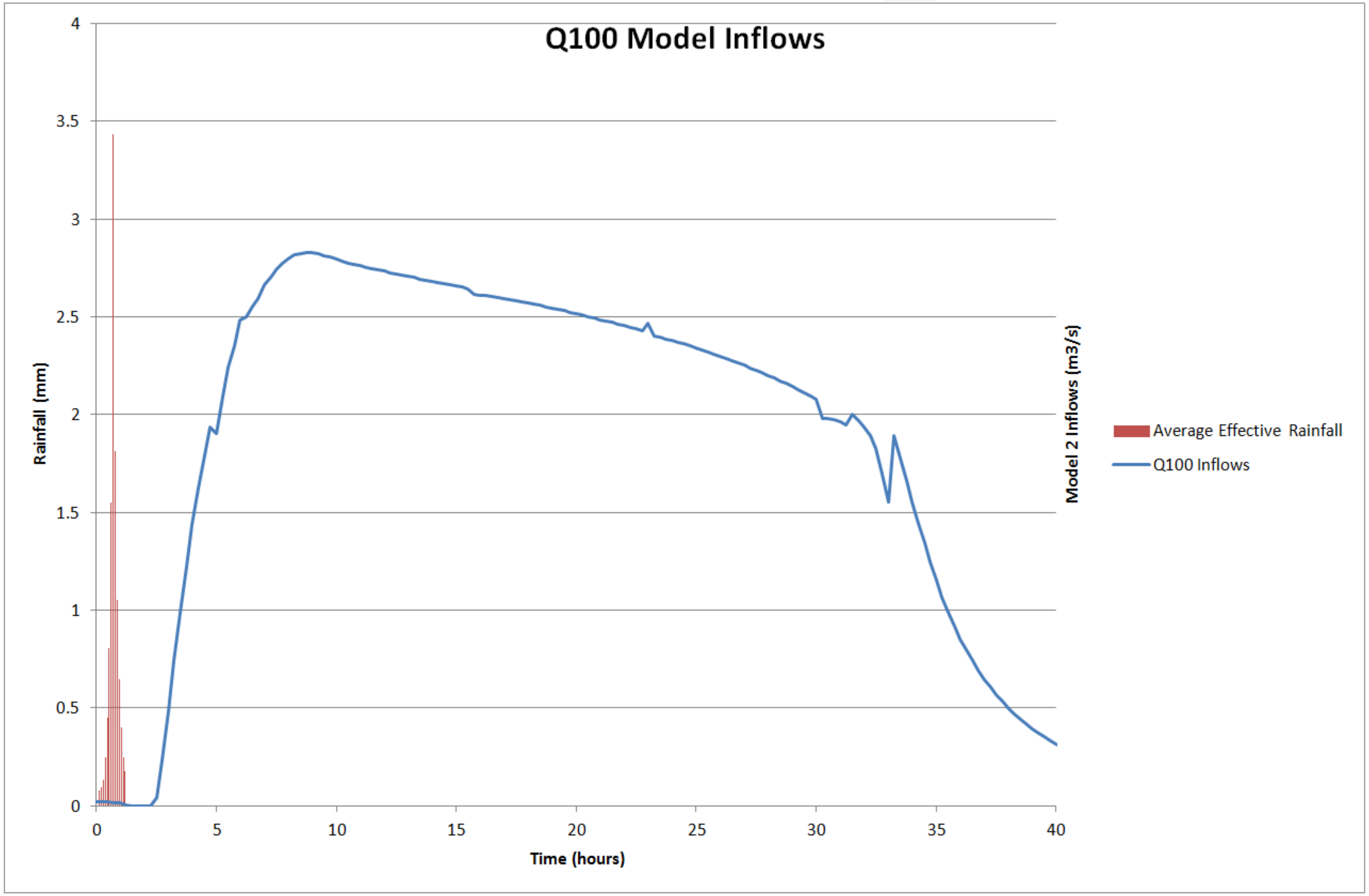
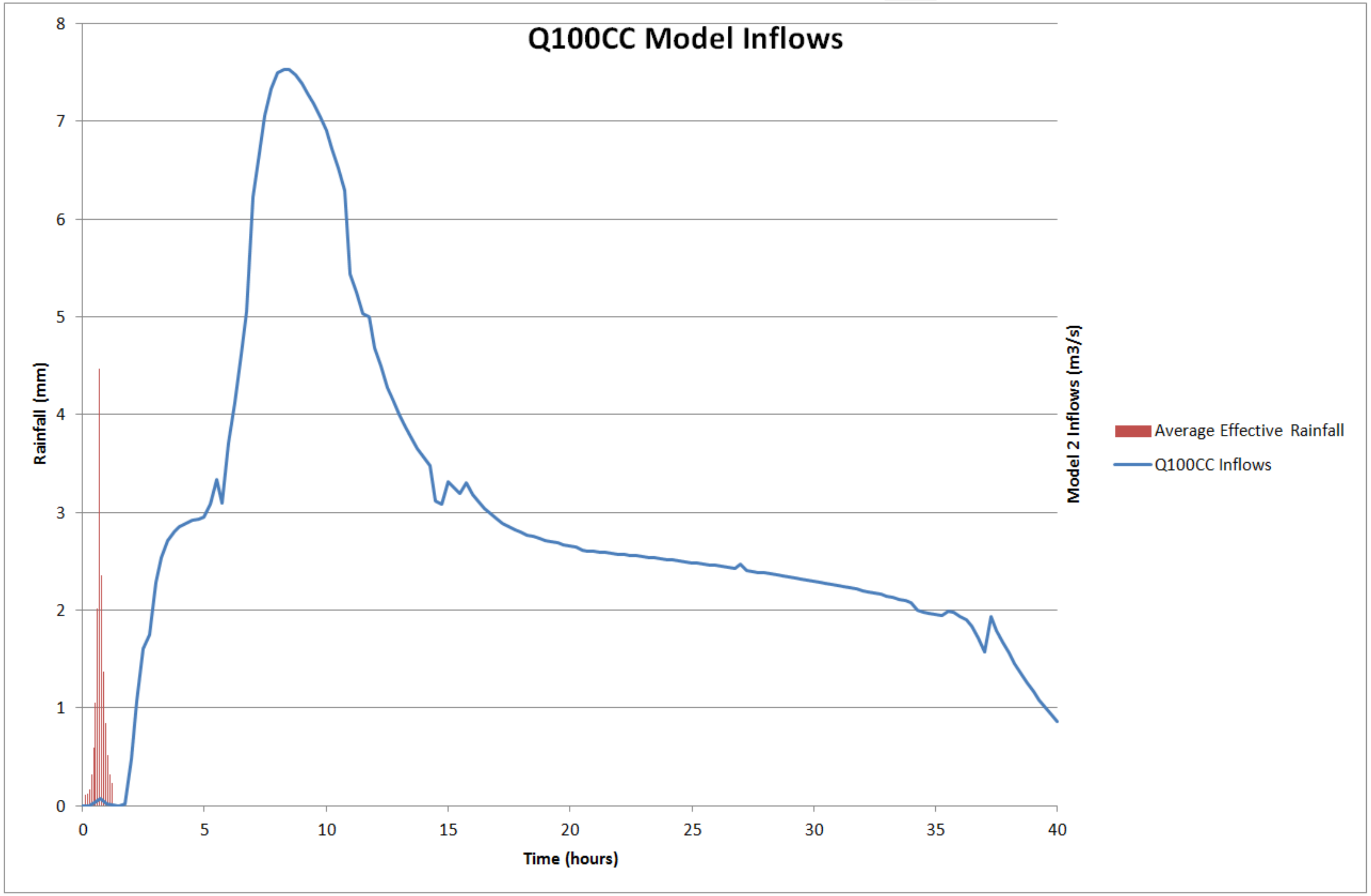


Figure C7 Q100CC Inflow Chart



MODEL RESULT REPORTING

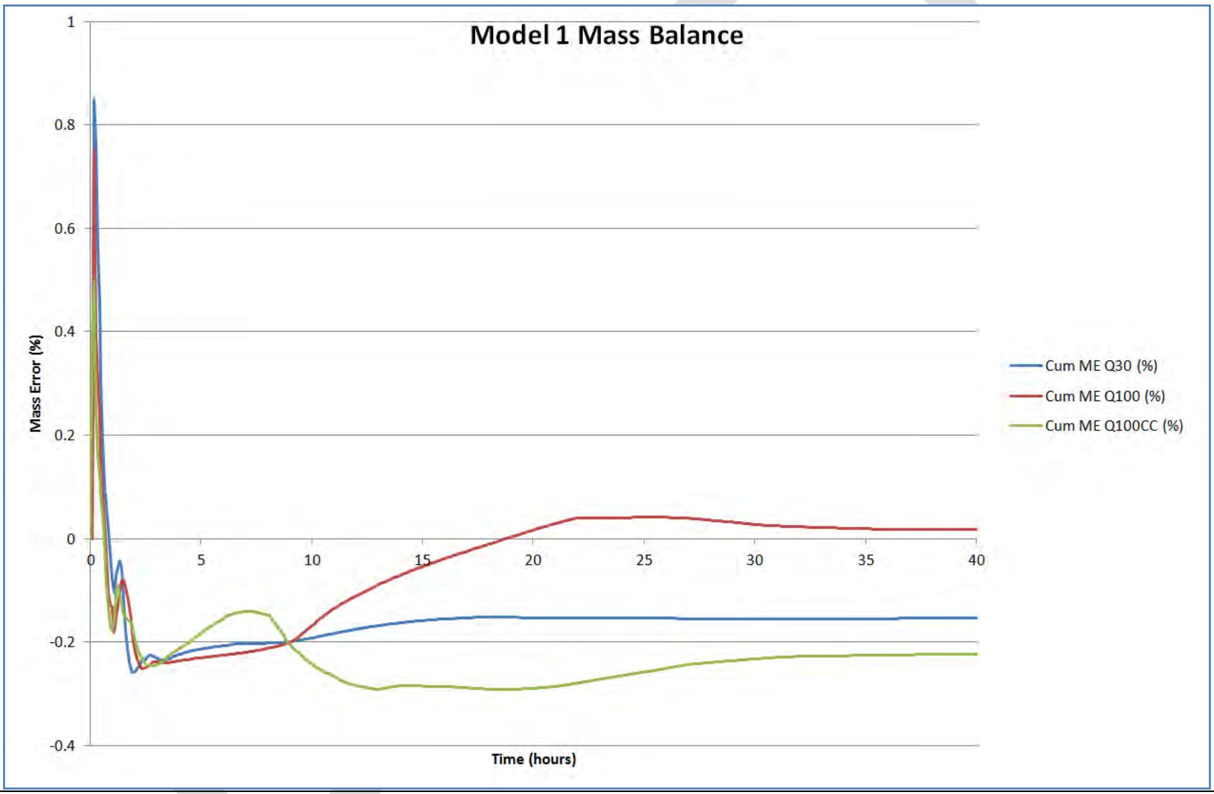
Model Stability

To increase the level of confidence that can be placed on model predictions, it is important that the stability of the model be assessed. Stability in a TUFLOW model is assessed by examining the cumulative error (or mass balance) of the model as well as the warnings output by the model during the simulation.

In direct rainfall modelling the inflows can lead to rapid wetting of the 2D domain causing fluctuations at the start of the simulation, as seen in the figure below.

The following figure shows that the cumulative error of the model is within the recommended range of +/- 1.5% for the entire model run. The peak at the beginning of the model run is representative of the high intensity rainfall event, with the spikes representing rapid wetting of cells for the event, settling once the peak has past and inflows to the model are then dependent upon the inflows from the upstream catchment.

Figure C 8: Design Storm Simulations- Model 1 Mass Balance



Model Sensitivity

Model sensitivity analysis was based on both Model 1 and 2 to assess the sensitivity of the simulation to changes in base parameters. Flow and volume were assessed along observed flow paths to determine any variation in results in response to the changes, and extents for flood outlines compared.

Sensitivity to Initial losses

The base (February 2014) model was tested to assess its sensitivity to changes in initial losses applied to the main surfaces represented within the catchment, testing was carried out using initial losses of 0mm, 5mm and 10mm. These initial losses have not been included for the "Design Event" scenarios as the effect of losses has been accounted for in the production of the effective rainfall hyetographs, and are not required in these events.

Results from the sensitivity testing showed no significant differences within the model output - the flow paths and areas identified as flooding remained the same. There were differences noted in the peak flows and volumes, accounted for by the varying volumes lost according to the Initial Loss setting. The design event tested is an extremely high intensity and these losses therefore will have limited impact upon the results of the assessment.

Industry standards generally accept that grassed areas will intercept the first 4-5mm of rainfall which occurs across a catchment, and given that sensitivity assessment shows this to have no significant impacts on the model an IL rate of 5mm has been applied to the verification model.

Sensitivity to Mannings Roughness

The sensitivity of the modelled water levels to channel and floodplain roughness was checked by varying the standard values of Manning's n for the base model

Results from the sensitivity testing show no significant differences within the model output - flow paths and areas identified as flooding remain the same. There is some negligible difference in peak flows and volumes, although they largely remain with the same tolerances, with a negligible lag due to the variance in runoff from the surfaces. For this study the watercourse is considered to be moderately sensitive to roughness, however careful consideration has been given to conservatively specifying Manning's n and there is therefore reasonable confidence in model results.

Sensitivity Analysis Summary

The sensitivity analysis demonstrates that the model can be deemed reliable and is not overly susceptible to errors in roughness or initial loss.

Flow Measurement

A methodology has been developed in order to assess the combination of 1D and 2D flow results simultaneously, determining the proportion each mechanism is contributing at specific locations.

As indicated Model 2 has been used to determine point inflows to the Model 1 1D network. Model outflows at the outlet have been determined by the Tuflow Plot Output (PO) system which has determined flow passing a cross section (representing the full width of flow at that location) at each model timestep.

The methodology utilises the Tuflow Point Output (PO) system which has determined 2-dimensional flow passing a pre-defined cross section generally perpendicular to flow paths. PO lines were digitised based on preliminary model results and refined iteratively to suit. 1 Dimensional flows passing are reported separately at discrete nodes within the 1D ESTRY network. Cumulative flows passing given points at particular locations were determined by spatially linking and accumulating 2D PO results with coinciding 1D nodal results.

FLOOD ALLEVIATION OPTION – MODEL BUILD METHODOLOGY

Preamble

Model 1 has been further utilised to assess the impact of flood alleviation measures outlined in Section 5 of the main report. The key features of these measures include:

- Attenuation / Detention of the Priory Lane Catchment;
- Attenuation of Ash Brook sub-catchment (agricultural lands north of Stevenage Road / west of A1(M));
- Culvert upgrades between AshBrk_02-12 (various diameters (0.825mØ min) increased to 1.35mØ);
- Culvert upgrade AshBrk_19 (1.05mØ increased to 1.5mØ).

Model Inflows

In replicating the attenuation/detention of the two catchments above the model was altered as follows:

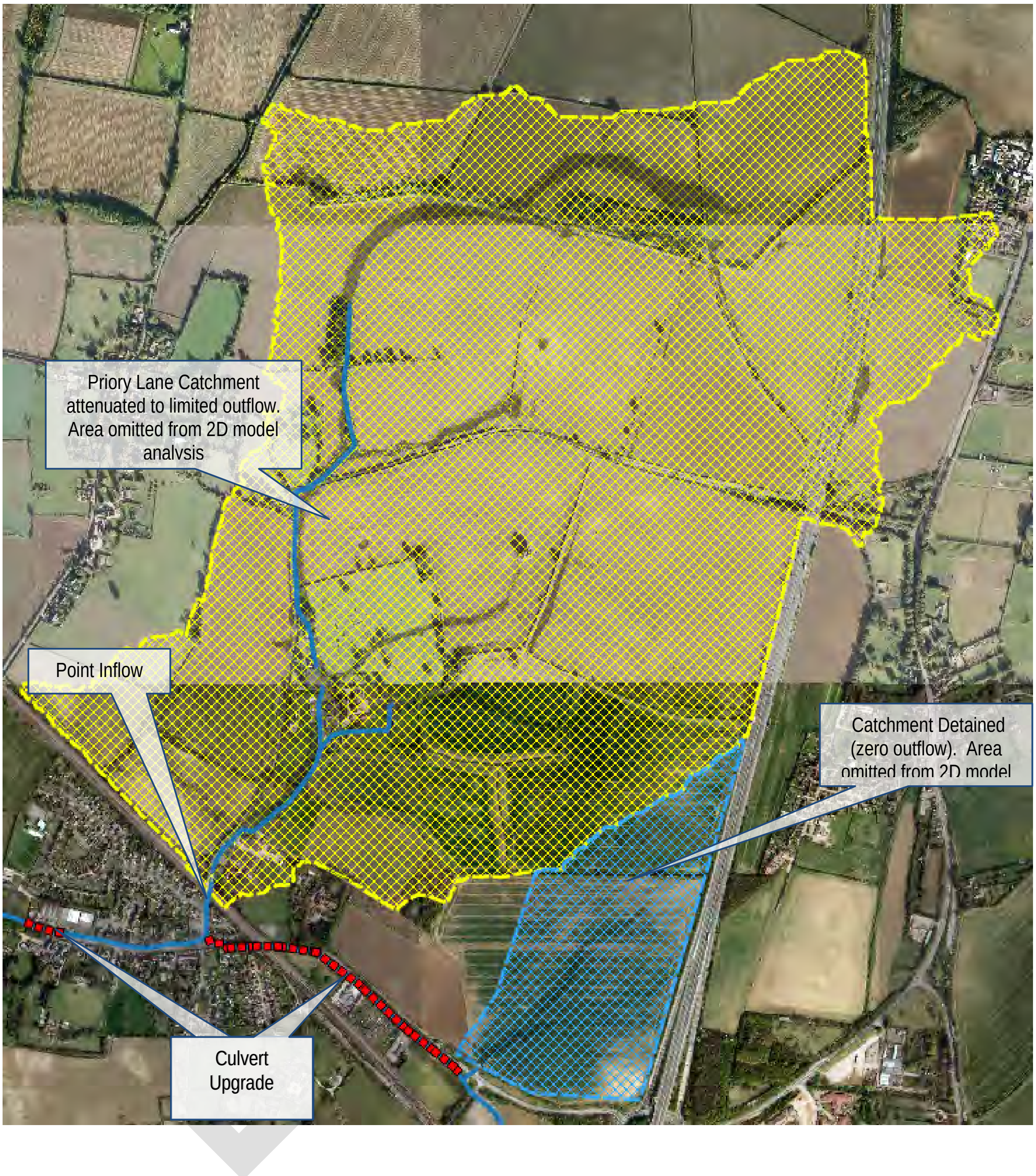
- For Priory Lane catchment, a point outflow hydrograph was determined at the downstream extent of the catchment (i.e. approximately the confluence with Ash Brook) for the Design events. The hydrograph was modified to cap outflows to no greater than 1.4 m^3/sec assuming 100% efficiency of a hypothetical upstream attenuation of flows. The hydrograph was introduced to the proposed scenario model as a point inflow to the 1D network at Bladon Close. The corresponding upstream catchment area was omitted from the model by applying no rainfall to the area and omitting the catchment extent from the2D model area.
- For the Lands North of Stevenage Road, the scenario assumed 100% detention of flows from the contributing catchment. No inflow was applied from the catchment. The corresponding upstream catchment area was omitted from the model by applying no rainfall to the area and omitting the catchment extent from the2D model area.

Structures

- Proposed respective culvert upgrades have been implemented by revising the 1D ESTRY property table for culvert structures to the proposed opening size. Replacement culverts adopted identical invert levels to that in the existing scenario. Replacement culverts adopted identical alignments to that in the existing scenario.
- Modelling makes no allowance for the constructability of culverts at such levels that may be constrained by cover requirements, utility clashes etc.

The modifications associated with the options as applied within the model are shown on the following figure.

Figure C9- Options Model - Proposed Alleviation



Appendix D

Cost Estimates

Alleviation Option 1

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Ref	Item	Measurement	Unit	Rate	Cost	Notes
1	Stevenage Road Culvert • AshBrk_02 - _12					
		Measurement	Unit	Rate	Cost	Notes
1.1	Install 1350 Replacement Culvert, including costs for working in live carriageway and carriageway reinstatement, assume there are no manholes, lateral connections	600	m	£ 1,800	£ 1,080,000	Per Table 1.2, Cost estimation for culverts – summary of evidence Report –SC080039/R4, Environment Agency 2014
1.2	E/O #1.1 for removal of existing culvert, installation of manholes, headwall, screens, restoration of lateral connections & ancillary works	5	%		£ 54,000	Assumed @ 5% culvert installation value
	Subtotal				£ 1,134,000	
	Allowance for preliminaries	6	%		£ 68,040	
	Allowance for Contract Contingencies	10	%		£ 113,400	
	Allowance for Optimism Bias	20	%		£ 226,800	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mid bound guidance for standard civil engineering projects
	Optimised Subtotal				£ 1,542,240	
2	Stevenage Road Culvert • AshBrk_19					
		Measurement	Unit	Rate	Cost	Notes
2.1	Install 1500 Replacement Culvert, including costs for working in live carriageway and carriageway reinstatement, assume there are no manholes, lateral connections	73	m	£ 1,800	£ 131,400	Per Table 1.2, Cost estimation for culverts – summary of evidence Report –SC080039/R4, Environment Agency 2014
2.2	E/O2.1 for removal of existing culvert, installation of manholes, headwall, screens, restoration of lateral connections & ancillary works	5	%		£ 6,570	Assumed @ 5% culvert installation value
	Subtotal				£ 137,970	
	Allowance for preliminaries	6	%		£ 8,278	
	Allowance for Contract Contingencies	10	%		£ 13,797	
	Allowance for Optimism Bias	20	%		£ 27,594	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mid bound guidance for standard civil engineering projects
	Optimised Subtotal				£ 187,639	
3	Catchment Detention					
	Priory Lane catchment					
3.1	Land Acquisition	5.6	ha	£ 46,000	£ 257,600	Based on an average £/Ha rate of £35k for agricultural land values per a review of a sample of 21 marketed sites in Hertfordshire on 16 July 2015
3.2	Construction of clay core embankments & misc earthworks to include trimming, pre	500	m3	50	£ 25,000	Assumes 5 no. locations with 0.5m impounding embankments over c. 100m length
3.3	E/O #3.2 for ancillary works	70	%		£ 17,500	Assumed @ 70% earthworks value
	Ash Brook north of Stevenage Road catchment					
3.4	Land Acquisition	1	ha	£ 46,000	£ 46,000	Based on an average £/Ha rate of £35k for agricultural land values per a review of a sample of 21 marketed sites in Hertfordshire on 16 July 2015
3.5	Construction of clay core embankments & misc earthworks to include trimming, pre	100	m3	50	£ 5,000	
3.6	E/O #3.5 for ancillary works	70	%		£ 3,500	
	Subtotal				£ 354,600	
	Allowance for preliminaries	6	%		£ 3,060	
	Allowance for Contract Contingencies	10	%		£ 5,100	
	Allowance for Land Value contingencies	50	%		£ 151,800	
	Optimism Bias (Capital Works)	66	%		£ 33,660	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume upper bound guidance for non-standard civil engineering projects (excludes land costs)
	Contingency (Estimating					
	Optimised Subtotal				£ 548,220	
4A.1	Property Level Protection (30-yr)					
4A.1	PLP Per Affected / Eligible Property	12	nr	£ 6,000	£ 72,000	Based on an average industry-adopted £/property rate
4A.2	E/O # for consultancy / survey works	10	%		£ 7,200	
	Subtotal				£ 79,200	
	Allowance for preliminaries	5	%		£ 3,960	
	Allowance for Contract Contingencies	5	%		£ 3,960	
	Optimism Bias	12	%		£ 9,504	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
	Optimised Subtotal				£ 96,624	
4B.1	Property Level Protection (100-yr)					
4B.1	PLP Per Affected / Eligible Property	14	nr	£ 6,000	£ 84,000	Based on an average industry-adopted £/property rate
4B.2	E/O # for consultancy / survey works	10	%		£ 8,400	
	Subtotal				£ 92,400	
	Allowance for preliminaries	5	%		£ 3,960	
	Allowance for Contract Contingencies	5	%		£ 3,960	
	Optimism Bias	12	%		£ 11,088	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
	Optimised Subtotal				£ 111,408	
4C.1	Property Level Protection (100-yr Climate Change)					
4C.1	PLP Per Affected / Eligible Property	39	nr	£ 6,000	£ 234,000	Based on an average industry-adopted £/property rate
4C.2	E/O # for consultancy / survey works	10	%		£ 23,400	
	Subtotal				£ 257,400	
	Allowance for preliminaries	5	%		£ 3,960	
	Allowance for Contract Contingencies	5	%		£ 3,960	
	Optimism Bias	12	%		£ 30,888	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
	Optimised Subtotal				£ 296,208	
	Total for Option (30-yr horizon)				£ 2,374,723	
	Total for Option (100-yr horizon)				£ 2,389,507	
	Total for Option (100-yr Climate Change horizon)				£ 2,574,307	

Alleviation Option 2

McCloy Consulting
Water Engineering Solutions

Property Level Protection (30-yr)						
PLP Per Affected / Eligible Property	31	nr	£ 6,000	£	186,000	Based on an average industry-adopted £/property rate
E/O # for consultancy / survey works	10	%		£	18,600	
Subtotal				£	204,600	
Allowance for preliminaries	5	%		£	10,230	
Allowance for Contract Contingencies	5	%		£	10,230	
Optimism Bias	12	%		£	24,552	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
Total for Option				£249.61k, say £250k		

Property Level Protection (100-yr)						
PLP Per Affected / Eligible Property	66	nr	£ 6,000	£	396,000	Based on an average industry-adopted £/property rate
E/O # for consultancy / survey works	10	%		£	39,600	
Subtotal				£	435,600	
Allowance for preliminaries	5	%		£	10,230	
Allowance for Contract Contingencies	5	%		£	10,230	
Optimism Bias	12	%		£	52,272	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
Total for Option				£508.33k, say £510k		

Property Level Protection (100-yr Climate Change)						
PLP Per Affected / Eligible Property	85	nr	£ 6,000	£	510,000	Based on an average industry-adopted £/property rate
E/O # for consultancy / survey works	10	%		£	51,000	
Subtotal				£	561,000	
Allowance for preliminaries	5	%		£	10,230	
Allowance for Contract Contingencies	5	%		£	10,230	
Optimism Bias	12	%		£	67,320	Optimism bias in accordance with the supplementary guidance provided in "Supplementary Green Book Guidance – Optimism Bias" (Table 3) and assume mind bound guidance for standard building projects
Total for Option				£648.78k, say £650k		