Resilience and Flood Risk

Robbery Bottom Lane, Welwyn, Hertfordshire

FLOOD INVESTIGATION

Final Report Version 3.0

10th October 2014

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Resilience and Flood Risk

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Quality Control

Action	Signature	Date
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Resilience and Flood Risk

Executive Summary

RAB Consultants has been commissioned by Hertfordshire County Council (HCC), in their role as Lead Local Flood Authority, to undertake a Flood Investigation under the Flood and Water Management Act 2010 (FWMA 2010) for Robbery Bottom Lane, Welwyn Hertfordshire.

Local residents report that the western side of Robbery Bottom Lane has been prone to flooding for many years. Flooding to properties occurred in 1993 and February 2009. More recently, several properties flooded during an event in December 2013, which was followed in 2014 with an even more significant flood. It is reported that up to nine properties flooded during the weekend of 7th and 8th February 2014.

The flood mechanism has been reviewed, modelled and compared with experience.

Robbery Bottom Lane is located on a natural fluvial flow route. A conveyance pipe below the road provides a small amount of flood flow capacity. The majority of flow will however pass above ground on the road. A natural bowl shape in the land, coupled with a raised junction with Lower Mardley Hill creates a ‘reservoir’ at the west side of Robbery Bottom Lane. Water collecting in the reservoir can only leave via the conveyance pipe and foul water sewer. With sufficient inflow the water level will be controlled by the Lower Mardley Hill ‘dam’.

Houses A, B, C, D, and E are identified as being at flood risk. Houses F, G and H are also expected to be at flood risk based on previous flood reports. Reports of flooding to driveways and garages towards the eastern end of Robbery Bottom Lane were also given. The flood modelling work and analysis of rainfall data suggest flood water will threaten those properties approximately once in every two years on average. Experience suggests once in every five years.

Several options for reducing flood risk have been proposed and a preliminary cost-benefit judgement has been made:

For short lead time benefits with low cost, a strategy of property-level resistance / resilience is recommended.

For a more robust level of protection in the medium term, the options of a flood defence wall and/or upstream attenuation storage are recommended to take forward for a more detailed review.

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1 Introduction

RAB Consultants has been commissioned by Hertfordshire County Council (HCC), in their role as Lead Local Flood Authority (LLFA), to undertake a Flood Investigation under the Flood and Water Management Act 2010 (FWMA 2010) for Robbery Bottom Lane, Welwyn Hertfordshire.

HCC's representative for the investigation is Emma Ryder, Partnership and Scheme Development Officer, Flood Risk Management Team.

The investigation is being led by Ray Pickering, Lead Consultant at RAB Consultants.

1.1. Flood and Water Management Act 2010

As required under Section 19 of the FWMA 2010, HCC as Lead Local Flood Authority, on becoming aware of a flood in its area, must, to the extent that it considers it necessary or appropriate to:

- investigate the incident;
- identify the Risk Management Authorities (RMAs) with relevant flood risk management functions;
- establish if the relevant functions have been exercised or if it is proposed to exercise them;
- publish its findings in a Flood Investigation Report; and
- consult and inform the relevant RMAs of its findings.

1.2. Hertfordshire Local Flood Risk Management Strategy 2013-2016

Policy 2 of the Hertfordshire Local Flood Risk Management Strategy sets out the requirement to investigate and report flood events. Flood events reported to the county council will be recorded and where necessary appropriately investigated in line with the criteria set out in the procedure "Recording and Investigation of Flood Events".

The flood event of the weekend of 7th and 8th February 2014 at Robbery Bottom Lane met the following criteria in the Hertfordshire Strategy requiring a detailed investigation:

Where internal flooding of five or more properties has occurred during one flooding incident. (The flooding of five or more properties is generally regarded as indicating a level of significance of a flooding event and this should give rise to an investigation.)

1.3. Aim of Investigation

HCC's aims of the flood investigation are provided in the Scoping Document in Appendix A. They are:

- to meet the statutory requirements for a flood investigation;
- to identify and map the local catchments for all water sources, both pluvial (surface water) and fluvial (rivers);

- to identify the causes, effects and potential solutions to flooding in the vicinity of Robbery Bottom Lane;
- to determine the relevant responsibilities of risk management authorities in relation to the management of pluvial and fluvial water sources in the local area of Robbery Bottom Lane;
- to where possible involve the local community in identifying the causes, effects and possible solutions to the flooding incident in Robbery Bottom Lane; and
- to determine what actions may be possible to reduce the risk of flooding in the vicinity of Robbery Bottom Lane.

1.4. Scope of Investigation

The following scope is provided by HCC in their Scoping Document in Appendix A:

- The investigation will be carried out in consultation with the Environment Agency, Hertfordshire Highways, Welwyn Hatfield Borough Council and Thames Water.
- The completed investigation will determine the Risk Management Authorities which have an interest in the flooding issue, as well as their roles, responsibilities, and the extent of any relevant powers.
- Hertfordshire Highways will be consulted regarding potential for CCTV investigation of the drainage system to be carried out around Robbery Bottom Lane. The extent of this will be advised by the appointed consulting firm carrying out the investigation.
- Once local rainfall and soil moisture deficit data has been obtained, the investigation will quantify the conditions under which the most recent flood events have occurred.
- The investigation will survey and map all relevant drainage infrastructure. HCC, Thames Water and Highways will be contacted to provide asset location maps.
- The investigation will use any available records to build as complete a picture as possible of the site's flood history.
- Details will be collected on exactly how many dwellings were flooded, the potential losses and impact to homeowners, inconvenience to road users, impact on emergency service response times, costs for highway authority to manage incidents, and direct damage/impact on highway infrastructure.
- The investigation will confirm the flooding mechanism and the probability of flooding to a depth that will pose significant threat to dwellings and render the road to be unusable to normal traffic and pedestrians.
- Actions that can be taken to manage the flooding within existing roles and resources e.g. increased maintenance, will be detailed.
- The investigation will outline the potential for any works that could be carried out to reduce the probability or impact of flooding together with cost estimates (suitable for RIBA workstage 2).

1.5. Site Details

Site name	Robbery Bottom Lane, Welwyn, Hertfordshire AL6 0UL
OS NGR	524840, 217630
Country	England (FWMA applies)
Local authority	Welwyn Hatfield Borough Council
County Council	Hertfordshire County Council

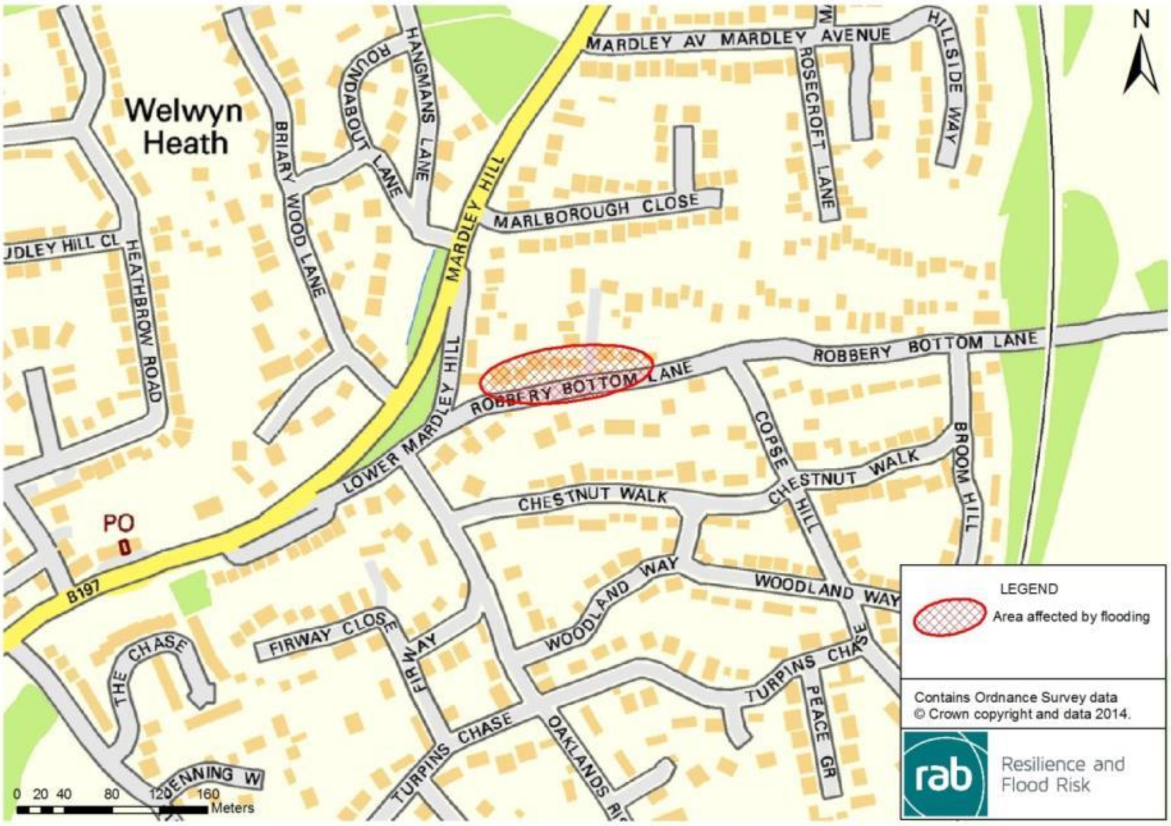

Figure 1 – Approximate indication of flood affected area

2 Background

Residents report that the west side of Robbery Bottom Lane has been prone to flooding for many years. Flooding to properties occurred in 1993 and in February 2009. More recently, several properties flooded during an event in December 2013, which was followed in 2014 with an even more significant flood. It is reported that up to nine properties flooded during the weekend of 7th and 8th February 2014, with driveways and garages affected towards the eastern end of the Lane.

It is reported that water flowed along the road from the east, notably emanating around a culvert inlet just east of the road. Water collected at the junction with Lower Mardley Hill. Road gullies on Robbery Bottom Lane were observed to be blocked or restricted with debris at the time. Of those houses that flooded, internal water depths were typically reported to be less than approximately 0.3m. One garage was reported to have flooded to 1.5m depth. Photographic evidence shows flood water to be virtually static at the junction with Lower Mardley Hill. Road (Figure 2). The arrival of flood water coincided with a storm. Water arrived within a few hours and drained after a day (although the fire service also pumped water away).

Figure 2 – Flooding close to the junction with Lower Mardley Hill

3 Hydrology

3.1. Fluvial component

A watercourse directs water from an upstream catchment down to Robbery Bottom Lane. The watercourse first appears just west of White Horse Lane.

The context of the local fluvial flow route is summarised in Figure 3 and described below.

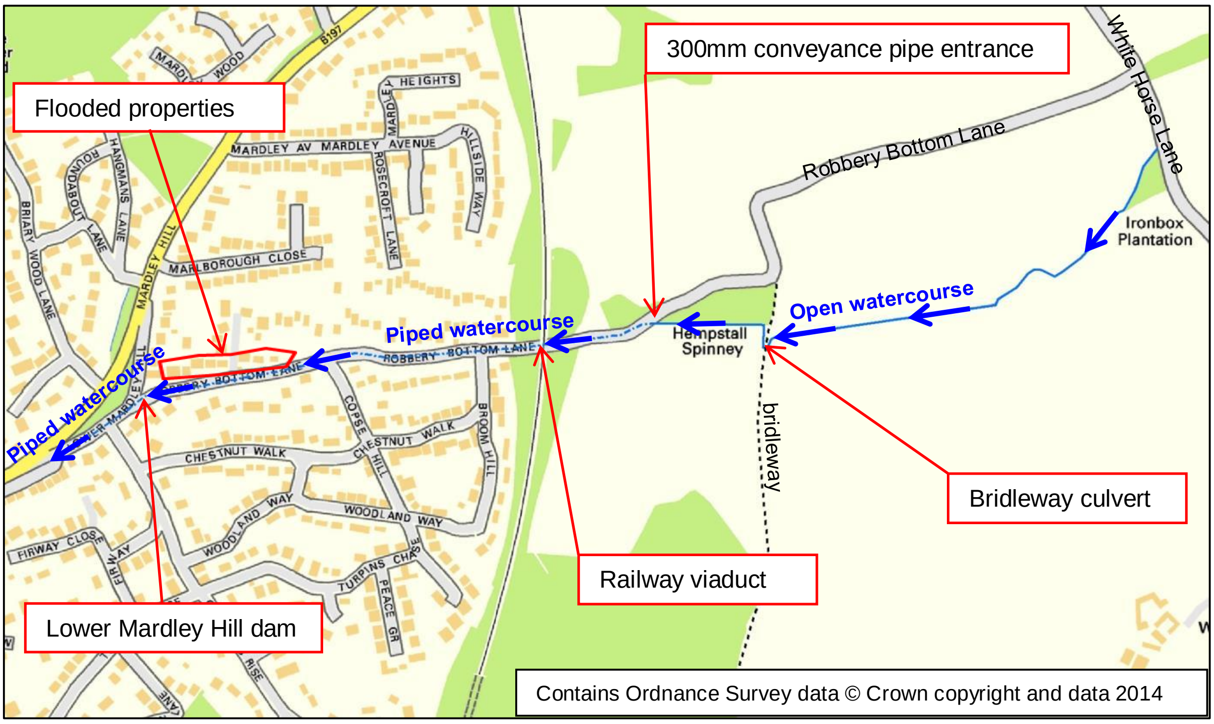

Figure 3 – Map showing the main features of the flow route along Robbery Bottom Lane

The watercourse flows west in an open channel from White Horse Lane along a field boundary before passing through a 0.45m plastic pipe beneath a bridleway.

Figure 4 – Bridleway culvert

From the bridleway culvert, the channel turns sharply north then sharply back to the west again, and continues west along a field boundary where it approaches Robbery Bottom Lane. At the lane, the flow enters a 0.3m culvert. The culvert includes a crude blockage protection grid. The culvert inlet shows debris and plant growth that would restrict water entry.

Figure 5 – Culvert at the junction with Robbery Bottom Lane

Photographic evidence from flooding in 2013 shows the culvert being overwhelmed, with water cascading down onto the lane, producing a shallow fast flow west towards the viaduct.

Figure 6 – Overflow from Robbery Bottom Lane culvert flowing west along the road

The flow conveyance culvert has been surveyed with a CCTV system (Appendix B), which reveals a single 0.3m pipe run along Robbery Bottom Lane and out along the footpath of Lower Marley Hill and beyond. The pipe survey reveals that road gullies designed to drain rainwater from Robbery Bottom Lane discharge into the fluvial conveyance culvert. The survey also reveals partial blockage of the pipe by root growth at 5 locations and a significant fracture.

Robbery Bottom Lane lies at the centre of the valley in which the watercourse flows. The road has a significant downhill gradient from the 0.3m culvert inlet west beneath the railway viaduct down to Broom Hill (approx. 1 in 100 slope). The road then falls less steeply down towards Lower Mardley Hill, before rising again at the road junction itself. The ground levels on Robbery Bottom Lane at the junctions with both Broom Hill and Lower Mardley Hill are essentially the same, 79.77m above Ordnance Datum (mAOD). The ground level between those points is lower, forming a bowl in the local landscape, with the lowest ground level of approximately 78.70mAOD in the road between houses X and A. The results of a topographic survey can be found in Appendix C.

The hydrology of the watercourse has been investigated to estimate the flows that will pass through Robbery bottom Lane. Estimations of the flood frequency curve relevant to the site were produced using the FEH statistical method and the Revitalised FSR/FEH rainfall runoff method.

The Flood Estimation Handbook (FEH) is a set of the national standard procedures for estimating flow rates in watercourses (used by for example the Environment Agency and DEFRA). It encompasses two primary methods: the statistical method and the Revitalised FSR/FEH rainfall runoff method (referred to as ReFH). The catchment area is identified using a digital map of Great Britain. The boundary is defined by a ridge in the landscape enclosing the point of interest, such that rain falling on the catchment area will travel by gravity down to the point of interest. Catchment descriptors are then extracted from a nationwide database that mathematically describes the catchment soil characteristics, ground shape and rainfall characteristics. In both methods, water flows are estimated using a statistical procedure that compares the catchment in question against a large database of flood flow records taken from a network of measuring stations located throughout the country.

Because the statistical method is based on a much larger dataset of flood events, and has been more directly calibrated to reproduce flood frequency on UK catchments, it will often be preferred to the ReFH method. Recent work has shown that the FEH methods provide the best flow estimates for small catchments (*Estimating flood peaks and hydrographs for small catchments: Phase 1, Project: SC090031, Environment Agency, 2014*). The statistical method appears, on average, to outperform ReFH for small rural catchments with moderate annual rainfall, such as at Robbery Bottom Lane.

The statistical method is therefore considered to offer the best peak flow estimates for Robbery Bottom Lane. The ReFH method will also be run as a comparison and to generate a hydrograph (a graph showing the rate of flow versus time passing a specific point in a watercourse).

The key technical details of the FEH analysis are given below for reference:

FEH statistical method:

The FEH statistical method was undertaken using WINFAP-FEH 3 software which has the latest updated methods embedded.

As there is no gauging station on the watercourse the ‘single site’ and ‘enhanced single site’ analysis methods are not possible. Consequently the ‘pooled method’ was used.

QMED was estimated from FEH CD-ROM 3 catchment descriptors using the updated method (*Kjeldsen T.R., Jones D.A. and Baliss A.C. 2008 Improving the FEH statistical procedures for flood frequency estimation. Environment Agency, Bristol, pp137*).

$QMED_{rural}$ = 0.91 m^3/s.

The catchment location and catchment descriptors are given below:

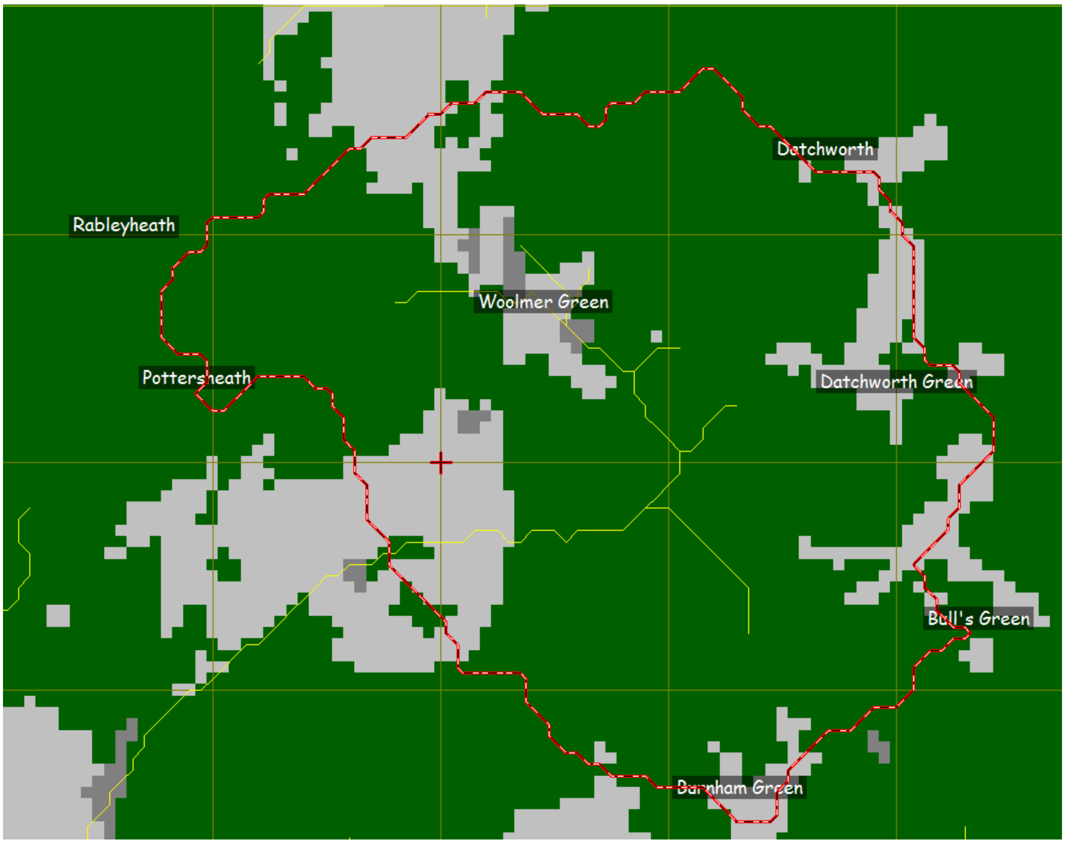

Figure 7 – Catchment at Lower Mardley Hill road junction taken from FEH CDROM 3

Subject Site Location : 524800 217600 [TL 24800 17600]
Catchment centroid : 525794 218206 [TL 25794 18206]

Catchment Descriptors

AREA :	7.25 km²	RMED-1H :	10.9 mm
ALTBAR :	107 m	RMED-1D :	30.3 mm
ASPBAR :	292 degrees	RMED-2D :	37.7 mm
ASPVAR :	0.10	SAAR :	652 mm
BFIHOST :	0.576	SAAR4170 :	619 mm
DPLBAR :	2.56 km	SPRHOST :	38.6
DPSBAR :	36.1 m/km	URBCONC1990 :	0.609
FARL :	1.000	URBEXT1990 :	0.0827
LDP :	4.48 km	URBLOC1990 :	1.042
PROPWET :	0.30	URBCONC2000 :	0.772
FPEXT :	0.0662	URBEXT2000 :	0.0986
FPLOC :	0.847	URBLOC2000 :	0.865
FPDBAR :	0.32 cm		

Catchment average DDF values

C :	-0.026	D3 :	0.274
D1 :	0.288	E :	0.318
D2 :	0.326	F :	2.478

1 km point DDF values for 525000 218000 [TL 25000 18000]

C(1 km) :	-0.028	D3(1 km) :	0.269
D1(1 km) :	0.296	E(1 km) :	0.321
D2(1 km) :	0.335	F(1 km) :	2.462

Figure 8 Catchment descriptors at Lower Mardley Hill road junction taken from FEH CDROM 3

All local donor sites identified within WINFAP-FEH 3 had significantly larger catchment areas compared to the catchment size of the watercourse. The closest donor site with best compromise of catchment descriptors was 38002 Ash@Mardock. The donor procedure was applied to QMED based on this catchment.

Urban adjustment was made (updated to 2014) as the catchment is slightly urbanised.

The donor adjusted and urban adjusted value of 0.99m^3/s was used for QMED.

A pooling group was created and optimised from all available gauging stations under the latest methodology (with in excess of 500 years of records).

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	30014 (Pointon Lode @ Pointon	0.742	36	2.645	0.410	0.327	1.156
2	31023 (West Glen @ Easton Wo	0.742	36	1.935	0.399	0.301	0.590
3	27051 (Crimple @ Burn Bridge)	0.803	36	4.610	0.219	0.122	0.425
4	44009 (Wey @ Broadwey)	0.839	31	1.679	0.345	0.259	0.171
5	26802 (Gypsey Race @ Kirby Gr	1.198	9	0.142	0.236	0.134	0.360
6	25019 (Leven @ Easby)	1.238	30	5.538	0.361	0.411	0.536
7	44006 (Sydling Water @ Sydling	1.307	34	0.861	0.231	0.087	0.198
8	45816 (Haddeo @ Upton)	1.334	14	3.427	0.318	0.449	1.156
9	205999 (Woodburn @ Control)	1.342	11	0.121	0.173	0.076	1.984
10	28033 (Dove @ Hollinsclough)	1.538	29	4.608	0.262	0.406	0.749
11	27010 (Hodge Beck @ Bransda	1.677	41	9.420	0.224	0.293	0.480
12	44008 (Sth Winterbourne @ W'b	1.755	29	0.406	0.390	0.340	0.476
13	203046 (Rathmore Burn @ Rath	1.822	26	10.996	0.126	0.115	1.506
14	25011 (Langdon Beck @ Langd	1.837	22	15.362	0.254	0.405	1.278
15	36009 (Brett @ Cockfield)	1.847	38	3.661	0.263	-0.103	1.677
16	36010 (Bumpstead Brook @ Bro	1.893	41	6.759	0.433	0.239	1.487
17	50009 (Lew @ Norley Bridge)	1.901	20	18.955	0.150	-0.233	2.877
18	22003 (Usway Burn @ Shillmoor	1.919	27	15.307	0.331	0.354	0.895
19							
20	Total		510				
21	Weighted means				0.291	0.225	

Figure 9 Pooling group taken from WINFAP FEH-3

A growth curve was produced from the pooling group using a Generalised Logistic distribution and applied to QMED to give the following flood frequency curve:

Table 1 – Statistical method flood frequency curve

Annual exceedance probability	Peak flood flow (m^3/s)
1 in 2 years	0.99
1 in 5 years	1.44
1 in 10 years	1.79
1 in 25 years	2.31
1 in 50 years	2.77
1 in 100 years	3.31

It can be observed that the members of the pooling group exhibit quite a wide range of catchment descriptors. This is due to the limited number of very small catchments in the FEH data set. Nonetheless, the statistical methodology manages the variation and the catchment of the watercourse is appropriate for the FEH statistical approach.

Revitalised FSR/FEH rainfall runoff method:

The catchment descriptors, as shown in Figure 8, were entered into the CEH ReFH spreadsheet version 1.4, along with a time step of 0.5 hours, rainfall duration of 4.5 hours, winter profile and all other values set to default. This yielded the following results:

Table 2 – ReFH flood frequency curve

Annual exceedance probability	Peak flood flow (m^3/s)
1 in 2 years	1.45
1 in 5 years	1.95
1 in 10 years	2.37
1 in 25 years	2.94
1 in 50 years	3.48
1 in 100 years	4.15

The peak flows obtained from the statistical method have been used in this report, along with the ReFH hydrograph scaled to the statistical method peak flows.

3.2. Surface water component

Robbery Bottom Lane sits at the bottom of a valley. The land slopes steeply to the north and the south. The adjacent catchment to the north and south is developed with houses and residential roads, some of which have formal road drainage and may also be formally drained by sewers, although there are no surface water assets indicated on the Thames Water register (Appendix D).

The hydrology calculations in Section 3.1 are based on a catchment that includes the whole of the adjacent residential area to the north and south. Consequently the adjacent urbanised streets are included and an urbanisation adjustment has been applied.

It is recognised however that rain falling onto nearby urbanised streets will bring water down to Robbery Bottom Lane in a mode directly related to the incoming rain and is therefore better represented by the modified rational method. A judgement has been made as to the local catchment considered to bring surface water flows on to the lane (Figure 10), as opposed to the wider fluvial catchment (Figure 7).

A separate consideration will be given to the effect of surface flows on Robbery Bottom Lane. It is not considered appropriate to analyse with a combined fluvial and surface water input due to the problem of combined probabilities and double counting catchment areas.

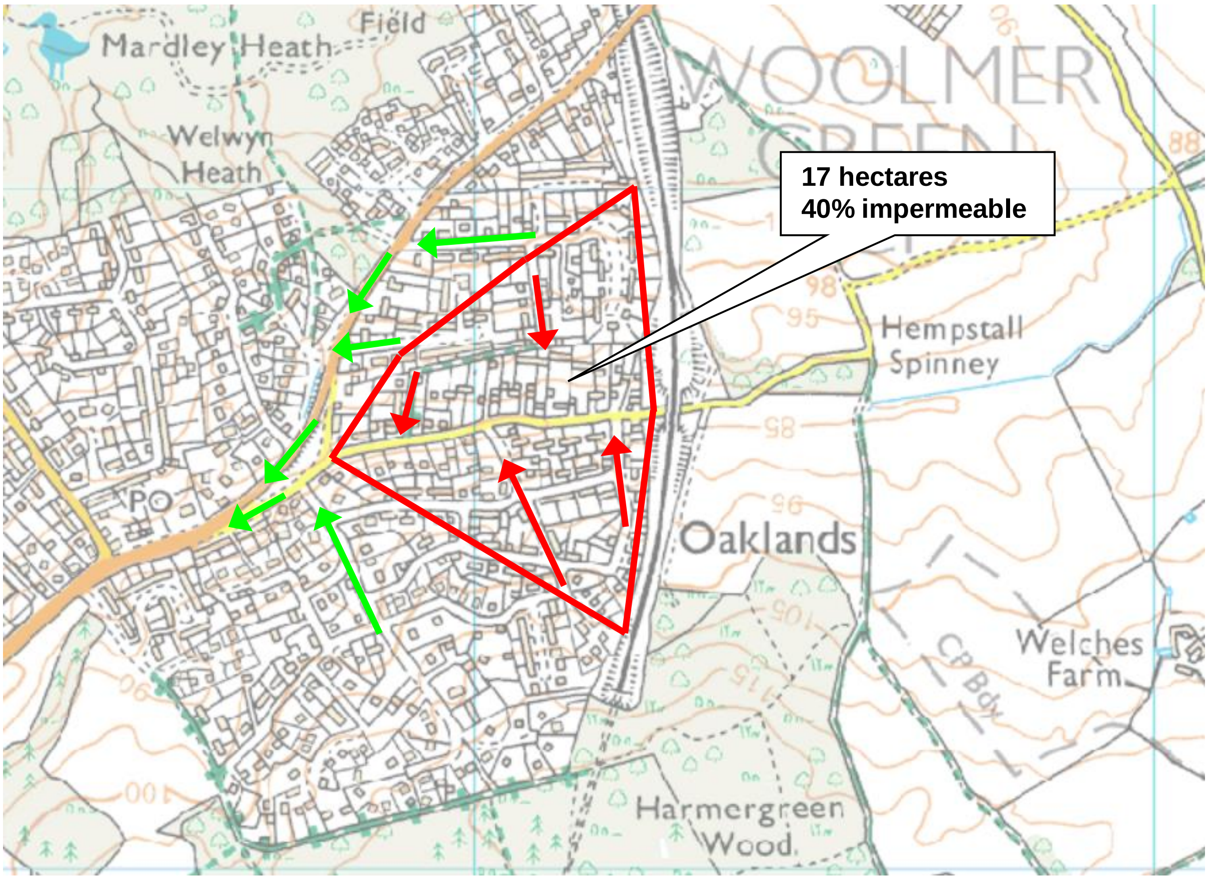

Figure 10 Map indicating the adjacent urbanised catchment that is expected to bring surface water flows direct to Robbery Bottom Lane (red arrows) and areas expected to direct surface water away downstream (green arrows)

3.3. Groundwater component

The Soilscapes website describes the soil at Woolmer Green as 'Slightly acid loamy and clayey soils with impeded drainage'.

Hertfordshire County Council has produced a local flood risk management strategy for 2013 – 2016 (*http://www.hertsdirect.org/docs/pdf/f/hertslfrmsall.pdf*). The report includes a groundwater emergence map which shows the probability of groundwater emergence over 1km squares. This indicates Woolmer Green to have a low risk of groundwater emergence.

A site visit was made at the end of April 2014 during which time the upstream watercourse was dry.

A CCTV survey of the conveyance pipe below Robbery Bottom Lane showed little water in pipes.

The above facts coupled with the relatively short duration of flooding suggests that groundwater is not the primary source of flood water.

The flow estimates from the FEH method and surface water calculations are considered the most appropriate for this work.

4 Modelling flood risk

4.1. Attenuation at the bridleway

The watercourse bringing water from the east passes through a pipe below a bridleway just upstream of Robbery Bottom Lane (refer to Figures 3 and 4).

The bridleway is raised relative to the valley and will act as a dam storing water upstream of the track. The pipe will act as an outlet control device, with excess flows overflowing the track, which will act as a secondary outlet control. The overall effect will be that of an attenuation reservoir, providing a localised attenuation to flows coming into Robbery Bottom Lane. The specific influence for the lane will not be captured in the statistical hydrology methods used in Section 3.1.

This arrangement has been modelled using Microdrainage 2014.1.1 Source Control module, which offers a simple and effective tool for assessing the effect of an attenuation reservoir. The pipe has diameter 0.45m, length 5m and invert level 84.250mAOD. The raised track has a level of 85.380mAOD and the weir coefficient has been assumed to be 1.65.

Survey details are included in Appendix C.

The upstream storage volume relationship was obtained by GIS analysis of LiDAR data:

Table 3 – Depth to water area relationship upstream of the bridleway

Contour	Enclosed area upstream of bridleway
84.250 mAOD	7,229 m^2
85.000 mAOD	15,404 m^2
86.000 mAOD	34,801 m^2
87.000 mAOD	69,794 m^2

The results of the analysis are summarised in Table 4 below:

Table 4 – Attenuated flows arriving at Robbery Bottom Lane

Annual exceedance probability	Peak flow arriving at the bridleway	Attenuated peak flow leaving the bridleway
1 in 2 years	0.99	0.31 m^3/s^*
1 in 5 years	1.44	0.87 $m^3/s^\dagger$
1 in 10 years	1.79	1.37 $m^3/s^\dagger$
1 in 25 years	2.31	2.02 $m^3/s^\dagger$
1 in 50 years	2.77	2.56 $m^3/s^\dagger$
1 in 100 years	3.31	3.18 $m^3/s^\dagger$

*No overflow across bridleway   †Overflow across the bridleway

It can be seen that the bridleway provides significant attenuation for low flows, where the 0.45m pipe acts as a constriction to flow. Only a small degree of attenuation is provided with high flows as water overflows across the bridge deck.

The maximum upstream storage volume with no overflow across the bridleway is approximately 16,000m^3.

4.2. Flood risk at the culvert on Robbery Bottom Lane

On leaving the bridleway, flows travel along an open channel down to the inlet of a 0.3m diameter culvert that runs below Robbery Bottom Lane, through to Lower Mardley Hill.

The culvert invert level is 81.440mAOD. The level of the surrounding containment bank is 82.19mAOD. Consequently a maximum water head of 0.75m will act on the pipe before water floods over on to the road. The flow rate of a 0.75m water head acting on a 0.3m pipe has been estimated from a range of sources:

Table 5 – Maximum flow rate in the Robbery Bottom Lane culvert

Source	Estimated peak flow rate
ROCLA Hydraulic Design Manual Inlet control	0.14m^3/s
ROCLA Hydraulic Design Manual Outlet control	<0.1m^3/s
Tables for the Hydraulic Design of Pipes, Sewers and Channels Ks=0.6-6.0mm, gradient=1:200	0.05 – 0.08m^3/s
Estimate using HECRAS Gradient=1:200	0.05m^3/s

Overall it is concluded that the Robbery Bottom Lane culvert has a capacity of approximately 0.1m^3/s. This is a very low capacity when compared with the incoming flows as per Table 4. The pipe is therefore expected to contribute little flow capacity compared with the incoming flood flow (for example the pipe capacity is 11% of the 1 in 5 year incoming flow and 3% of the 1 in 100 year incoming flow). Overflow onto the road is expected perhaps once or twice per year on average. High flood flows will almost entirely be conveyed above ground along Robbery Bottom Lane.

4.3. Flood risk at Robbery Bottom Lane

Robbery Bottom Lane is located in the base of a valley, within a natural fluvial flow route.

The eastern half of the lane, from the railway viaduct, slopes down relatively steeply and is thus expected to manage significant flows with only a shallow water level. This is reflected in there being no flood problems reported in this area.

The western half of the lane however is enclosed by the higher Lower Mardley Hill road, effectively creating a dammed reservoir with three routes of outflow (i) the 0.3m watercourse culvert (ii) a 0.3m foul water drain (refer to Appendix D) and (iii) overflow across the Lower Mardley Hill 'dam'.

This reservoir arrangement has been modelled using Microdrainage 2014.1.1 Source Control module, which offers a simple and effective tool for assessing the effect of a dammed reservoir. A pipe outlet was set with diameter 0.424m (a single pipe with cross-sectional area equivalent to 2x 0.3m diameter pipes), length 20m, gradient 0.005 (typical upstream gradient of the lane) and invert level 77.890mAOD (assumed to be 1m below road level and contributing a total of 100m^3 of below ground water storage). The Mardley Hill 'dam' was set as a weir of width 7m, weir coefficient 1.65 and crest level 79.770mAOD.

Survey details are included in Appendix C. The reservoir storage volume relationship was obtained from survey data and OS contour lines:

Table 6 – Depth to water area relationship at Robbery Bottom Lane

Contour	Enclosed area upstream of dam
77.890 mAOD	100 m^2 (below ground)
78.890 mAOD	100 m^2 (lowest road level)
79.770 mAOD	8,971 m^2
85.000 mAOD	58,530 m^2

Fluvial flows were tested using the attenuated output from the bridleway model as an input hydrograph. The results of the analysis are summarised in Table 7 below:

Table 7 – Predicted fluvial flood levels at Robbery Bottom Lane

Annual exceedance probability	Peak flow coming into the lane	Fluvial - Peak flood level
1 in 2 years	0.31 m^3/s	78.818 mAOD*
1 in 5 years	0.87 m^3/s	79.790 mAOD†
1 in 10 years	1.37 m^3/s	79.844 mAOD†
1 in 25 years	2.02 m^3/s	79.887 mAOD†
1 in 50 years	2.56 m^3/s	79.913 mAOD†
1 in 100 years	3.18 m^3/s	79.945 mAOD†

*Water below road level †Above ground flooding with overflow across the dam

Surface water flows were tested using a connected area of 6.8ha (40% of 17ha) in the model, with assumed time of entry evenly distributed up to 30 minutes (600m distance, 1:25 slope across ground that is a combination of tarmac, compressed soil, grass with obstruction by buildings). A storm duration of 16hrs was used for this analysis as this is in line with rainfall records (discussed below).

Table 8 – Predicted surface water flood levels at Robbery Bottom Lane

Annual exceedance probability	Surface Water - Peak flood level
1 in 2 years	78.194 mAOD*
1 in 5 years	78.238 mAOD*
1 in 10 years	78.268 mAOD*
1 in 25 years	78.339 mAOD*
1 in 50 years	78.380 mAOD*
1 in 100 years	78.435 mAOD*

*Water below road level

Ground floor levels of houses A, B, D and E are 79.44mAOD, 79.11mAOD, 78.91mAOD and 80.03mAOD respectively. The fluvial model predicts that houses will flood about once in every 2 years on average. The surface water model predicts no above ground flooding.

Flooding to properties has been reported in 1993, February 2009, December 2013 and February 2014, which averages approx. once in every 5 years.

An estimate of the flood level in February 2014 can be made from photographs taken at the time, judged against nearby surveyed ground levels.

 Flood level ~79.8mAOD	 Flood level ~79.6mAOD
 Flood level ~79.4mAOD	 Flood level ~80.0mAOD

Figure 11 Photographs of flooding in February 2014

The photographs appear to have been taken some time after the storm has passed, so they may not have captured the peak flood level. The owner of house E reported 0.2m of water internally (9 inches), which would equate to a flood level of approx. 80.20mAOD. Averaging the flood level estimates gives 79.8mAOD, which is close to the level of the Lower Mardley Hill dam (79.77mAOD) and close to the modelled 1 in 5 year annual probability fluvial flood (79.790mAOD).

Rainfall data was obtained from the Environment Agency that includes the December 2013 and February 2014 events (Appendix E). Four gauges surrounding Robbery Bottom Lane were included. The supplied values were 24 hour rainfall totals. A more detailed cumulative total graph indicates that the December event had duration 16 hours, while the February event had 20 hour duration. An estimate of an equivalent annual exceedance probability was made for each event.

Table 9 – Rain gauge data

Rain gauge	Date	Rainfall total	Equivalent annual exceedance probability (6 hr)
Mill Green	23/12/2013	33.4mm	1 in 3 years
Mill Green	06/02/2014	32.4mm	1 in 2 years
Stevenage	23/12/2013	26.0mm	1 in 2 years
Stevenage	06/02/2014	30.0mm	1 in 2 years
Thunridge	24/12/2013	21.5mm	1 in 1 years
Thunridge	06/02/2014	37.8mm	1 in 4 years
Whitwell	23/12/2013	28.6mm	1 in 2 years
Whitwell	06/02/2014	29.8mm	1 in 2 years

Annual exceedance probability for the December 2013 event = 1 in 2 years.

Annual exceedance probability for the February 2014 event = 1 in 3 years.

Figure 12 Location of rain gauges relative to Robbery Bottom Lane (background taken from OS OpenData on 02.09.2014)

A more detailed breakdown of rainfall at Stevenage, Mill Green and Whitwell was subsequently provided for the February 2014 event. This revealed that there were in fact two separate showers. The first started from around midday on the 6th and ended around 19:00 that evening. The second started at midnight and ended around 09:00 on the 7th. Of the rainfall totals given in Table 9, approximately 25% fell on the afternoon of the 6th with 75% falling during the early hours of the 7th. Analysing the second, more significant rainfall, over a 9 hour period yields an annual exceedance probability of 1 in 2 years at all three locations.

The Environment Agency also provided soil moisture deficit (SMD) values for a relevant gauge (identified as 'Lee-Chalk'). This covered the whole of 2013 and 2014 up to and including April. The results show near continuous zero SMD during both winter seasons (2012/2013 and 2013/2014), which covers the two most recent floods. A significant storm was also recorded on 24th August 2013, with similar rainfall to that in December 2013 and February 2014. In August 2013 however SMD was typically 90 – 125, with no major flooding reported.

The Met Office report for winter 2013/2014 (*http://www.metoffice.gov.uk/climate/uk/summaries/2014/winter*):

'It was also the wettest winter in the long running England and Wales Precipitation series from 1766. There were more days of rain during the winter than any other in a series from 1961.'

The accompanying rainfall amount map indicates this part of Hertfordshire received 175-200% of the 1981-2010 rainfall average in winter 2013/2014.

In contrast, the Met Office report that winter 2012/2013 was only marginally wetter than the 1981-2010 rainfall average, with Hertfordshire receiving 110-130% of the average (*http://www.metoffice.gov.uk/climate/uk/summaries/2013/winter*). When taken with the SMD results for the same winter, this suggests that near saturation of the ground may be a fairly typical condition at Robbery Bottom Lane during the winter.

The results suggest that three conditions are required for flooding on Robbery Bottom Lane: (1) winter season, therefore near saturated ground (2) a prolonged spell of extreme wet weather, limiting any more temporary water storage opportunities (3) a heavy, but not exceptional, storm (annual exceedance probability 1 in 2 years and duration of several hours).

The fluvial model predicts flooding affecting houses once in two years on average. The return period of the storms that caused the last two flood events have an annual exceedance probability of approx. 1 in 2 years. So there is apparently good consistency between the model and the rainfall measurements.

From experience, residents report 4 flood events effecting houses in the last 21 years. This suggests the frequency of flooding in reality may be lower than the 1 in 2 year estimate theoretically derived in this report. It should be noted however that 4 flood record data points are not sufficient to provide a good quality estimate of flood probability.

It has been discussed above that not just a storm of sufficient rarity (duration and intensity) is needed to drive flooding, but also an exceptionally wet winter season. The probability of all 3 conditions being met will be lower than just the storm probability alone.

In the absence of a record of measured water flows and levels on Robbery Bottom Lane, the reservoir model for Robbery Bottom Lane cannot be calibrated or verified. The results are therefore considered 'indicative' of flood risk.

The estimation of surface water catchment linked to Robbery Bottom Lane and modelling analysis indicates that surface water runoff rates and volume are a minor component of flooding compared with the fluvial component. This result however is based on the assumption of clean pipes in perfect condition. In reality, residents report road gullies regularly blocking with tree debris and material washed down from the unsurfaced side roads. There is very little storage capacity above ground, on the road. This, coupled with several driveways being set lower than the adjacent road means that some flooding on the road and around properties is possible, with blocked gullies, from surface water alone.

5 Options for flood risk reduction

The flood mechanism has been reviewed, modelled and compared with observation in Section 4.0.

Robbery Bottom Lane is located on a natural fluvial flow route. A conveyance pipe below the road provides a small amount of flood flow capacity. The majority of flow will however pass above ground on the road. A natural bowl shape in the land, coupled with a raised junction at Lower Mardley Hill creates a ‘reservoir’ at the west side of Robbery Bottom Lane. Water collecting in the reservoir can only safely leave via the conveyance pipe and foul water sewer. With sufficient inflow the water level will be controlled by the Lower Mardley Hill ‘dam’.

The topographic survey (Appendix C), coupled with a site visit, shows that the gardens of houses A, B, C, D, and E are level with, or lower than, the adjacent road and as such are expected to flood regularly, each time water is on the road.

The ground floor levels of houses A, B, and D are set lower than the Lower Mardley Hill ‘dam’, and so these properties are at particular risk of flooding. While house E is 0.26m higher than the dam, it is still considered at risk given water levels will be raised above the dam during high flows. The garage of house C is also at particular risk of flooding and appears to be in a low spot along the Lane experiencing significant flood depths. While the topographic survey did not include houses F, G and H, all three homeowners reported flooding in the space below the suspended floor in February 2014, with the water level getting close to the ground floor.

A summary of damage to properties from the event of February 2014 is included in Appendix F.

Table 10 – Summary of key levels

Location	Level (mAOD)
Ground floor of house number A	79.44
Ground floor of house number B	79.11
Ground floor of house number C	80.5 (approx.)
Garage floor of house number C	78.43
Ground floor of house number D	78.91
Ground floor of house number E	80.03
Level of Lower Mardley Hill ‘dam’	79.77

5.1. Reduce the inflow into the Robbery Bottom Lane ‘reservoir’

A range of continuous fluvial flow rates were tested in the model of Robbery Bottom Lane to establish the maximum flow rate predicted to avoid flooding. A surface water component was also introduced under the same conditions as that relating to the results in Table 8.

The results show that for events of 1 in 10 year annual exceedance probability or more likely, the fluvial flow would need to be restricted to 0.2m^3/s to avoid flooding. For less frequent flood events, the fluvial flow would need to be restricted to 0.1 m^3/s to avoid flooding. This is a very high degree of attenuation.

Flood storage would be needed upstream of the restriction to achieve this. The most practical place for this would be upstream of the bridleway, where some attenuation is already occurring. Estimates of the amount of flood storage needed are given in Table 11.

Table 11 – Estimates of upstream storage volume

Probability	Peak fluvial flow in	Tot fluvial volume in	Tot. volume out	Total storage needed	Existing available storage upstream of bridleway	Additional storage required
1 in 2 years	0.99 m^3/s	21,220 m^3	9,720 m^3 at 0.2m^3/s	11,500 m^3	16,000 m^3	0 m^3
1 in 5 years	1.44 m^3/s	30,865 m^3	9,720 m^3 at 0.2m^3/s	21,145 m^3	16,000 m^3	5,145 m^3
1 in 10 years	1.79 m^3/s	38,367 m^3	9,720 m^3 at 0.2m^3/s	28,647 m^3	16,000 m^3	12,647 m^3
1 in 25 years	2.31 m^3/s	49,513 m^3	4,860 m^3 at 0.1m^3/s	44,653 m^3	16,000 m^3	28,653 m^3
1 in 50 years	2.77 m^3/s	59,373 m^3	4,860 m^3 at 0.1m^3/s	54,513 m^3	16,000 m^3	38,513 m^3
1 in 100 years	3.31 m^3/s	70,948 m^3	4,860 m^3 at 0.1m^3/s	66,088 m^3	16,000 m^3	50,088 m^3

5.2. Increase the outflow from the Robbery Bottom Lane 'reservoir'

The existing 0.3m diameter conveyance pipe has little capacity compared with the incoming fluvial flows. A culvert diameter of approximately 1.0 – 1.2m would be required to manage up to 1 in 100 year annual probability flows with no above ground flooding (dependent upon culvert shape, material and depth).

A replacement increased size culvert would need to be laid through to a suitable downstream discharge location. This is likely to be into the Mimram River in Welwyn, i.e. replacing the whole run of existing conveyance pipe. This is expected to be a very expensive option.

Alternatively, a pumping station could be installed to remove flood water collecting on Robbery Bottom Lane into a safe discharge route. Thames Water have no record of available surface water sewers close by. In any case a surface water drainage network is unlikely to have the capacity to manage what is essentially a watercourse. There is an open watercourse approximately 60m north of the lane, just west of Mardley Hill, that may have sufficient capacity to receive this flood water. The pumping station would need to be capable of removing water at a rate in excess of 3.0m^3/s to provide significant betterment. The discharge point would need assessing to ensure downstream capacity. The location is indicated in Figure 13.

Figure 13 Potential option for pumping flood water from Robbery Bottom Lane (background taken from OS OpenData on 02.09.2014)

5.3. Reduce the Robbery Bottom Lane 'reservoir dam' level

The raised road junction at Lower Mardley Hill forms a dam holding water in the basin at the west side of Robbery Bottom Lane. Flooding could be significantly reduced by lowering the ground at the junction such that floodwater has an open route to flow downhill west along Lower Mardley Hill.

While this would be an effective solution for Robbery Bottom Lane there would be consequences elsewhere. Lowering the road junction would increase the gradient of the already steep Lower Mardley Hill road. Flood water would flow west unrestricted into Lower Mardley Hill road and Great North Road. This may put others at increased flood risk. Currently Robbery Bottom Lane is potentially acting as an attenuation storage area protecting those downstream.

5.4. Property-level flood risk reduction

A flood event with annual probability 1 in 100 years is expected to produce a flood level of approximately 79.95mAOD. The relevance of this flood level in terms of flood depth is given in Table 12.

Table 12 – Potential flood depths

Location	Flood depth
House A	1.1m on the drive 0.5m inside the house
House B	1.0m on the drive 0.8m inside the house
House C	1.5m in the garage and on drive outside Ground floor of house 0.6m higher than flood level
House D	1.2m on the drive 1.0m inside the house
House E	Approx. 1m on the drive Shallow flooding inside the house
House F	Flooding expected in the space below the floor
House G	Flooding expected in the space below the floor
House H	Flooding expected in the space below the floor

An effective flood defence scheme could be provided by the construction of a flood wall at affected property boundaries with Robbery Bottom Lane. A wall height of 80.35mAOD would be appropriate given modelling errors and the water level report from the owner of house E. This would make the wall at most 1.5m higher than adjacent ground. The wall would need to be returned north along Lower Mardley Hill, Larch Lane and at house H boundary, extending up to existing ground that is above 80.35mAOD (see Figure 14). Flood proof gates of the same height would be required to enable access to properties.

The defence wall would enclose a small catchment area to the north, the impact of which has been tested for the higher risk western zone. The enclosed area has been estimated to be approximately 1.5ha (Lower Mardley Hill to the west, Marlborough Close to the north and Larch Lane to the east). On the assumption that runoff occurs from 40% of this area then approximately 400m^3 of water would be generated during a 16 hour 1 in 100 year annual probability storm, which if collected onto land associated with houses X – E on Robbery Bottom Lane (approx. 0.25ha excluding house footprints) would generate an average water depth of 0.16m. It therefore seems unlikely that internal flooding would occur from the enclosed catchment. Nonetheless it would be prudent to provide a pumping system north of the defence wall to evacuate any water that collects or leaks through the flood gates.

Non-return valves (perhaps augmented by high quality manual shut-off values) would be needed to prevent flood water defeating the defence wall via the foul water drainage system.

Figure 14 Recommended location of flood wall (background taken from OS OpenData on 02.09.2014)

Measures applied directly to houses would offer some flood risk reduction.

Examples of water-exclusion measures include:

- Flood doors / door barriers on all entries;
- Non-return valves on drains;
- Sump pumps;
- Air brick covers;
- Checking and sealing gaps in brickwork.

Examples of flood resilience measures, to limit the damage from water entry and speed up the refit, include:

- Solid floors;
- Raised electrics;
- Water resistant plaster;
- Hard wood.

Each property at risk would need to be surveyed to provide a bespoke set of recommendations.

5.5. Preliminary analysis of options

Table 13 – Cost – benefit of options

Option	Advantages	Disadvantages	Approx. construct cost	Judgement of cost/benefit (including expected failure rate and impact elsewhere)
Upstream storage.	• Reproduces a natural process. • Benefits all downstream receptors. • Low risk of failure during a flood.	• Needs agreement from 3rd party landowners.	£200k	**Medium cost/benefit**
Upgrade conveyance pipe.	• Physical impact of change will be below ground. • Benefits all downstream receptors.	• May increase risk to downstream receptors. • Possible constraints with installing a large culvert.	£500k	**High cost/benefit**
Pumping station.	• Works limited to a fairly small area of land.	• May need agreement from landowners to locate the unit. • Risk of pump failure. • Limited options for discharge point. • May increase risk to downstream receptors.	£150k	**Assessment of impact elsewhere is required**
Reduce level of Lower Mardley Hill 'dam'.	• Works limited to a very small area of land.	• Increased gradient on Lower Mardley Hill. • Increased risk to downstream receptors.	£250k	**Assessment of impact elsewhere is required**

Option	Advantages	Disadvantages	Approx. construct cost	Judgement of cost/benefit (including expected failure rate and impact elsewhere)
Flood defence wall.	• Works limited to a fairly small area of land. • No involvement of wider landowners.	• Flood gates are a weak link in the chain. • May need manual deployment. • No benefit to downstream receptors.	£200k	**Low cost/benefit**
Property-level resistance and resilience	• Quick to install. • No involvement of wider landowners.	• Limited effectiveness.	£60k	**Medium cost/benefit**

N.B. The costs are indicative only, based on experience, with no formal quotes having been obtained.

Green indicates low cost/benefit ratio. Yellow indicates medium cost/benefit ratio. Red indicates high cost/benefit ratio, or where further work is needed to estimate ratio.

6 Conclusion

RAB Consultants has been commissioned by Hertfordshire County Council (HCC), in their role as Lead Local Flood Authority, to undertake a Flood Investigation under the Flood and Water Management Act 2010 (FWMA 2010) for Robbery Bottom Lane, Welwyn Hertfordshire.

Local residents report that the western side of Robbery Bottom Lane has been prone to flooding for many years. Flooding to properties occurred in 1993 and February 2009. More recently, several properties flooded during an event in December 2013, which was followed in 2014 with an even more significant flood. It is reported that up to nine properties flooded during the weekend of 7th and 8th February 2014.

The flood mechanism has been reviewed, modelled and compared with experience.

Robbery Bottom Lane is located on a natural fluvial flow route. A conveyance pipe below the road provides a small amount of flood flow capacity. The majority of flow will however pass above ground on the road. A natural bowl shape in the land, coupled with a raised junction with Lower Mardley Hill creates a 'reservoir' at the west side of Robbery Bottom Lane. Water collecting in the reservoir can only safely leave via the conveyance pipe and foul water sewer. With sufficient inflow the water level will be controlled by the Lower Mardley Hill 'dam'.

Houses A, B, C, D, and E are identified as being at flood risk. Houses F, G and H are also expected to be at flood risk based on previous flood reports. The flood modelling work and analysis of rainfall data suggest flood water will threaten those properties approximately once in every two years on average. Experience suggests once in every five years.

Several options for reducing flood risk have been proposed and a preliminary cost-benefit judgement has been made:

For short lead time benefits with low cost, a strategy of property-level resistance / resilience is recommended.

For a more robust level of protection in the medium term, the options of a flood defence wall and/or upstream attenuation storage are recommended to take forward for a more detailed review.

7 Recommendations

The following suite of recommendations should be considered by the relevant RMAs, namely HCC as Lead Local Flood Authority, HCC as highways authority and Welwyn Hatfield Borough Council. The LLFA will facilitate discussions between RMAs and relevant land owners regarding the feasibility and viability of the recommendations.

- Discuss the findings of this report with affected residents and wider community, including local landowners.
- Work with the local community to create a community flood plan.
- Identify and remove trees and shrubs that are linked to gulley blockage.
- Provide a formal road surface for the unadopted roads of Copse Hill and Broom Hill to limit debris and silt being washed down into the gullies.
- Implement a regular gulley watch scheme and cleaning regime.
- Clear and repair the existing highway conveyance culvert.
- Replace the conveyance pipe trash screen in line with latest best practice.
- Organise property-level surveys and implement a resistance / resilience strategy, in coalition with homeowners, for rapid benefit.
- Move towards a robust solution in coalition with the local community.
- Take forward the options of a flood defence wall and/or upstream attenuation storage for a more detailed review.

Resilience and Flood Risk

Appendix A - HCC Scoping Document v1.1

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Resilience and Flood Risk

Appendix B - CCTV drainage survey

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Resilience and Flood Risk

Appendix C - Topographic survey

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Appendix D - Thames Water asset map

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Resilience and Flood Risk

Appendix E - Rain gauge data

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Appendix F – Summary of damage to properties in Feb 2014

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